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AERONAUTICAL DESIGN STANDARD HANDBOOK

ROTORCRAFT AND AIRCRAFT QUALIFICATION (RAQ) HANDBOOK

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CHAPTER 1
INTRODUCTION

This chapter describes the purpose and scope of this handbook, introduces the concept of air vehicle qualification, and provides an overview of qualification methods.

1-1 PURPOSE

The purpose of this handbook is twofold. First, it is intended to serve as a tutorial for persons unfamiliar with the airworthiness qualification process. This includes Government and contractor personnel who are involved in development of requirements or members of the design team who are not directly involved in the qualification process. In this context the handbook provides an overview of the airworthiness process for developing requirements. It describes air vehicle and typical system requirements as a guide for airworthiness qualification. Second, it is intended to serve as a reference guide for those involved in preparing airworthiness qualification documentation. This includes persons who are responsible for generating and reviewing documentation that establishes the airworthiness of systems and subsystems. Requirements for and examples of airworthiness documentation are covered in the Appendices to this handbook.

1-2 SCOPE

This handbook addresses the airworthiness qualification of air vehicles and related systems. The air vehicle and systems to which an airworthiness qualification program is applicable might be completely new or might be the result of major modification of a previously qualified system. This handbook is for guidance only. It cannot be cited as a requirement. If it is, the contractor does not have to comply. It is not intended to provide mandatory or regulatory requirements that must be achieved during the course of a program. Such requirements will be included in the specific contractual requirements for the program. Excluded from the discussions of this handbook are tests normally conducted after completion of airworthiness qualification testing, such as force development test and experimentation (FDTE) tests that are intended to provide insight into the type of force structure best suited to the operation of the air vehicle.

1-3 DEFINITIONS OF ROTORCRAFT AND AIRCRAFT*

1-3.1 ROTORCRAFT

A rotorcraft is defined as a heavier-than-air air vehicle that depends principally for its support in flight on the lift generated by one or more rotors and may include static lifting surfaces contributing less than half the required lift. An airworthy rotorcraft is a rotorcraft whose capability to function satisfactorily when used within prescribed limits has been demonstrated.

1-3.2 AIRCRAFT

An aircraft is defined as a powered (heavier-than-air) air vehicle whose principal lifting surfaces are statically positioned, i.e., fixed-wing airplane. Similarly, an airworthy aircraft is one whose capability to function satisfactorily within prescribed limits has been demonstrated.

* Note: Reconfigurable air vehicles, e.g., tilt rotor and tilt wing air vehicles, have unique features that are not specifically covered in this handbook except for a reference to a vertical takeoff and landing (VTOL) air vehicle specification, but they may be qualified by combining rotorcraft and aircraft qualifications and defining unique qualification requirements to demonstrate satisfactory operation of their transient and unique features.

1-4 INTENDED AUDIENCE

This handbook is intended for both Government and contractor audiences. For Government design team personnel this handbook provides an overview of the philosophy of airworthiness qualification and a source of detailed references upon which to base contractual airworthiness qualification program requirements. For contractor design team personnel this handbook provides a guide to responding to requests for proposals (RFPs) and to implementing and executing airworthiness qualification programs.

1-5 AIR VEHICLE QUALIFICATION

The paragraphs that follow provide a description of the purpose, scope, and techniques of air vehicle airworthiness qualification.

1-5.1 PURPOSE

The main purpose of air vehicle qualification is to ensure that the product meets its intended requirements. Airworthiness qualification, specification compliance verification, military qualification, first article validation, flight safety parts qualification, and structural integrity verification are all processes leading to qualification of systems, subsystems, and components. All of these processes include test methods and techniques used to ensure continued validity of the qualification results in expected environments. Each has a different focus, but all lead to the ultimate goal of qualification. Although treated separately in the following subparagraphs, these activities are often interrelated and overlap during the conduct of air vehicle qualification programs. The purpose of each is discussed in the subparagraphs that follow.

1-5.1.1 Airworthiness Qualification

Airworthiness qualification is defined as an analysis, design, test, and documentation process used to determine that an item—air vehicle system, subsystem, or component—is airworthy. The primary purpose of airworthiness qualification is to demonstrate that the air vehicle has the capability to function satisfactorily and safely when used within prescribed limits. In addition, airworthiness qualification is required to ensure that a system or component is properly integrated into an airworthy platform. Airworthiness qualification is conducted to ensure the overall risk of operating the air vehicle is minimal.

1-5.1.2 Specification Compliance Validation

Specification compliance validation is defined as the process used to determine that an item meets its established requirements. The purpose of specification compliance validation is to show through inspection, analysis, demonstration, and/or testing that an item satisfies all contractual performance specification requirements. Even though specification compliance validation is primarily a process used to demonstrate that the contractor has met the requirements of the contract, much of the data may be used to substantiate the airworthiness of the system.

1-5.1.3 Military Qualification

Military qualification is defined as a test and documentation process used to ensure the military utility of an item is established. Its purpose is to ensure that an item will perform adequately in a tactical environment. Thus military qualification usually includes extensive testing requirements over a wide range of environmental conditions.

1-5.1.4 First Article Validation

First article validation is the process used to determine that the first item produced by either the original developer or an alternate source meets its physical performance requirements. The purpose of first article validation is to ensure that the manufacturing processes employed yield an acceptable product that will retain the properties of previous qualification. The first article validation process is usually conducted after the item being procured enters the production phase of development. This validation is also used to verify that the production tooling and processes have not changed the characteristics that were qualified on a prototype.

1-5.1.5 Flight Safety Parts Qualification

Flight safety parts qualification is defined as a process of identification and intensive analysis, testing, control, and management of parts that have been determined to be critical to the operational safety of an air vehicle. The purpose of flight safety parts qualification is to ensure not only that these critical parts are properly designed, analyzed, manufactured, and tested as part of the air vehicle qualification program but also that critical characteristics are identified and the manufacturing process is established and frozen. The primary differences between qualification of flight safety parts and qualification of other parts are the increased level of management and the increased level of technical detail required for flight safety parts.

1-5.1.6 Structural Integrity Verification

Structural integrity verification is defined as a process used to establish, evaluate, and substantiate the structural integrity—airframe strength, rigidity, damage tolerance, and durability—of an air vehicle. The purpose of structural integrity verification is to ensure compliance with the structural design criteria. Structural integrity verification is used to verify that load paths and stresses are as predicted and to identify poor structural design details to alleviate and prevent (where possible) future maintenance difficulties.

1-5.2 SCOPE

The range of the scope of determinations and tests that are the basis for each aspect of qualification is discussed in the following subparagraphs. Determinations are findings supporting qualification substantiation that may be verified by data review, inspections, or other actions that require no further tests or analyses.

1-5.2.1 Airworthiness Qualification

Airworthiness qualification is a progressive assessment process performed at the component, subsystem, and system levels to ensure that a system meets airworthiness requirements. The scope of determinations and tests that are the basis for airworthiness qualification includes determinations of the desired operating envelope, testing to verify operations within that envelope, and establishing any limit actions to assure safe operation. The process of airworthiness qualification includes engineering analysis, formal inspections, design reviews, safety assessments, contractor demonstrations, and contractor and Government qualification tests. The requirements for airworthiness qualification are developed by the procuring activity and documented in the Airworthiness Qualification Plan (AQP). The Airworthiness Qualification Specification (AQS) defines the contractor's obligation to conduct specific analyses, reviews, tests, surveys, and demonstrations to fulfill the requirements and objectives specified in the AQP.

1-5.2.2 Specification Compliance Validation

Specification compliance validation is a comprehensive assessment of whether a system performs in compliance with the specification requirements. The emphasis is on performance, and the quality assurance portion of the system specification should normally contain a compliance matrix that indicates how compliance with each paragraph of the specification is determined. The scope of a specification compliance validation matches the specification. For example, a subsystem-level specification compliance validation would address the subsystem-level specification requirements.

1-5.2.3 Military Qualification

Military qualification may be achieved by establishing that an item possesses the required military utility by either analysis or test. The scope of military qualification is the process by which an item is tested for performance, reliability, and maintainability in the full range of its expected operating environments. Expected environments for military qualification include, but are not limited to, possible global field conditions, i.e., extreme cold, sand and dust, altitude, etc.; weapon effects, such as blast, radiation and ballistic impacts; and human interface and engineering considerations in global military environments for operability and maintainability.

1-5.2.4 First Article Validation

First article validation consists of establishing that the article was manufactured according to its applicable processes and procedures and that the manufactured part meets its performance requirements in its specified environment. The critical aspect of first article validation is ensuring that the production manufacturing procedures and processes can result in a product of the same performance level as the product resulting from the prototype development and qualification effort. The scope of determination and test that constitutes first article validation is a subset of previous qualification to reconfirm performance and additional testing to validate manufacturing processes.

1-5.2.5 Flight Safety Parts Qualification

The scope of determinations and tests that are necessary for flight safety parts qualification (FSPQ) is the detailed identification of characteristics of parts that are critical to sustaining safe flight and the identification of tests for those characteristics. FSPQ activities include analyzing the design of flight safety parts, testing at the component level for specific flight safety characteristics of the part, and establishing inspection criteria and part tracking requirements.

1-5.2.6 Structural Integrity Verification

Structural integrity verification encompasses the establishment of acceptable structural design criteria, adequate materials, process and joining methods, design analyses, load analyses, stress analyses, damage tolerance analyses, vibration analyses, materials tests, full-scale static tests, fatigue tests, and flight and ground loads surveys.

1-5.3 GENERAL TECHNIQUES

Qualification may be performed at the component, subsystem, or system level. General qualification techniques include testing, analysis, modeling, similarity (equivalency), and combinations of these techniques.

The techniques described may be applied individually or in combination depending upon the specific circumstance of a program. The application of total quality management and concurrent engineering principles and techniques to qualification requires early involvement in the design process of not only the designers of the item but also of those involved in the testing, manufacture, and support of the item. Application of these principles and technique ensures that the design process produces an item that is testable, producible, and supportable.

1-5.3.1 Testing

Testing involves applying the scientific principles of experimentation to characterize the properties of an item under controlled conditions. A test has a stated objective, a predefined set of procedures to be performed during its conduct, a method for collecting and assessing the test data, a set of pass-fail criteria, and a description of the test results.

1-5.3.2 Analysis

An analysis is an evaluation of the characteristics of an item performed on the basis of engineering and scientific principles to determine whether the item meets its performance requirements.

1-5.3.3 Modeling

Modeling techniques involve the investigation of the properties of a model—either physical or conceptual—of the real system in order to infer the characteristics of the real system.

1-5.3.4 Similarity

Similarity qualification is based on the concept that if two items are similar with respect to a characteristic of interest and one of the items has been previously qualified, the similar items may also be considered for qualification. A statement of similarity without any basis for comparison is insufficient and should not be accepted.

1-5.4 DEVELOPMENT TECHNIQUES

Qualification techniques that apply primarily during the development portion of the life cycle of an item include analyses, modeling, prototyping, informal and formal prequalification testing under controlled, known conditions, and qualification testing. Issues unique to rotorcraft include hovering performance, vibratory characteristics, and transitional flight performance. Issues unique to aircraft with fixed-wings include high-speed landing gear considerations, stall characteristics, cabin pressurization, and thrust/propeller reversals.

1-5.5 SUSTAINMENT TECHNIQUES

Qualification techniques that apply primarily during the operational and support phase of the life cycle of an item include testing and similarity. During the operational and support phase, qualification activities center primarily on changes to and improvement of an existing design, and similarity techniques are often applicable. When such techniques are not applicable, test and analysis may be used as appropriate. Also of significant importance during sustainment is the verification of characteristics, such as durability, that could not be fully assessed during a development program because of limited test time. Another qualification technique that applies during the sustainment phase is the assurance that replacement parts or repair items meet or exceed the criteria established by the original manufacturer. This is otherwise known as the qualified parts program.

1-6 QUALIFICATION ITEMS, TIMING, AND OBJECTIVES

Items that require qualification include components, subsystems, systems, and modifications to systems that ensure satisfactory performance of the item.

1-6.1 INTRODUCTION

The time span of a piece of military equipment development can be viewed as a life cycle in which the item passes through various stages. Typically, these life cycle phases are concept exploration and definition, demonstration and validation, engineering and manufacturing development, production and deployment, and operation and support. Demilitarization and disposal should be considered during all life cycle phases because of the potential safety considerations, e.g., hazardous material, that carry forward to the final activity of the life cycle. If a mission need cannot be satisfied by a nonmaterial solution, i.e., change in doctrine, operational concepts, tactics, training, or organization, a Mission Need Statement (MNS) is developed. The MNS is a broad statement of need rather than system-specific solutions. Phase 0 begins with approval of the MNS. Descriptions of the life cycle phases follow.

1-6.1.1 Concept Exploration and Definition (Phase 0)

During concept exploration and definition, conceptual alternatives to satisfy mission needs and airworthiness requirements are defined.

1-6.1.2 Demonstration and Validation (Phase I)

During demonstration and validation a likely candidate or candidates to satisfy the stated need is(are) tested to show that the selected candidate(s) is(are) viable.

1-6.1.3 Engineering and Manufacturing Development (Phase II)

During engineering and manufacturing development, design engineering and testing are performed to define an end-item that satisfies the military need. The main product of engineering and manufacturing development is documentation of information for use in the production of the end-item for field use.

1-6.1.4 Production and Deployment (Phase III)

During production and deployment the item is manufactured based on the data developed in the engineering and manufacturing development phase. The manufactured item is sent to the using unit or to a depot for storage.

1-6.1.5 Operations and Support (Phase IV)

The operations and support phase consists of use of the system by operational units and the associated training, supply, and maintenance activities. It also includes removal of weapons, environmentally safe detoxification or containment of hazardous material, deformation of expended life items to prevent reuse, and commercial resale or recycling.

1-6.2 NEW SYSTEM

A new system is defined as a newly designed system that requires performance of a full range of development activities. Typically, it requires engineering development, prototype fabrication and testing, and production efforts.

1-6.2.1 Items

Qualification is an incremental process that typically is performed on components, subsystems, and systems. These items are normally prototype hardware fabricated during the development process.

1-6.2.2 Timing

Because qualification is an incremental buildup process, timing is critical to the success of a qualification program. Components should be qualified before the subsystem into which they will be integrated is qualified. The subsystem-level tests and analyses should achieve certain minimum goals prior to initiation of system-level tests. Similarly, numerous analyses and ground tests should be successfully completed prior to flight testing. Flight testing is an incremental, progressive activity during which periodic assessments of progress are made prior to proceeding to the next phase of the qualification program.

1-6.2.3 Objectives

The objectives of qualification during development are to ensure that a newly developed item meets its intended requirements. Because the item is newly developed, it can be expected to require significantly more qualification effort than modification programs.

1-6.3 MODIFICATION

A modification program is defined as a change to an existing system to provide an added capability or exploit technological advances. Modifications can range from minor changes to a component to major changes affecting the entire system. Minor changes, however, do not usually require qualification. Modifications that would measurably affect the airworthiness of an aircraft include but are not limited to

1. Those that could affect
   a. Structural integrity
   b. Propulsion, transmission, and drivetrain stability and control
   c. Air vehicle flight performance
   d. Aerodynamic characteristics, including rag
   e. Control response and stability
   f. Electromagnetic characteristics
   g. Navigational system effectiveness
   h. Flight control system authority and effectiveness
   i. Weight and balance
   j. Flight control system logic and software.
2. Those that could restrict the flight crew in the performance of normal duties
3. Those that could increase the danger to the crew in the event of an accident
4. Those that incorporate a source of energy which could be hazardous, such as explosive ordnance, explosive or flammable fluids, and laser energy
5. Those that could affect the operating limits and/or emergency procedures specified in the operator's manual, see AR70-62, *Airworthiness Qualification of US Army Aircraft System (Ref. 1).*
6. Those that could affect the currently approved ordnance configuration or its controlling software.

1-6.3.1 Items

The qualification test articles that are normally available during modifications may be a combination of prototype hardware for those items undergoing modification and production hardware for those items already developed and not requiring modification. As in new developments, the components, subsystems, and system may undergo qualification depending on the nature and magnitude of the modification effort.

1-6.3.2 Timing

The timing discussions of subpar. 1-6.2.2 apply to a modification program as well. Specific timing considerations are a function of the magnitude and nature of the modification effort.

1-6.3.3 Objectives

The objectives of qualifying a modification are to ensure that the changes incorporated do not adversely impact the system from an airworthiness standpoint and that the desired capabilities or performance improvements as expressed in the changed objective for the item have been achieved.

1-7 SOURCE QUALIFICATION

Source qualification, applicable primarily at the part or component level, is the qualifying of a producer's manufacturing and inspection processes and procedures as being acceptable for the production of specified items.

1-7.1 QUALIFIED PARTS LISTS (QPL)

When a supplier has demonstrated that he can consistently produce an item in accordance with the requirements of an applicable specification, that manufacturer's item is placed on the QPL for that specification. The agency responsible for the particular specification establishes the criteria for and determines compliance with requirements for QPLs.

1-7.2 SOURCE-CONTROLLED ITEMS

The concept of source-controlled items is to use existing items known to be effective in the system being qualified without detailed knowledge of the item or its critical characteristics. This usually is applied to complex subsystems in which one or more adequate products exist, typically involving critical proprietary processes that are not practical to duplicate.

1-7.3 SPECIFICATION CONTROL ITEMS

Specification control items are items that are certified by their manufacturer to have been built and tested in accordance with an applicable specification. For electronic equipment the Defense Electronic Supply Center (DESC) conducts audits to ensure that a source meets the requirements of the specification or standard.

1-7.4 ALTERNATE SOURCES

During the course of or subsequent to the original qualification process, alternate sources may be qualified by demonstrating that they can produce the item to a performance and quality level equivalent to that of the original source. The purpose of alternate sourcing is to eliminate dependency on a single source for a critical item. A procurement contract may stipulate that the contractor developing an item is required to participate in the selection and qualification of alternate sources.

1-8 USE AS TEXTBOOK, REFERENCE, AND PREPARATION GUIDE

This handbook has a number of intended uses. First, as a textbook, it provides an overview of airworthiness qualification programs and testing by describing the elements and procedures necessary for successful accomplishment of an airworthiness qualification program. Second, this handbook provides a tutorial text on airworthiness qualification for new personnel by providing "how-to" instructions on structuring an Airworthiness Qualification Program. Finally, this handbook is intended to be a reference for preparing each of the following documents: Airworthiness Qualification Plan (AQP), Airworthiness Qualification Specifications (AQS), Contractor Flight Release (CFR), Airworthiness Release (AWR), Statement of Airworthiness Qualification (SAQ), and Airworthiness Qualification Substantiation Report (AQSR) both in terms of essential elements as described in the appendices to the handbook and required content as described in the body of this handbook. *The Department of Defense Index of Specifications and Standards* (DODISS) (Ref. 2) is used to identify unclassified federal and military specifications and standard, QPLs, military handbooks, and those industry documents coordinated for Department of Defense (DoD) use. The DODISS is composed of an alphabetical listing and a numeric listing, and it contains procedures for ordering these documents.

REFERENCES

1. AR 70-62, *Airworthiness Qualification of US Army Aircraft System*, 15 July 1978.

2. *Index of Specifications and Standards*, Department of Defense, published yearly.

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CHAPTER 2
AIRWORTHINESS QUALIFICATION PROGRAM

This chapter discusses the elements of airworthiness qualification programs. The Airworthiness Qualification Plan, Airworthiness Qualification Specification, and Airworthiness Qualification Substantiation Report are discussed. In addition, discussions are included on airworthiness test management, standard and specification tailoring, survey versus demonstration requirements, and the use of other airworthiness certification criteria.

2-1 INTRODUCTION

Upon receipt of an approved Mission Need Statement (MNS) a Test Integration Working Group (TIWG) should be established and chaired by a program manager (PM). The composition and responsibilities of the TIWG are described in subpar. 2-5.2.1. Also the US Army Training and Doctrine Command (TRADOC) should prepare an Operational Requirements Document (ORD). The ORD and System Threat Assessment Report (STAR), if any, should be used to develop a system specification and a Test and Evaluation Master Plan (TEMP). Department of Defense Regulation (DoDR) 5000.2-R, *Mandatory Procedures for Defense Acquisition Programs (MPDAPs) and Major Automated Information Systems (MAIS) Acquisition Program*, (Ref. 1) establishes the requirement for a TEMP. The TEMP is an iterative planning and scheduling document. The purpose of a TEMP is to serve as a management tool to ensure that the necessary elements of a test program are defined, to ensure that adequate coordination is effected among the agencies requiring test data, to ensure that adequate testing is planned for arriving at type classification and production decisions, and to provide justification for test resources including the number of prototypes to be used during testing. The TEMP also provides the justification to combine tests, to conduct them concurrently, or to eliminate them in order to avoid duplicate and unnecessary testing. The critical technical parameters and critical operational issues defined in the TEMP form the basis for the test requirements. Responsibility for the preparation of a TEMP belongs to the program manager in cooperation with the members of the TIWG. The types of airworthiness tests that should be included in the TEMP, the test agency, test hardware, and objective for each test are summarized in Tables 2-1 and 2-2. Chapter 11 provides details for preparation of a TEMP. Often the development of an Airworthiness Qualification Plan (AQP) parallels development of the TEMP. The AQP provides general guidance for required engineering analyses, formal inspections, design reviews, safety assessments, contractor demonstrations, and all contractor and Governmental qualification tests essential to defining and implementing the procurement of an air vehicle.

2-2 AIRWORTHINESS QUALIFICATION PLAN (AQP)

An Airworthiness Qualification Plan is developed by the procuring activity and included in the request for proposal (RFP) to communicate the requirements of the Government for airworthiness qualification to the contractor. The AQP is the basis upon which the contractor prepares his Airworthiness Qualification Specification (AQS) in response to the RFP. Appendix A, “The Elements of an Airworthiness Qualification Plan”, describes the purpose, content, scope, references, test accomplishment, test

TABLE 2-1. SUMMARY OF TEMP TEST REQUIREMENTS--AIR VEHICLE SYSTEM

TEST TYPE	TEST AGENCY	TEST HARDWARE	TEST OBJECTIVE
Contractor's Airworthiness Qualification Tests (AQT)	Contractor	Models Mockups Components Subsystems Allied Equipment Prototype System	Development: Prove out assemblies, components, and the total air vehicle Qualification: Determine design limits and flight envelope Demonstration of adequacy of air vehicle to function safely within flight envelope
Preliminary Airworthiness Evaluation	Materiel Developer (TACOM)	Prototype System	Verification of flight envelope and preliminary contract compliance Provide quantitative and qualitative flight test data Detection of deficiencies and evaluation of corrections Provide preliminary operational use data
Airworthiness and Flight Characteristics	Materiel Developer (TACOM)	Prototype System	Final verification of flight envelope and contract compliance Achievement of applicable military specifications Detailed stability, performance, and handling characteristics Operational characteristics for technical manuals Adequacy of the system, subsystems, and allied equipment under extreme environmental conditions
Endurance	Contractor	Prototype System	Determination of endurance and reliability of basic design Determination of adequacy of design changes to correct deficiencies revealed during prior tests
Operational User Tests	Operational Evaluation Command	Prototype System	Determination of the degree to which the system meets the characteristics of the requirements document Determination of inspection cycles Development of operating and maintenance costs Determination of component service life and quick change kits Refinement of manpower, equipment, skills, and training requirements

TABLE 2-2. SUMMARY OF TEMP TEST REQUIREMENTS--ALLIED EQUIPMENT

TEST TYPE	TEST OBJECTIVES	RELATION TO SYSTEM TEST
Engineering Design Tests (EDT)	Determination of the inherent structural, mechanical, electrical, and physical properties Determination of human and safety implications	Contractor development and airworthiness qualification tests
Contractor Demonstration (CD)	Demonstration of performance against contract specifications Determination of human performance requirements	Contractor development and airworthiness qualification tests
Research and Development Acceptance Tests (RDAT)	Determination that specifications of development contract have been fulfilled Serves as basis for acceptance or rejection of prototypes	Preliminary airworthiness evaluation
Developmental Tests	Determination of technical performance, reliability, maintainability, endurance, and safety characteristics of the item and its maintenance package Determination of human factor implications of design and materials	Airworthiness and flight characteristic test
Operational Tests	Determination of the military worth of the item Determination of the degree to which the item meets the characteristics of the requirements document	Operational tests

management, and documentation generation of the AQP.

2-3 AIRWORTHINESS QUALIFICATION SPECIFICATION (AQS)

The Airworthiness Qualification Specification defines the contractor's obligation to conduct specific analyses, reviews, tests, surveys, and demonstrations to fulfill the requirements of the AQP. The function of the AQS is to establish the requirements for test and evaluation of the system. In turn, the data generated by the AQS requirements are the basis for issuance of airworthiness releases and the Airworthiness Qualification Substantiation Report (AQSR). Appendix B, "The Elements of an Airworthiness Qualification Specification (AQS) and Their Contents", provides a detailed discussion of AQS requirements.

2-4 SURVEY VERSUS DEMONSTRATION TEST REQUIREMENTS

Surveys and demonstrations are two types of tests typically defined and required in an AQS. The purpose of each is to establish system performance characteristics. The difference is that surveys are performed to document physical characteristics or the current performance status of the design, whereas demonstrations establish whether or not a system performs adequately against stated requirements. Survey requirements should state clearly the intended purpose of the test and the expected use of the survey data. Demonstration requirements should define the pass-fail criteria against which the system will be judged. Because of the significant difference in the nature of surveys and demonstrations, the choice between the two should be carefully weighed when establishing the AQS requirements.

2-4.1 SURVEYS

A survey is the act of collecting information, measuring, determining, and assembling data to define the characteristics or capabilities of an item. A limited sampling of facts to indicate, extrapolate, or predict what a complete collection of facts and analysis would reveal is also a survey. The purpose of the survey is to determine the current state of the design with respect to established system performance requirements. The contractor's obligation is to plan and conduct the test, to collect the data, and to report the test results in accordance with the AQS. There is no obligation to correct deficiencies by virtue of the survey requirements alone. A survey incurs an obligation to collect valid data but does not obligate compliance with pass-fail criteria. Examples of typical surveys are provided in Table 2-3. Three general categories of surveys are simple surveys, verification and effect surveys, and surveys for analysis.

2-4.1.1 Simple Survey

A simple survey is a data collection effort to establish baseline performance characteristics and the impact of the modification relative to this baseline. Simple surveys are performed for specific reasons and collect limited amounts of data. The number of test runs and the amount of data collected are dependent upon the type of subsystem or component being analyzed. A simple survey would be a design support test to obtain engineering design data.

2-4.1.2 Verification and Effect

Verification and effect surveys are frequently conducted on modified systems to determine the impact of the modification and whether minimum performance characteristics are still met. Such surveys are usually partial samplings, not full and comprehensive tests. An example is to measure baseline performance and any change in performance after a modification.

2-4.1.3 Survey for Analysis

A survey for analysis is conducted to collect data for analysis because there is no practical method of directly measuring the desired characteristic. A flight load survey is an example of a survey for analysis. The survey provides data that may be compared with design loads or stresses for flight conditions in the maneuver spectrum defined for the air vehicle. The load data may be used to perform fatigue damage analysis and fatigue life calculations. The survey is correct and complete if valid data are acquired regardless of the correlation with analytical results. The AQS may require the repeat of certain surveys to support analytical requirements when conditions warrant. Such conditions may include changes in the configuration or operating conditions.

2-4.2 DEMONSTRATIONS

A demonstration is the act of proving with measurements made during the actual performance of the act or accepted analysis that a requirement has been met. The demonstrations are the proof required for approval of airworthiness qualification and the basis for establishing safe operating limits for rated, but not test rated, pilots in the expected operating environment. The obligation of the contractor is not only to conduct the test and collect valid data but also to meet contractually specified pass-fail

TABLE 2-3. EXAMPLES OF SYSTEM SURVEYS

EXAMPLE	DESCRIPTION
Flight Load Survey	Loads data obtained throughout flight envelope for all critical components Provides data for preliminary estimate of fatigue lives Determines whether resonant frequencies of critical components are tuned to the frequencies of the primary exciting forces
Engine Vibration Survey	Flight and ground tests Conducted to verify that engine vibrations do not exceed the allowable limit specified in the engine model specification
Propulsion System Temperature Survey	Flight and ground temperature monitoring Conducted to verify that engine(s) , engine accessories, engine fluids, airframe structure, transmission system, gear brakes, heat exchangers, etc., do not exceed their allowable temperature limits
Total System Vibration Survey	Flight and ground vibration monitoring Conducted during accelerated and unaccelerated flight over the full range of the flight envelope and of the allowable rotor speeds Provides data to substantiate compliance with vibratory comfort requirements and demonstrate air vehicle is free from excessive vibrations affecting structural integrity or ability to perform its mission
Crew Environment Survey	Conducted to demonstrate compliance with new environmental requirements under all specified operating conditions and modes Includes crew comfort considerations related to performance degradation and contamination characteristics
Infrared (IR) Signature Survey	Demonstrates that the IR signature is reduced to acceptable levels Documents its IR signature for use in countermeasure studies, tradeoffs, and requirements

criteria per the AQS, system specification, and statement of work. Inherent in that obligation is that if initial demonstrations are unsuccessful, corrective actions must be implemented to eliminate the deficiencies, and the test must be fully or partially repeated, depending on circumstances. This cycle is referred to as “test, analyze, fix, test”. It is important to state clearly the contractual pass-fail and retest cycle criteria in the AQS to ensure that demonstration requirements are fully delineated.

2-4.2.1 Testing

Demonstration of system performance requirements may be accomplished by direct measurement of a required characteristic. This method is appropriate for quantitative requirements that are clearly measurable. An example is demonstration of the achievement of specified vibration levels for avionics equipment mounting points. The mounting points would be instrumented, the air vehicle would be flown under specified conditions, data would be recorded, and a determination would be made as to whether the recorded vibration levels fall within the specified range of acceptability.

2-4.2.2 Action

Some specification requirements are not quantitative in nature but require that a capability to perform a function be provided. The adequacy of maintenance training and procedures, as written in the manuals, is demonstrated by having troops perform the procedures (by the book) on an actual air vehicle. Qualitative maintainability requirements are also demonstrated in this manner. Demonstration of achievement of this requirement would be the accomplishment of the action or procedure under the specified conditions by a person or persons representative—in terms of physical characteristics, abilities, and training—of the crew member populations.

2-4.2.3 Analytical

Some quantitative specification requirements either are not directly measurable at all or are not directly measurable at a specified design point or under a specified set of conditions. An example of the first situation is the fatigue life of nonflight-critical components. It might be impractical to attempt demonstrating the achievement of such requirements through test because testing would be prohibitively long and because failure could have catastrophic results. The alternative is to measure the loads and stresses and compare them analytically with the physical properties of the item to predict fatigue life. An example of the second situation is the requirement to demonstrate the range performance requirements for a target-sighting system under specified climatological and atmospheric conditions. The specified conditions may seldom, if ever, occur concurrently, and waiting to test under those conditions would not be practicable. The alternative is to make measurements at conditions different from the specified conditions and to make the appropriate adjustments. In both situations analytical techniques must be used to determine the achievement of requirements. It is essential that the analytical technique used to demonstrate requirements be validated. Also the AQS should specify the data collection efforts required to support the analysis.

2-5 AIRWORTHINESS QUALIFICATION PROGRAM—TEST MANAGEMENT

The successful conduct of an airworthiness qualification program requires both flexible and vigilant control of the test program. Flexibility allows for proper reaction to unforeseen contingencies. Vigilance is necessary to minimize the impact of undesirable events through early detection and corrective action implementation and to ensure valid results. These factors are crucial for both proper qualification assurance and achieving qualification within schedule and cost.

2-5.1 PLANNING

Preparing an Airworthiness Qualification Plan centers on test sequencing. An AQP should account for test-analyze-fix-test cycles and for the fact that test article and test facility availability may pace a program. Prudent test sequencing requires a progressive buildup of test objectives. Inappropriate sequencing may increase program risk and lead to invalid results if configuration changes alter a critical performance characteristic. No specific sequence of analyses or tests for airworthiness qualification is given in this handbook because the definition and scheduling of tests will be altered by new or novel features, by the risk to the performance of these features and equipment, by economic considerations, and by delivery constraints.

The contractor should propose a schedule for the AQS that will result in a logical sequence of analysis and test efforts to minimize the risks. A minimum risk program would require that all components be well-developed prior to subsystem testing, that critical subsystems be qualified prior to total air vehicle system testing, and that all operational conditions for the air vehicle be tested prior to first flight. Each of the test phases would be preceded by sufficient analyses to assure that design requirements have been met and that successful completion of subsequent tests is probable. The manufacture and assembly of preproduction air vehicles should be undertaken concurrently with the qualification program because this is practical and will prevent an unreasonably long and expensive program.

Given this discussion, certain minimum test precedence requirements normally apply. A test of the power and propulsion system should be completed on the ground prior to first flight. This test may be conducted with either a tied down air vehicle or a simulated vehicle containing all required subsystems. In addition, the structural static test program should have demonstrated the adequacy of the airframe for design limit loads. Included in this requirement is landing gear drop testing. Further, sufficient component fatigue test data should be available to assure that the service life of fatigue-critical components is adequate for initial flight testing.

Prior to initiation of ground tie-down test, the principal components of the drive system should have completed adequate testing including maximum rated torque and speed and pertinent transient conditions.

Demonstration requirements for individual subsystems, as defined by pertinent military specifications, may require an analysis of system capability and performance be submitted for approval together with appropriate subsystem drawings and descriptions prior to test initiation. Such stipulations should not affect qualification schedules. The analyses required are performed during design of the system and must therefore be completed well in advance of subsystem testing.

The RFP for a specific model air vehicle will typically indicate the number of prototypes to be assigned to test and qualification programs. Should these RFP guidelines not include specific assignments, such as for structural testing, flying qualities and flight performance testing, avionics and armament testing, the contractor should be required to define use of the assigned air vehicle in the proposed schedule. In addition to minimizing risk, proposal preparation for prototype use and test sequencing should also consider cost and schedule impacts.

2-5.2 TEST INTEGRATION

The extremely complex and interrelated issues associated with the conduct of a development program require close coordination among numerous Government agencies. A Test Integration Working Group should be established as a forum to effect coordination of and solve routine problems in the test and evaluation process. There are members and associate participants. Also there are many interface groups, such as the Threat Coordinating Subgroup, Computer Resources Working Group (CRWG), Manpower and Personnel Integration (MANPRINT) Joint Working Group, Safety Working Group, and Live-Fire Test and Evaluation Working Group, that have a close tie with the TIWG. TIWG and the CRWG are described in the subparagraphs that follow.

2-5.2.1 Test Integration Working Group

A TIWG is an integrated product team (See subpar. 4-6.9.) that is chartered to structure the test and evaluation (T&E) program and integrate the various T&E and milestone requirements. It is chaired by the program manager or the materiel developer (PM/MATDEV) and includes qualified representatives who have been entrusted to speak for their parent organizations. The purposes of a TIWG are to optimize the use of appropriate T&E expertise, instrumentation, targets, facilities, simulations, and models to implement test integration; to integrate test requirements; to provide input to the PM/MATDEV to review and give preliminary approval of the TEMP; to resolve cost and scheduling problems; and to ensure T&E common goal planning, execution, and reporting. During the conduct of a development program, the TIWG may conduct risk assessments and may provide program modification recommendations because of problem situations.

TIWG participants are selected to fill the needs of the program they support. Generally, the principal TIWG members are the PM/MATDEV, the combat developer, the developmental and operational testers, the developmental and operational independent evaluators, and a logistician. Other specialties that may be included as principal are a trainer, a threat integrator, and a survivability/lethality analyst.

An associate member of a TIWG is a nonvoting member who provides a needed supportive role to address necessary T&E requirements and to support subordinate working groups. The TIWG may require subgroups to perform specialized tasks, define the details of the T&E program, handle the interfaces with other disciplines, prepare for testing, and develop supporting T&E documentation. The TIWG will charter, as necessary, a Reliability, Availability, and Maintainability (RAM) Working Group (RAMWG) and a Supportability T&E Working Group (STEWG). The RAMWG is co-chaired by the materiel developer and the combat developer to address RAM issues, such as failure definition and scoring criteria, RAM Rationale Annex, and data collection. Further details of this subgroup are contained in AR 702-3, *Army Materiel Systems Reliability, Availability, and Maintainability*, (Ref. 2). The STEWG is chaired by the materiel developer's Integrated Logistic Support (ILS) manager and coordinates the TIWG activities with the Integrated Logistic Support Management Team. Topics to be coordinated include supportability test issues, test requirements, and logistic demonstration requirements in the TEMP. Further details of this subgroup are contained in AR 700-127, *Integrated Logistic Support*, (Ref. 3).

Additional information regarding TIWG and test and evaluation is included in Department of the Army (DA) Pamphlet (PAM), *Operational Testing and Evaluation Methodology and Procedures Guide*, (Ref. 4).

2-5.2.2 Computer Resources Working Group

The Computer Resources Working Group is established by the PM/MATDEV to assist in the management of system computer resources. Membership of the CRWG includes the PM/MATDEV, the combat developer, the developmental and operational testers, the developmental independent evaluator, the operational independent evaluator, and the postdeployment software support activity. The function of the CRWG is to review and resolve computer resource issues that may impact the acquisition, deployment, and support of a weapon system. Risks associated with computer resource development are assessed, and recommendations for program modifications to mitigate those risks are activities of the CRWG. Specifically, the objectives of the CRWG are:

1. To improve the acquisition management of computer resources in the system
2. To increase the visibility of computer resources in the overall life cycle of the system
3. To decrease the proliferation of unique computer resources in the Army inventory by requiring the use of standard hardware and portable software to the maximum extent possible
4. To promote the use of higher order language (HOL), compilers, and other labor-saving and management of software tools
5. To provide for early planning in the development and test of the system to ensure compliance with policy, procedures, and plans and standards established for the acquisition of computer resources
6. To facilitate the preparation, review, and approval of a Computer Resources Management Plan (CRMP) for the system

7. To eliminate unnecessary redundancy in testing. Inherent in these functions is identification of the requirements for computer resource test facilities.

2-5.3 TEST COORDINATOR

A test coordinator is a representative of the procuring activity who is located at a test site—a Government or contractor test facility. The duties and responsibilities of the test coordinator are

1. To maintain liaison with the contractor in order to determine start and completion dates and the duration of each test

2. To develop and implement a procedure for rapid and timely witness or observer notification of tests, cancellations, and rescheduling

3. To design and distribute test-witnessing forms

4 . To provide witnesses or observers with written data and information, such as plant procedures, and forms on which to record data and observations

5. To brief each witness or observer on the status of the test including preceding and subsequent tests

6. To forward completed witness reports and comments to the procuring activity

7. To witness or observe tests when an authorized witness or observer has not been appointed or is absent.

2-5.4 GOVERNMENT PLANT ACTIVITY

The Government plant activity function is normally carried out by the Defense Plant Representative Office (DPRO). The DPRO is an extension of the procuring activity located at the site of the contractor. The authority of the DPRO is delegated by the procuring contracting officer (PCO) by making the DPRO the administrative contracting officer (ACO). This on-site representative of the procuring activity is responsible for contract administration and quality control and monitors the contractor to the full extent of the capability of the DPRO. Because it is impractical for the DPRO to assemble engineering talent equal to the expertise available throughout the US Army Materiel Command (AMC) commodity commands, the DPRO relies heavily on the commodity commands for assistance. Engineering data required to be developed and submitted under the contract is submitted to the procuring activity via the DPRO. The DPRO reviews the data submittals for completeness and for compliance with the applicable specifications and contractual requirement. The recent trend is toward reduced Government oversight, which is to be replaced by more reliance on contractor verification of the completeness and accuracy of submitted data. The program manager and the appropriate specialists should review and approve the submitted data for content and completeness.

2-5.5 TEST VERSUS SPECIFICATION MATRICES

A useful method of portraying test requirements is the test versus specification matrix. One such matrix is the environmental test method versus the specification. Such matrices may be developed at the component, subsystem, and system levels. Another useful matrix shows the test procedures and test reports cross-referenced to the

AQS requirements. Also system performance specification requirements are cross-referenced to the specific test procedures and test reports, which substantiate the achievement of the requirement. Table 2-4, "Test vs Specification Matrix", provides an example of the information to be included.

2-5.6 CONTRACTOR FLIGHT RELEASES

A Contractor Flight Release (CFR) is a technical document and transmittal letter signed by the appropriate PCO authorizing an element of industry to operate an Army air vehicle of an approved configuration within prescribed limitations by using established procedures. The purpose of a CFR is to control to a reasonable level the risk to Government assets and the amount of liability. A CFR is used when the Government holds ground and flight risk and a contractor pilot is the pilot-in-command. When a CFR is issued, the air vehicle is believed to be safe, and it is believed that no undue risk is being taken on the part of the flight crew, the contractor's management, or the Government. A CFR is usually required for initial ground and flight testing, i.e., prior to initial engine run-up, rotors turning, ground resonance testing, etc., provided that the air vehicle and property are not covered by a separate lease agreement. CFRs are not intended to be controlling configuration management documents, although they are related to approved configurations. As described in AR 95-20, Volume 2, *Government Flight Representative Guidance*, (Ref. 5), the Government Flight Representative (GFR) is responsible for the surveillance of all contractor flight operations involving Government air vehicles and other air vehicles for which the Government is assuming some of the risk of loss or damage. The GFR approves flight crew members, qualification training, and the contractor's flight operations procedures. Appendix C provides a detailed discussion of the requirements for a contractor flight release.

2-5.7 AIRWORTHINESS RELEASES

An Airworthiness Release (AWR) is a technical document that provides interim operating and maintenance information necessary for safe flight operation of an air vehicle system, subsystem, and allied equipment. The significant difference between a flight release for industry and an Airworthiness Release for Government operation of an Army air item is that of safety assurance. When an AWR is issued, the air vehicle is known to be safe based on analyses, demonstration of air vehicle and equipment, and demonstration of limitations, or a determination has been made that the remaining risks are acceptable. An AWR is required prior to operation of a new air vehicle system or a fielded air vehicle system that has undergone a major modification. Also an AWR is required prior to operation of an air vehicle with Federal Aviation Administration (FAA), US Air Force (USAF), National Aeronautics and Space Administration (NASA), or US Navy (USN) airworthiness approval if the air vehicle has been modified without certifying agency approval. Finally, an AWR is required anytime an Army pilot is going to be the pilot-in-command of a nonstandard configured air vehicle or an air vehicle that has not been issued a Statement of Airworthiness Qualification (SAQ). The SAQ may be issued temporarily as an interim SAQ after qualification is essentially complete but pending final documentation approval.

Appendix D provides a detailed discussion of the elements of an Airworthiness Release.

TABLE 2-4. TEST VS SPECIFICATION MATRIX

SYSTEM SPECIFICATION PARAGRAPH	TEST, SURVEY, AND DEMONSTRATION REQUIREMENTS	WBS	SOW PARAGRAPH	AQS PARAGRAPH	PIDS DOCUMENT NUMBER	REMARKS
3.2.7.2.1 3.2.7.2.2 3.2.11.5.1	Shake Test	3322	C.3.14.B	2.8.5.2.4.1	N/A	Requires MMA mass model dummy. IAW Section 5.1 of ADS-27. ADS-1 IAW Ground Test Plan. Document Number MSIP000050-205, Rev. B, Appendix N
3.2.7.2.1 3.2.7.2.2 3.2.1.1.5 3.2.11.5.1	Flight Vibration Survey	5321 5333	C.3.19.A	3.8.5.2.4.2	N/A	ADS-1, Section 4.0 of ADS-27
3.2.7.1, 3.7.15 and sub	Crew Environmental Survey	511A 5322 5331 5334 534	C.3.1.6 C.3.13.B C.3.14.A C.3.14.D C.3.15	3.8.5.2.3	DRC-P-H101890	For additional information see ADS-1, ADS-9, and ADS-27. Also see MSIP00050-212P, MSIP000050-205, Rev. B, Appendix T.
3.7.15.4 3.7.15.4.1 3.7.15.4.2	Environmental Control System Test	511A 5333	C.3.1.G C.3.14.C	3.8.5.2.5 3.8.5.2.B	DRC-P-H101930	
3.7.15.4	ECS Demonstration	511A 5332 5333	C.3.1.G	3.8.5.3.8	DRC-P-H100030A DRC-P-H101930	LRU loss of cooling air aircraft IAW design curve
3.7.8.3 3.7.8.3.2 3.7.8.3.9	IPAS Demonstration	511A 5117 5332 5333	C.3.1.F C.3.14.B C.3.14.C	3.8.5.3.5 3.8.5.8.6	DRC-P-H100330A DRC-P-H101930	
3.7.12 through 3.7.12.7	Armament Fire Control and System Survey	5331 5333 53334 534	C.3.14.A C.3.14.C C.3.15	3.8.5.2.4	DRC-P-H106000A DRC-P-H400030A	Survey with Hellfire missile, folding fin aerial rockets, and turreted gun.
3.7.6.2	Flight Controls Handling Qualities System Survey	5333	C.3.14.C	2.8.5.2.8	DRC-P-H1000SQA DRC-P-H1032SQA	Aircraft only, no FCR LRUs required
3.7.10 to 3.7.11	Communications Subsystem Survey	513 5322 5332 5333	C.3.2 C.3.10.D C.3.13.B C.3.14.B C.3.14.C	3.8.5.2.9	DRC-P-H300730A	Survey as needed to characterize fully antenna subsystem performance.
3.7.10 to 3.7.11	Communications Subsystems Demonstration	513 5322 5332 5333	C.3.2 C.3.13.B C.3.14.B C.3.14.C	3.8.5.3.10	DRC-P-H300730A	

WBS = Work Breakdown Structure SOW = Statement of Work AQS = Airworthiness Qualification Specification PIDS = Prime Item Development Specification

2-6 REQUIREMENTS TAILORING

The subparagraphs that follow discuss requirements tailoring concepts applicable to design, development, and airworthiness qualification. The primary benefits of tailoring are the reduction in time and funds required for development and qualification.

2-6.1 GENERAL PHILOSOPHY

"Tailoring" describes the selective application of standards and specifications in the design and development process. Selective application includes use of only a portion of the standard or specification, modifications of the standard or specification, or use of an alternative standard or specification. To ensure the suitability of an item or process for a specific application and to establish feasible, cost-effective design requirements, all design attributes should be considered. Tailoring is a method of controlling the extent to which the specification dictates design detail, which can inhibit innovation. The degree of tailoring is a function of the type of development. For a major or minor new development program, tailoring may be minimal. For nondevelopmental items or modification programs, tailoring could be extensive to take into account the previous qualification efforts and demonstrated use. Tailoring may be applied to the level (component, subsystem, or system) for which specific testing will be required. Tailoring may also be applied to the extent of data and documentation required to be furnished to the Government as well as to the ownership of the design and data.

2-6.2 CONSIDERATIONS

There are three primary considerations that enter into all tailoring decisions. These are technical relevance, assessment of risk, and resource requirements. An application of these considerations would be the need for additional airworthiness qualification for an item that has already undergone similar qualification, e.g., Federal Aviation Administration or foreign agency certification. The questions to be answered are then

1. How similar are the qualification conditions to the new intended use of the system (technical relevance)?
2. What consequences result from not performing certain qualification efforts (risk assessment)?
3. What are the cost and schedule requirements associated with the qualification effort (resources)?

2-6.2.1 Technical Relevance

Technical relevance deals with the degree to which a specification requirement is applicable to the situation under consideration. For example, a general specification requirement for new equipment may deal with conditions that may not be encountered by a limited use system. The requirement could be modified or tailored on the basis of technical relevance. For modified equipment the requirement to comply fully with current standards may be waived (tailored) because these standards were not in force at the time of the original design. Secondary and indirect effects must also be considered. If, for example, it is decided to tailor the requirement to delete shipboard compatibility because it is not currently applicable, it may later be necessary to provide that capability due to changing circumstances in the future use of the system. Accordingly, the design may be required to be compatible, but testing and qualification may be deleted for the present program.

2-6.2.2 Assessment of Risk

Whenever a tailoring decision is under consideration, there is a risk that the decision may ultimately have a negative impact. The decision maker's judgment as to the probability of occurrence of the undesirable event along with the impact (severity) of the event combine to form an assessment of risk. This technique of combining severity and probability is discussed further in Chapter 3. A factor that enters into assessing severity is the ease with which corrective actions for the undesirable event can be implemented. Obviously, easy fixes have low severity. The amount of tailoring a decision maker allows should be related to the probability and severity of risk. As the risk increases, the amount of allowed tailoring of standards and specifications should decrease.

2-6.2.3 Resources

Achievement of full specification or standard compliance may require an inordinate amount of resources. When a requirement is tailored on the basis of resource requirements, it is necessary to determine the value of the effort by means of economic analysis that considers the cost of test specimens, facilities, and conducting tests. This value must be compared with the cost and benefit of other program activities to ensure that activity priorities are still valid. Requirement specifications and standards are not generally tailored because of program funding constraints alone. However, tradeoffs should provide the most cost-effective system that meets the overall system performance requirements. If it is determined that tailoring to reduce cost by reducing resources is not prudent, the impact of requesting additional funds or resources must be assessed against negative impacts on program viability if preestablished thresholds would be breached.

2-7 OTHER AIRWORTHINESS CRITERIA ADOPTION

In addition to the US Army, the US Air Force, the US Navy, the Federal Aviation Administration, and the National Aeronautics and Space Administration also provide airworthiness qualification and certification. Their criteria are similar in that they seek to ensure that air vehicles operated under their cognizance are safe. They differ in that they serve different needs. In addition to safety the military agencies concern themselves with the military utility and effectiveness required by the various services. AR 70-62, *Research and Development Airworthiness Qualification of US Army Aircraft Systems*, (Ref. 6) documents policy for airworthiness qualification of air vehicle systems, subsystems, and allied equipment undergoing development and for major modifications to standard and nonstandard air vehicles. It also implements policy for issuance of airworthiness releases for flight performance and operational flight evaluation testing of domestic and foreign-made commercial air vehicles with potential military application, modified surrogate air vehicles, and foreign military air vehicles.

2-7.1 CIVIL AGENCIES

The FAA or NASA certification would be adopted for systems whose existing performance limits are similar in nature to the military requirements because the air vehicle was designed for a similar intended use. Some Army rotorcraft were certified under 14 CFR, Part 27, *Airworthiness Standards: Normal Category Rotorcraft*, (Ref. 7). Other aircraft were certified under 14 CFR, Part 23, *Airworthiness Standards: Normal Utility, Acrobatic, and Commuter Category Airplanes,* (Ref. 8) or 14 CFR, Part 25, *Airworthiness Standards: Transport Category Airplanes,* (Ref. 9). The extent to which the intended military use differs from the previous certified flight envelope and environment dictates the extent of partial or complete requalification necessary.

TABLE 2-5. SELECTED FEDERAL AVIATION REGULATIONS

PART	TITLE	APPLICATION
1	*Definitions and Abbreviations*	General definition of terms
21	*Certification Procedures for Products and Parts*	Procedural requirements for type certificates, materials, parts, and processes
23	*Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes*	Performance, flight characteristics, controllability and maneuverability, and stability
25	*Airworthiness Standards: Transport Category Airplanes*	Performance, flight characteristics, controllability and maneuverability, and stability
27	*Airworthiness Standards: Normal Category Rotorcraft*	Performance, flight characteristics, controllability and maneuverability, and stability
29	*Airworthiness Standards: Transport Category Rotorcraft*	Performance, flight characteristics, controllability and maneuverability, and stability
33	*Airworthiness Standards: Aircraft Engines*	Reciprocating and turbine engine design, construction, durability, and safety
35	*Airworthiness Standards: Propellers*	Propeller design, construction, and test
39	*Airworthiness Directives*	Reporting of unsafe conditions in parts or products
91	*General Operating Flight Rules*	Rules governing aircraft operations within the United States
125	*Certification and Operations: Airplanes Having a Seating Capacity of 20 or More Passengers or a Maximum Payload Capacity of 6000 Pounds or More*	Certification procedures, crew requirements, and flight operations rules
133	*Rotorcraft External--Load Operations*	Operation and certification rules for aircraft with external loads in the United States

Table 2-5 presents those air vehicle characteristics that could be adopted based on FAA certification. It should be noted that the FAA, because it is a regulatory agency, certifies to a minimum level of safety and does not qualify performance utility for any intended use. Also FAA regulations are not generally retroactive.

2-7.2 MILITARY

The circumstances under which other US military certification would be adopted are those for systems similar enough in nature and intended use. The extent to which the intended US Army military use and previous certification efforts differ dictates the extent of partial or complete requalification necessary. The discussions of par. 2-6, "Tailoring", apply here.

2-7.3 FOREIGN

The circumstances under which foreign certification would be adopted are those for systems similar enough in nature and intended use and for which there exists a foreign agency approval recognized by a US agency or a US international agreement. Again, the extent to which the intended military use and previous certification efforts differ dictates the extent of partial or complete requalification necessary. The discussions of par. 2-6, "Tailoring", apply here.

2-8 AIRWORTHINESS QUALIFICATION SUBSTANTIATION REPORT (AQSR)

An Airworthiness Qualification Substantiation Report is prepared and published upon successful completion of the airworthiness qualification program. The AQSR is the final report summarizing the results of the airworthiness qualification effort and detailing specification compliance. Its purpose is to provide a single document to trace the airworthiness qualification decision. The report should be revised as needed to document subsequent modifications and airworthiness decisions.

2-8.1 VOLUME I—AIRWORTHINESS QUALIFICATION FINAL REPORT

Volume I of the AQSR, *Airworthiness Qualification Final Report*, summarizes the qualification program and system performance limits. It provides a description of the air vehicle, a description of the airworthiness qualification program including program schedule and test program summary, a structural demonstration summary, component lives, operating restrictions, and a qualification data summary and index for both contractor data and Government data. Appendix F, subpar. F-2.1, provides a detailed discussion of the first volume of the AQSR.

2-8.2 VOLUME II—SPECIFICATION COMPLIANCE BY PARAGRAPH

Volume II of the AQSR, *Specification Compliance by Paragraph*, documents each system performance specification result. It provides a paragraph compliance list with a reference to the proof of compliance. Appendix F, subpar. F-2.2, provides a detailed discussion of the second volume of the AQSR.

2-9 STATEMENT OF AIRWORTHINESS QUALIFICATION (SAQ)

A Statement of Airworthiness Qualification is a final AWR that is issued in conjunction with the AQSR. The statement is based on the final results of engineering tests conducted on the air vehicle and its subsystems or allied equipment. Issuance of this statement coincides with type classification Standard A, if applicable, and normally completes the airworthiness qualification program. The SAQ contains a description of the configuration of the air vehicle, operating instructions and procedures, limitations and restrictions, and requirements for sustaining airworthiness. Appendix E contains a detailed discussion of the SAQ.

REFERENCES

1. DODR 5000.2-R, *Mandatory Procedures for Defense Acquisition Programs (MDAPs) and Major Automated Information Systems (MAIS) Acquisition Program*, 15 March 1996.

2. AR 702-3, *Army Material Systems Reliability, Availability, and Maintainability*, 1 May 1982.

3. AR 700-127, *Integrated Logistic Support*, 16 December 1986.

4. DA PAM 73-1, *Operational Testing and Evaluation Methodology and Procedures Guide*, 15 October 1979.

5. AR 95-20, *Contractor's Flight Operations*, 3 April 1979.

6. AR 70-62, *Airworthiness Qualification of US Army Aircraft Systems*, 15 July 1978.

7. 14 CFR, Part 27, *Airworthiness Standards: Normal Category Rotorcraft*, US Government Printing Office, Washington, DC, 1 January 1994.

8. 14 CFR, Part 23, *Airworthiness Standards: Normal Utility, Acrobatic, and Commuter Category Airplanes*, US Government Printing Office, Washington, DC, 1 January 1994.

9. 14 CFR, Part 25, *Airworthiness Standards: Transport Category Airplanes*, US Government Printing Office, Washington, DC, 1 January 1994.

CHAPTER 3
SYSTEM SAFETY

This chapter presents the system safety aspects of air vehicle qualification. Topics include the system safety process, safety and hazard analysis, and flight safety parts. In addition, requirements are presented for the System Safety Program, System Safety Management Plan, and System Safety Program Plan.

3-1 INTRODUCTION

System safety is defined as "The application of engineering and management principles, criteria, and techniques to optimize safety within the constraints of operational effectiveness, time, and cost throughout all phases of a system life cycle.", MIL-STD-882, *System Safety Program Requirements*, (Ref. 1).

A System Safety Program (SSP) is a formal approach to elimination of hazards through engineering design and analysis, management, and supervisory control of conditions and practices. The SSP encompasses the accomplishment of system safety management, research, and engineering tasks and is an essential element of the airworthiness qualification of the system.

Typical air vehicle system safety tasks during the development process are depicted in Fig. 3-1. Milestones or checkpoints for system safety within the development process should be established at the outset of an air vehicle development program. Typical milestone tasks delineated in MIL-STD-882 (Ref.1) are shown in Fig. 3-1 opposite the equivalent tasks in the air vehicle development process. (These milestones are considered only typical and not necessarily complete in number.) The system safety activity starts early in the conceptual stage of air vehicle design and continues throughout the entire process. The system safety process described in this chapter is applied in an iterative manner as the program progresses.

3-2 OBJECTIVES

The objectives of an SSP are to ensure that

1. Safety, consistent with mission requirements, is designed into the system in a timely, cost-effective manner.
2. Hazards associated with each system are identified, evaluated, and eliminated, or the associated risk is reduced to a level acceptable to the managing activity (MA) throughout the entire life cycle of a system. Risk should be described in risk assessment terms.
3. Historical safety data, including lessons learned from other systems, are considered and used.
4. Minimum risk is sought in accepting and using new designs, materials, and production and test techniques.
5. Actions taken to eliminate hazards or reduce risk to a level acceptable to the MA are documented.
6. Retrofit actions required to improve safety are minimized through the timely inclusion of safety features during research and development and acquisition of a system.
7. Changes in design, configuration, or mission requirements are accomplished in a manner that maintains a risk level acceptable to the MA.

8. Consideration is given to safety, ease of disposal, and demilitarization of any hazardous materials associated with the system.

9. Significant safety data are documented as "lessons learned" and are submitted to data banks as proposed changes to applicable design handbooks and specifications. (Ref. 2)

3-3 SYSTEM SAFETY PROCESS

The system safety process is shown graphically in Fig. 3-2 and described in the subparagraphs that follow. This process shows a logical approach to attaining the system safety objectives in par. 3-2. The process is repeated as necessary in an iterative fashion at every level of complexity in the design of a system until the requisite assurance of the system hazard level is attained. An integral part of the system safety process is hazard tracking, which is a closed loop system used to identify, monitor, and eliminate hazards. Hazard tracking is developed early in the system safety process and is used throughout the process to document and track hazards and the progress made toward resolution of the associated risk.

3-3.1 KNOWN PRECEDENT (BLOCK A, FIG. 3-2)

From the beginning a System Safety Program should be based on the experience and knowledge gained from previous operations in correcting design deficiencies that have resulted in the accidental loss of or damage to materiel or injuries or death to personnel. Those design features categorized previously as having hazards are also identified, and the hazards corrected if required. It is essential that designers of future air vehicles benefit from all previous experience that affects safe operation.

3-3.2 SYSTEM DELINEATION (BLOCK B)

The boundaries of the system under consideration and its constituent elements are defined clearly as early as possible and revised as required during the system life cycle. Such delineation establishes the limits for succeeding steps in the process and reduces complex systems to manageable parts. Any entity can be labeled a "system" provided it is accurately defined.

3-3.3 IDENTIFICATION OF FLIGHT SAFETY PARTS (BLOCK C)

Flight safety parts are parts whose failure or malfunction could result in an unsafe condition. The handling of flight safety parts is discussed in par. 3-13.

3-3.4 SYSTEM HAZARD ANALYSIS (BLOCK D)

The heart of system safety is the analysis of a system and its elements in a methodical manner. Beginning with preliminary hazard analyses of design concepts and continuing through an integrated hazard analysis of the complete system, this analytical process distinguishes system safety from other separate, but closely interfacing, disciplines. The contractor should select the methodology and techniques for hazard analysis best suited for the particular system element under consideration and for the applicable level of detail design.

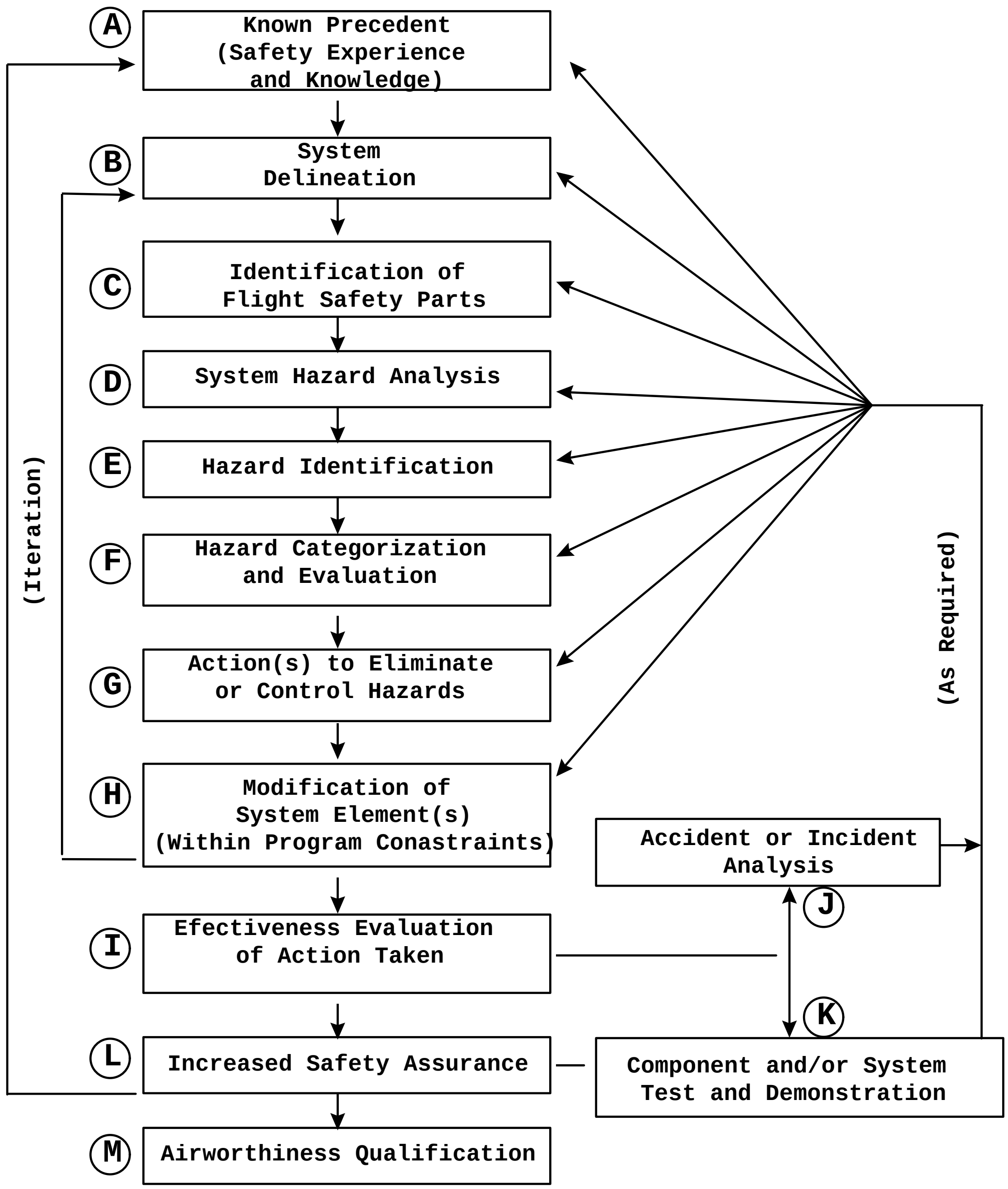

Figure 3-2 System Safety Process

3-3.5 HAZARD IDENTIFICATION (BLOCK E)

By using systematic hazard analyses, the design engineer identifies those features of a system that potentially may cause damage, loss, or injury. Such identification assists the designer in his or her initial efforts by calling attention to undesirable features or deficiencies that can be either eliminated or controlled efficiently early in the design process. As the design proceeds, additional hazards are identified through the system safety process.

3-3.6 HAZARD CATEGORIZATION AND EVALUATION (BLOCK F)

It is impractical to eliminate all hazards identified in a system. The appropriate action to be taken as a result of hazard identification depends on how often the hazard occurs, i.e., frequency, and the impact of the consequences that result from the hazard occurring, i.e., severity. The factors of hazard frequency and severity establish the residual risk of the system. Categorization of hazards according to criteria specified by the procuring activity serves to guide corrective action based upon assessment of the potential residual risk. Evaluation of identified hazards and hazard risk management require relating a hazard to its impact on mission effectiveness, system performance, and program success. This categorization and evaluation are essential parts of the decision-making process to determine appropriate corrective action.

3-3.7 ACTION(S) TO ELIMINATE OR CONTROL HAZARD(S) (BLOCK G)

The system safety process produces no useful result until some action is taken to eliminate or control identified hazards. The effect of alternative courses of action in the design process and tradeoff studies to eliminate or control identified hazards should be considered. Thus management is presented with a tool with which decisions can be made based on other program constraints.

3-3.8 MODIFICATION OF SYSTEM ELEMENTS (BLOCK H)

Any action taken in Block G necessarily results in the modification of some element or elements of the air vehicle system. As a result, the delineation of the system (Block B) should be revised accordingly. The system safety process is then repeated as required until no unacceptable additional hazards are generated by the system modification. This step ensures that a new hazard is not inadvertently introduced into the system while another hazard is being eliminated.

3-3.9 EFFECTIVENESS EVALUATION OF ACTION TAKEN (BLOCK I)

Actions taken to correct hazards as a result of the system safety process are evaluated on how effectively they achieve the system safety objective. A satisfactory evaluation results in increased assurance in the level of safety of the system (Block L).

3-3.10 ACCIDENT OR INCIDENT ANALYSIS (BLOCK J)

The occurrence of an accident or incident of course leads to an unsatisfactory evaluation. The analysis of such an accident or incident experience should reveal any deficiencies in the conduct of the system safety program and direct corrective action to the appropriate step in the process.

3-3.11 COMPONENT AND/OR SYSTEM TEST AND DEMONSTRATION (BLOCK K)

Analytical techniques alone are not sufficient to identify system hazards adequately, and this inadequacy is determined in Block I. Tests and demonstrations normally conducted as part of an air vehicle development program are planned and conducted to reveal such inadequacies. In addition, these tests and demonstrations serve to verify the results of the system safety process and to contribute to the assurance desired. Should system testing reveal additional problems, corrective action is applied at the appropriate step in the process.

3-3.12 INCREASED SAFETY ASSURANCE (BLOCK L)

The assurance that the objectives of system safety are being met is cumulatively increased as the program progresses and contributes increased knowledge to subsequent cycles of the process (Block A).

3-3.13 AIRWORTHINESS QUALIFICATION (BLOCK M)

Ultimately, the system safety process results in data and information that serve as an essential element of airworthiness qualification. The methods and procedures to be followed are prescribed in the Airworthiness Qualification Specification (AQS).

3-4 ANALYTICAL METHODOLOGIES AND TECHNIQUES

Hazard analysis is the heart of the system safety process and requires inductive thought as well as deductive reasoning. An analysis may be either qualitative or quantitative. A qualitative analysis is generally conducted first to provide a departure point for the quantitative analysis. A qualitative analysis examines events to determine the possible existence of hazards, the accidents that could result, possible effects, and safeguards. A quantitative analysis permits comparison of the changes in probabilities if safeguards or alternative designs are used in the system. Results of quantitative analysis may be probabilistic or relativistic, i.e., using comparisons based on judgment.

The ultimate purpose of hazard analysis is to aid management in reaching the determination that the objectives discussed in par. 3-2 have been achieved within the constraints of the particular air vehicle development program. In addition, these analyses form a baseline which can be evaluated objectively by someone other than a system safety analyst to measure the effective influence of subsequent design changes.

There are several types of widely used analyses for system safety. Selection of the analytical methodology or technique to be used in a given program is the responsibility of the contractor and depends upon the level of detail required by program phases, requirements for qualitative and quantitative results, and the particular capabilities developed by the contractor. Methodology selection should maximize use of the design detail available at the particular phase of the program to ensure the analysis is as comprehensive as possible, and is thorough and accurate. MIL-STD-882 (Ref. 1) should be used as a guide for analyses, methods, and techniques. Also MIL-HDBK-764, *System Safety Design Guide for Army Materiel*, (Ref. 2) may be used as a guide.

MIL-HDBK-764 describes techniques of analysis such as fault hazard analysis (FHA), fault tree analysis (FTA), sneak circuit analysis (SCA), and failure, modes, effects, and criticality analysis (FMECA) that have value for hazard analysis. In addition, Ref. 2 identifies analysis techniques, such as circuit logic analysis, interface analysis, mapping, Monte Carlo simulation, contingency analysis, environmental factors analysis, critical incident technique, and mock-ups, that can be used to support these analyses.

3-5 KNOWLEDGE OF HAZARDS

The system safety analyst should have a thorough knowledge not only of air vehicle engineering but also of hazardous conditions.

For example, major rotorcraft configurations—such as the type of rotor, e.g., articulated or bearingless, the method of directional control, and the control system concept—have inherent safety implications. The tradeoffs used to reach a decision regarding these configurations should include system safety considerations. In addition, hazards are more likely to be present at interfaces between subsystems than within a single subsystem. Some examples of possible interfaces that could lead to hazards are fuel system to engine fuel lines, clearance between components, and connectors that can be improperly installed.

The system safety analyst must also be aware of those conditions that have been proven by past experience to be hazardous for air vehicles. The consideration of hazards must not be limited to those conditions involving only hardware. Software is an important consideration. Also the interactions of air vehicles with personnel who operate and maintain them and those between personnel and the environment in which the air vehicles are used provide potentially hazardous conditions, which should be considered during design. Some examples of possible interrelationships that could lead to hazards are the height of the main rotor above the ground and the location of the pilot with respect to the rotor path.

3-6 CLASSIFICATION OF HAZARDS

Since it is impossible to eliminate or control all hazards, they are usually ranked by degree of severity, i.e., consequences in operation of the air vehicle. Four hazard levels ranging from negligible to catastrophic are defined and established in MIL-STD-882. These are listed in Table 3-1 along with their effect on personnel safety, examples of functional hazards, and definitions. Table 3-2 provides MIL-STD-882 probability levels along with an example of quantitative probabilities. Quantitative probabilities should be developed for each weapon system to meet specific program requirements. For any given hazard a degree of severity and probability of occurrence may be assigned. Table 3-3 shows how those two aspects of a hazard may be combined to arrive at a risk

TABLE 3-1. HAZARD SEVERITY CATEGORIES

DESCRIPTION	CATEGORY	EXAMPLES OF FUNCTIONAL HAZARDS	EFFECT ON PERSONNEL	DEFINITIONS
CATASTROPHIC	I	System nonfunctional; not economically salvageable. Total loss.	Personnel suffer death or serious or multiple injuries precluding return to current duties.	Death, system loss, or severe environmental damage.
CRITICAL	II	Major subsystem(s) nonfunctional. Hazard requires immediate corrective action.	Personnel suffer serious or multiple injuries requiring extended rehabilitation before return to current duties.	Severe injury, severe occupational illness, major system or environmental damage.
MARGINAL	III	Flyable aircraft; mission equipment or one of redundant subsystems nonfunctional. Hazard can be countered or controlled.	Personnel suffer injury requiring short-term recuperation before return to current duties.	Minor injury, minor occupational illness, or minor system or environmental damage.
NEGLIGIBLE	IV	Mission capable with minor performance loss or no immediate effect. Deferrable maintenance.	Personnel suffer minor injury that does not interrupt current duties.	Less than minor injury, occupational illness, or less than minor system or environmental damage.

TABLE 3-2. HAZARD PROBABILITY

DESCRIPTION	LEVEL	GENERIC DEFINITION (MIL-STD-882)	EXAMPLE: MEAN OPERATING HOURS BETWEEN OCCURRENCES	EXAMPLE: EXPECTED NUMBER OF OCCURRENCES PER 100,000 FLIGHT HOURS
FREQUENT	A	Likely to occur frequently	< 10	> 10,000
PROBABLE	B	Will occur several times in life of item	10 - 100	1000 - 10,000
OCCASIONAL	C	Likely to occur sometime during life of item	100 - 1000	100 - 1000
REMOTE	D	Unlikely but possible to occur in life of item	1000 - 10,000	10 - 100
IMPROBABLE	E	So unlikely, it can be assumed occurrence may not be experienced	> 10,000	< 10

severity category. The table also shows that for each risk severity category, a level of Army management authority has been assigned to accept the residual risk associated with the particular hazard in question. For example, a risk whose hazard severity is judged to be “critical” and whose hazard probability is “probable” would have a risk severity category of “HIGH” associated with it. For an Army Materiel Command (AMC)- Aviation (Table 3-3(A))-developed system, the Commander AMC would be the management authority for acceptance of a “HIGH”-risk hazard. For an Aviation-Program-Executive-Office (PEO) (Table 3-3(B))-developed system, the Army Acquisition Executive (AAE) or his designee would be the management authority level for acceptance of a “HIGH”-risk hazard. Similarly, for a hazard whose severity is considered “negligible” and whose hazard probability is frequent, the corresponding hazard risk assessment is “LOW”. The program manager or equivalent is the management authority for the acceptance of a “LOW” risk.

TABLE 3-3. RISK SEVERITY CATEGORY MATRIX

(A) ARMY MATERIEL COMMAND -AVIATION

SYSTEM SAFETY MANAGMENT DECISION AUTHORITY MATRIX

LEVEL	DECISION AUTHORITY
HIGH	CG AMC
MEDIUM	MSC CDR*
LOW	PMs/ITEM MGRs

		HAZARD PROBABILITY				
		FREQUENT	PROBABLE	OCCASIONAL	REMOTE	IMPROBABLE
SEVERITY		A	B	C	D	E
CATASTROPHIC	I					
CRITICAL	II		HIGH			
MARGINAL	III			MEDIUM		
NEGLIGIBLE	IV					LOW

*CG AMC if PMs report directly to HQ AMC

(B) AVIATION PROGRAM EXECUTIVE OFFICE

TAILORED SYSTEM SAFETY MANAGEMENT DECISION AUTHORITY MATRIX

LEVEL	DECISION AUTHORITY
HIGH	AAE or DESIGNEE
MEDIUM	PEO or EQ
LOW	PM or EQ

		HAZARD PROBABILITY				
		FREQUENT	PROBABLE	OCCASIONAL	REMOTE	IMPROBABLE
SEVERITY		A	B	C	D	E
CATASTROPHIC	I					
CRITICAL	II		HIGH			
MARGINAL	III			MEDIUM		
NEGLIGIBLE	IV					LOW

CGAMC	=	Commanding General, US Army Materiel Command
MSC	=	major subordinate command
CDR	=	commander
PM	=	program manager
MGR	=	manager
PEO	=	program executive office
EQ	=	equivalent

The decision authority matrix can be tailored upon authorization from the "HIGH" risk hazard authority. Both examples in Table 3-3 are tailored for aviation. The tables are identical except for the decision level authorities.

3-7 RESOLUTION OF HAZARDS

Hazards are resolved through elimination or control. Documentation of actions is by means of substantiation of hazard resolution. These two aspects of system safety—hazard control and substantiation—are addressed in the subparagraphs that follow.

3-7.1 CONTROL METHODS

MIL-STD-882 discusses methods of resolving hazards. The first and most desirable method is to eliminate an identified hazard by selection of a design in which the hazard does not appear. If elimination of a hazard is impossible or uneconomical, the next step is to make the design tolerant of the hazard.

Three ways of making a design tolerant of identified hazards are stipulated in MIL-STD-882 in descending order of desirability. The first alternative is to reduce the significance of the hazard through the use of appropriate safety devices. Ideally, such devices should not require human intervention but should operate automatically if the specified hazardous condition arises.

The next choice is to place warning devices in the system to make known to the crew the existence of a hazardous condition. These devices would require human intervention to respond to the warning produced. Audio or visual indicators are commonly used in these instances, but there is a limit to the number of such devices that can be effectively used in one system design. Also such features must be coordinated closely with the human factors engineering function.

The final and least desirable choice is to prepare, disseminate, and enforce special operating procedures for an identified hazardous condition. However, these procedures are a weak link in achievement of system safety because of the inability to verify communication of the procedure to the person who must operate in accordance with such procedures.

3-7.2 SUBSTANTIATION OF HAZARD RESOLUTION

Once each possible hazard has been analyzed for its significance and resolution of the hazard is determined, there is need for assurance that proper corrective action has been taken. This can be accomplished by inspections, additional analyses, and design reviews. Catastrophic, critical, and other identified hazards should not rely solely on warnings, cautions, or procedures for control of risk.

A particular type of design review that can be effective for system safety is an electronic mock-up review. Functional mock-ups can also become an excellent method of identifying additional potential hazards. Also an electronic mock-up brings the subsystems together at an early stage, i.e., before interface problems become too expensive to change.

Fig. 3-3, taken from MIL-HDBK-764(MI) (Ref. 2), provides a sample format for documenting the identification, risk assessment, and corrective action for hazards. There are also automated hazard-tracking systems that can serve this purpose.

The System Safety Risk Assessment (SSRA), as defined by Army Regulation (AR) 385-16, *System Safety Engineering and Management*, (Ref. 3), provides a comprehensive evaluation of the safety risk being assumed for a system. It contains identification of the item or system, and for each re sidual hazard, a description of the hazard and its severity and frequency, a source document or reference, alternative actions that could reduce the hazard level, and a recommendation from the project office regarding risk acceptance. Additionally, the SSRA includes recommendations from the appropriate safety manager, the combat developer, and the materiel developer as to acceptability of the residual risk. Finally, the decision of the appropriate acquisition manager is also recorded in the SSRA.

The Health Hazard Assessment (HHA) is performed by applying biomedical and psychological knowledge and principles to identify, evaluate, and control the risk to the health and effectiveness of personnel who test, use, or service the system. The results of the HHA should be included as an addendum to another required analysis report, such as the System Hazard Analysis Report. The HHA task and format should not be confused with the Health Hazard Assessment Report (HHAR), which is prepared by the Government using data provided by the HHA.

Fig. 3-4, taken from Ref. 4, shows a sample Safety and Health Data Sheet which might be used as part of the internal control process of an organization to record health and safety actions. The Safety and Health Data Sheet along with System Safety Risk Assessments are also documentation requirements supporting the materiel release process.

3-8 SYSTEM SAFETY MANAGEMENT PLAN

The System Safety Management Plan (SSMP) is a description of the planned methods to be used by the Government to monitor the contractor's system safety program and to manage the system safety risks associated with residual hazards.

3-8.1 PURPOSE

The purpose of the SSMP is to define formally the responsibilities and authorities related to the system safety aspects of a program.

3-8.2 CONTENTS

Typically, the SSMP defines the internal management responsibilities of the Government, schedule, and procedures for accomplishment of the system safety management functions that follow:

1. Coordinate and execute procedures to assure appropriate interface with other management functions, e.g., quality assurance, maintenance, research, and development.
2. Establish an audit program to ensure that the objectives and requirements of system safety are attained.
3. Perform liaison with other agencies and commands as needed to attain system safety objectives.
4. Ensure that enough competent persons are assigned to the system safety engineering and management programs to assure proper implementation of system safety.
5. Evaluate, as part of source selection evaluation, the ability of the contractor to include system safety aspects in the final product.
6. Establish the policy and requirements to develop system safety in sufficient detail to identify the safety and health hazards of a system and to remove or control them.
7. Prescribe procedures for management participation in system risk acceptance for residual hazards.

Item/System identification: ________________________________ ________________________________

1. Safety Evaluation Letter/Reports: ________________________________ ____________________

a. Safety Assessment Report: ________________________________ _______________________

b. Safety Analyses/Studies: ________________________________ ________________________

c. Development Test(s): ________________________________ ___________________________

d. Operational Test(s): ________________________________ ____________________________

e. Production Test(s): ________________________________ _____________________________

2. Item does (does not) contain radioactive materials and (if it does) is properly licensed by (NRC #______________________and/or DA Authorization #_______________________as appropriate).

3. Item does (does not) contain explosives/hazardous materials and (if it does) has the following

hazard classifications:a. Quantity-Distance Class: ________________________________ ______

b. Storage Compatibility Group: ________________________________ ____________________

c. DOT Class: ________________________________ ________________________________ ___

d. DOT Marking: ________________________________ ________________________________

e. Conveyor Spacing Distance: ________________________________ _____________________

4. Item does (does not) contain munitions. If it does:

a. Compatibility of the following weapon/ammunition components has been established:

________________________________ ________________________________ _______________

________________________________ ________________________________ _______________

________________________________ ________________________________ _______________

________________________________ ________________________________ _______________

b. Range safety data (for inclusion in AR 385-62 or AR 385-63) was (will be) finalized

(date)________________________________ ________________________________ _________

Sample format, contractor format or program tailored format may be used.

Figure 3-4 Safety and Health Data Sheet (Ref. 4)

8. Provide system safety data for inclusion in requirements documents.

9. Review and approve System Safety Program Plans.

10. Provide a safety readiness position for program milestone reviews or documents associated with reviews, such as Decision Coordinating Papers or Army program memoranda.

11. Review and approve safety verification documents.

12. Provide safety input to major review boards, such as the Level 1 Configuration Control Board and the Materiel Release Review Board.

13. Assist in safety assessments and other reviews for fielded systems.

14. Establish indicators to measure the effectiveness of the system safety effort.

3-9 SYSTEM SAFETY PROGRAM PLAN (SSPP)

System safety should be considered early in any development process. Although concept evaluation becomes the primary focus early in the program, system safety should be an important factor in evaluation of the design concepts. Requirements and methods needed to ensure safety should be considered early. This can be accomplished during all phases of development with a well-defined SSPP. The contractor should propose an SSPP for approval by the Government. The SSPP is a written plan used to outline the steps required to ensure the activities of system safety engineering, system safety management, and other disciplines and functions are used and coordinated to guarantee system safety. The following subparagraphs describe the purpose and content of the SSPP.

3-9.1 PURPOSE

The purpose of the SSPP is to provide a basis of understanding between the contractor and the procuring activity as to how the System Safety Program will be incorporated into the development effort.

3-9.2 CONTENTS

The SSPP should define the System Safety Program scope and objectives. As a minimum, each SSPP should describe the four elements of an effective system safety program: a planned approach to task accomplishment, qualified people to accomplish tasks, authority to accomplish tasks through all levels of management, and appropriate resources—both manning and funding—to assure tasks are completed. The scope is described, and a list of tasks and activities is provided.

The SSPP describes the system safety organization or function within the organization of the total program, the responsibility and authority of system safety personnel, and the staffing of the system safety organization. In addition, it should describe the procedures by which the contractor will integrate and coordinate the system safety efforts and the process through which contractor management decisions will be made.

The SSPP should define System Safety Program milestones, provide a program schedule of safety tasks, and to preclude duplication, identify integrated system activities, i.e., design analyses, tests, and demonstrations, applicable to the System Safety Program but specified in other engineering studies.

The SSPP describes general engineering requirements and design criteria for safety, describes safety requirements for support equipment, and operational safety requirements for all appropriate phases of the life cycle up to and including disposal. It describes the risk assessment procedures and the hazard severity categories, hazard probability levels, and system safety precedence that should be followed to satisfy the safety requirements of MIL-STD-882. It states the quantitative and qualitative measures of safety to be used for risk assessment including a description of the acceptable risk level. It describes closed-loop procedures used to take action to resolve identified hazards.

With respect to hazard analyses, the SSPP describes the analysis techniques and formats to be used in qualitative or quantitative analysis to identify hazards, their causes and effects, hazard elimination, or risk reduction requirements and how those requirements are met. It describes the depth within the system to which each technique is used, including hazard identification associated with the system, subsystem, component, personnel, ground support equipment, Government-furnished equipment (GFE), facilities, and their interrelationship in the logistic support, training, maintenance, and operational environments. It also describes integration of the subcontractor's hazard analyses with overall system hazard analyses.

With respect to system safety data, the SSPP describes the approach to be used to research, distribute, and analyze pertinent historical hazard or mishap data. It identifies deliverable data by title and number. It identifies nondeliverable system safety data and describes the procedures used for access by the procuring activity and to retain data of historical value.

The SSPP describes the verification—test, analysis, inspection, etc.—requirements for ensuring that safety is adequately demonstrated. It identifies the certification requirements for safety devices or other special safety features. It describes the procedures used to ensure test information is transmitted to the procuring activity for review and analysis, and it provides procedures used to ensure safe conduct of all tests.

The SSPP describes the techniques and procedures of an audit program to be used by the contractor to ensure the objectives and requirements of the system safety program are being accomplished.

The SSPP describes the safety training for engineering, technical, operating, and maintenance personnel. It describes the mishap and hazardous malfunction analysis process including alerting the procuring activity to hazardous conditions.

The SSPP identifies in detail the interface between system safety and all other applicable safety disciplines such as nuclear safety, range safety, explosive and ordnance safety, chemical and biological safety, laser safety, nonionizing radiation safety, and any others. In addition, it identifies the interface between system safety and all other support disciplines such as maintenance, quality control, reliability, human factors engineering, medical support (health hazard assessments), and any others.

The SSPP can be submitted as part of a contractor's proposal, or it can be submitted shortly after the start of the contract.

3-10 SAFETY ANALYSES AND ANALYSIS TECHNIQUES

Safety analyses and analysis techniques, as described in MIL-STD-882 and MIL-HDBK-764, are the preliminary hazard analysis, the subsystem hazard analysis, the system hazard analysis, and the operation and support hazard analysis. Although there are a number of other MIL-STD-882 (Ref. 1) tasks, such as preliminary hazard list, health hazard assessment, test and evaluation safety, safety verification, and safety compliance assessment, these tasks are not described in this handbook.

3-10.1 PRELIMINARY HAZARD ANALYSIS

The preliminary hazard analysis (PHA) is the first of a series of safety analyses conducted during the life cycle of a system or item of equipment. The PHA is used to obtain an initial risk assessment of a concept or system. PHA effort should be started during the earliest phases of the program so that safety considerations are included in tradeoff studies and design alternatives. A carefully executed PHA should provide the following information:

1. Specific potential hazards in a proposed system
2. The probable magnitude and frequency of each adverse effect to a proposed system with and without the recommended safeguards. This information can be used in tradeoff studies of alternatives.
3. Proposed measures to eliminate or control the potential hazards
4. The safety-critical equipment and situations upon which the designers must focus their hazard elimination or control efforts
5. Potential events (accidents) that should be subjected to detailed analysis when additional information becomes available
6. Potential personnel errors that can lead to accidents avoidable by design features such as interlocks, warnings, and procedural instructions
7. Identification of specific safety essentials that satisfy requirements in standards, specifications, or similar documents
8. Notes on accidents, near misses, and other potential safety problems uncovered during experience with predecessor systems
9. Potential hazards whose control should be verified through specific safety testing.

3-10.2 SUBSYSTEM HAZARD ANALYSIS

The subsystem hazard analysis (SSHA) identifies hazards associated with the design of subsystems. The analyses should include evaluation of component failure modes, critical human error inputs, and hazards resulting from functional relationships among components and equipment comprising each subsystem. The methods involved in the SSHA are similar to the PHA but are focused on at the subsystem level.

As a minimum, each subsystem should be examined. If a subsystem has been in use for some time, it may be unnecessary for the analysis to go below the subsystem level because the hazards of the subsystem have been identified and corrective action taken. If a subsystem is new and has not had prior use, it may be necessary for the analysis to go to the component level.

The SSHA report should provide the following items:

1. A summary of the results
2. A list of identified hazards that includes the information that follows:

a. Component(s) Failure Mode(s). All failure modes that can result in a hazard are discussed. Generally, failure modes explain "how" something fails.

b. System Event(s) Phase. The mission phase of the system when the hazard is encountered is addressed.

c. Hazard Description. A complete description of the hazard is given.

d. Effect on Subsystem and/or System. The effect of the hazard on the subsystem should be considered. Also the possible upstream and downstream effects should be considered.

e. Risk Assessment. A risk assessment for each hazard, as defined in MIL-STD-882 or other documents applicable to the system, should be given.

f. Recommended Action. The action that should be taken to eliminate the hazard is presented. Various courses of action should be discussed, where appropriate. The recommended actions should be in sufficient detail to be of value to the design engineer.

g. Effect of Recommended Action. The change in the risk assessment that the recommended action will effect should be discussed.

h. Remarks. This block should be used for any information, such as references, administrative information, or data on previous similar systems, that has not been included in other parts of the report.

i. Status. The status of action(s) taken to reduce or control the hazard should be given.

Various methods of analysis have been developed to obtain the data necessary for the SSHA. These include the failure modes effects and criticality analysis, the fault hazard analysis, the fault tree analysis (FTA), and the sneak circuit analysis.

3-10.3 SYSTEM HAZARD ANALYSIS

The system hazard analysis (SHA) is necessary to define the safety interfaces between subsystems and to identify possible safety hazards in the overall system. Typically, it will determine whether system hazards can be eliminated or controlled with design safeguards. The need for procedural safeguards, however, should be recommended only as a last resort. The SHA is usually initiated during the early stages of development and updated as the system matures in order to reflect design changes and any new mission requirements or procedures that might affect system safety.

The SHA analyzes the effect that each subsystem has on all of the others during the normal and abnormal operation of each, but more importantly, it analyzes the operation of the system as a whole. The SHA should establish that separate units and subsystems can be integrated into a safe system. The operation of one unit or subsystem should not impair the safe performance of, or cause damage to, another unit or subsystem within the system. Because the human reactions required for normal system operation are considered part of the system, "human error" should be considered as a possible failure mode in the SHA. Lastly, the environment should have an effect on the system and must be considered in the SHA. The value of an SHA lies in its identification of

1. Interface problems
2. Dependent failure problems
3. Synergistic hazards
4. Additive hazards.

When a safety level has been defined for a specific system, proof that the design satisfies that safety requirement can be obtained only by preparing an SHA. Other safety analyses, studies, test reports, experience with related systems, and program data, such as reliability reports, provide useful support of the SHA.

3-10.4 OPERATION AND SUPPORT HAZARD ANALYSIS

Operation and support hazard analyses (O&SHAs) are methods by which designers and analysts can evaluate the prescribed (and possible alternative) operation and maintenance procedures, foresee potential problems, and take corrective action.

There are two types of O&SHA, i.e., procedure analysis and contingency analysis. The procedure analysis is an evaluation of the adequacy of the various types of operating procedures. The contingency analysis is a study of operational situations that could develop into emergencies and ways to prevent these situations from happening. Each method can be applied equally well to all types of operation.

Most of the considerations in a procedure analysis O&SHA will generally review

1. The procedures by which the equipment will be used or could be misused
2. The consequences of material or procedural human failures
3. The means by which the consequences and failures can be minimized.

A contingency is considered to exist if a system is not in a normal operating state and conditions are such that an accident might occur unless corrective action is taken immediately. This definition assumes that

1. There is some corrective action that can be taken.
2. There is time to take corrective action before an accident occurs.

The contingency analysis should be conducted for any materiel that could become involved in an accident. Even minor items might be improved through small design changes suggested by a contingency analysis. In addition to equipment redesign, the contingency analysis may also suggest changes to the operating procedures and the development of emergency procedures.

3-11 SAFETY CONSIDERATIONS IN NEW TECHNOLOGY

New technologies present unique system safety challenges because by their very nature little experience in their use has been collected and analyzed. The historical database is therefore lacking in determining safety aspects of new technologies. This fact highlights the need for thorough analysis and testing of new technologies prior to their incorporation into systems.

As a first example, consider the situation of a new composite material used in an air vehicle. The curing process might result in the release of hazardous materials during the manufacturing process, during normal use, in the course of maintaining or repairing the material, or during a postcrash fire. A subsystem hazard analysis would identify the new material as presenting such a potential hazard and would lead to the development of corrective actions to minimize the hazard.

As another example, consider a software programmable bus network controller that allows the transfer of data between electronic subsystems on an air vehicle. A latent “bug” in the control software might cause the loss or delay of critical information needed by another subsystem. An SHA would identify the bus network as a critical interface between subsystems and would underscore the need for thorough analysis and evaluation of the proper functioning of the bus software.

Finally, consider an artificial intelligence (AI) or expert system onboard an air vehicle. The system processes threat information from various sensors and provides the pilot with recommended course information to navigate safely among the threat systems. Erroneous advice from such a system due to unforeseen contingencies could have disastrous effects. A properly conducted O&SHA would provide the mechanism for formally assessing contingencies, analyzing their impact on the system, and providing recommendations for corrective actions.

Software system safety deals with developing safety requirements for the system and the software within the system, ensuring accurate translation of safety specification requirements into the design and code of the software, identifying software that controls or influences safety-critical hardware functions, ensuring that the actual coded software does not cause identified or unidentified hazardous functions to occur or inhibit desired functions, and ensuring safety design requirements are thoroughly tested. The requirements for software system safety are delineated in MIL-STD-882. Procedures for conducting safety analyses of software are described in MIL-HDBK-764.

3-12 SAFETY TESTS

Safety tests should be incorporated into appropriate test plans. When approved by the procuring activity, partial verification of safety characteristics or procedures may be demonstrated by laboratory test, functional mock-ups, or model simulation. The detailed test plans for all tests should be reviewed to ensure that

1. Safety, as defined in the requirements documents, is demonstrated adequately.
2. The testing will be carried out in a safe manner.
3. All additional hazards introduced by testing procedures, instrumentation, test hardware, etc., are properly identified and minimized.

3-13 FLIGHT SAFETY PARTS (FSP) PROGRAM

The Flight Safety Parts (FSP) Program is intended to provide enhanced life cycle management and control of parts critical to the safe operation of air vehicles. The governing document for flight safety parts policy is US Army Aviation Systems Command (AVSCOM) Regulation 702-7, *Flight Safety Parts Program Management*, (Ref. 5).

The process of identifying and controlling FSPs should be a total life cycle activity. Because an FSP program generally remains critical throughout its life cycle, a program should be established to address identification and control of FSPs from development through procurement, production, and final disposition. The procuring activity (PA) should establish a program for FSPs. The PA should require that the air vehicle and engine contractors include management and control of FSPs as part of their overall program plan.

In general, the process of identification of FSPs should be based primarily on engineering judgment. Also past experience on similar systems and hazard analyses should play a vital role in the process. The intent is to identify each item that might create a critical condition in terms of safety or loss of the end-item if the part breaks, malfunctions, or is missing during use. Once an item is designated as an FSP, the appropriate engineering drawings should be updated to identify all critical characteristics. FSPs should also be identified in all overhaul, repair, and maintenance publications.

A critical characteristic is any feature throughout the life cycle of an FSP, such as dimension, tolerance, finish, material or assembly, manufacturing or inspection process, operation, field maintenance, or depot overhaul requirement that if nonconforming, missing, or degraded, could cause the failure or malfunction of the FSP. Critical characteristics determined during the manufacturing process are termed "manufacturing-critical" characteristics. Critical characteristics that are not introduced during the manufacture of a part but are critical in terms of assembly and installation, e.g., proper torque, are termed "installation-critical" characteristics.

One of the most important aspects of the FSP program should be the control of critical characteristics. Control means those actions and techniques that receive special consideration and attention to detail, e.g., manufacturing and assembly procedures, frozen planning, certification of special processes, intensified inspection and verification procedures, recordkeeping and maintenance, traceability audits, vendor control, and nonconformance control. Once a part has been identified as an FSP, there are several key elements that should be used for its control:

1. All critical characteristics should be identified by the designers. Technical drawings and data packages (if any) should be updated to show the FSP and highlight its critical characteristics.

2. The planning documents by which the part is manufactured and quality inspected should be approved by a "high-level" interdisciplinary board to ensure proper controls are in place to maintain the critical characteristics. Once approved, the procedures should be "frozen" and should not be changed, varied, or waived. Only a formal change, again approved by the board, should constitute any change in procedure.

3. All critical characteristics of the FSP that can be nondestructively inspected and tested should receive 100% inspection by qualified inspectors for every part manufactured. Parts having critical characteristics that require destructive testing, i.e., strength of material, heat treatment, etc., should be tested on the basis of statistical samples taken from every lot and every batch. A sample should be tested from every lot and batch without exception.

4. Manuals, including depot maintenance work requirements (DMWRs) should be revised as needed to include the critical characteristics. No repair or overhaul action should be permitted to deviate from the drawing specification for the critical characteristics. These documents are typically prepared by a contractor and submitted for Government approval.

Acceptance of parts that do not conform to the specified critical characteristics should not be authorized through actions of the Materiel Review Board. If possible, parts may be reworked to satisfy the specifications, or requirements, given on the drawing. Requests for waivers of and deviations from critical characteristics should be classified as major or critical and should be submitted for Government approval on a case-by-case basis. Any change of the critical characteristics usually requires reexamination of the product, retest, or engineering analysis of the part and process before it is considered.

A description of the procedures to identify, qualify, maintain records, monitor, and dispose of FSPs may be found in the subparagraphs that follow.

3-13.1 IDENTIFICATION OF FLIGHT SAFETY PARTS

The process of identifying candidate flight safety parts should be primarily one of risk management involving engineering judgment and experience. This process should include review of drawings, materials, loads, flight spectrum, fatigue analyses, reliability analyses, form, fit, and function, installation requirements, and failure data. The criteria that follow should be used to identify flight safety-critical aircraft parts:

1. *Airframe*. Any part whose failure or malfunction affects the safe operation of an air vehicle is a candidate for an FSP. Final selection of an FSP should be considered if Item a and any other of Items b through e are affirmative:

a. Primary failure or malfunction affects the safe operation of the air vehicle.

b. A part has a predicted or demonstrated finite life.

c. A 10% reduction in laboratory working strength would result in an unlimited life becoming a finite life.

d. Loss of function could occur because of improper assembly or installation.

e. Fabrication of the part involves a manufacturing process that, if performed improperly, has a high probability of changing material properties significantly, i.e., degrading the strength of the part.

2. *Engine*. An FSP for engine-type parts is defined as any part, assembly, or installation containing a critical characteristic whose failure, malfunction, or absence could cause an undirected engine shutdown or a catastrophic engine failure resulting in loss or serious damage to an air vehicle or serious injury or death to the occupants. Engine FSP identification should be based on assessment of potential associated risk using hazard severity and probability of occurrence as discussed in MIL-STD-882, *System Safety Program Requirement*, (Ref. 1).

3-13.2 FLIGHT SAFETY PARTS QUALIFICATION

To assure continuous availability of the product, FSP vendors should be qualified in advance of procurement actions. Vendor qualification provides a means for early completion of long, complex, or expensive tests, such as fatigue and flight tests, some of which would otherwise be required after each award and without any insurance that the vendor's parts would be acceptable. Typically, a Qualified Product List (QPL) is used to record all qualified vendors from whom FSPs can be procured. Vendors should qualify by meeting the test requirements, such as fatigue, interchangeability, and endurance, for each FSP. The requirements of establishing a QPL, testing, etc., are discussed in DoD 4120.3-M, *Defense Standardization Program Policies and Procedures*, (Ref. 6). Qualification of FSP vendors should include but not necessarily be limited to the demonstration of FSP critical characteristics. Engine FSP vendors might not be required to demonstrate full-life limits due to cost and other constraints. Engine endurance testing and low cycle fatigue testing plus spin-pit testing could be used to demonstrate a portion of part life in lieu of demonstrating the full life. Also an increased level of quality assurance should be required for all FSPs even if previously qualified. See par. 3-13 for 100% inspection requirements, waivers, and deviations.

3-13.3 FLIGHT SAFETY PARTS RECORDS

All flight safety parts should be given a serial number whenever possible. Otherwise, lot or bag and tag procedures should be substituted. All manufacturing or inspection process control requirements relating to the flight safety part should be traceable to the time and location of production. Records should provide the traceability required to enable after-the-fact verification of all aspects of material, manufacture, special processing, assembly, and inspection of critical characteristics. These special records allow the rapid recall of fielded suspect flight safety parts if a deficiency in manufacturing or processing is encountered. Typically, these records are required to be kept by the manufacturer or delivered to the Government for retention until the last part in the record is removed from service.

3-13.4 FLIGHT SAFETY PARTS SURVEILLANCE

The FSPs Surveillance Program should include a formal process for sampling all FSPs on a recurring basis. The surveillance effort should use data obtained from the FSP Program for the following purposes:

1. To confirm the validity of requirements used during the initial design and qualification of FSPs
2. To monitor the effects of use on parts to demonstrate that replacement and overhaul intervals are adequate and safe relative to actual use
3. To assess new parts continually to ensure minor design and manufacturing changes do not affect FSPs in a detrimental manner
4. To confirm degraded mode limits or effects due to wear, corrosion, fretting, and damage
5. To ensure that repair procedures do not degrade the critical characteristics
6. To determine the impact on FSPs of any previously unknown or known degraded conditions
7. To ensure that processes are adequate to control time-related internal procedures of previously approved vendors (if any) and that new vendors are not impacting the integrity of the FSPs
8. To ensure that undefined changes in rotorcraft usage, new environments, or long-term effects do not impact the integrity of FSPs.

3-13.5 FLIGHT SAFETY PARTS DISPOSITION

Flight safety parts that have been removed from service because they fail inspection criteria, fail in service, or whose life limit has been reached should be destroyed to preclude the inadvertent reinstallation of the part or its remanufacture. This extra effort is necessary because the reuse of such parts could lead to failures resulting in unsafe operation of the air vehicle. Air vehicle development programs should have a disposition clause to control flight safety parts and prevent installation of nonconforming FSPs on production units.

REFERENCES

1. MIL-STD-882C, *System Safety Program Requirement*, 19 January 1993.

2. MIL-HDBK-764(MI), *System Safety Engineering Design Guide for Army Materiel*, 12 January 1990.

3. AR 385-16, *System Safety Engineering and Management*, 3 May 1990.

4. AMC Supplement to AR 385-16, System Safety Engineering and Management, US Army Materiel Command, Alexandria, VA, 23 March 1992.

5. AVSCOM Regulation 702-7, *Flight Safety Parts Program Management*, US Army Aviation Systems Command, St. Louis, MO, 13 August 1990.

6. DoD 4120.3-M, *Defense Standardization Program Policies and Procedures*, July 1993.

CHAPTER 4

This chapter presents typical requirements for technical reviews, data, and documentation necessary to support the qualification of rotorcraft and other air vehicles. Information on technical reviews include program progress reviews, preliminary and critical design reviews, flight and firing readiness reviews, software reviews, special technical reviews, and integrated product team reviews (IPTs). Data and documentation requirements are provided for component, subsystem, and system qualification.

4-1 **INTRODUCTION**

Technical reviews , data and documentation form the basis for presenting the status and results of the airworthiness qualification process. They are the means by which the contractor conveys to the Government the technical characteristics of the item under development or modification. By the same token, Government review and comments to contractor reviews, data, and documentation are the vehicle for the Government to present its assessment of the contractor's qualification activities. This chapter addresses the various types of reviews that might be required; however, integrated product team (IPT) reviews are preferred, see Department of Defense Regulation No. 5000.2-R, *Mandatory Procedures for Major Defense Acquisition Program (MDAPs) and Major Automated Information System (MAIS) Acquisition Program*, (Ref. 1).

4-2 CONTRACT DATA

Contract data include such things as test plans, test reports, technical analyses, specifications, drawings, and other reports that are generated during the development process and delivered to the Government as a contractual requirement. These data serve several functions, including configuration control, documentation of test results, and provide the basis for reprocurement. The data may be informative only, or for review, approval, or other action.

4-2.1 REQUIREMENTS

Proposed data requirements should be established by an Integrated product team (IPT). Only the minimum data needed to permit cost-effective support of research, development, production, cataloging, provisioning, training , operation, training, maintenance, and related logistics functions over the life cycle of the item should be acquired.

TABLE 4-1 provides a representative sample of data items that may be required to support a qualification effort. This table is a representation of a management tool only, and does not pertain to any specific program. The table shows the reference in the airworthiness qualification plan (AQP) which requires the preparation of the data, a description of the data, a reference to the data item description (DID) (subparagraph 4-2.2), the submittal requirements for the data, and the form in which the data is to be presented.

4-2.2 DATA ITEM DESCRIPTIONS

The DID is a redefined description for a specific type of data, and it specifies how the data is to be prepared and presented. DoD 5010.12.1, The Acquisition Management Systems and Data Requirements Control List (AMSDL), periodically updated, (Ref. 2) provides a list of Office of Management and Budget

(OMB) cleared current data item descriptions that have been assigned OMB control number 0704-0188

TABLE 4-1

TASK-DATA MATRIX

AQP Para	Data Description	DID	Submittal Requirements	Form
1.5.4.1	Airworthiness Qualification Spec (AQS)	DI-CMAN-80008A	60 MAC	Hard copy and MS-Word Disk
1.5.5.2	Specifications	DI-E-1104A	90 DAC	Hard Copy
6.2.5.2	NBC Contamination Survivability Final Report	DI-MISC-80711	FF	Hard Copy
6.3.1.1	Test/Inspection Reports	DI-NDTI-80809A	60 DAT	Hard Copy
6.3.1.2.	Scientific and Technical Report	DI-MISC-80711	As Required	Hard Copy
6.3.8.2	Electromagnetic Interference Test Plan	DI-EMCS-60201A	120 DAC	Hard Copy

MAC Months after contract award
D With Draft Proposal
DAC Days after contract award
DAT Days after test
F With Final Proposal Flight
M Monthly

The AMSDL is used to find DIDs by identification number, title, and subject matter. Requests for individual DIDs or the AMSDL will be honored from military activities, Government agencies, private industry, and individuals.

4-2.3 CONTRACT DATA REQUIREMENTS

The formal and contractual mechanism for the Government to require the preparation and submittal of data is through the Contract Data Requirements List (CDRL), DD Form 1423. The CDRL is the portion of contract that identifies the specific data that the contractor should prepare and submit as part of its effort under the contract. The CDRL contains the reference number and title of the data item being procured; the DID (paragraph 4-2.2) number; and a reference to the portion of the contract (usually a statement of work or system specification) that requires the generation of the data item. In addition, the CDRL includes administrative data such as the Government office of primary technical responsibility of the submittal; location for performance of Government inspection and approval; frequency of submittal of the data; and the number of copies and required medium for submittal.

Continuous Acquisition and Life-cycle Support (CALS) (previously known as Computer-Aided Acquisition and Logistics Support) is the Department of Defense (DoD) effort to migrate from a manual, paper-intensive defense system operation to an integrated highly automated acquisition and support process. Based on modeling efforts reflected in the current CALS Architecture Study, the Director of Defense Information created the DoD Enterprise Model to depict the activities and data needed to accomplish the defense mission. CALS will expand the architecture to include the bridge linking DoD with industry and international participants. CALS will also define the infrastructure required to integrate DoD and industry databases into one logical weapon system database - referred to as the Integrated Weapon System Database (ISWDB). A key initiative supporting this goal is optimization of information technology and the construction of a National Infrastructure - "Information Superhighways." All new contracts should require on-line access to, or delivery of, their programmatic and technical data in digital form, unless analysis shows that life-cycle time or life-cycle cost would be increased by doing so, DoDR 5000.2-R, (Ref. 2).

4-3 CLASSIFIED AND CONTROLLED DATA

Classified dat a and its' related requirements are discussed in the subparagraphs which follow.

4-3.1 CLASSIFIED DATA

Classified data is data that the US Government has determined to be of such a nature that its uncontrolled release would be detrimental to US security interests. Requirements for safeguarding classified data are described in paragraphs 4-3.1.1 and 4-3.1.2 for Army and contractor activities, respectively.

4-3.1.1 Army Requirements

AR-380-5, *Department of the Army Information Security Program*, (Ref. 3) is the Army's implementation of the requirements for information security. It establishes a system for classification, downgrading, and declassification of information requiring protection in the interest of National security. It contains policy and procedures for safeguarding such information and provides for program oversight and administrative sanctions for violations. Specific topics addressed include classification, declassification and downgrading, marking of information, safekeeping and storage, access, dissemination, accountability, disposal and destruction, security education, foreign Government information, special access programs, program management, and safeguarding Joint Chiefs of Staff papers. Key to determining the classification of technical data of a program is the security classification guide for that program. The guide is a document issued by an authorized original classifier that prescribes the level of classification and appropriate declassification instructions for the information.

4-3.1.2 Industrial Requirements

Executive Order 12829, *National Industrial Security Program*, (Ref. 4) and DoD 5220.22-M, *National Industrial Security Program Operating Manual*, (Ref. 5) establish the requirements for safeguarding classified information provided to industrial, commercial, and educational institutions under the provisions of a DoD Security Agreement (DD Form 441). These documents provide specific information as to whom will have access to classified information, how that information is to be shipped, stored, and disposed of, and the record keeping activities required for classified information. In addition to the requirements of these DoD publications, each organization that has classified information safeguarding responsibilities is required to establish and follow its own "standard practice procedures" (SPP) that take into account the organization's specific situation. Further, organizations that use computers for processing classified information are required to develop and implement an Automated Information System (AIS) addendum to the SPP.

4-3.2 CONTROLLED DATA

The Congress declared it to be the policy of the United States to use export controls to the extent necessary to restrict the export of goods and technology that could make a significant contribution to the military potential of any other country or combination of countries that would prove detrimental to the national interests. Controlled data is that type of data whose distribution is limited and requires special handling but yet whose content does not warrant marking it as classified data. Sensitive test reports that may reveal critical characteristics of a weapon system are an example of such controlled data. Controlled data should have an appropriate distribution statement as provided for in DoD Directive 5230-24, *Distribution Statements on Technical Documents*, (Ref. 6) on such data.

4-4 APPLICABLE DOCUMENTS

Documents that are included in a contract, specification, plan, or other requirement's document by reference are referred to as applicable documents. Tiering from one specification or standard to another is discouraged. All requirements should be tailored to the performance needs and should be clearly specified in the contract. The use of government specifications and standards should be minimized if not eliminated. Use of widely available commercial standards, such as ASTM, ANSI, FARs, IEE, SAE, etc., should be encouraged.

4-5 PROGRAM PLANS

The purpose of program plans is to provide a road map for determining how the qualification effort is to be accomplished. Program plans belong to the Project, Program, or Weapons System Manager (PM) and are to be used by the PM to manage program execution throughout the life-cycle of the program. Program plans are a description of the detailed activities necessary to carry out program strategies. The PM, in coordination with the PEO, determines the type and number of program plans. Three or more plans might be required, such as an integrated program plan, airworthiness qualification plan, and a test and evaluation master plan (TEMP). Data generated in performance of the work required by these plans is submitted in accordance with CDRL requirements. A brief description of each of the aforementioned plans follows:

1. Integrated Program Plan - The integrated program plan should provide a road map for the entire project. It should define the following:

a. Integrated product team - Intended use of product teams. Number of teams and their purpose. Contractor support and participation in Government integrated teams.

b. System Safety - a basis of understanding between the contractor and the procuring activity as to how system safety requirements will be incorporated into hardware, software, and operating instructions and procedures.

c. Reliability - a basis of understanding between the contractor and the procuring activity as to how reliability performance requirements, reliability growth requirements, reliability tests, and reliability data will be identified, incorporated, accomplished or collected.

d. Human Factors - scope and obligation of the contractor to meet human factors performance requirements and obtain human factors data.

e. Maintainability - a basis of understanding between the contractor and the procuring activity as to how maintainability performance requirements will be identified, and demonstrated.

f. Other - a basis of understanding between the contractor and the procuring activity as to what other engineering activities, such as configuration control, producibility , transportability, weaponization, advanced quality system, etc., are required for execution of the contract.

2. Airworthiness Qualification Plan - An airworthiness qualification plan should be prepared by the procuring activity and included in the request for proposal or request for quotation. An integrated product team approach should be used for preparing the plan. This plan should provide general guidance on engineering analyses, design reviews. safety assessments, contractor demonstrations, and all contractor and Government qualification tests considered essential to defining and implementing the procurement of any major Army air vehicle, major modification, and its allied equipment. This general information than will provide the basis for an airworthiness qualification specification which should be prepared by the contractor.

3. Test and Evaluation Master Plan - planning document used to generate

detailed test and evaluation plans to ascertain schedule and resource implications. The TEMP should provide a road map for integrated simulation, test, and evaluation plans, schedules, and resource requirements necessary to accomplish the test and evaluation program.

4-6 TECHNICAL REVIEWS AND AUDITS

The PM decides how the program is to be managed. The PM may choose to have formal or informal periodic reviews, or could rely on continuous integrated product team reviews. Also, the PM could rely on the contractor to propose the type of reviews and audits to be used. The agenda for these reviews should be coordinated between contractor and government representatives several weeks prior to the meeting. Meetings should not only provide for Government oversight; but, should also provide insight. The objectives and typical requirements of the following type reviews will be discussed in this paragraph:

Program Progress Reviews
Preliminary Design Reviews
Critical Design Reviews
Flight Readiness Reviews
Firing Readiness Reviews
Special Technical Reviews
Software Reviews
Configuration Audits
Technical Interchange Reviews
Integrated Product Team Reviews

4-6.1 PROGRAM PROGRESS REVIEWS

A Program Progress Review is a periodic review conducted by the contractor to present the status of the development program. It is at this review that Government representatives gain knowledge of the overall progress of the contractor's activities. The contractor should describe the status of his design effort in terms of the number of drawings and specifications released versus a projected release schedule. The program progress review should include but not be limited to a system requirements review (SRR) where the system/segment specification (SSS), the proposed computer languages, and processing hardware architecture are reviewed; and also a system design review (SDR) where the system/segment design document (SSDD) and a preliminary software requirements specification (SRS) are reviewed. Estimates of software lines of code written versus projections should also be presented. The results of analysis work to substantiate that design requirements will be met may be discussed. As the development effort progresses, the contractor would typically present test results and planned testing activities. It is at these reviews that problems are identified either by the contractor or Government representatives and that potential solutions are discussed and reviewed in subsequent meetings. The frequency of these reviews and the specific topics covered are strongly dependent on the stage of developments.

4-6.2 PRELIMINARY DESIGN REVIEWS

The preliminary design review (PDR) is a formal review of the basic design approach for a configuration item or a functionally related group of configuration items. It is conducted after the development specifications are developed. During the PDR, special attention is directed toward interface documentation, high risk areas, long lead times, and system level trade studies that integrate preliminary design concepts. Software and hardware PDRs have the same objectives and are conducted in a similar manner, but may address different issues related to the qualification process. The objectives of these one time formal reviews could also be satisfied by integrated product team reviews. Qualification relevant data and issues to be addressed at a hardware PDR include:

1. A preliminary design synthesis that shows that the selected design will meet its development specification requirements
2. The results of tradeoff studies that show the alternatives considered for the design and the basis for the selection of the proposed approach
3. Functional flows, requirements allocation and tractability data, and schematic diagrams
4. Layout drawings showing the functional relationships between elements
5. Analyses showing the results of environmental control and thermal design aspects
6. Analyses showing proper consideration of electromagnetic compatibility aspects of the design
7. Power distribution and grounding aspects of the preliminary design, including power regulation and compatibility between power generation and utilization equipment
8. Preliminary mechanical and packaging design of consoles, racks, drawers, printed circuit boards, and connectors
9. Safety engineering considerations
10. Security engineering considerations
11. Survivability and vulnerability (including nuclear, biological, and chemical as well as signatures and crashworthiness) considerations
12. Design margins - cycle margins, memory margins,
13. Preliminary lists of materials, parts and processes
14. Built-In-Test
15. Reliability , availability, and maintainability data, including failure modes and effects
16. Weight and balance status
17. Development test data
18. Interface requirements
19. Instrumentation interfaces and requirements for flight test telemetry
20. Development schedule
21. Mock-ups, models, breadboards, or prototype hardware when appropriate
22. Producibility and manufacturing considerations
23. Value engineering considerations
24. Transportability, packaging, and handling considerations
25. Human engineering and biomedical considerations
26. Standardization considerations
27. Description and characteristics of commercially available equipment
28. Existing documentation for commercially available equipment
29. Data processing hardware , e.g., microprocessors, programmable array logic (PAL), programmable logic devices (PLD), and gate arrays to be provided with the system
30. Review considerations applicable to computer resource hardware items as appropriate, e.g., microprocessor, non-volatile memory (NVM), and application specific integrated circuits (ASIC).
31. Life cycle cost analysis
32. Armament compatibility

33. Corrosion prevention/control considerations

34. Status of Quality Assurance Program

35. Support equipment requirements

Typical issues to be addressed at a software critical design review (CDR) include:

1. Functional flow
2. Storage allocation data
3. Control function description
4. Computer Software Configuration Item structure
5. Built-In-Test
6. Security considerations
7. Reentrance considerations
8. Computer software development facilities
9. Relationship between the computer software development facility and the operational system
10. Software development tools
11. Software test tools
12. Maintenance and upgrade interfaces, requirements, and techniques
13. Description and characteristics of commercially available computer resources
14. Existing documentation for commercially available computer resources
15. Software support resources
16. Operation and support documents
17. Software related CDRL items
18. Supplemental data (e.g.; software files, procedures) required for use with the "make-from" hardware device should be documented.

Firmware has both hardware and software parts separately handled at the applicable PDRS. The memory portion of firmware is usually referred to an embedded memory. Firmware is defined as software that has been implemented in hardware using memory devices such as read only memory (ROM), programmable ROM (PROM), erasable PROM (EPROM), and electrically erasable PROM (EEPROM). These devices, and other similar devices which are genetically referred to as integrated circuits, allow software to be permanently implemented and not easily changed.

4-6.3 CRITICAL DESIGN REVIEWS

The Critical Design Review is conducted prior to the release for fabrication or production in the case of hardware or prior to the initiation of coding in the case of software. During the CDR, the detailed design for each configuration item is disclosed in the form of a draft product specification (Type C) and related engineering drawings. The approved detailed design from this review serves as a basis for final production planning and often initial fabrication. In the case of software, completion of the CDR initiates the development of source and object code. A primary objective of the CDR should be to insure the qualification requirements will be met. The objectives of these one time formal reviews could also be satisfied by integrated product team reviews. For a hardware CDR, the following issues are typically addressed:

1. Adequacy of the detail design as reflected in the draft hardware product specifications in satisfying the hardware development specification requirements.
2. Adequacy of the detailed engineering drawings for the hardware configuration item, including schematic diagrams.
3. Adequacy of the detailed design in the following areas:
   a. Electrical design
   b. Mechanical design

c. Environmental control and thermal design aspects

d. Electromagnetic compatibility

e. Power generation and grounding

f. Electrical and mechanical interface compatibility

g. Mass properties

h. Survivability and vulnerabili ty (including nuclear, biological, and chemical, as well as signatures and crashworthiness considerations)

4. Interface control drawings

5. Mock-ups, breadboards, and prototype hardware

6. System allocation document

7. Initial manufacturing readiness

8. Preliminary value engineering change proposals

9. Life cycle costs

10. Detail design information on all firmware

11. Verification that corrosion prevention and control considerations are compatible with the operating environment

12. Status of quality assurance program.

At the CDR for systems that incorporate software, the following deliverables would be reviewed for accuracy and suitability:

1. Software detailed design data, data base design, and interface design documents

2. Supporting documentation describing results of analyses and testing

3. System allocation document

4. Progress on activities required by the PDR

5. Schedules for remaining milestones

6. Updates of software related CDRL items.

4-6.4 FLIGHT READINESS REVIEWS

Flight readiness reviews are conducted prior to first flight, prior to any subsequent flight for which the configuration of the air vehicle or software has significantly changed, and prior to conducting flight test activities which have not been covered in previous flight readiness reviews. The objective of the review is to ensure that all airworthiness and qualification relevant issues have been addressed and that the hardware and software are sufficiently mature to warrant proceeding with flight testing. Data required for presentation at flight readiness reviews includes (yet, is not limited to include) analysis data, results of design support test, component design and qualification data, subsystem design and qualification data, and system design and qualification data, operating procedures, limitations and restrictions, software version descriptions for flight critical processors, modeling complete, and remaining hazard analysis for software and hardware. See integrated product team reviews.

The nature of the data and degree of detail of data presented at the flight readiness review must be such that they will support the anticipated contractor flight releases and/or airworthiness releases. See integrated product team reviews.

4-6.5 FIRING READINESS REVIEWS

Firing readiness reviews are conducted to ensure that the system hardware and software are sufficiently mature to allow safe weapons firing. Included as a firing readiness review is the pre-first-live-firing weapon firing review. This review is conducted before the first live firing. Qualification data to be presented include missile or projectile trajectory and structural clearance information, weapon firing modes, firing inhibits for specific flight conditions, clearance, jettison analysis or jettison results, ripple firing effect on engine performance, firing impact zone safety footprint, susceptibility to electromagnetic radiation emitters, ordnance compatibility information, weapon system excursion limits, primary and emergency weapon stores jettison information, provisions for protecting the crew from weapon gases, and blast pressure distribution information. The nature of the data and degree of detail should be such that they will support the anticipated weapon firing activities to be authorized by the contractor flight releases and airworthiness releases. Additional firing readiness reviews should be conducted when the proposed firing tests differ significantly from those approved by previous firing readiness reviews. See integrated product team reviews.

4-6.6 SPECIAL TECHNICAL REVIEWS

Special technical reviews may be conducted any time that such reviews are necessary for the proper progress of the qualification program. For example, in order to support his design activities, the contractor may have decided to build a mock-up for the purpose of identifying and demonstrating interface requirements between subsystems. The most expedient way for the Government to review the results of the mock-up activities may be to attend a special technical review convened for that purpose. As another example, a specific technical problem may arise which would require a special technical review to be conducted. The contractor would present the problem and possible alternative solutions. Government reviewers would discuss the situation and implications on technical, schedule, cost, and contractual issues and provide direction or guidance as necessary. As a last example, a backlog of data may have occurred which precludes the conduct of a test event until the data is reviewed. The most efficient and expedient way to resolve the problem may be for the Government to review the backlogged data at a special technical review. See integrated product team reviews.

4-6.7 SOFTWARE REVIEWS

In addition to the software PDRs and CDRS, software also undergoes software specification reviews (SSRs), SDRS, and software Test Readiness Reviews (TRR). The SSR is a formal review of computer software configuration item (CSCI) requirements as specified in the software specifications. The purpose of the SSR is to review the software and interface requirements stated in the software requirements specification (SRS) and the interface requirements specification (IRS) for completeness and tractability to the system specification. The TRR is a formal review of readiness to begin formal CSCI testing. The purpose of the software TRR is to confirm that the computer software configuration item is ready for formal qualification testing. See integrated product team reviews.

4-6.8 CONFIGURATION AUDITS

A configuration audit is an audit conducted against a configuration item to ensure that it meets requirements. Two types of configuration audits could be conducted, the functional configuration audit (FCA) and the physical configuration audit (PCA). The objective of the FCA is to verify that the configuration item's actual performance complies with its hardware development or software requirement and interface requirements' specifications. Test data are reviewed to verify that the hardware or computer software performs as required by its functional or allocated configuration identification. For configuration items developed at Government expense, an FCA is a prerequisite to acceptance of the configuration item. For software, a technical understanding is reached on the validity and the degree of completeness of the software test reports, and, as appropriate, computer system operator's manual, software user's manual, computer system diagnostic manual, computer resources integrated support document, upgraded operation and support documents, software programmer's manual, and firmware support manual.

The PCA is the formal examination of the as-built version of the configuration item against its design documentation in order to establish the product baseline. As a result of acquisition reforms, the contractor is totally responsible for the physical configuration. Except for validation of technical manuals, the procuring activity will not typically perform a physical audit. The contractor should be required to update the technical manuals, anytime the physical configuration changes. For software, a technical understanding is reached on the validity and the degree of completeness of the software test reports, and, as appropriate, computer system operator's manual, software user's manual, computer system diagnostic manual, computer resources integrated support document, upgraded operation and support documents, software programmer's manual, and firmware support manual.

4-6.9 INTEGRATED PRODUCT TEAM (IPT) REVIEWS

The objectives of the aforementioned reviews could be satisfied on a continuous basis by IPTs. The Secretary of Defense has directed that as many functions as possible, including oversight and review, should be performed using IPTs, DoDR 5000.2-R, (Ref. 1). IPTs are cross-functional teams that are formed for the specific purpose of delivering a product for an external or internal customer. These IPTs should function in a spirit of teamwork with participants empowered and authorized, to the maximum extent possible, to make commitments for the organization or the functional area they represent. IPTs are composed of representatives from all appropriate functional disciplines. IPTs operate under the following broad principals:

1. Open discussions with no secrets.
2. Qualified, empowered team members
3. Consistent, success-oriented, proactive participation
4. Continuous "up-the-line" communications
5. Reasoned disagreement
6. Issues raised and resolved early

4-7 COMPONENT DESIGN AND QUALIFICATION DATA

This paragraph describes the design and qualification data applicable at the component level. The contractor is totally responsible for the physical design. Normally, qualification involves a review of performance, interface, safety, and the various "Itities", such as reliability and maintainability, via analysis and test reports. Engineering drawings are also useful for this purpose but not always essential. Performance and interface specifications are preferred for new procurement and for procurement of commercially developed components, reference chapter 5, subparagraph 5.11.1. Widely available commercial specifications and standards which satisfy the government's preference for performance based specifications are also acceptable. In those cases where the Government must pay for development of the design, the Government typically is entitled to full rights in data; hence, procurement of engineering and manufacturing drawings or computer aided design and manufacturing data should be considered. Contractor's form and format is usually acceptable. Also, the contractor could remain the repository for this data. Except for reprocurement of an identical component, performance and interface verification data should be required for all components. The data should define all design specific performance requirements, all as integrated and as installed characteristics, and all key functional and physical attributes to be measured. Further, a software requirements specification might be needed for embedded software, etc. Logistics considerations usually dictate the type of data and required rights in data. For the case of contractor logistics support, only qualification data should be required.

4-7.1 STANDARD AND QUALIFIED PARTS DATA

For standardization purposes, a program establishes its Program Part Selection List (PPSL). The PPSL is generally established and managed by the contractor, but may be approved by the government. Items on the list are approved for use in the design provided that they meet the performance and interface requirements of the system. As long as the part usage is consistent with its original qualification criteria, the part may generally be used in the design without additional qualification requirements. The PPSL becomes the governing document for part selection for the subject contract in order to control the scope of total parts population, compress the variety of part types, and to direct contract and subcontract designers to approved parts. The contractor could be required to submit their list for Government review.

4-7.2 STRUCTURAL COMPONENTS DATA

Paragraph 4-7 defines the type of data which should be required. Structural performance criteria should be defined in terms of mission, crashworthiness, and dynamic performance requirements. Also, the PA should require demonstration of compliance by means of analysis and test reports. Structural analysis should include material composition, heat treatment characteristics, finish characteristics, and geometric shape. Also, tensile strength, modulus of elasticity, fatigue life, modulus of rupture, shear strength, endurance limit, compressive strength and hardness should be included, as applicable. In contrast to most metals, composite materials exhibit structural characteristics which are strongly dependent on the direction of the applied load. In describing composite material characteristics, it is necessary to specify the direction of the applied load with respect to the directional characteristic of the material. Analysis may include determination of the loadings that are critical to the component, and substantiation of the structural adequacy. Structural component testing may include fatigue testing, failure mode testing, and ultimate strength testing.

4-7.3 ENGINE AND DRIVE TRAIN COMPONENTS DATA

Paragraph 4-7 defines the type of data which should be required. Engine and drive train components include as examples, gears, bearings, shafts, couplings, clutches, housings, turbine blades, compressor blades, discs, nozzles, seals, combustors, ignitors, and fuel controls. Component qualification data describing these components may be in the form of performance specifications, analyses, and reports. Examples of bearing characteristics are static load carrying capacity (radial and trust), dynamic load capacity, life, efficiency, friction, and speed rating. Examples of gear characteristics are load capacity, mesh ratio, contact ratio, backlash, surface durability, lubrication requirements, and hardness. Shafts are characterized by their ability to withstand combined bending and torsional stresses which may either be steady, variable, or a combination of the two. Lubrication characteristics, cooling and wear tests, gear patterns, and power limits are all applicable to engine and drive train components.

4-7.4 HYDRAULIC-PNEUMATIC-FUEL SYSTEMS COMPONENTS DATA

Paragraph 4-7 defines the type of data which should be required. Hydraulic , pneumatic, and fuel systems share the common characteristics of pressurized fluids. Examples of components which comprise these systems include tubes, pipes, hoses, fittings, valves, couplers, pumps, fans, accumulators, and filters. These components, as part of subsystems, are used to actuate controls, deliver fluids such as fuel and lubricants, and to provide environmental control. Component qualification data used to describe these components typically include schematics and diagrams, and test and analysis reports. Examples of information included as part of the data are working pressure or vacuum (the pressure or vacuum at which the component is designed to operate), fluid compatibility (the types of fluids which will come in contact with the component), fire resistance (the temperature and pressure conditions at which the fluid will ignite), ballistic tolerance (the degree to which the component can withstand an impact from a projectile), and grounding requirements (the necessity to electrically connect components to avoid electrical potential differences between components). Filters separate unwanted contaminants from a fluid. They are characterized by flow rate (the amount of fluid which can pass through the filter per unit time), clean pressure drop (the pressure difference which the filter presents to fluid moving through it), cold surge (pressure rise at start up when cold), its contaminant effectiveness (the size and fraction of particles in the case of particle contamination or the amount of contaminant such as water in the case of non particle filtering which the filter can separate from the fluid), the contaminant load capacity, and the bypass characteristics.

4-7.5 ELECTRONIC COMPONENTS DATA

Paragraph 4-7 defines the type of data which should be required. Also, descriptions from manufacturers' data books along with industry and military specifications and standards provide a description of the operation of the parts along with appropriate hints and warnings. Electronic and schematic diagrams show the logical layout. Timing diagrams show critical timing requirements. Truth tables combined with the logic diagrams and timing diagrams describe the output states of a logic device based on its input states. MIL-HDBK-175, *Microelectronics Device Data Handbook*, (Ref. 7) and MIL-HDBK-978 , *NASA Parts and Application Handbook*, (Ref. 8) present detailed information on the characteristics of electronic devices. These handbooks address basic process and design considerations, system design considerations, testing, specifications and procurement, along with the reliability and physics of failure.

Typical electronic components are as follows:

1. Linear passive components - resistors, capacitors, thermistors, inductors, crystals, delay lines, and electromagnetic interference (EMI) filters
2. Semiconductors - transistors, diodes, thrusters, and transorbs
3. Micro electronics - integrated circuits, microprocessors, memory devices, comparators, and amplifiers
4. Interconnect hardware - wire, cable, terminal blocks, connectors, plugs, and sockets
5. Electromechanical components - switches, relays, solenoids, and motors
6. Hybrid and printed circuit assemblies .

Examples of terms which are used to define these devices are as follows:

1. Electronic characteristics , e.g., voltage and current levels (power supply requirements, input and output signal levels, and switching thresholds), impedances (resistance, capacitance, and inductance), frequency information (frequency response and frequencies of operation), transient response times, time delays, signal distortions, and noise level generation and suppression.
2. Thermal characteristics - power dissipation, junction to case thermal resistance, and ambient junction temperatures
3. Packaging characteristics - hermeticity, thermal expansion, mounting, size, weight, and strength
4. Reliability characteristics - failure rates, testing levels, and rating requirements
5. Handling - electrostatic discharge, storage, and soldering
6. Environmental requirements - temperature range, cooling, electrical loading, fanout, impedance, and timing.

4-7.6 OPTICAL COMPONENTS DATA

Paragraph 4-7 defines the type of data which should be required. Examples of optical components are lenses, mirrors, prisms, lasers, and detectors.

Lenses and mirrors are characterized by their effective focal length, effective entrance and exit apertures, aberration characteristics, wavelength or wave band of interest, and transmission percentage. Lenses depend upon the index of refraction principle for shaping and bending of rays. The lens material, however, has absorption characteristics that are wavelength dependent. Mirrors and lenses usually have optical coating for minimizing light reflections or transmission. In addition to diffraction effects, which broaden focused light to a defined blur circle in lenses and mirrors instead of a point, optical aberrations, such as spherical, coma, astigmatism, and chromatic aberration, cause degradation to image resolution and contrast. A lens designer will balance aberration reduction against satisfying design specifications. The terms used here are defined and pictorially represented in any good lens design textbook.

Prisms are used to bend light into specified angle but not focus it. Angles of reflection and transmission in the prism are controlled by the accuracy of angle fabrication and quality of coatings.

Laser design uses optics - mirrors and lenses to build cavity interferometers. Lasers can use crystal, diode, gas, or organic liquids to produce stimulated radiated emission. Terms used to define laser characteristics are wavelength, beam divergence, power output, pulsed or continuous wave, and pointing control of the beam.

Detectors convert optical radiation into electronic signals or images by the pyroelectric, photo conductive or photo voltaic, etc., effect. Detectors are wavelength dependent and combinations of detector systems can detect optical radiation from the new ultra violet (0.3 micron) through the long wave infrared (0.8 micron and longer). Characteristics of detectors include signal to noise (SIN), noise equivalent power (NEP), or net equivalent temperature (NET), instantaneous field-of-view (IFOV), electrical bandwidth (BW), optical responsitivity (R), and D-star performance.

4-7.7 FLIGHT SAFETY PARTS DATA

Detail specifications and engineering drawings might be required for flight safety parts. Critical characteristics and the procedures necessary to ensure that these critical characteristics have been achieved should be identified. Commercial specifications and standards may be used in lieu of detailed military specifications and standards, unless no practical alternative exists to meet the user' s needs. The data should define all design specific performance requirements, all as integrated and as installed characteristics, and all key functional and physical attributes to be measured. For additional information see Chapter 1, paragraph 1-5.2.5.

4-7.8 MATERIALS DATA

Relevant information for materials and processes are usually used in the design and construction of Army air vehicles can be found in ADS-13, *Air Vehicle Materials and Processes*, (Ref. 9). The design standard addresses the general material data including: material properties, corrosion protection requirements, temperature effects, minimum gauge of materials, fracture toughness, characteristics of steel, aluminum, magnesium alloys, organic materials, fiber reinforced materials, transparent materials, lubrication requirements, materials used for survivability , radioactive materials, and process selection. The contractor should be totally responsible for design and for satisfying the performance requirements of the specification. For additional information concerning materials and testing, see Chapter 7.

Relevant information pursuant to the establishment of data basis for composite material properties and design allowables can be in Chapter 7, paragraph 7-6, and also in ADS-35, *Composite Materials for Helicopters*, (Ref. 10). The design standard addresses material property requirements, generation of material allowables, design considerations, and control of processing. Specific topics of discussion include:

1. Physical properties : description, material content, density, glass transition temperature, moisture absorption, flammability resistance
2. Mechanical properties : tensile properties, compressive properties, flexural properties, fatigue properties, creep

properties, damage tolerance, and bearing strength

3. Chemical properties : environmental resistance, solvents/cleaners/air vehicle fluids

4. Thermal properties : thermal expansion coefficients, thermal conductivities, heat capacity/specific heat, thermal/oxidative stability, thermal mechanical stability, thermal transitions

5. Electrical properties : dielectric constant, dielectric strength, dissipation factor, surface resistivity/volume resistivity.

Materials data is often required to support documentation requirements of a process specification (Chapter 5).

4-8 SUBSYSTEM DESIGN AND QUALIFICATION

Data required at the subsystem level should be basically the same as that described for components in paragraph 4.7. These specifications, analyses, test plans, and test reports should include diagrams, etc. Subsystem survey data may be used as the basis for analysis in qualitative and relational assessments and as the basis for derivation of pass/fail criteria that cannot be directly measured. Under specified conditions, formal demonstration of qualification characteristics provides a basis for subsystem description data. Relevant information needed for performing a detailed analysis of the performance, handling qualities, rotor dynamics, airframe dynamics, and acoustics of a proposed new development or derivative air vehicle can be found in ADS-10, *Air Vehicle Technical Data*, (Ref. 11). The design standard addresses the following:

1. Air vehicle dimensional data - drawings, tabulated dimensions, and areas

2. Description of the rotor system - rotor data, radial distribution of blade properties

3. Airfoil section data

4. Airframe aerodynamic data - aerodynamics of the fuselage, drag buildup, stability and control derivatives

5. Rotor structural dynamics data - blade mode shapes, data for ground resonance model

6. Airframe structural dynamics data- airframe modal data, description of airframe mounted absorbers and isolators

7. Aerodynamic surface data - surface 3-dimensional force and moment data, rotor wake aerodynamic interference

8. Control system data - system description, control travel, cockpit to swashplate linkages, swashplate to blade linkages

9. Propulsion and drive system data- system performance losses.

4-8.1 ENGINE, TRANSMISSION, AND DRIVE SUBSYSTEMS,

The type of data required for engines, transmissions, and drive subsystems should be basically the same as that described for components in paragraph 4.7, except that subsystem description and qualification data should include:

1. Propulsion system schematic drawings showing the functional arrangement, location, and identification of all pertinent components of the subsystems and elements: lubrication, fuel, air induction, cooling, power transmission, auxiliary power, engine inlet anti-icing filtering or particle separator, accessory drives, firewalls, infrared radiation suppression, exhaust, controls, and smoke abatement. For turbine engines, a report of the calculation of duct losses should be submitted with the induction system schematic drawing. An analysis of the

propulsion system cooling and exhaust systems should be submitted, showing temperature and pressure design limits for fuselage and components, required airflow, and heat generation. These analyses should be submitted with schematic drawings of these systems.

2. Propulsion system installation drawings, excluding fuel and oil tanks, detailing the location, mounting, vibratory isolation, and access for inspection and maintenance of all systems and elements: engine, auxiliary power plant, fuel, lubrication, air induction, cooling, starting, propulsion controls, engine inlet anti-icing, filtering or particle separator, accessory drives, infrared radiation suppression, power transmission, and smoke abatement. For power transmission systems, including gearboxes, drawings also will include lubrication system, bearings, and gearing; typical views of transmission housing including mounting provisions; typical cross sections and details of clutch mechanism, free-wheeling devices, rotor brake, shafting and shaft supports, and torque-limiting devices.

Relevant information for propulsion system ground and flight surveys and demonstration requirements can be found in ADS-1B-PRF, *Rotorcraft Propulsion System Airworthiness Qualification Requirements, Ground and Flight Test Surveys,* (Ref. 12). Relevant information concerning the preparation and submittal of test reports can be found in ADS-50-PRF (Ref. 14).

Relevant information to assist in the definition of technical data required *Propulsion System Technical Data* for air vehicle technical proposals can be found in ADS-9, , (Ref. 13). This document includes the requirements for system analyses such as stress, fatigue, cooling, torsional stability, and dynamic and diagnostic system analysis.

Relevant information pursuant to defining the gas turbine engine performance characteristics, ratings, and performance can be found in ADS-50-PRF, *Rotorcraft Propulsion Performance and Qualification Requirements and Guideline* (Ref. 14). Typical data requirements can be found in ADS-25, *Engine Performance Data,*
(Ref. 15).

4-8.2 FUEL AND OIL SUBSYSTEMS 4-8.2 FUEL AND OIL SUBSYSTEMS

The type of datarequired for fuel and oil subsystems should be basically the same as that described for components in paragraph 4.7, except that installation and schematic diagrams should also be required. Analyses for the fuel subsystem should include; but, not necessarily be limited to include capacity, flow rates, transfer rates, vulnerability, and fuel feed capabilities. Additional data for external tanks should include analysis of transfer rates, and jettison capabilities. Data for the oil subsystem and oil distribution subsystem should include analyses of the flow, filtering, cooling, and lubricating capabilities. Maintenance data should be provided for the fuel and oil system. This should include the requirements and procedures for purging the fuel system using nitrogen inerting systems.

Aerial refueling subsystem (as tanker and/or receiver) data should include refueling capability data such as aerial refueling envelope of altitude versus true airspeed, fuel transfer rate versus pressure at the reception coupling or receiver nozzle; weight and balance related information, and tanker package and component descriptions.

4-8.3 ROTOR, PROPELLER, AND PROPROTOR SUBSYSTEMS

The type of data required for rotor, propeller, and proprotor subsystems should be basically the same as that described for components in paragraph 4.7, except that installation and schematic diagrams should also be required. Relevant information on describing rotor, propeller, and proprotor subsystems can be found in ADS-10 (Ref. 11). Further, the reports required for qualification should include structural analyses, flutter and divergence analysis, aeroelasticity analysis, and performance analysis. Model, wind tunnel, and tower test data should be provided to support these analyses. For alternative tail rotor equivalent thrust systems, special data may be required. This may include theory of operation, special limitations, wind tunnel results, and flight test data.

4-8.4 HYDRAULIC AND PNEUMATIC SUBSYSTEMS

The type of data required for hydraulic and pneumatic subsystems should be basically the same as that described for components in paragraph 4.7, except that installation drawings , schematic diagrams , and a detailed description of flow distribution, filtering, pressure, and maintenance requirements and capabilities may also be required. Hydraulic applications primarily include flight control and utility functions. Pneumatic applications may include such functions as engine starting, auxiliary utility systems, and emergency backup systems. In addition, analyses should be required to document safety, maintenance, and vulnerability characteristics and performance. The data should be sufficiently detailed to substantiate that performance requirements have been achieved.

4-8.5 LANDING GEAR

The type of data required for landing gear subsystems should be basically the same as that described for components in paragraph 4.7, except the following should also be required:

1. A general arrangement drawing of the landing gear, showing the side view elevation relationship of landing gear to fuselage structure, and to the most forward and most aft center of gravity (CG) locations.

2. Three-view drawing(s) of the main and auxiliary gear showing principal members. If the gear is retractable, it should be shown in the fully extended and retracted positions, and the most critical clearance dimensions of the wheel well between structural members and other equipment should be identified. The principal members of the gear should include outlines of the shock strut, drag brace, tension strut, torque arms, jackpoints, towing and tiedown fittings, wheels (and brackets, if used), retraction and extension linkages, actuators, shrink linkages, steering and/or shimmy damper, uplocks, and downlocks. Wheel and tire toe-in and/or camber angles in relation to the axle or strut should be indicated. Outline of door linkages should be shown in relation to gear linkages and functions. Type of material and heat treatment information should be listed or indicated for all principal members of the gear.

3. Nose steering , towing, and turnover angle drawing, consisting of a plan view showing the tread and wheel base of landing gear and distance between dual wheels; maximum nose steering angle and corresponding minimum turning radius about the main gear; maximum auxiliary gear swivel-angle for towing using towbar and minimum turning radius about the

main gear; and turnover angle with the most critical CG location.

4. Tiedown arrangement drawing, consisting of a plan view showing the complete tiedown configuration; attachments to rotorcraft gear; fuselage, wing, and tail fittings; and angles extending to ground tiedown points

5. Air vehicle jacking drawing, showing location of jacks and air vehicle jackpoints, including all fuselage and/or wing points, and wheel axle and/or strut points

6. Landing gear design report

7. Landing gear specification or specification control drawings, as applicable, for the wheel tire

a. Nose or tail wheel

b. Nose or tail wheel tire

c. Nose shock strut

d. Nose gear steering and shimmy damper

e. Solid tail and/or bumper wheel

f. Bumper wheel tire

g. Main wheel and brake assembly

h. Main wheel tire

i. Main wheel shock strut

j. Anti-skid brake control system

k. Main and nose gear actuators

l Ski installations and/or emergency flotation gear

m. Rotor brake

n. Steering and damper.

4-8.6 ELECTRICAL SUBSYSTEMS

The type of data required for electrical subsystems should be basically the same as that described for components in paragraph 4.7, except that the following data should also be required:

1. AC and DC electrical load analyses. Information pursuant to this purpose can be found in MIL-E-7016 , *Analysis of Aircraft Electrical Load and Power Source Capability*, (Ref. 16). Specific analyses that should be performed are:

a. Preliminary load analysis , which should form the basis for selecting power generation equipment and for design of generation and distribution system

b. Intermediate load analyses incorporating significant load or power source changes subsequent to the submittal of the preliminary load analysis

c. Final corrected load analysis , which should be marked "Final Corrected" and will include all changes incorporated in the complete air vehicle. If no changes have been made to data previously submitted, a new cover sheet should be submitted stating no changes have been made. The values entered in this analysis should be measured values.

2. Wiring diagrams showing sufficient equipment internal circuitry to allow for understanding the system function. A brief description of any system or equipment not having readily recognizable operating functions should be included with the following diagrams:

a. Preliminary wiring diagrams , consisting of both elementary, single-line functional diagrams and schematic functional diagrams of the power distribution and lighting systems

b. Master wiring diagrams , consisting of installation schematic wiring diagrams giving information of interconnection of components. This should include identification of wires, connectors, junction points, terminal blocks, and equipment. Information pursuant to the selection of wire and cable is given in Appendix A of MIL-W-5088, *Aerospace Vehicle Wiring*, (Ref. 17). Also, information pursuant to for assigning significant wire identification codes is provided in Appendix B of MIL-W-5088.

3. General arrangement drawings of the electrical equipment installation showing the location of all major items of electrical equipment

4. Exterior light installation drawings showing location and visibility characteristics. Relevant information can be found in MIL-L-6730, *Aircraft Exterior Lighting Equipment*, (Ref. 18).

5. Nonstandard electrical equipment specifications and substantiating data. Relevant information can be found in MIL-STD-7080 *Selection and Installation of Aircraft Electronic Equipment*, (Ref. 19).

6. Cooling requirements for electronic and avionics systems.

7. Specific information on the electrical subsystem should be included in the following electrical subsystem design documents (ESDDs):

a. Preliminary ESDD (prior to electrical hot bench testing):

(1) Complete descriptions and diagrams that identify all source capacities (under all conditions) and all possible distribution configurations. Automatic and manual electrical subsystem monitoring and control of air vehicle and ground power source.

(2) Specific circuit identification and details including, normal and peak power consumption, wire size, all protective and switching devices between each load and its normal power bus, and the proposed grounding, types and ratings of all protective and switching devices.

(3) Fault current (magnitude and duration) estimates for all sources and the current capacity of all bus feed and bus-tie contractors in series with those sources.

b. Final ESDD (subsequent to electrical subsystem hot bench testing): In addition to final revisions of the information identified in the preliminary ESDD, the final ESDD should include test data from the electrical hot bench testing. The testing should include, but not be limited to, simulated fault conditions and measurements of the fault current magnitude and duration for all possible fault conditions. Test results should verify the performance of all fault protection in the electrical subsystem including the source protection, bus feed, and bus-tie contractors. In addition, hot bench test data should verify that the power quality is in accordance with MIL-STD-704, *Aircraft Electrical Power Characteristics*, (Ref. 20) for all operational conditions of electrical subsystem (normal, abnormal, and emergency). Basically this is a performance and interface standard; however, a waiver is required to cite this standard.

4-8.7 AVIONIC SUBSYSTEMS

This category of equipment includes electronics associated with communications, navigation, crewstation controls and displays, aircraft survivability equipment, radar and visionics equipment, antennae, data buses and bus controllers, central processors, flight instruments, and the myriad of other air vehicle subsystems that have electronic boxes dedicated to special functions, such as secure voice and tempest controlled systems. Tempest is an unclassified short name referring to investigation and studies of compromising emanations. This refers to unintentional, intelligence bearing signals that, if intercepted or analyzed, will result in disclosure of national security information transmitted, received, handled, or otherwise processed by any information processing system. It is sometimes used synonomously for the term compromising emanation, e.g., tempest tests and tempest inspections. The type of data required for avionic subsystems should be should be basically the same as that described for components in paragraph 4.7, except that the following may also be required:

1. General arrangement drawings of equipment installations showing the location of all major items of electronic equipment and their interconnections

2. Drawings, schematics, interface control drawings, and performance data in sufficient detail to substantiate that the performance and interface requirements have been achieved.

3. Antenna system drawings , schematics, interface control drawings, and performance data in sufficient detail to substantiate that the design requirements have been achieved

4. Test plans and test reports to substantiate the environmental qualification of the electronic equipment. Guidelines for environmental testing are provided in MIL STD-810, *Environmental Test Methods and Engineering,* (Ref. 21)

5. Test plans and test reports to substantiate the electromagnetic environmental effects (E3) qualification of the electronic equipment

6. Classified plans and test reports as needed for qualification of secure voice and other tempest controlled systems

7. System safety and hazard analysis data

8. Software data as applicable

9. General qualification assurance and operational readiness data

10. Survivability data, as applicable

11. Radome engineering data, defining the radome and its characteristics, including overall transmissibility curves, boresight shaft characteristics, radar tracking noise, effects of equipment located in or affixed to the radome, and the changes to electrical characteristics resulting from radome heating

12. Navigation engineering data to determine navigation equipment performance in terms of accuracy for both piloting and weapon delivery functions. Also, data to describe overall navigation equipment architecture, interfaces with other air vehicle systems, expected accuracy for each navigation mode, error budgets for various sensor inputs, and algorithms used to integrate the various sensor inputs, (e.g., use of Kalman filter). Data might be classified or restricted.

13. Air data typically include total pitot pressure, static pressure, air density, slip angles, and temperature to validate accuracy of various equipment receiving pitot static directly or through an electronic air data conversion. These data may be for analysis of atmospheric effects on overall performance, i.e., navigation accuracy

4-8.8 CREWSTATIONS DISPLAYS AND CONTROLS

The type of data required for crewstation displays and controls should be basically the same as that described for components in paragraph 4.7 and avionic subsystems in subparagraph 4-8.7, except that layout drawings, human engineering analyses, subsystem modeling data, and subsystem functional descriptions should also be required. Information pursuant to qualification can be found in MIL-STD-250, *Aircrew Station Controls and Displays for Rotary Wing Aircraft,* (Ref. 22) and
MIL-STD-1472, *Human Engineering Design Criteria for Military Systems, Equipment, and Facilities,* (Ref. 23). For multifunction displays , additional description characteristics include character size, display modes, display brightness and contrast control data

necessary to substantiate that the displays will be visible in all specified lighting conditions. Virtual cockpit helmet data should include display characteristics, mass properties of the helmet, and helmet tracking system accuracy. Voice interactive systems should include any special learning requirements for the system to adapt to the wide range of voice characteristics of potential users, and the vocabulary range and resulting actions of the system. For pilot's associate systems, descriptions of functions and the basis for the system's decision making should be described. Special training or learning required by the system should also be provided.

Air vehicle interior lighting characteristics should be described in terms of schematic and layout drawings, function descriptions of lighting switches and controls, and luminance and illuminance measurements. Information pursuant to establishing performance and validation requirements for air vehicle interior lighting can be found in MIL-L-85762, *Aircraft Interior Lighting, Night Vision Imaging System (NVIS) Compatible*, (Ref. 24).

4-8.9 CREWSTATIONS EQUIPMENT

The type of data required for crewstations equipment should be basically the same as that described for components in paragraph 4.7, except that the contractor should also furnish drawings of all seat assemblies and installation for crew and passengers, and litters for medical evacuees. If applicable, these drawings should show range of adjustment and include all safety belt, shoulder harness, or other restraint installations and controls; parachute provision take-up mechanisms or devices; tracks; catapults or rockets motors, rails, operating gear, stabilizing, and other components or subassemblies required for ejectable seats. The sequence of emergency escape operations using the ejectable seats should be indicated. Further, the following additional data may be required to support subsystem qualification:

1. Heating and venti lating system installation drawings and data
2. Thermal insulation installation drawings
3. Cabin pressurization installation for pressurized air vehicles, including heating, cooling, and ventilating provisions
4. Engineering data for air-conditioning and pressurization systems which cover the air vehicle profile should include an air supply for cooling and demonstrate that moisture does not condense within electronic components. In addition, the means used for eliminating entrapped moisture should be indicated
5. Installation drawings and data of acoustical insulation
6. Anti-icing and/or deicing, defogging, and defrosting installation data as follows: wing and empennage anti-icing system, all transparencies requiring protection, and systems for protection of periscope lenses, fuel vents, radomes, antennas, and stores

Crashworthiness characteristics should be described for the air vehicle. Data will include design criteria and features incorporated to achieve crashworthiness requirements along with analyses and test plans and reports which substantiate achievement of requirements. Information pursuant to an evaluation of crashworthiness can be found in Appendix 1 of ADS-11, *Survivability Program Rotary Wing*, (Ref. 25).

Flight recorder data should include a description of the storage medium, storage capacity, parameters monitored, and the equipment's ability to withstand crash conditions.

Nuclear, biological, and chemical (NBC) protection provisions should be described by schematic and layout drawings, and functional descriptions which provide the specific design features incorporated to provide NBC protection. Specific protection levels should be addressed.

Aviation life support equipment data should include the capability, operation, and limitations of such equipment.

4-8.10 PASSENGER FURNISHINGS

The type of data required for passenger furnishings should be basically the same as that described for components in paragraph 4.7, except that schematics and layout drawings and reports and analyses which describe the functional characteristics of these items should also be provided. Intercom data should include system capabilities and interfaces with electrical and communication subsystems. Fire retardant properties of materials used in passenger furnishings should be described in terms of their placement in the air vehicle and capability to withstand temperature extremes. Soundproofing materials' data should be provided to show their location and acoustic attenuation characteristics.

4-8.11 HOISTS

The type of data required for hoists should be basically the same as that described for components in paragraph 4.7, except that cargo and rescue hoist qualification data should describe the load capacities of the equipment, angle of application (cone angle), etc. Achievement of performance and interface requirements should be validated by means of analysis and test reports. Data should be provided as to any flight restrictions applicable to hoist operation.

4-8.12 CARGO PROVISIONS

Cargo provisions should be described in term of schematics and layouts showing the openings and location of the cargo compartments, their capacities, tiedown limits and locations,.floor loading restrictions, and balance considerations. Reports and analyses should be provided to show that the design satisfies specification requirements.

4-8.13 LAVATORIES AND GALLEYS

The type of data required for lavatories and galleys should be basically the same as that described for components in paragraph 4.7, except that the data should include schematics and layout drawings detailing location and operation, storage capacities, disposal provisions, and special corrosion prevention considerations. Lavatory data should include, but not be limited to; portable water and waste tank capacity, operation procedures, maintenance requirements, and fill and dump provisions and restrictions. Galley data should include maintenance and operation data, storage location and capacities, and human factors analysis.

4-8.14 TARGETING, ARMAMENT, AND FIRE CONTROL

The type of data required for targeting, armament, and fire control subsystems should be basically the same as that described for components in paragraph 4.7, except for the additional information needed to validate performance, such as ground and flight test results for each armament fire control subsystem. Information pursuant to this purpose can be found in ADS-20, *Armament/Fire Control System Survey*, (Ref. 26). Typical ground and flight test data requirements that should be submitted for qualification of these subsystems are as follows:

1. Armament/fire control operations
2. Armament/fire control boresight
3. Arming procedures
4. Display resolution
5. Display characteristics
6. Sensor and field of view switching
7. Target acquisition/designation subsystem characteristics for:
    a. Laser designation
    b. Laser range finding
    c. Laser spot tracking
    d. Cooling performance
    e. Weapons accuracy
    f. Boresight retention
    g. Environmental qual ification; see MIL-STD-810 (Ref. 21) for guidance
    h. Electromagnetic environmental effects (E3); see subparagraph 4-9.11.

4-8.15 SOFTWARE DATA

Typically, a software requirements specification (SRS), interface requirements specifications (IRS)(defines the relationship among two or more entities, or software unit, software unit in which the entities share, provide, or exchange data, version description document (VDD), software test descriptions (STDs) and reports for validating performance and determining airworthiness should be required. The SRS should be updated as test and evaluation proceeds. Also, other data could be required. Information pursuant to this purpose can be found in MIL-STD-498, *Software Development and Documentation*, (Ref. 27). For additional information concerning software and the use of the Ada programming language , see DoD Regulation 5000.2-R, (Ref. 1). DoD Directive 3405.1, *Computer Programming Language Policy*, (Ref. 28), establishes the DoD policy and prescribes procedures for using the Ada programming language. The VDD is used by the contractor to release computer software configuration items (CSCI) versions to the Government. The term "version" may be applicable to the initial release of a CSCI, to a subsequent release of that CSCI, or to one of multiple forms of the CSCI released at approximately the same time (e.g., to different sites). The VDD is used by the Government to track and control versions of software to be released to the operational environment. The VDD is used as part of the configuration management applied to a CASI. Any executable code regardless of the storage medium should be considered as software and documented as a CSCI. JIAWG categories should be considered. Also, any data stored in nonvolatile memory and used by a CSCI is part of that CSCI and should be included in the documentation of that CSCI.

Qualification testing for a CSCI is defined in the software test description (STD). Information pursuant to integration and testing of airborne processor hardware, and software can be found in ADS-32, *Airborne Processor Hardware, Software and Interfacing Device Systems Integration*, (Ref. 29).

The Software Test Report (STR) is a permanent record of qualification testing performed on a CSCI. The STR summarizes test discrepancies and references their corresponding problem or change reports. Also, the STR may be used by the contractor as a basis for re-testing of a CSCI.

4-9 SYSTEM DESIGN AND QUALIFICATION DATA

The air vehicle taken as a whole should be considered the end item system. Other portions of the air vehicle are subsystems or components of the end item air vehicle. Integrated subsystems are often tested as part of the end item system. The procuring activity usually includes a system specification and an airworthiness qualification plan as part of its request for proposal. The contractor usually is required to submit their proposed system specification, proposed airworthiness qualification specification (AQS), and other system design and qualification data. System design and qualification data includes the data which describes the air vehicle and its subsystems (such as diagrams and physical drawings), test plans and test reports, and analyses and integration data. This data is used to substantiate airworthiness, and also that specified performance and interface requirements have been satisfied. Data is typically derived from the results of design analysis, sample tests, simulation models, subsystem mock-ups and installed subsystems. Subsystem survey data may be used as the bases for analysis in qualification and relational assessments in determining system level characteristics. Also, subsystem survey data may be used as the bases for derivation of pass/fail criteria that cannot be directly measured. Formal demonstrations of qualification characteristics are normally required by the airworthiness qualification specification (AQS) to show the air vehicle complies with the requirements of the detailed specification.

4-9.1 CHARACTERISTIC AND PERFORMANCE DATA

Air vehicle system characteristics may be described by drawings, analyses, and reports. All basic aerodynamic data used in the calculation of the air vehicle performance such as the geometric characteristic data defining the air vehicle configuration, and the documents and references showing the derivation of the data (drawings, analyses, substantiating calculations, tests) should be provided. Refer to ADS-10 (Ref. 11) for typical requirements regarding the reporting of air vehicle dimensional data, description of rotor subsystems, airfoil section data, airframe structural dynamics data, aerodynamics surface data, control subsystem data, and propulsion and drive subsystem data. Air vehicle drawings, should show to a practical degree major structure; propulsion and power train and gearboxes; equipment; armament; useful load items; normal entrance ways, emergency exits, and escape hatches; and location of crew, passengers, and their equipment. System level analyses and reports should be sufficiently detailed to substantiate that performance and interface requirements have been achieved, and provide sufficient characteristic and performance data for generation of charts required for flight performance and limitations in the operators manual. This should include: lift and drag data; nondimensional hover and forward flight performance curves; blade stall and compressibility limits; net thrust, power available and fuel flow variation versus appropriate altitudes, temperatures, and speeds; and a complete aerodynamic description of the air vehicle. Information pursuant to determining aerodynamic performance properties can be found in subparagraph 4-9.5 and ADS-40, *Air*

Vehicle Flight Performance Description, (Ref. 30).

4-9.2 STRUCTURAL DATA

Structural qualification data includes drawings, design criteria, analysis and test results which substantiate that the air vehicle meets the required structural performance and interface requirements. Analyses data should be provided for structural strength, vibration, fatigue, mechanical stability, and static, dynamic, landing, and crash loads. Information pursuant to the establishment of structural design criteria for Army rotorcraft can be found in ADS-29, *Structural Design Criteria for Rotary Wing Aircraft*, (Ref. 31). Vibration analysis and testing is an important part of the structural data qualification requirements. Relevant information for establishing vibration requirements for rotorcraft, rotorcraft subsystems, and equipment requirements can be found in ADS-27 , *Requirements for Rotorcraft Vibration Specifications, Modeling and Testing*, (Ref. 32). When analytical models are used to substantiate structural requirements, detailed documentation of the analytical methodology, the analytical model used, and the analytical results should be delivered to the Government. Information pursuant to establishing crashload analysis and test data requirements can be found in MIL-STD-1290, *Light Aircraft and Rotary Wing Aircraft Crash Resistance*, (Ref. 33).

Structural drawings should include a plan and elevation view of the fuselage structure showing centerlines of all main members; general distribution of main structural material with typical cross sections of stringers, bulkheads, and frames; and typical views of rotor pylons, masts, stabilizing surfaces, booms, landing gear, engine mount, and jacking and/or hoisting sling attachment fittings and carry-through structures, and installation and assembly of fixed and movable sections of cockpit or cabin enclosures, including all operating and emergency controls. The drawings should be in sufficient detail to show the method and materials employed in reinforcing and mounting transparent components and hinges, tracks, rollers, guides, lift assemblies, and other components of movable section mechanisms; the method of latching movable sections in open, closed, and intermediate positions; and the method of emergency operating of jettisonable movable sections. If power operation is used, the drawing should be accompanied by calculations indicating the power and time required for both normal and emergency actuation under critical loading conditions.

Information pursuant to the conduct of structural demonstrations can be found in ADS-24, *Structural Demonstration*, (Ref. 34). The primary objectives of the test are to demonstrate the safe operation of the air vehicle to the maximum attainable operating limits consistent with structural design, and to verify the loads used in the structural analyses and static tests are not exceeded at the structural design limits of the V-n diagram.

4-9.3 PROPULSION AND POWER TRAIN DATA

Paragraph 4-8.1 provides data requirements for engines, transmissions and drive subsystems. At the system level, data provided should include drawings, analyses, and test to substantiate the achievement of engine/airframe compatibility, critical temperatures, inlet and exhaust characteristics, fuel flow and consumption, lubrication, accessory drives, and fire detection and fire suppression subsystems requirements.

Relevant information pursuant to preparation and submittal of propulsion subsystem analysis can be found in ADS-9 (Ref. 13). Specific performance capabilities such as drain/fill rates, capacities, crash load factors, operating limits, indicating subsystem accuracy' s, engine control rigging/hysteresis characteristics, and operating procedures and capabilities should be determined by analysis and test. The torsional stability of the rotorcraft drive subsystem should be completely analyzed and the results of the analysis showing both gain margin and phase margin throughout the operational envelope should be included.

Engine installation and interface data should include the drawings, analyses, and interface requirements necessary to ensure proper function, operation, and control of the engine. Turboshaft engines installed in rotorcraft, torsional stability is a major concern. The damping or attenuation of signals at the rotorcraft rotor frequency is a stability requirement. Additional information pursuant to establishing installation and interface data requirements may be obtained in ADS-26, *Engine Installation Data*, (Ref. 35). The ADS-1B-PRF (Ref. 18) provides the qualification requirements which are needed to verify compliance with allocated performance requirements. Included in the engine/airframe interface tests are compatibility tests to evaluate the torsional stability and control response characteristics of the engine, and surveys pertinent to engine vibration, propulsion subsystem cooling, air induction, and exhaust subsystem.

The ADS-25 (Ref. 15) provides information for establishing data requirements for engine performance characteristics, ratings, and performance data presentation. The performance data should include flowrates, pressure, frictional loads, power consumption and torque requirements.

4-9.4 FATIGUE LIFE DATA

The contractor should be responsible for submitting data to substantiate that it has met or exceeded specified fatigue lives. As measured flight loads and full scale component fatigue strengths become available, lives should be computed using a mission spectrum. The usage spectrum should be provided by the procuring agency. Also, the minimum B-10 life of bearings should computed by the contractor. These computational analyses should be submitted to the procuring agency as part of a report. Also, the procuring agency will usually require preparation and submittal of S-N curves, test plans, and test reports. Typically, a flight load survey is conducted to determine the component stress levels (mean plus oscillatory) resulting from each flight condition in the operational maneuver spectrum and over the operational range of gross weight, airspeed, CG, and altitude. Thereafter, a report is submitted to the procuring activity which compares flight load survey data to the S-N curve data to determine component fatigue life characteristics.

4-9.5 AERODYNAMIC PROPERTIES

Aerodynamic properties' data includes drawings, analyses, plans, and reports which should be submitted to the procuring agency as a means of validating the achievement of specified performance requirements. Data may be obtained from wind tunnels, models, and flight simulators. A flight simulation mathematical model and documentation showing model inputs, outputs, flow logic, and equations used may be used to characterize aerodynamic properties. Data obtained from models and simulations should be validated, and the mathematical models should be delivered-as data. other reports include aerodynamic flutter, aeroelastic stability, aerodynamic stability and control (natural frequencies, damping, and response of both aircraft and control system), flying qualities, and ground resonance. Compound, tilt rotor, and other multimedia air vehicles require unique data and description of the air vehicle's transition mode characteristics.

Aerodynamic component drawings should include data on airfoil characteristics, aerodynamic center, plan form area, span, aspect ratio, chord (tip to root), sweep angle of quarter chord, orientation with respect to fuselage reference system, thickness (tip and root), and control surface data.

Handling Qualities data is required for assuring that no limitations on flight safety or on the capability to perform intended mission will result from deficiencies in flying qualities. Relevant information can be found in ADS-33, *Handling Qualities Requirements for Military Rotorcraft*, (Ref. 36). The data provided should include response time, hover and low speed data, forward flight data, transition between rotor-borne and wing-borne flight, controller characteristics, failures, transfer between response types, and ground handling and ditching characteristics.

An aerodynamic data report should show the planned aerodynamic and flutter investigation program and schedule. This report should outline the purpose and scope of each proposed investigation; indicate the test facilities to be employed and test dates and occupancy time required; describe the scale and type of models to be constructed and tested; and present the ranges of test variables to be investigated.

1. Interim Letter Reports. These should be submitted immediately following completion of testing at each test facility. They should cover items, such as tests conducted, scope, contractor's observations of the tests, including any difficulties encountered, significant results, and any conclusions or recommendations based on inspection of the available preliminary test results.

2. Aerodynamic Test Data Reports. These should present the basic aerodynamic data and test results obtained from the investigations conducted in contractor-furnished and private test facilities. Aerodynamic test data obtained from Governmental facilities will be provided by the facility. The reports should identify the configurations tested, any differences from the configuration tested and reported on previously, and from the current air vehicle configuration. Graphic presentation is desired with reference (if possible) to axes consistent with the stability and control and estimated flying quality report.

3. Flutter Analysis Reports. These reports should compare the flutter and divergence limit speeds for the rotor blades and for the fixed lifting and control surfaces of the rotorcraft. Flutter analysis reports for other air vehicles should include the flutter and divergence limit speeds for all lifting and control surfaces.

4-9.6 WEIGHT AND BALANCE DATA

The contractor should establish a system of weight control and reporting. Information pursuant to this purpose can be found in MIL-W-25140, *Weight and Balance Control System (for Aircraft and*

Rotorcraft), (Ref. 37). Weight and balance control and management generally includes data on intent, approach, and methods to be used to insure minimal weight and balance variations within constraints of specification design requirements, program cost and schedule. The MIL-STD-1374, *Weight and Balance Data Reporting Forms for Aircraft (Including Rotorcraft)*, (Ref. 38) describes standard weight statements and forms, Parts I, II, and III, for procurement of weight and balance data, and for instructions for uniform compilation of the required weight and descriptive data. The ADS-16, *Weight and Balance Substantiation Report Format and Technical Content,* (Ref. 39) describes the type of weight and balance data reporting typically required with the submission of a proposal. In general, weight and balance data required for a proposal are the data describing the contractor's weight and balance management plan. The ADS-19, *Weight and Balance Status Report-Reason for Change (SRFC) Format and Technical Content,* (Ref. 40) describes the basic requirements for MIL-STD-1374, Part III, (Ref. 38) standard reasons for change to be used with the "Government/Contractor Responsibility Changes Since Last Report" pages of the Weight and Balance Status Reports. These reports of changes provides the Government a means to monitor the weight and balance management of the program.

4-9.7 SYSTEM VIBRATION DATA

Information pursuant to establishing vibrational related requirements for development and qualification of rotorcraft, subsystems and equipment to be installed on rotorcraft, including external stores can be found in ADS-27 (Ref. 32).

Early during the development, the contractor should submit modeling data sufficient to show that no vibrational problems will exist, or submit sufficient data to enable full system modeling by the procuring activity. Modeling data includes rotor and airframe compatibility, engine and airframe compatibility, and stores and airframe compatibility. Compatibility data includes data to show vibratory loads do not exceed limits specified, resonant amplifications are not present, and all components and subsystems will meet their functional and reliability requirements when subjected to the vibration levels as installed on the air vehicle.

Vibration test data includes airframe shake tests data, rotor blade and hub properties' determination data, component shake table tests data, flight vibration survey data, and production acceptance test data.

4-9.8 ACOUSTICAL NOISE DATA

Acoustical noise data include results of surveys of the internal and external acoustical environment indicating measurement locations and measured levels in terms of amplitude and frequency. The data should be sufficiently detailed to substantiate achievement of design requirements. Information pursuant to the determination that an acoustical environment that will not cause personnel injury, interference with voice or other communication, cause fatigue, or in any other way degrade way degrade overall system effectiveness can be found in MIL-STD-1472 (Ref. 23).

4-9.9 CLIMATIC DATA

Climatic tests are performed under simulated conditions and in actual climatic zones. Climatic data is used to demonstrate adequate safety of operation and compliance with applicable specifications, and formulate recommendations for design changes, if required. Climatic data reports should describe the conditions under which the system has been subjected, as well as the operating modes tested. All anomalies should be described.

4-9.10 ICING DATA

Icing data should include descriptions of surfaces with anti-icing or de-icing provisions, as well as the level of protection provided. Test data should include descriptions of test conditions, test set ups, and results. Data should substantiate the capability of the windshield subsystem to maintain required visibility, power is adequate to maintain flight, adequacy of the electrical and de-ice subsystems, air vehicle controllablity, and that vibration and ice shed characteristic are acceptable.

4-9.11 ELECTROMAGNETIC ENVIRONMENTAL EFFECTS DATA

ADS-37-PRF, *Electromagnetic Environmental Effects (E3) Performance and Verification Requirements,* (Ref. 41) establishes E3 performance and verification test criteria for implementation at all stages in the life cycle of the air vehicle, subsystems, and components. The E3 control plan is a planning document used to describe the E3 program, document the design criteria and testing requirements. The purpose of the E3 control plan is to define E3 activities. It addresses the following content requirements:

1. Responsibility and authority for E3 implementation and management
2. Personnel
3. Methods for ensuring compliance with requirements
4. Predicted problem areas
5. Radiation characteristics
6. Approach to cable design
7. Impact of corrosion control requirements
8. Design criteria for lighting protection
9. Design criteria for electrification
10. Implementation of design changes
11. Special requirements, test methods, and limits
12. Facilities to be used for testing
13. Vendor design review and coordination
14. Spike protection requirements
15. Bonding criteria
16. Grounding criteria
17. off the shelf equipment
18. Interference control specifications
19. Electromagnetic compatibility board

20. Criticality category and degradation criteria

21. Spectrum utilization

22. Schedule and milestones

Test data should substantiate the performance and interface conformance of all electrical and electronic subsystems to the requirements indicated in ADS-37-PRF (Ref. 41); MIL-STD-461, *Requirements for the Control of Electromagnetic Interference, Emissions, and Susceptibility,* (Ref. 42); and MIL-STD-462, *Measurement of Electromagnetic Interference Characteristics,* (Ref. 43). A waiver is required to cite the later two documents. Qualification data for electromagnetic interference and electromagnetic compatibility should include test conditions tested and the results to document the radiated emissions, radiated susceptibilities, and their system effects.. Also, lightning strike test data should include structural, as well as electromagnetic, effects data to substantiate that critical components including rotor blades, fuel subsystem components, and weapon subsystems remain flight worthy during and after the strike.

Special analysis and tests may include hazards of electromagnetic radiation to ordnance (HERO), hazards of electromagnetic radiation to fuel (HERF), and hazards of electromagnetic radiation to personnel (HERP). Data should demonstrate that the levels of electromagnetic radiation is not hazardous to personnel, nor cause hazards to fuel or ordnance through inadvertent ignition or duding.

Nuclear electromagnetic pulse data includes a listing of piece parts, materials, components, assemblies, and subsystems to be tested with detailed information concerning tests and parameters to be measured before, during, and after the test.

4-9.12 WEAPON SYSTEM (SUBSYSTEM)

Air vehicle weapon subsystem and installation data required for qualification includes error budgets, boresighting, acquisition, tracker lock-on and tracking, man-in-the-loop control, weather and obscurant effects, stabilization, test targets, and scene clutter. The data should substantiate achievement of performance and interface requirements. Typical data requirements are as follows:

1. Functional diagrams showing all items of the entire armament subsystem. These diagrams should identify each item and should include the functional relationships and purposes of the items.

2. Equipment installation and arrangement drawings showing the location of all major items of armament equipment for which provision has been made, and the location of exterior equipment. The interconnection to subsystems, such as hydraulic, pneumatic, and electrical should be shown. Drawings of the console mount and control panel in relation to all other control panels in each compartment.

3. Air vehicle armament characteristic report.

4. Contractor furnished equipment (CFE) armament performance and interface data.

4-9.13 EXTERNAL STORES DATA

Air vehicle external stores qualification data should include analyses, tests, and reports to substantiate performance and safe operation of the air vehicle with the stores. Data should include impact on performance (i.e., climb rate, power required, air speed restrictions, etc.), handling qualities, and allowable jettison flight envelopes. External stores data should also include descriptions of asymmetrical loading, weight and balance effects, fuel disconnects, forced ejection, and hang-fire effects data. Simulations of stores separation characteristics may be used.

4-9.14 SURVIVABILITY

Air vehicle survivability data, including analysis, test results, and reports should be provided to substantiate that the air vehicle meets the survivability requirements of the system specification. Data should be provided that describes and documents the effectiveness of armor panels, Air vehicle Survivability Equipment (ASE)(such as radar detectors and jammers, flares, etc.), nuclear hardening, and crash resistance. Installation drawings showing extent, shape, thickness, and type of armor equipment and other protective features, and structure in the vicinity; and installation and removal features for removable armor and other features should be provided. Ballistic capability of the armor in terms of caliber, velocity, and obliquity should be indicated.

The contractor's proposal should explain the means which they will use to define the survivability characteristics of the air vehicle and also satisfy survivability performance requirements of the contract. The contractor should submit analyses, plans, and reports which are sufficient to demonstrate that the survivability performance requirements of both the system specification and airworthiness qualification specification have been satisfied. Data to be provided include ballistic hardening, directed energy, nuclear hardening, NBC hardening, and crashworthiness.

Information pursuant to establishing minimum crash resistance criteria can be found in MIL-STD-1290 (Ref. 33). Addressed are crash resistance, design impact conditions, general crash survivability design factors, and testing.

4-9.15 ENGINE AND FLIGHT CONTROL ELECTRONICS DATA

Data that should be submitted include drawings, engineering data, and calculations for the engine and flight control subsystems. Also, drawings should be submitted that include an engineering layout showing location of subsystem components, range of movement of controls and control surfaces, diagrams and other engineering data as appropriate. Test plans and test reports should substantiate the environmental qualification of the engine and flight control systems. Relevant information can be found in MIL-STD-810 (Ref. 21). Also, test plans and test reports should be submitted to substantiate the electromagnetic environmental effects (E3) qualification of the engine and flight control systems in accordance with subparagraph 4-9.11.

A control subsystem can be configured as either "feed forward" or "feedback." A feed forward subsystem commands the item under control without watching what the item does. On the other hand, a feedback servo mechanism senses the states of the item under control and takes appropriate action to minimize the difference between the sensed states and the desired states.

Sufficient data should be submitted for all control subsystems that are configured as feedback servo mechanisms to substantiate the following:

1. Stability

2. Algorithm reliability. The substantiation effort should incorporate both theoretical and application specific analysis, making use of mathematical derivation, established figures of merit, and simulation. Areas of concern include the following as applicable:

a. Adaptive limiter adjustments

b. Adaptive gain adjustments

c. Adaptive filter (e.g., notch) adjustments

d. Adaptive control law configurations

e. State estimators and system identifiers

f. New, non-classical control methodologies

3. Fault tolerances

4. Transient response.

The substantiation effort should incorporate theory of operation, simulation, and hardware mock-ups (if practical). All simulation models should contain any existing nonlinear hardware traits, such as hysteresis, deadbands, limiters, nonlinear forces, and static friction. The substantiation should analyze the following response topics as applicable:

1. Command input

2. Load perturbation and disturbance

3. Parameter changes (force, damper, mass, or spring)

4. Effects of actuator limiting (position or rate)

a. Control state "wind-up"

b. Methods used to alleviate adverse responses from wind-up providing for acceptable performance throughout a transient event

c. Measuring the amount of wind-up

d. Calculating the amount of wind-up, the assumptions, sensitivities, and reliability

e. Tuning out wind-up effects, the sensitivities, and reliability

f. Inaccuracies

g. Smoothness of various control function transitions (e.g., on/off and mode changes)

h. Effect of control implementation and modeling fudge factor gains, biases, and functions; their relative contributions, sensitivities, and reliability

i. Effect of 50ms bus switching power interruptions (Relevant information can be found in MIL-STD-704 (Ref. 20).)

j. In-flight power interruption from other causes, such as a nuclear event

5. The pilot's sense of controllability and predictability. This subject combines the repeatability of transient responses, the gradual change of a transient response with respect to a gradually changing input command of load distribution profile, and the pilot's sense of an expected and appropriate response to an input command or load disturbance.

In addition to the above data, special data may be required for stability augmentation subsystems, autopilots, engine controls, instrument landing subsystems, and totally unmanned air vehicles. In particular, all failure modes of these subsystems should be analyzed and tested (either in the air vehicle or simulator) to determine any impact to handling qualities or safe operation of the air vehicle. Also, data should be provided to demonstrate proper integration of the subsystems. For example, flight control inputs made by the autopilot should not generate an unacceptable engine response.

4-9.16 SYSTEM ENDURANCE DATA

Air vehicle qualification data should include analyses showing achievement of endurance requirements, a description of the test conditions, and results in terms of flight time or operating time before it becomes necessary for major subsystem overhaul or replacement. Because endurance requirements are often stated in terms of very long periods of operation, actual testing is usually not practicable.

4-9.17 SYSTEM SAFETY DATA

Typically the air vehicle system safety data to be submitted include:

1. Hazard analyses which defines the safety interfaces between subsystems and to identify possible safety hazards in the overall system. Relevant information can be found in MIL-STD-882, *System Safety Program Requirements*, (Ref. 44).
2. A system safety program plan (SSPP) (paragraph 3-9) or the applicable portion of an overall integrated plan which defines the SSPP scope and objective and provides a basis of understanding between the contractor and the procuring activity as to how the system safety program will be incorporated into the development effort.
3. System specification - defines the safety performance requirements for the air vehicle and each contract end item.
4. Flight Safety Parts - identification of all safety of flight parts, their critical characteristics, and serialization records (paragraph 3-13).

4-9.18 INTERFACE CONTROL DOCUMENTS

Formal interface documentation should be required as part of the systems engineering process to provide an exact definition of every interface by medium and by function. The interface control document (ICD) should include descriptions of the following interfaces: physical, environmental, sensitivities, signal characteristics, logic interfaces, and special data requirements. Interface Memorandums and Interface Agreements are used to define the responsibilities and methods for implementing interface changes. Airframe-Engine Integration Plans are used to develop and define the engine to airframe interfaces and test requirements. Interface control documents provide the formal documentation of the design requirements that allow effective integration of components and subsystems from separate procurements.

4-9.19 MISCELLANEOUS

Miscellaneous data includes descriptions of:

1. Cartridge-actuated devices used in any system, such as canopy jettisoning, hoist cable guillotine, flight refueling, hose guillotine, and emergency escape door actuation. The list should show clearly the type, quantity, and subsystem in which the devices are used. Relevant information can be found in ADS-31, *Cartridge and Propellant Actuated Devices,* (Ref. 45).

2. Commercial specifications, source control drawing, or performance and interface specifications for each mechanical, hydraulic, and pneumatic nonstandard part such as bearings, bolts, cable connecting fittings, power transmission chains, loop clamps, eyelets, fasteners, etc.

3. Special material part lists such as structural adhesive bonding list, specific adhesives and adherents used, and the facing and core materials of sandwich construction (needed for maintenance and repair).

4. Finish specifications (needed for maintenance and repair).

5. Report of material and processes development and evaluation, consisting of a summary technical description of materials and processes research, development and evaluation work which has been conducted or planned under the development contract.

6. If a component containing a radioactive element requiring a license from the Nuclear Regulatory Commission (NRC) is used in the air vehicle, the procuring activity should be notified of the need for a license as soon as the design has been sufficiently defined.

7. Nomenclature and nameplate data.

4-10 GENERAL QUALIFICATION ASSURANCE AND OPERATIONAL READINESS DATA

The qualification process should include the data required to demonstrate the quality of data collected, and should include data to substantiate the operational readiness of the system. This paragraph discusses general qualification assurance data requirements; testability, standardization, and producibility; reliability and related data requirements; training and trainers data; transport data; MANPRINT data; logistics data; battle damage,corrosion and interoperability data; and ship compatibility data.

4-10.1 GENERAL QUALIFICATION ASSURANCE

General qualification assurance data includes the collection-of test plans and test reports which comprise the qualification process. The test plans describe how, and under what conditions the tests were to be conducted; what data were to be collected; and what instrumentation were required. The test report describes the results of the test and any deviations that were made to the test plan. Instrumentation and calibration data should be included in the test report, and should contain the accuracy levels required of the instrumentation and calibration equipment. If special test facilities are required, a description of the test facilities and its unique capabilities should be provided. Simulations validation data (par. 6-8) should also be provided if the simulation is to be used to generate qualification data..

4-10.2 TESTABILITY, STANDARDIZATION, AND PRODUCIBILITY

System testability data should include testability criteria, testability analyses, fault insertion procedures (and rationale for selected faults) and results of fault detection and isolation tests. The test method (on-board automatic testing, built-in test, common test equipment and troubleshooting procedures) should be described. Standardization data includes standard parts lists, and standard maintenance tools and procedures, as applicable. Producibility data will include specific design provisions incorporated for ease of production, as well as the expected benefits to be gained from those provisions.

4-10.3 RELIABILITY AND RELATED DATA

Reliability and related data establish the reliability, availability, and maintainability (RAM) characteristics of the system. Reliability allocations are the means of apportioning reliability requirements to subsystems and components. Reliability predictions allow the designer to determine the design's potential for meeting requirements. Failure data collection provides a means for quantitatively assessing the degree of achievement of reliability requirements and form the basis for tracking corrective actions to eliminate or reduce the frequency of occurrence of failure modes encountered. The FMECA summarizes the failure modes and evaluates their effects on the performance of the system. It presents the results in a manner useful for severity level assessments and testability analyses. Reliability growth curves are useful as management tools for establishing reliability test requirements necessary to achieve reliability goals and to assess the effectiveness of failure corrections.

Warranty data should include warranty provisions, length of warranty, exclusions, and methods for obtaining repairs under the warranty.

4-10.4 TRAINING AND TRAINERS

Training and trainers data include system descriptions, trainee prerequisites, skills to be acquired, and the significance of the training to the qualification process.

4-10-5 TRANSPORT DATA

The transportability report describes the transportability characteristics of the system in terms of transportation modes, preparation requirements (time, support equipment, tools), special procedures, and requirements for restoring the system to an operational condition.

4-10.6 MANPRINT

The manpower and personnel integration (MANPRINT) data compendium is descibed in the following subparagraphs. MANPRINT is an engineering analysis and management process to identify and articulate requirements and constraints of human resources, human performance, and hazards to personnel so these matters will influence system design. The contractor is responsible for selecting the engineering and management process needed to satisfy associated performance and interface requirements. However, relevant information for measurement of operator workload can be found in ADS-30 , *Human Engineering Requirements for Measurement of Operator Workload,* (Ref. 46).

4-10.6.1 MANPOWER

Manpower refers to required human resources. Data on manpower necessary to operate and maintain the system should be provided. This data should include the determination of the organization, skills, and personnel numbers required to operate and support the equipment.

4-10.6.2 PERSONNEL

Personnel data in terms of grade and skill levels necessary to operate and support the equipment should be provided.

4-10.6.3 TRAINING

A description of training required to impart the requisite knowledge, skills, and abilities that are required to operate and maintain the system should be provided. This data should include identification of critical tasks and the prescribed training standard.

4-10.6.4 HUMAN FACTORS

Human Factors data should be provided to address the people-equipment interface. This data supports the requirement for the human capability to operate and maintain the system be included in the design of the air vehicle. The data includes the measurements to demonstrate the capabilities to reach, lift, see, communicate, comprehend, and to act to the functions and circumstances required.

4-10.6.5 SYSTEM SAFETY

System safety concerns encompass all personnel and equipment which may be affected by program plans and operations. Pertinent data from all testing should be provided to form a basis to evaluate safety characteristics. Safety critical items and operations should be identified, and documentation should be provided to show these issues have been controlled to reduce the hazards to an acceptable level of risk. System safety is addressed in detail in Chapter 3.

4-10.6.6 HEALTH HAZARDS

Health hazard data in terms of the application of biomedical knowledge and principles to identify, evaluate, eliminate, or control risks to the health and effectiveness of personnel requirements should be provided. Health hazard considerations relevant to the operation and maintenance of the system should be provided. These data should include the identification and evaluation of health hazards presented by radioactive materials, radio frequency emitters, toxic gases, laser devices, toxic and carcinogenic materials, gaseous emissions, blast overpressure, and harmful noise sources.

4-10.7 LOGISTICS

The Logistic Support Analysis Record (LSAR) documents the results of the Logistic Support Analysis (LSA). LSAR data are comprised of: operation and maintenance requirements, reliability and maintainability characteristics, failure mode and effects analysis, criticality and maintainability analysis, operation and maintenance task summary, operation and maintenance task analysis, personnel and support requirements, support equipment or training material description and justification, unit under test and automatic programs, facility description and justification, skill evaluation and justification, support item identification, and transportability engineering characteristics.. one of the main purposes of the LSAR is to document the extent to which the contractor has satisfied in the design for maintainer requirements as depicted in MIL-STD-1472 (Ref. 23). In addition, the detailed design of the maintainer and maintainer equipment interface should be analyzed and included in the LSAR.

4-10.8 BATTLE DAMAGE, CORROSION, AND INTEROPERABILITY

Battle damage repair data should be provided in the-form of field procedures necessary for expedient repair of battle damaged air vehicle. These data include reparability criteria based on extent and type of damage, inspection procedures, and necessary materials and tools.

Corrosion prevention data include a description of the techniques used to prevent corrosion. In addition, any data required to ensure the integrity of the corrosion preventive procedures should be provided for inclusion in the technical manuals. Design and operating features incorporated to meet international standardization requirements should be described and included in the international standardization report.

4-10.9 SHIP COMPATIBILITY

Ship compatibility features should be described. Included will be electromagnetic compatibility consideration as well as physical characteristics, such as the air vehicle dimensions, air vehicle tie down provisions, and blade folding provisions. This data should be in sufficient detail to determine the capabilities to operate the air vehicle from a given ship.

4-11 TECHNICAL DATA PACKAGE

The TDP is a technical description required to define and document an engineering design or product configuration (sufficient to allow duplication of the original items), and is used to support production, engineering, and logistics activities. The Government typically requires the right during the term of the contract, to purchase from time to time, “Technical Data Packages” (TDPs). Upon written notice of the Government’ s intent to purchase TDPs or technical assistance, the contractor is normally given 60 calendar days after receipt of such notice, which proposal should include the costs of preparation and reproduction of such TDPs, and the amount to be paid as compensation for the data/software/patent rights included the TDPs and/or the cost of providing technical assistance. The scope of these additional data rights to be acquired pursuant to this clause cover only the uses of the contractor' s data consistent with Government Purpose Rights under DFARS 252.227-7013 with conversion to unlimited rights. Information pursuant to this purpose can be found in MIL-T-31000, *Technical Data Packages, General Specification For*, (Ref. 47).

4-11.1 ENGINEERING DRAWINGS AND ASSOCIATED LISTS

Conceptual design drawings, development design drawings, and product drawings are all part of the technical data package (TDP). Conceptual design drawings and associated lists define design concepts in graphic form, and include appropriate textual information required for analysis and evaluation of those concepts.

Developmental design drawings and associated lists provide sufficient data to support the analysis of a specific design approach and the fabrication of prototype hardware for test or experimentation. Drawings and lists required to present a design approach may vary from simple sketches to complex drawings, or a combination of both product drawings and associated lists provide the necessary design, engineering, manufacturing, and quality assurance requirements information necessary to enable the procurement or manufacture of an interchangeable item that duplicates the physical and performance characteristics of the original design activity. Product drawings reflect the level of design maturity that the item has attained.

Contractor format, development design drawings are the minimum requirements for a developmental project.

Minimum TDP requirements consist of all applicable technical data, such as plans, drawings, and associated lists, specifications, standards, performance requirements, quality assurance provisions, packaging data, manufacturing data, manufacturing operation/process sheets, and corresponding equipment/tooling requirements.

4-11.2 PERFORMANCE SPECIFICATIONS

A performance specification states requirements in terms of the required results with criteria for verifying compliance, but without stating the methods for achieving the required results. A performance specification defines the functional requirements for the item, the environment in which it must operate, and interface and interchangeability characteristics. Relevant information concerning the format and contents of a performance specification can be found in MIL-STD-961, *Standard Practice for Defense Specifications*, (Ref. 48)

4-11.3 MANUFACTURING AND PROCESS SPECIFICATIONS

Manufacturing and process specifications are applicable to a service which is performed on a product or material. Examples of processes are: heat treatment, welding, plating, packing, microfilming, marking, etc. Process specifications cover manufacturing techniques which require a specific procedure in order that a satisfactory result may be achieved. Contractor' s should use commercial products, processes and practices to reduce development, production and operational costs. However, performance requirements should still be satisfied. The DoD strongly discourages the development of manufacturing and process specifications; except, where the DoD alone has the technological expertise to specify a military unique process.

4-11.4 TOOLING DRAWINGS

Performance specifications, commercial specifications, or source control drawings which describe all performance and interface requirements will usually be acceptable. Additional information on tooling drawings may be obtained in MIL-T-31000 (Ref. 47).

4-12 DATA MANAGEMENT

Technical data are recorded information used to define a design and to produce, support, maintain, or operate items of defense materiel. These data may be recorded as graphic or pictorial delineation's in media, such as drawings or photographs; text in specifications or related performance or design type documents; in machine forms, such as punched cards, magnetic tape, computer memory printouts; or may be retained in computer memory. Examples of recorded information include engineering drawings and associated lists, specifications, standards, process sheets, manuals, technical reports, catalog item identifications, and related information..

The objectives of the DoD program for the management of technical data are to assure optimum effectiveness and economy in the support of systems and equipment within the Defense establishment. The management of these data is not an end in itself, but is supportive in nature.

4-12.1 TAILORING DATA REQUIREMENTS

Tailoring of data refers to the selective application of data requirements so that only the minimum necessary data is procured. Only the minimum data needed to permit cost effective support of research, development, production, cataloging, provisioning, training , operation, maintenance, and related logistics functions over the life cycle of the item will be acquired. Paragraph 2-6 provides additional discussion of tailoring principles. TABLE 4-1 illustrates that the requirements can be selectively applied in the specification of deliverable data. In TABLE 4-2, it can be seen that appropriate category selection can be used in application of specification requirements.

TABLE 4-2

EXAMPLE DOCUMENT SUMMARY LIST

Document	Title	Specification Reference	Date	Category
SAE ARP 1281B	Actuators: Aircraft Flight Controls, Power Operated, Hydraulic, General Specification For	3.5.2.1	1993	Guidance
ASTM-D-1655A	Aviation Turbine Fuels	3.5.2.2	1995	Guidance
STANAG 3294, ED3, AMD 5	Aircraft Fuel Caps and Fuel Cap Access Covers	3.1.2.3	1973	Mandatory
DoDD 3405.2	Use of Ada on Weapons Systems	3.5.2.4		Mandatory
FAR 27.610	Lightning Protection	3.3.1.3	1 January 1991	Mandatory
FAR 27.303	Factor of Safety	6.2.7	1 January 1991	Mandatory

4-12.2 REPORTS AND DATA

Reports and data can be submitted in the form most appropriate for its intended usage. The CDRL specifies the form, format, and copy quality of deliverable data. CALS data, for example, is typically submitted in digital format. In addition to paper and digital data, qualification data may be submitted in the form of still photograph, video tape, or motion picture, as appropriate. Data developed for purposes other than qualification assurance can still provide valuable qualification assurance information. In the preparation of data, it should always be remembered that data content is significantly more important than data format.

4-12.3 DATA SUBMITTAL

The CDRL DD Form 1423 provides the specific data submittal requirements. Data are normally distributed directly to those Government offices having technical cognizance of the data with transmittal letter provided to the Contracting Office and/or the Data Management Office. Data may be submitted in a digital form and may be available on floppy disk, compact disk, or by direct access to the contractor's computer. The procuring activity must ensure that the delivered digital data can be received, stored, retrieved, and used by the Government. CALS implementation (paragraph 4-2) will result in more and more data being submitted or accessed by electronic means.

4-12.4 RECORDS AND MANUALS

An air vehicle inventory record provides the means for documenting the air vehicle’ s configuration in terms of installed equipment and location of the installed equipment.

The flight log book is used for tracking the operation of the air vehicle in terms of who flew the air vehicle, when and where it was flown, and the purpose of the flight. It is also used to track the operating time of the air vehicle, to record faults encountered, and to track deferred maintenance actions.

Maintenance performed, inspection requirements, and component time-change requirements are recorded in the maintenance log books.

The Operator’ s Manual contains a description of the operation of the air vehicle, its configuration, operating limits and restrictions; weight, balance, and loading information; flight performance data, and normal and emergency procedures. The Operator’ s Manual also contains the operator’ s and crew members normal and emergency amplified checklists. The Operator’ s checklist contains a condensed version of the applied checklists. Relevant information for air vehicle manuals and checklists can be found in MIL-M-63029, *Manuals, Technical: Requirements for Operator's Manuals and Checklists for Aircraft*, (Ref. 49) provides air vehicle manual data requirements.

Maintenance manuals provide detailed troubleshooting and repair procedures for the air vehicle, as well as detailed part information necessary to perform the repair.

The repair parts and special tool list (RPSTL) documents the repair parts and special tools required for all maintenance actions on the air vehicle, and provides the basis for developing maintenance manual information.

4-13 CONFIGURATION MANAGEMENT

The contractor should be required to maintain configuration control and status accounting through best commercial practices and throughout the length of the contract, except that the procuring activity should maintain control of all performance, interface, and flight safety parts specifications. The contractor’ s means for satisfying configuration control, such as Electronic Industries Association (EIA) Standard IS-649, *Configuration Management* (Ref. 51) should be described in their response to a request for proposal. The configuration management effort should include identifying, documenting, and verifying the functional and physical characteristics of an item; recording the configuration of an item; and controlling changes to an item and its documentation. It should provide a complete audit trail of decisions and design modifications, reference DoD Regulation 5000.2-R (Ref. 1). See paragraph 4-11 for additional information.

In those cases where the procuring activity maintains control, an engineering change proposal should be used to change the specification.

An engineering change proposal (ECP) is a proposed engineering change and documentation by which the change is described, justified, and submitted to the procuring activity for approval or disapproval. The ECP may be in contractor format; however, there should be two class of ECPs:

An ECP should be classified as a Class I ECP if:

1. the functional configuration identification, allocated configuration

identification, or product configuration identification, once established, is affected to the extent that any of the following requirements would be outside specified limits or specified tolerances:

a. performance;

b. reliability , maintainability, or survivability ;

c. weight, balance, moment of inertia;

d. interface characteristics;

e. electromagnetic characteristics; or

f. other technical requirements specified in the functional configuration identification or allocated configuration identification or product configuration identification.

2. a change to the product configuration identification, once established, impacts one or more of the following:

a. government furnished equipment (GFE);

b. safety;

c. deliverable operational, test, or maintenance computer software associated with the configuration item or computer software configuration item being changed;

d. compatibility or specified interoperability with interfacing configuration items or computer software configuration items, support equipment/software, spares, trainers, or training devices/equipment/software;

e. configuration to the extent that retrofit action is required;

f. delivered operation and maintenance manuals for which adequate change/revision funding is not provided in existing contracts;

g. preset adjustments or schedules affecting operating limits or performance to such extent as to require assignment of a new identification number;

h. interchangeability, substitutability, or replaceability as applied to configuration items and to all subassemblies and parts except the pieces and parts of non-reparable subassemblies; or as applied to computer software configuration items and to all computer software components and computer software units;

i. sources of configuration items or reparable items at any level defined by source control drawings; or

j. skills, manning, training , biomedical factors, or human engineering design.

k. Any of the following contractual factors are affected:

(1). cost to the Government, including incentives and fees;

(2). contract guarantees or warranties;

(3). contractual deliveries; or

(4). scheduled contract milestones.

An ECP should be classified as a Class II ECP if the change identifies a minor change to a configuration item or its documentation that can be effected entirely by a contractor within the scope of the current contract effort without changing the Government approved configuration identification other than to incorporate the Class II change into the product configuration identification. Examples of Class II changes are:

1. changes that do not affect interchangeability, substitutability, or replaceability of configuration items, or when reparable, their subassemblies and parts;

2. substitution of parts or material which do not have a functional, logistic, or reliability impact;

3. changes in documentation only (e.g., correction of errors, addition of clarifying notes or views, addition, deletion

or correction of non-executable comment lines-of code to software).

Prior to manufacture of an item, if a contractor considers it necessary to depart from the mandatory requirements of a performance or interface specification, the contractor may request that a deviation be authorized. As an example, if a component will no longer be capable of performing its intended function or satisfying specified interface requirements, contractual authorization in the form of an approved waiver is required prior to the delivery of items incorporating known departure from documentation.

An item which through error during manufacture does not conform to the configuration identification should not be delivered unless a waiver has been processed and approved by the procuring activity.

4-13.1 FUNCTIONAL BASELINE

The functional baseline configuration is established with the initially approved documentation describing a system's or item's functional characteristics and the verification required to demonstrate the achievement of those functional characteristics. Typically, a system specification developed at the initiation of a development program would constitute a functional baseline. The contracting agency will usually retain control of the functional baseline.

4-13.2 ALLOCATED BASELINE

The allocated baseline configuration is established with the initially approved documentation describing an item's functional and interface characteristics that are allocated from those of a higher level configuration item, interface requirements with interfacing configuration items, additional design constraints, and the verification required to demonstrate the achievement of those specified functional and interface characteristics. Typically, prime item development specification (PIDS) and interface control document (ICD) are used to describe the allocated baseline. These are also prepared early in the development cycle. For software, the allocated baseline is documented by the approved SRS and IRS following SSR.

4-13.3 ALLOCATED BASELINE EXPANSION

As additional requirements become allocated to lower level configuration items, the allocated baseline is expanded to cover these additions. Changes to the baseline are approved and documented through SCNs and the Change Control Board (CCB).

4-13.4 PRODUCT BASELINE

The product baseline configuration is established with the initially approved documentation describing all of the necessary functional and physical characteristics of the configuration item, any required joint and combined operation's interoperability characteristics of a configuration item (including a comprehensive summary of the other service(s) and allied interfacing configuration items or systems and equipment), and the selected functional and physical characteristics designated for production acceptance testing and tests necessary for the support of the configuration item. Typically, the product baseline is established at the end of development (following successful FCA and PCA) when the design has matured sufficiently to enter production.

4-14 GOVERNMENT INDUSTRY DATA EXCHANGE PROGRAM (GIDEP)

The Government-Industry Data Exchange Program (GIDEP) is a cooperative data interchange among Government and Industry participants seeking to reduce or eliminate expenditures of time and money by making maximum use of existing knowledge. Relevant information can be found in MIL-STD-1556, *Government Industry Data Exchange Program (GIDEP) Contractor Participation Requirements*, (Ref. 50). GIDEP provides a means to exchange certain types of data essential during the life cycle of systems and equipment. GIDEP was initially established to minimize duplicate testing of parts and materials through the interchange of environmental test data and technical information among contractors and Government agencies involved in design, development, and fabrication of Government-funded equipment. Information contained within the GIDEP storage and retrieval system includes environmental test reports and procedures, reliability specifications, failure analysis data, failure rate data, calibration procedures, and other technical information related to the application, reliability, quality assurance, and testing of parts and related materials. To enable immediate data access, all information is computer indexed and recorded on microfilm. Unclassified and non-proprietary test reports and other technical information generated by a participant are submitted to the GIDEP Operations Center. This information is reviewed for program applicability, indexed for computer retrieval, processed for microfilming, and automatically distributed to qualified contractors and Government agencies participating in GIDEP.
TABLE 4-3, "DATA AVAILABLE IN GIDEP," provides details of the GIDEP.

4-15 LESSONS LEARNED

4-15.1 THE SAFETY DATA BASE.

The safety database provides mechanism for recording safety related incidents. Data is maintained concerning the cause and corrective actions taken to preclude recurrence. Review of the database information provides insight on avoiding similar incidents in future designs and operations.

4-15.2 THE COMBAT DATABASE

The combat database is means of storing and retrieving operational combat deficiencies. Its value lies in the fact that operational combat situations often cannot be simulated, no matter how realistic the test scenario. Lessons learned from combat situations are valuable considerations for future design.

4-15.3 THE LOGISTIC DATABASE

The logistic database provides a means of collecting and disseminating logistics related lessons learned. It contains information on repair problems, supply, support equipment, manuals, and other documentation. Again, examining lessons from the past will help preclude their future occurrence.

TABLE 4-3

DATA AVAILABLE IN GIDEP

DATA INTERCHANGE	CONTENTS
Engineering Data Interchange (EDI)	Engineering studies, testing, specification preparation, data processing and analysis, manufacturing processes planning and selection, quality assurance, non-stand parts justification data
Failure Experience Data Interchange (FEDI)	ALERTs/SAFE-ALERTs (actual or potential problems with parts, components, materials, manufacturing processes, equipment or safety conditions), diminishing manufacturing sources and material shortages
Reliability and Maintainability Data Interchange (RMDI)	mathematical modeling and reliability, maintainability/logistics data and methods
Metrology Data Interchange (MDI)	calibration procedures, plans, and methods

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None

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LIST OF ACRONYMS AND ABBREVIATIONS

ABL	=	Allocated baseline
AIS	=	automated information system
AJPO	=	ada joint program office
AMSDL	=	acquisition management systems and data requirements control list
ANSI	=	american national standards institute
AQP	=	airworthiness qualification plan
ASIC	=	application specific integrated circuit
ASTM	=	american society for testing & materials
BW	=	bandwidth
CALS	=	continuous acquisition and life-cycle support
CCB	=	change control board
CDR	=	critical design review
CDRL	=	contract data requirements list
CFE	=	contractor furnished equipment
CG	=	center of gravity
CI	=	configuration item
CID	=	commercial item description
CSCI	=	computer software configuration item

D	=	with draft proposal
DAC	=	days after contract award
CID	=	commercial item description
DoD	=	department of defense
DODISS	=	department of defense (dod) index of specifications and standards
DSSE	=	developmental software support environment
E3	=	electromagnetic environmental effects
ECP	=	engineering change proposal
EDI	=	engineering data interchange
EEPROM	=	electrically erasable prom
EIA	=	electronic industries association
EMI	=	electromagnetic interference
EPROM	=	erasable prom
ESDD	=	electrical subsystem design documents
F	=	with final proposal
FAA	=	federal aviation administration
FAR	=	federal aviation regulation
FBL	=	functional baseline
FCA	=	functional configuration audit
FEDI	=	failure experience data interchage
FF	=	before first flight
FMECA	=	failure mode, effect, and criticality analysis

GFE	=	government furnished equipment
GIDEP	=	government-industry data exchange program
HERF	=	hazards of elctromagnetic radiation to fuel
HERO	=	hazards of electomagnetic radiation to ordnance
HERP	=	hazards of electromagnetic radiation to personnel
HWCI	=	hardware configuration item
ICD	=	interface control document
IEE	=	institute of electrical and electronic engineers
IFOV	=	instantaneous field-of view
IPT	=	integrated product team
IRS	=	interface requirements specification
ISWDB	=	integrated weapon system database
LCSSE	=	life cycle software support environment
LSA	=	logistic support analsis
LSAR	=	logistic support analysis record
M	=	monthly
MAC	=	months after contract award
MANPRINT	=	manpower and personnel integration
MDI	=	metrology data interchange
NATO	=	north atlantic treaty organization
NBC	=	nuclear, bilogical, and chemical
NEP	=	noise equivalent power
NET	=	net equivalent temperature

NRC	=	nuclear regulatory commission
NVIS	=	night vision imaging system
NVM	=	nonvolatile memory
OMB	=	office of management and budget
PAL	=	programmable logic devices
PBL	=	product baseline
PCA	=	physical configuration audit
PDL	=	program design language
PDR	=	preliminary design review
PIDS	=	prime item development specification
PLD	=	programmable logic devices
PPSL	=	program part selection list
PROM	=	programmable rom
R	=	responsitivity
RAM	=	reliability, availability, and maintainability
RMDI	=	reliability and maintainability data interchange
ROM	=	read only memory
RPSTL	=	repair parts and special tool list
SAE	=	society of automotive engineers
S/N	=	signal to noise
SDDD	=	software detailed design document
SDR	=	system design review

SIE	=	special inspection equipment
SMD	=	standardized military drawings
SPP	=	standard practice procedure
SQPP	=	software quality program plan
SRFC	=	status report-reason for change
SRR	=	system requirements review
SRS	=	software requirements specification
SSDD	=	system segment design document
SSPP	=	system safety program plan
SSR	=	software specification review
SSS	=	system/segment specification
STANAG	=	standardization agreement
STD	=	software test description
STLDD	=	software top level design document
STR	=	software test report
TDP	=	technical data package
TRR	=	test readiness review
UUT	=	unit under test
VDD	=	version description document

CHAPTER 5
QUALIFICATION ASSURANCE

The qualification assurance topics of hardware and software quality assurance, instrumentation and calibration, plans and reports approval, test witnessing, test facility validation, simulation validation, testability, test-analyze-and-fix, procurement specifications, make or buy planning, special tooling, standardization program, and producibility are addressed.

5-1 INTRODUCTION

This chapter introduces and explains the aspects of hardware and software quality assurance and their relationships to the airworthiness qualification process. Common elements of the quality assurance program are the tasks of determining, ensuring, documenting, and maintaining contractual specification compliance. The objectives of qualification assurance are to provide a true and factual assessment confirming critical system characteristics and to provide adequate information and controls in order to duplicate the items in the required quantities and have each possess the same critical characteristics as the items that underwent the original qualification process. Proper application of these considerations allows smooth transition from development to production with minimal effort or duplication of activities.

5-2 HARDWARE QUALITY ASSURANCE PROGRAM

The objectives of a hardware quality assurance program are to ensure that contractor-developed and -produced hardware items meet specification requirements. The program applies to all activities conducted under the contract. The Hardware Quality Assurance Program (HQAP) complements the objectives of the airworthiness qualification program. Determination of safe performance capability and operating limits for production air vehicles by airworthiness qualification is dependent on the ability of hardware quality assurance to duplicate the critical characteristics of the qualified article in production units. The program should be conducted in a manner that assures adequate quality throughout all areas of contract performance, such as manufacturing, processing, assembly, inspection, test, packaging and shipping.[*] All supplies and services under the contract, whether manufactured or performed in the contractor's plant or at any other location, should be controlled by the contractor by means to be defined by the contractor. In general, management standards should not be specified in Government solicitations.

The quality program, including procedures, processes, and product, should be documented by the contractor and subject to review by the Government.

5-2.1 QUALITY ASSURANCE PROGRAM ELEMENTS

Table 5-1 provides a list and description of typical elements of quality

[*]American Society of Quality Control (ASQC) Q9000 series standards (Refs. 1 through 5) and statistical process control rather than inspection and test are favored for future contracts. An advanced quality system (AQS), such as "Design for Six-Sigma Manufacturability", should be considered. Therefore, ASQC Q9000 series standards (Refs. 1 through 5) and other advanced quality systems may be substituted for the quality system described in this chapter. Six-Sigma Manufacturability is an advanced quality system, which differs from a traditional quality system by emphasizing prevention of defects rather than after-the-fact detection of defects.

TABLE 5-1. TYPICAL QUALITY ASSURANCE PROGRAM ELEMENTS

ELEMENT	DESCRIPTION
Quality Program Management	Organization Initial quality planning Work instructions Records Corrective action Costs related to quality
Facilities and Standards	Drawings, documentation, and changes Measuring and testing equipment Production tooling Inspection equipment Advanced metrology and requirements
Control of Purchases	Responsibility Supplier control Purchasing Data
Manufacturing Control	Materials and materials control Production processing and fabrication Completed item inspection and testing Handling, storage, and delivery Nonconforming material Statistical quality control and analysis Indication of inspection status
Coordinated Government and Contractor Actions	Government inspection at subcontractor or vendor facilities Government property

assurance. Contractors should be encouraged to propose commercial means to satisfy these elements.

The quality program management element prescribes typical means for effective management of the quality function. The organization and methods used for the quality function are prescribed by the contractor. Typically these are determined through initial quality planning. Early in the contract, the contractor conducts a complete review of contract requirements to determine the needs for special controls, processes, test equipment, fixtures, tooling, and skills required to assure product quality. Work instructions often provide the criteria needed to perform the work functions and to supervise, inspect, and manage work. Records are usually used to document the results of inspections and tests and indicate the acceptability of work or products and the action taken in connection with deficiencies. Corrective actions result from the discovery of situations that could result in delivery of defective supplies, services, technical data, standards, or other elements of contract performance and could create excessive losses, delays, or cost. The final aspect of quality management could include maintenance and use of quality cost data.

The facilities and standards element typically deals with establishing and maintaining baseline information against which product performance can be compared. Procedures should be established to assure the adequacy, completeness, and currentness of drawings and related technical data. Inspection and test equipment should be calibrated routinely to ensure that it meets the requirements for accuracy, repeatability, and traceability. Accuracy standards and inspection criteria should also be established for production tooling that is used as inspection media.

The control of purchases element typically addresses the need to ensure that supplies and services procured by a contractor from his vendors and suppliers conform to contract requirements. It should be the contractor's responsibility to ensure that qualified suppliers are selected, that quality requirements are transmitted to the suppliers, that adequacy of procured items is evaluated, and that provisions for early information feedback and correction of nonconformances are established. In the proposal the contractor should be required to identify the means by which these responsibilities will be satisfied.

The manufacturing control element deals with incoming inspection of material, production processing and fabrication, handling, storage and delivery, control of nonconforming material, statistical quality control, and indication of inspection status. Receiving inspections assess the acceptability of incoming material. In the proposal the contractor should be required to identify the means by which the needed controls will be satisfied.

The coordinated Government and contractor actions element addresses Government inspection at subcontractor or vendor facilities and the procedures for Government-furnished material. To assist the Government representative at the contractor's facility, the Government may inspect supplies or services at their source. When material is furnished by the Government, the contract should establish procedures to examine, inspect, test, and identify the material.

5-2.2 QUALITY ASSURANCE PROGRAM INCORPORATION

The contractors should be required to identify in their proposals the applicable hardware quality assurance program and standards. The same requirements should be included in the Airworthiness Qualification Specification (AQS). Any unique requirements applicable to the program may also be addressed in the contract or AQS. If no requirement for a Quality Assurance Program exists in the contract, critical elements of the program should be specified in the AQS. These requirements should be sufficiently detailed to identify the required tasks clearly.

5-3 SOFTWARE QUALITY

The objectives Of a Software Quality Assurance Program should be to ensure that all software developed and produced by the contractor satisfy critical characteristics and meet performance requirements. The scope of the Software Quality Assurance Program applies to all activities performed under the contract and includes deliverable and non-deliverable software, embedded software, and software support. The Software Quality Assurance Program complements the objectives of the airworthiness qualification program. Determination of the safe performance capability and operating limits for production air vehicles by airworthiness qualification is dependent on the ability of software quality assurance to duplicate the critical characteristics of the qualified article in the production units. The critical characteristics of software include functions, logic, timing, and both human/software and hardware/software interfaces that influence operational control. Airworthiness degrades if operational control causes improper response to inputs, does not respond to inputs, or allows hazardous conditions to exist. The contractor's software quality program should ensure the quality of

1. Deliverable software and its documentation
2. The processes used to produce deliverable software
3. Nondeliverable software.

Contractors should be required to define in their proposals and specifications the means by which they will satisfy these objectives. Ultimately, the contractor should be responsible for quality and performance. Several related commercial standardization documents are ASQC Q9001, *Quality Systems—Model for Quality Assurance in Design, Development, Production, and Servicing*, (Ref. 2) and IEEE STD 1298/SAA 3563.1, *Software Quality Management System*, (Ref. 6).

5-3.1 SOFTWARE QUALITY ASSURANCE PROGRAM ELEMENTS

Table 5-2 identifies and describes typical elements of a Software Quality Assurance Program. The contractor(s) should be encouraged to propose commercial means to satisfy these elements.

The first element of a Software Quality Assurance Program relates to Evaluation of Software. This could be achieved through ongoing evaluations of all software to assure that

1. The software complies with the contract requirements, and emphasis is placed on reliability and software system safety.
2. The software adheres to the overall integrated plan.

The Evaluation of Software Documentation element could entail an evaluation of the software portion of the integrated plan to ensure it complies with the contract, with other software plans, and with system-level requirements. It could include the evaluation of other software documentation to ensure that each document adheres to the required format and that each document complies with the contract.

The Evaluation of the Processes Used in Software Development element could include an ongoing evaluation of software management, evaluation of software engineering, evaluation of software system safety, evaluation of software qualification, evaluation of software configuration management, evaluation of software corrective actions, evaluation of documentation and media distribution, evaluation of storage, handling, and delivery, and evaluation of other processes used in software development.

The Evaluation of the Software Development Library element could be accomplished by ensuring that

1. The library and its operation comply with the contract and adhere to the software plans
2. The most recent authorized version of materials under configuration control is clearly identified and is the one routinely available from the library
3. The previous version of materials under configuration control is clearly identified and controlled to provide an audit trail that permits reconstruction of all changes made to each configuration item.

The Evaluation of Nondevelopmental Software element could be accomplished by assuring that

1. Objective evidence exists prior to its incorporation that it performs its required functions reliably and safely.
2. It was placed under internal configuration control prior to its incorporation.
3. The data rights provisions are consistent with the contract.

The Evaluation of Nondeliverable Software element could be accomplished by

TABLE 5-2. TYPICAL SOFTWARE QUALITY ASSURANCE PROGRAM ELEMENTS

ELEMENT	DESCRIPTION
Evaluation of Software	Assurance that Software bears no adverse system safety impact. Software complies with contract. Software adheres to software plans.
Evaluation of Software Documentation	Evaluation of software plans Software plan compliance with contract Software plan consistency with other software plans and with system-level plans
Evaluation of Processes Used in Software Development	Evaluation of Software management Software engineering Software system safety Software qualification Software configuration management Software corrective actions Documentation and media distribution Storage, handling, and delivery Other processes used in software development
Evaluation of the Software Development Library	Assurance that Library and operation comply with the contract and plans. Most recent authorized version of materials under configuration control are identified and available. Previous versions of materials under configuration control are identified for audit trail purposes.
Evaluation of Nondevelopmental Software	Assurance that Nondevelopmental software performs required func-tions reliably and safely. Nondevelopmental software was placed under internal configuration control prior to use. Data rights provisions are consistent with contract.
Evaluation of Nondeliverable Software	Assurance that Software performs required functions. Software was placed under internal configuration con-trol prior to use.
Evaluation of Deliverable Elements of the Software Engineering and Test Environments	Assurance that deliverable elements Comply with contract and software plans Perform required functions reliably and safely Place under configuration control prior to use Data right provisions are consistent with contract
Evaluation of Subcontractor Management	Assurance that Subcontractor-developed software and documentation satisfy prime contract requirement. Baseline requirements for subcontractor are estab-lished and maintained. Software quality program requirements are imposed on subcontractor. Access for contractor review at subcontractor's facility. Contracting agency has right to review subcontractor.

TABLE 5-2. (Cont'd)

ELEMENT	DESCRIPTION
Evaluations Associated With Acce ptance Inspection and Preparat ion for Delivery	Assurance that All required software products are available for review. All required procedures have been performed. All deliverables have been updated to reflect all ap-proved changes.
Participation in Formal Reviews and Audits	Assurance that all review products are available and that all required preparations have been made. Presentation of evaluation of status and quality of each development product. Assurance that all action items resulting from review have been performed.

evaluation of each nondeliverable software item used in the automated manufacturing of deliverable hardware or in the qualification or acceptance of deliverable software, or hardware could be evaluated to ensure that

1. Objective evidence exists prior to its intended use that it performs the required functions.

2. It was placed under internal configuration control prior to its use.

The Evaluation of Deliverable Elements of the Software Engineering and Test Environments element could be accomplished by the contractor's evaluation of each deliverable element of the software engineering and test environment to assure that

1. It complies with the contract and adheres to the software plans.

2. Objective evidence exists prior to its use that it performs required functions.

3. It was placed under internal configuration control prior to its use.

4. The data rights provisions are consistent with the contract.

The Evaluation of Subcontractor Management element could entail the contractor's evaluation of all subcontractor activity to assure that

1. All subcontractor-developed software and related documentation deliverable to the contracting agency satisfy the prime contract requirements.

2. A set of baseline requirements is established and maintained for the software to be developed by the subcontractor.

3. Applicable software quality program requirements are included or referenced in the subcontract or purchase documents for the subcontractor.

4. Access is available for contractor reviews at subcontractor and vendor facilities.

5. The contracting agency has the right to review all software products and activities required by the subcontract at the subcontractor facilities to determine compliance with the subcontract.

The Evaluations Associated With Acceptance Inspection and Preparation for Delivery element could be accomplished by the contractor to assure that

1. All required software products are available and ready for contracting agency inspection.

2. All required procedures have been performed and evidence of satisfactory completion of these procedures is available for contracting agency inspection.

3. All deliverable software and documentation have been updated to reflect all changes approved by the contracting agency and scheduled for inclusion.

The final element, Participation in Formal Reviews and Audits, could require that

1. Prior to each review and audit, the contractor assures that all required products will be available and ready for contracting agency review and that all required preparations have been made.

2. At each formal review and audit the contractor presents an evaluation of the status and quality of each of the development products reviewed.

3. Following each formal review and audit, the contractor assures that all software-related action items assigned to the contractor have been performed.

5-3.2 SOFTWARE QUALITY ASSURANCE PROGRAM INCORPORATION

Just as with Hardware Quality Assurance Program requirements, Software Quality Assurance Program requirements may be specified by reference in the contract, system specification, or AQS. Any unique requirements applicable to the program may also be addressed in the contract, system specification, or AQS. If no requirement for a Quality Assurance Program exists in the contract, critical elements of the program should be specified in the AQS

5-4 INSTRUMENTATION AND CALIBRATION FOR TESTING

Instrumentation is the means by which physical variables are measured. It is comprised of sensors and data transmitting, receiving, displaying and recording equipment. Calibration procedures involve a comparison of the particular instrument with (1) a primary standard, (2) a secondary standard with a higher accuracy than the instrument being calibrated, or (3) a known input source. The objective of instrumentation and calibration is to collect evidence that a characteristic value is present under specified conditions. The presence of this value provides the basis for determining that a specification requirement has been met and therefore forms a basis for airworthiness qualification.

5-4.1 INSTRUMENTATION PLANS AND REVIEWS

A separate instrumentation plan should not be required by the PA; however, instrumentation requirements should be included in the contract and Airworthiness Qualification Specification. The contractor should be responsible for data reduction and analysis, which the PA should review and approve. The criteria for instrumentation selection includes tradeoffs between instrumentation cost, required accuracy, facility use and availability, and data reduction and processing requirements. The contractor's proposal should detail its data collection methods, proposed flight instrumentation equipment, data reduction and processing requirements, and the proposed data reduction facilities equipment. Also the proposal and system specification should address the extent to which built-in test equipment (BITE) onboard the air vehicle will be used as well as the requirements for external instrumentation. Differences in instrumentation requirements during various test phases should also be addressed.

Instrumentation reviews should be conducted when instrumentation issues are sufficiently complex to warrant direct interface between Government and contractor personnel. Such issues might involve the use of Government facilities or the requirement for highly specialized instrumentation. A thorough review of demonstration requirements is necessary to identify the parameters to be measured and the instrumentation methods to be used for measurement. An integral part of this review is identification of the accuracy requirements for measurements since these will drive the complexity, sophistication, and cost of the instrumentation system.

5-4.2 FLIGHT TEST INSTRUMENTATION

Air vehicle flight test instrumentation typically records air vehicle attitudes, rates, accelerations, pitot-static data, temperatures, flow rates, and human-factors-related parameters. Typical instrumentation sensors include accelerometers, strain gages, temperature and pressure sensors, flow sensors, position sensors, vibration sensors, and audio- and video-sensing devices. In addition, instrumentation may be provided to record cockpit switch settings and flight crew activity. Output of electronic displays may be recorded for analysis of system performance. For onboard digital communication busses, bus monitoring devices monitor and record bus traffic. The monitoring may be selective, in which case only specific types of bus messages are monitored, or it may capture all bus activity.

Signals from sensors are passed through signal-conditioning circuits, such as amplifiers and filters, prior to recording. Recording may be performed onboard the air vehicle or on the ground with telemetry devices used to communicate the data from the air vehicle to the ground. Often, a combination of both recording methods is used. The recording medium may be either magnetic (tape or disk), solid-state (flash memory, random access memory (SRAM), erasable programmable read-only memory (EPROM)), or optical. Data may be recorded in either analog or digital formats. Digital recording allows the application of digital signal processing techniques, which greatly enhance the capability for later data reduction.

Data processing is the activity that turns raw data into results, which may be compared with performance requirements. Processing may take place in real time, i.e., as the data is being gathered, or it may be performed after the test. Real-time data processing has the advantage of providing immediate feedback on test progress and results and allows for a quick reaction to test progress. This advantage can greatly reduce the need for test time and facilities by allowing on-the-spot correction of problems or other intervention by test personnel during the test. Certain data reduction processing requirements may be so computationally intensive that they can be performed only after completion of the test.

It is essential that prior to the test the data collection and processing system be validated to ensure that valid results are generated. Validity of data is determined by comparing data processing results with independently generated or determined data.

5-4.3 RANGE INSTRUMENTATION

Range instrumentation includes time-, space-, and position-information sensors; transponders; and range-time receivers. Specialized range instruments are also used to determine air vehicle acoustic, optical, infrared, and radar signatures. Instrumented targets, both moving and stationary, are required to perform weapon system effectiveness testing. The instrumentation system should be able to provide time-tagged information relative to target position, velocity, and acceleration. Meteorological conditions at the target area, such as visibility conditions (which include both naturally occurring and man-made obscurants), temperature, precipitation conditions, and atmospheric attenuation at the specific wavelength of the sensors under test should be recorded. Instrumentation should also be provided that will allow determination of weapon impact or weapon miss distances in both the cross-range and downrange directions. For tests involving missiles, the missiles may also be instrumented.

5-4.4 CALIBRATION REQUIREMENTS

Calibration should be performed to ensure the accuracy of the instrumentation. The contractor should be required to establish and maintain a system to calibrate all measuring and test equipment used in the fulfillment of contractual requirements. The contractor should identify in its proposal the calibration standards to be used for performance of the contract. ISO 10012-1, *Quality Assurance Requirements for Measuring*, (Ref. 7) and ANSI Z540-1, *Laboratories, Calibration, and Measuring Test Equipment*, (Ref. 8) are considered satisfactory commercial standards, and there could be others. Measurement standards used by the contractor to calibrate measurement and test equipment should be traceable to a specific standard and have the accuracy, stability, range, and resolution required for its intended use. If targets are used for weapon system effectiveness testing and their specific condition at the time of the test is significant to the test outcome, these targets should be calibrated also. For example, if thermal bar pattern targets are used to test thermal imaging system performance characteristics, they should be calibrated so that target conditions at the time of the test are well understood. Similarly, if the test involves electromagnetic measurements, it is necessary to calibrate the test equipment to the electromagnetic environment at the time of the test in order to understand properly the environmental effects on test results.

5-5 APPROVAL OF PLANS AND REPORTS

Plans and reports undergo approval cycles internally within both the contractor's organization and the Government.

Internally the plan or report is prepared by the originating organization and signed off by those organizations or individuals having review or approval responsibility.

The contract data requirements list (CDRL) specifies the nature of the approval required for all data submittals including plans and reports. The objectives of the approval of the plans and reports are to

1. Ensure that the contractor submits those documents in accordance with the requirements of the contract
2. Ensure that the appropriate Government personnel can determine and document the contractor’s accomplishment of contractual requirements.

Generically, plans and reports submitted to the Government for approval are distributed within the Government to the appropriate engineering and program management personnel. They prepare their comments and submit them to the individual with primary technical responsibility for the subject matter covered by the plan or report. That individual collects Government inputs and consolidates them after resolving any potential conflicting comments. Plans and reports may be approved as submitted, approved subject to the incorporation of Government comments, or rejected if the document is not responsive to Government requirements. Government comments to plans and reports are forwarded to the contractor via the contractual channel. If the contractor is required to correct deficiencies identified in the plans and reports, the procuring agency typically will specify a required response time for their correction.

Usually, test plan and report preparation, coordination, and approval generate many draft versions with errors and omissions. Thus controlled release of test plans and reports by a document control activity provides a source of known version(s) of the documents approved for use. This procedure assures that the correct tests are performed and that an accurate record of the test conducted and its results are available to document the qualification.

5-6 TEST WITNESSING

The test witness is responsible for reviewing the plans of test(s) and the contract requirements (system specifications, etc.) and for being familiar all aspects of the test(s) to be witnessed. As a Government representative, the test witness is responsible for verifying the contractor's test report. As early as possible, the witness should inform the test coordinator of any special requirements in the areas that follow (if applicable):

1. Specific documentation and data, e.g., plans, reports, and drawings, that will be used in witnessing activities
2. Special briefings unique to his areas of interest
3. Portion of the test to be witnessed.

The test witness should review and countersign the test report prepared by the contractor. This constitutes verification of the scope and details of the test and that the test was conducted with or without deviations from the Government-approved test plans. It does not necessarily indicate concurrence in the conclusions presented. The witness or observer should provide an evaluation of the test to the test coordinator and should also discuss any requirements for special witnessing reports with the coordinator.

A generic AQS requirement for test witnessing follows:

Based on the contractor's master test schedule, the procuring agency will designate those tests that require Government witnessing. Prior to any required test, survey, or demonstration and prior to component or subsystem disassembly following same, the test coordinator designated by the procuring activity shall be notified in sufficient time to witness the test or disassembly. If the test interpretation requires specific engineering knowledge, the test coordinator shall be notified by the contractor a minimum of five (5) working days prior to the test. No designated test will be conducted without the test coordinator or his representative being present. Deviation from these procedures is subject to case-by-case approval of the procuring activity.

The test coordinator should be responsible for ensuring that a qualified witness is present during the important phases of a test program. For tests that are considered a significant part of the qualification program, the test witness(es) generally should be provided by the procuring activity.

5-7 TEST FACILITY VALIDATION

The objective of test facility validation is to assure that the contractor's test facility is adequate for achieving its airworthiness qualification functions. The criteria used to establish a requirement for test facility validation depends on the extent to which the airworthiness qualification objectives are dependent on the adequacy of the test facility and the degree of previous use of the facility by the contractor for similar purposes.

Generally, a test facility may be validated by defining its intended function and showing evidence that it is properly equipped and staffed for that intended function. Equipment considerations should include test fixtures, stimulus capabilities, measurement capabilities, data pro-cessing capabilities, tools, support equipment, interface equipment, and suitability of the facility to conduct flight-test operations.

Staffing considerations should include appropriate engineering and technical personnel to set up, perform, and analyze test activities.

An example of a typical Airworthiness Qualification Specification (AQS) requirement for test facility validation follows:

"The contractor shall conduct a test facility validation for [name of test facility] for the purpose of providing objective evidence that the facility is suitable for achieving the airworthiness qualification objectives of [name of test]. The validation shall include a complete description of the facility to include intended uses, test fixture descriptions and capacities, stimulus capabilities, measurement capability, data processing capabilities, and interfacing equipment. The validation will also describe specific tests conducted to demonstrate that the facility is capable of producing valid results."

Types of facilities that may require validation include whirl towers, engine test facilities, wind tunnels, dynamic component integration facilities, electronic component integration facilities, and hardware/software integration facilities.

5-8 SIMULATION VALIDATION

Simulations and their role in the airworthiness qualification process are discussed in detail in Chapter 6. The objective of simulation validation is to show that the simulation adequately represents the system being modeled with respect to the critical characteristics under consideration by the simulation. The criteria used to establish simulation validation requirements depend on the extent to which the contractor intends to use simulation activities to fulfill airworthiness qualification objectives. For example, a simulation intended to be used to predict performance during the concept exploration phase will generally require less data to substantiate validation than if the simulation or model is intended to be used for or to replace qualification data.

Simulation validation requirements are also dependent on the degree of abstraction between the real-world item being modeled and the simulation. The greater the degree of abstraction, the greater the number and types of simplifying assumptions are made about the real world in order to consider only the most fundamental variables and their interactions.

Simulation validation requires exercising the simulation over as wide a range of possible conditions and the confirmation from independent data and analysis that the simulation yields valid results. Simulations used to predict design performance and used for qualification purposes may also require verification of model data versus measured data and may require accreditation by a third party.

Several different methods may be used to validate simulations. They include expert consensus, comparison with test data, peer review, and independent review.

A general simulation validation requirement for incorporation into an AQS is as follows:

"The contractor shall prepare a simulation validation for [name of simulation]. The validation shall describe the airworthiness objective to be accomplished by the simulation. It shall also describe the simplifying assumptions inherent in the simulation and their impact on results. The contractor shall provide a comparison of simulation data and independently obtained data to demonstrate that the simulation yields valid results."

5-9 TESTABILITY

Testability is a characteristic of design that allows the status—operable, inoperable, or degraded—of an item to be determined and the isolation of faults within the item to be performed in a timely manner. Testability may be achieved through the combination of external resources, such as automatic test equipment (ATE), and internal capability, such as self-diagnostics and built-in test (BIT).

MIL-STD-2165, *Testability Program for Systems and Equipments*, (Ref. 9) or an equivalent handbook, may be used as a guide to testability requirements (including BIT), testability analysis, prediction and evaluation, and preparation of testability documentation; however, the standard should not be specified or referenced in solicitations. Tasks described in this standard are intended to be tailored to the particular needs of the system or equipment acquisition program. Testability requirements should be based on mission needs and system performance requirements. Also testability requirements should be closely linked to logistic and maintainability performance requirements. The contractor should be required to identify in the proposal the means to be used to satisfy the testability requirements.

DARCOM-P 34-1, *Built-in-Test Design Guide*, (Ref. 10) presents the fundamentals of BIT, provides an overview of the different approaches and requirements available to the designer and the acquisition manager, and discusses standardized methods used to evaluate these different approaches.

5-9.1 GENERAL TESTABILITY FEATURES

Testability should be achieved through incorporation of appropriate design features to allow for fault detection and isolation. Such features should include functional grouping, separation of functions, and accessibility of test points. If the specific system components that provide a function are grouped together, the loss of that function should be readily attributed to the failure of the grouping providing that function. Generally, if the components providing the function are widely distributed throughout the system, isolation of the fault becomes much more complicated and ambiguous. If functions are separated, a component failure is likely to affect only one function rather than multiple functions. Again, this approach yields a more testable design. Ample test points should be provided throughout a system. These testability features provide benefits in both an operational environment and the course of the airworthiness qualification process by providing a means to identify system mission performance capability.

5-9.2 AUTOMATIC TEST EQUIPMENT (ATE)

The concept of ATE is to permit automatic test and diagnostic of equipment while minimizing manual test requirements. The objective of ATE testability is to ensure that an item (usually electronic in nature) can be tested outside the system in which it is installed by automatic test equipment. To accomplish this, the item should be able to accept stimulus from an outside source and provide the necessary response. By providing appropriate stimulus and analyzing the response, the ATE is able to determine the status of the item and, if the item is degraded or failed, isolate the failure to permit repair. The advantages of ATE testability over BIT are that it usually allows a greater number of parameters to be tested and results in a lower initial hardware cost because the test circuitry does not have to be included in every item produced. An ATE testability capability furthers the airworthiness qualification objectives by allowing determination that an item meets performance requirements at all stages of development and use—during the development stage, when it is produced, after storage, and after repair.

5-9.3 SELF-DIAGNOSTICS AND BUILT-IN TEST (BIT)

Self-diagnostics and built-in test refer to the capability to determine the operational status of an item while installed in the system. BIT may be of a continuous nature or initiated by the operator or maintainer. Continuous, or on-line, BIT places demands on the system and should therefore be limited to immediate detection of critical functions. Operator- or maintainer-initiated, off-line, BIT is usually used for fault isolation purposes. Advantages of BIT capability over ATE testability include the fact that BIT allows instantaneous performance monitoring; eases the burden on the operator; reduces the requirements for shop facilities, equipment, and personnel; and generally reduces life cycle cost.

Properly designed and functioning BIT contributes to the objectives of the airworthiness qualification process by assuring that the system is performing acceptably during development, during operation, and after repair.

5-9.4 NONDESTRUCTIVE TEST AND EVALUATION (NDTE)

The objective of nondestructive test and evaluation is to determine the integrity of parts by measurement or inspection without damage or destruction. The test is intended to reveal conditions at or beneath the exterior surface of a part or material that cannot be evaluated solely by visual examination with or without magnification or by dimensional measurement. In general, NDTE should be used to determine the condition of materials, whereas BIT and ATE should be used to determine the condition and functionality of electronics. NDTE techniques include but are not limited to electromagnetic (eddy current) testing to inspect welds, measure coating thickness, and determine electrical conductivity; ultrasonic testing; ultrasonic contact inspection of weldments; radiographic inspections; ultrasonic adhesive bond testing; temper etch inspection; fluorescent penetrant methods; magnetic particle methods; and halogen leak detection methods.

The use of NDTE should be integrated into the design process to ensure that the materials, manufacturing techniques, and other design characteristics are compatible with the NDTE techniques used to monitor the integrity of flight-critical parts.

5-10 TEST-ANALYZE-FIX-TEST (TAFT)

The test-analyze-fix-test (TAFT) sometimes also referred to as “test-analyze-and-fix” (TAAF), is central to the qualification process. Airworthiness qualification is more than just testing and reporting the results, good or bad. The TAFT principles ensure that the qualification program not only uncovers deficiencies in a system but also provides a mechanism for identification and incorporation of fixes required to complete and pass qualification. TAFT requirements should be included in Airworthiness Qualification Plans (AQP) and Airworthiness Qualification Specifications.

A TAFT program identifies and corrects performance-related problems or deficiencies and reliability problems. Integral to TAFT is a closed-loop data collection system that captures the circumstances of occurrence of the problem or deficiency. The appropriate contractor organization is assigned the responsibility to identify the cause of the problem or deficiency and to develop the necessary corrective action. Upon incorporation of the corrective action, the performance of the system is monitored to ensure that the problem does not recur.

Periodic reporting to the Government provides the procuring activity with visibility of development status and potential problem areas. TAFT is applicable throughout all phases of the airworthiness qualification effort from initial design model activities through component and subsystem qualification to system-level qualification efforts. The effectiveness of TAFT is enhanced by ensuring that test conditions and operating profiles reflect intended operating conditions to the maximum extent possible.

Ideally, corrective actions should be incorporated as soon as they are developed and available. This should allow the best opportunity to determine that the corrective action has (1) fixed the problem that necessitated the action and (2) not introduced any unintended problems or deficiencies. Schedule constraints, however, often dictate that test activities continue even though known fixes have not yet been incorporated. This is usually the result of insufficient test hardware or other test resources. From a cost and management standpoint it may be desirable to incorporate fixes in blocks as opposed to one at a time. This, however, could lead to a significant lag between fix identification and fix incorporation. Too long a lag could greatly reduce the effectiveness and benefits of the TAFT. Specific contractual requirements should be established to limit the amount of lag in fix incorporation. The criteria used to determine how quickly a fix should be incorporated include the severity or criticality of the problem, the extent of effort required to identify the cause, the extent of effort required to develop the corrective action, the extent of effort required to incorporate the corrective action, and the impact of incorporating the corrective action into other ongoing test activities.

5-11 DEFENSE SPECIFICATIONS, STANDARDS, AND HANDBOOKS

The Department of Defense (DoD) no longer specifies detailed military process specifications and standards in its contracts and solicitations without an appropriate waiver. It is DoD policy to use international and domestic non-Government specifications and standards to the maximum extent possible instead of federal and military specifications and standards. Perfor-mance specifications should be developed in preference to detailed specifications. For any pro-cess, practice, or method that is described by a non-Government standard used by commercial firms, DoD activities should use the non-Government standard instead of developing or revising a DoD standard. If a suitable non-Government standard is not available, DoD activities should consider working with industry on a technical committee to develop a new standard or revise an existing non-Government standard. Handbooks have replaced a number of standards, but they should be used only as guides. Additional information concerning specifications, standards, and handbooks is in the subparagraphs that follow.

5-11.1 SPECIFICATIONS

MIL-STD-961, *Department of Defense Standard Practice for Defense Specifications*, (Ref. 12) establishes the format, content, and procedure for the preparation of performance specifications and associated documents prepared either by Government activities or under contract.

Requirements in performance specifications should describe what is required and the form, fit, or function of the item. Interface requirements that are not adequately defined by form, fit, and function should also be included. Performance specifications should not describe how a requirement is to be achieved, require the use of specific materials or parts, or give detailed design or construction requirements beyond those needed to ensure interchangeability with existing items. For a general specification to be designated a "performance specification", the requirements in its associated specification, specification sheets, or MS sheets should also be stated as performance requirements.

"Detailed specifications" may consist of all detailed requirements or a blend of perfor-mance and detailed requirements. To the greatest extent possible, detailed specifications should be in terms of performance. They should specify materials, design or construction requirements, or "how to" requirements only to the extent necessary to ensure the adequacy, safety, and interchangeability of the item being acquired.

5-11.2 STANDARDS

MIL-STD-962, *Department of Defense Standard Practice for Defense Standards and Handbooks*, (Ref. 11) provides definitions and format and content direction. DoD standards should be prepared only when it is necessary to capture military-unique requirements. Non-Government standards should be used to describe commercial or industry practices, processes, and methods. There are five types of DoD-prepared standards: interface standards, standard practices, test method standards, manufacturing process standards, and design criteria standards.

DoD interface standards should be developed to specify the physical, functional, or military operational environment interface characteristics of systems, subsystems, equipments, assemblies, components, items, or parts to permit interchangeability, interconnection, interoperability, compatibility, or communications. Many, if not most, standards have interface elements. To be designated an interface standard, establishing mandatory interface requirements should be the primary function of the document. If interface criteria are just one of many design criteria requirements, developing a design criteria standard should be considered.

DoD design criteria standards should be developed to specify military-unique design or functional criteria that must be adhered to during development of systems, subsystems, equipments, assemblies, components, items, or parts. These design criteria are not primarily related to requirements that affect interchangeability, interoperability, interconnection, compatibility, or communications. Adherence to these design criteria standards, however, will affect the manufacturing of a product. Some examples include military-unique design selection, nuclear blast protection, safety requirements, and human factors requirements.

DoD standard practices should be developed when it is necessary to specify procedures on how to conduct nonmanufacturing functions. Standard practices should be developed only for services that, at least some of the time, are obtained via contract from private sector firms. Standard practices should not be used if non-Government standards are the typical commercial vehicle used to procure a particular type of service.

Test method standards should be developed to specify specific test methods, procedures, or protocols. Military test method standards should reflect test methods that are unique to the DoD such as tests for the high levels of shock encountered in the landing of an air vehicle on an aircraft carrier. A DoD test method standard should be developed only if it reflects a military-unique requirement.

The DoD strongly discourages development of manufacturing process standards. The role for DoD process standards is limited to situations in which the DoD alone has the technological expertise to specify a military-unique process.

The DoD also strongly discourages development of management process standards. It is not the policy of the DoD to create standard management approaches across all programs and all contractors. Contractors should be allowed the flexibility to manage programs in innovative ways that can improve quality, reduce costs, and introduce the latest technological advances.

5-11.3 HANDBOOKS

MIL-STD-962, *Department of Defense Standard Practice for Defense Standards and Handbooks*, (Ref. 11) provides definitions and format and content direction for handbooks prepared either by Government activities or under contract. Handbooks are developed following the processes described for standardization documents in DoD 4120.3-M, *Defense Standardization Program, Policies, and Procedures*, (Ref. 13) except there will not be any interim handbooks. The procuring activity (PA) should not cite handbooks as requirements in solicitations, contracts, or any type of technical document. Rather than develop mandatory standards that require a single approach when other approaches may also be acceptable, a handbook offers an opportunity to preserve institutional memory and offer solutions that have worked without mandating those solutions. Handbooks are good for providing lessons learned; classifying items, materials, or processes; defining terms; listing abbreviations or acronyms; providing interpretation; offering different technical options; and any other type of guidance information. If a handbook is cited as a requirement, contractors may disregard the requirement and interpret the contents as guidance only.

5-12 MAKE OR BUY PLAN

Make or buy plans are not required during research and development. Also these plans are not required if prototypes or hardware is involved, but no significant follow-on production under the same contract is anticipated. Further, make or buy decisions are primarily affordability and cost related. As such, make or buy plans and decisions do not affect airworthiness qualification decisions. It is primarily a program issue. See FAR Subpart 15.7, *Make or Buy Programs*, (Ref. 14) and DFAR Subpart 215.7, *Make or Buy Programs*, (Ref. 15).

5-13 SPECIAL TOOLING

One of the critical functions in assuring repeatability in the manufacturing and assembly cycle is tool control. The tools used in the manufacturing and fabrication cycle must have the capacity to reproduce each detail, subassembly, and assembly in accordance with the accepted design configuration. As engineering design changes are proposed, they should be reviewed for their impact on applicable tooling. The quality assurance function should be intimately involved in establishing the need for, proofing, and controlling special tooling.

Detailed specifications covering the fabrication of tools to be employed in the manufacture and assembly of an air vehicle should be provided. In addition, detailed process instructions for the use of the tools in production, for recheck and/or recalibration, and for inspection of the parts produced by the tool should be developed.

Master tool control normally is the only practical method of coordinating tooling and ensuring interchangeability. The accuracy and ease with which mating assemblies fit or are individually interchangeable are dependent on the control of size, shape, and matching interface conditions at attachment points.

A program of inspection and tool verification to be used in the manufacture of the contract end-item should be developed.

5-14 STANDARDIZATION PROGRAM

A properly conducted standardization program facilitates the achievement of airworthiness qualification and quality assurance program by imposing a structured method for minimizing the variety of parts used in a new design. The objectives of the program are to

1. Maximize use of standard parts, materials, and processes in order to lower cost, to reduce downtime, and to facilitate interchangeability
2. Maximize repetitive use of features and items
3. Maximize use of common publications, manuals, training aids, and materials
4. Provide the documentation for future reuse of the innovations initially used under the current contract
5. Provide for common usage of equipment, parts, and materials in order to promote commonality among weapon systems.

MIL-HDBK-402, *Guidelines for the Implementation of the DoD Parts Control Program*, (Ref. 16) is a guide intended for use by military departments and agencies and associated contractors. However, unless otherwise specified in the contract, parts control and parts standardization should be conducted by using best commercial practices, industry standards, and the contractor's policies and procedures. This should apply to mechanical, electrical, and electronic parts. The contractor should be required to identify in the proposal and specification the applicable commercial practices, standards, policies, and procedures that will be followed to accomplish these objectives.

5-15 PRODUCIBILITY

Producibility is defined as the repeatability and relative ease of producing an item or system. It is governed by the characteristics and features of a design that enable economical fabrication, assembly, inspection, and testing using available production techniques. The basic concept of producibility is to ensure that there is a coordinated effort between design engineering and manufacturing engineering to create a functional design that can be easily and economically fabricated. This activity requires tradeoffs among life cycle costs, performance, reliability, and producibility. The scope of producibility is variable and evolutionary based on the stage of the qualification program. A major program in the conceptual stage should consider system performance requirements while contemplating broad areas of producibility on a general scale, i.e., basically envisioning global manufacturing capabilities. During the next phase, integrated design and producibility considerations should be narrower in scope and greater in number than during the preceding phase and should create opportunities to achieve significant cost and schedule benefits as the hardware design evolves and before the design becomes too fixed to be altered economically. Finally, a major program in the full-scale development phase will emphasize specific producibility studies in far greater depth and basically build on the studies, decisions, and concurrent design and producibility activities that have gone before. Proper and early consideration of producibility principles reduce the risks associated with the transition from development to production. Addressing producibility as an integral part of the design process minimizes the chances of introducing problems associated with the transition from a prototype manufacturing environment to a production environment and thereby ensures a qualified prototype design can be built in production quantities using production methods. The contractor should be required to define in the proposal and specifications the means by which specified levels of producibility will be assured and demonstrated. A separate plan should not be required. The procuring activity should include producibility performance requirements in the contract. The air vehicle contractor (AC) should be required to define in the proposal the means by which producibility will be assured. MIL-HDBK-727, *Design Guidance for Producibility*,(Ref. 17) provides an exposition of the factors that determine whether or not an item is acceptable from a producibility point of view. Actual examples of good and bad producibility practices are provided. The interrelationships of the producibility functions with the design process and development process functions are discussed. Tools and techniques useful in the producibility function and used by the producibility engineer are described and illustrated. Common producibility considerations are discussed. Specific considerations for metal components, plastic components, composite components, mechanical assemblies, electronics, and other items are discussed.

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CHAPTER 6
MODELING

This chapter describes various modeling techniques applicable to the airworthiness qualification process. Section I discusses physical models used to represent system characteristics of interest including aerodynamic models, inert physical mock-ups, functional subsystem mock-ups, and ground test vehicles. Section II addresses simulations, including simulation bases, emulators, simulators, and simulations, as software environments.

SECTION I
PHYSICAL MODELS

6-0 LIST OF SYMBOLS

D = characteristic length, m (ft)
R_n = Reynolds number, dimensionless
v = air velocity, m/s (ft/s)
μ = absolute viscosity, Pa·s (lbf·s/ft^2)
ρ = air density, kg/m^3 (slug/ft^3)

6-1 INTRODUCTION

Models and mock-ups are used extensively during air vehicle design and development. Scale models are generally used early in the design to investigate aerodynamic effects and interactions using wind tunnels and flow tanks. Results of scale model testing provide the designer insights into the aerodynamic characteristics of the air vehicle being developed. The data obtained from models may be used to predict flight limitations, performance, and handling quality characteristics. For example, a powered force model (PFM) could be used to determine whether the horizontal stabilizer design is adequate to provide positive longitudinal stability.

At an early stage in the development cycle, a full-scale air vehicle mock-up or computer-aided engineering substitute should be fabricated to function as a design tool to determine the optimum air vehicle configuration. Computer-aided substitutes are capable of a degree of functional realism that is comparable to a physical mock-up.
This mock-up should be capable of demonstrating the compatibility of the ground handling, maintaining, loading, and operating requirements of the air vehicle and its equipment. Particular regard should be given to crew and passenger stations, cargo and weapon provisions, equipment arrangement, and propulsion system installations. Visibility for the flight crew, lighting, effective clearances, and personnel safety also should be considered. Individual subsidiary mock-ups may be required for specific areas such as crew stations and lighting. Also functional mock-ups should be fabricated for most subsystems.

The full-scale mock-up may be used to assist in packaging and in arrangement tradeoff studies for selected components. Such a mock-up offers a three-dimensional presentation for other engineering disciplines, such as maintainability, reliability, producibility, and system safety, to evaluate and plan subsequent test demonstrations. Mock-ups are routinely used as design tools to establish effective arrangements or to resolve subsystem interface problems as they affect form, fit, and function.

6-2 AERODYNAMIC MODELS

Aerodynamic models are scale models intended to allow investigation of the interactions between the air vehicle or air vehicle section and the fluid (air) through which it travels. Aerodynamic models should conform to the shape of the actual object being modeled. These scale models are important for flight limit investigations because they give designers an early insight into the aerodynamic characteristics of the air vehicle long before full-scale hardware is built. Deficiencies found through this early investigative work can be corrected with much less effort than if discovered later in the development. This paragraph describes airfoils and two-dimensional aerodynamic shapes, flow tanks, wind tunnels, force models, powered force models, and icing tunnels and icing mock-ups. Fig. 6-1 provides a pictorial example of each of these types of models.

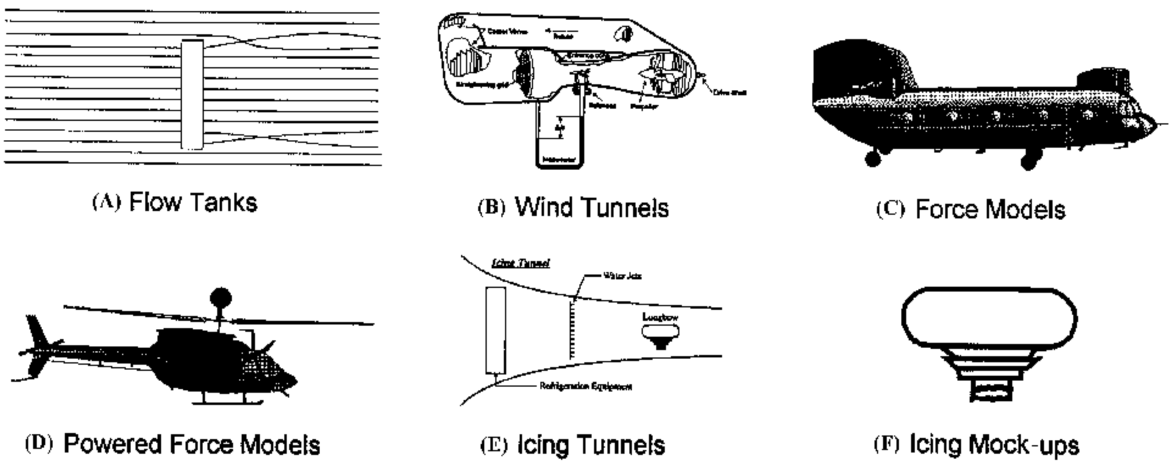


Figure 6-1. Aerodynamic System and Environment Models

6-2.1 AIRFOILS AND TWO-DIMENSIONAL AERODYNAMIC SHAPES

An airfoil or aerodynamic shape is a structure, piece, or body designed to obtain a useful reaction upon itself in its motion through the air. Airfoil and two-dimensional aerodynamic shapes are used to determine the aerodynamic characteristics of a particular shape, namely, the drag coefficient, the lift coefficient, and the moment coefficient for an infinite aspect ratio. These coefficients are functions of the angle of attack of the airfoil section. From these coefficients the lift, drag, and moment generated by an airfoil may be determined and used to make early predictions of performance characteristics.

6-2.2 FLOW TANKS

Flow tanks (usually water tanks) are used to provide a visualization of the aerodynamic flow about an object. They consist of a chamber, a means (pump) of producing a fluid flow around the object being modeled, and a means of seeding the fluid flow with a visible tracer, such as smoke or dye. In most cases the tracer is introduced upstream of the object being tested and thus set up a series of parallel streams in the fluid flow. The tracer may also be introduced in the flow stream through holes in the aerodynamic model. As the fluid flows around the model, these parallel streams become disturbed by the object, and this disturbance provides a visualization of the flow around the object. When properly scaled for fluid differences, flow tanks can be used to visualize the airflow around the object. They can also be used to visualize the airflow aerodynamics of wingtip vortices around a wing and flow about the main rotor and tail rotor. These types of preflight data are useful for predicting flight characteristics, such as separation turbulence and interference, prior to actual flight experience. The objective is to detect any defect or design deficiency and to evaluate fixes.

6-2.3 WIND TUNNELS

Wind tunnels provide a means of simulating air vehicle flight by moving air over a stationary scale model of the air vehicle. This allows the measurement of aerodynamic data and evaluation of aerodynamic design. The tunnel typically consists of a large closed circuit tube. The tube contains a propeller (usually shaft driven), which creates the flow of air. Corner vanes minimize turbulence where the airflow must turn a corner. The chamber in which the model is mounted (the throat) has a reduced cross-sectional area and corresponds to the throat of a venturi; thus a local increase in air velocity is created. The model is mounted on scales or other force measurement devices. Wind tunnel facilities often have unique characteristics that require testing to be performed at specific sites. Principal characteristics that affect tunnel results are air density, pressure at the throat, free-stream pressure, cross-sectional area at the throat, and cross-sectional area at the settling chamber. The critical parameter that must be matched between the model situation and the actual physical (full-scale) conditions of flight is the dimensionless Reynolds number R_n, which is defined as

$$R_n = \frac{Dv\rho}{\mu}, \text{dimensionless} \quad (6\text{-}1)$$

where

R_n	=	Reynolds number, dimensionless
D	=	characteristic length, m (ft)
v	=	air velocity, m/s (ft/s)
ρ	=	air density, kg/m^3 (slug/ft^3)
μ	=	absolute viscosity, Pa·s (lbf·s/ft^2).

Matching Reynolds numbers is no guarantee of perfect similarity; however, since the wind tunnel conditions are not completely uniform and include wall effects not encountered in the free air, model and actual air vehicle matching is seldom achieved. Examples of measured parameters obtainable from wind tunnel testing include lift and drag characteristics, flow pressures and separation characteristics over control surfaces, and general pressure/velocity distributions. Tunnel characteristics that could affect results must be considered during test design. Examples of typical tunnel characteristics that should be considered include test section size, maximum velocity capability, inherent tunnel turbulence, and temperature/humidity control. Some of these facility-dependent characteristics enable valid measurements only at specific facilities. Table 6-1 lists several major facilities and their capabilities. Additional information on wind tunnel

TABLE 6-1. WIND TUNNELS

FACILITY	TEST SECTION, m (ft)	MAXIMUM VELOCITY, m/s (mi/h)	SPECIAL CAPABILITY
NASA Ames Moffett Field, CA	12.2 ´ 24.4 (40 ´ 80)	116 (260)	Full-scale, high-speed
NASA Ames Moffett Field, CA	12.2 ´ 36.6 (40 ´ 120)	39 (87)	Full-scale, low-speed
NASA Langley 16-ft Transonic Langley, VA	4.9 ´ 4.9 (16 ´ 16)	0.7 to 1.2 Mach	Transonic flow
NASA Langley LAL 20-ft Spin Langley, VA	6.1 (20) 12-sided polygon	23 (52)	Spin testing
Boeing Research Wind Tunnel Seattle, WA	1.5 ´ 2.4 (5 ´ 8)	58 (130)	Low turbulence
Boeing BVWT Philadelphia, PA	6.1 ´ 6.1 (20 ´ 20)	97 (217)	VSTOL
WP 10- ´ 7-ft Wright-Patterson AFB, OH	3.0 ´ 2.1 (10 ´ 7)	156 (348)	High-speed, low-turbulence flow visualization
DTNSRDC Anechoic Carderock, MD	24. ´ 2.4 (8 ´ 8)	52 (117)	Sound studies
University of Notre Dame, Notre Dame, IN	0.6 ´ 0.6 (2 ´ 2)	24 (53)	Smoke tunnels

locations and capabilities may be obtained from Ref. 1. The aerodynamic data collected from wind tunnel tests provide another significant building block in the substantiation of qualification characteristics by providing essential aerodynamic information. With the advancing capabilities of computational fluid dynamics (CFD), it appears possible to reduce the amount of wind tunnel test time required for future development programs.

6-2.4 FORCE MODELS

Reduced-scale air vehicles and three-dimensional sections, such as wings and fuselage, are the types of physical models subjected to wind tunnel testing. The types of aerodynamic data that can be validly measured from these models include lift, drag, and moment characteristics. Precautions are required in mounting the model and conducting the test so the results of the test are not affected. Examples of these precautions are ensure the natural frequency and structural strength of the mount are adequate for the intended purposes, ensure proper calibration of balances, and ensure proper use of available correction factors, ensure model is properly sized to avoid excessive air blockage. The measured aerodynamic data form a basis for flight simulation and subsequent qualification.

6-2.5 POWERED FORCE MODELS

Powered force models are reduced-scale models that include powered rotors, control surfaces, and other moving parts. These models often are 15 to 30% scale and/or dynamically similar models of the air vehicle. With these models, rotor/body, rotor/rotor, and rotor/tail mutual aerodynamic interference effects can be investigated. With dynamically scaled models, aeroelastic stability problems can be determined and investigated early in the acquisition process. The special types of data that can be measured from these models include air inlet and exhaust area pressures at all flight attitudes and velocities, flow pressures and separation characteristics over control surfaces, and weapon exhaust gas flow.

6-2.5.1 Aerointerference Models

Aerointerference models are used to determine the aerodynamic impact of one aerodynamic surface on another. Examples include the impact of main rotors on tail rotors and the impact of wings on tail surfaces. Aerointerference models may be force models or powered force models and thus require the same types of precautions to ensure accurate data. Further, more elaborate instrumentation to measure aero-interferences may require special precautions to prevent distortion of the test results by instrumentation intrusion in critical airflow areas.

6-2.5.2 Aeroelastic Models

Aeroelastic models are used to determine the interactions of aerodynamic forces, elastic forces, and inertial forces in order to establish the aerodynamic characteristics of air vehicles. Aeroelastic models are used for dynamic stability tests to investigate dynamic behavior dominated by rigid body modes of motion and during flutter tests to investigate dynamic instabilities caused by the elasticity of the structure. Aeroelastic models are generally excited during dynamic stability tests and flutter tests through the use of jerk wires that permit a rapid change in attitude and/or oscillations in attitude of the model relative to the airstream. Just as in the case of wind tunnel testing, a dimensional analysis must be performed for the aeroelastic model to determine the critical parameters linking the real world and the model. Factors entering into aeroelastic model similarity include mass, frequency, length, modulus of elasticity, and area moment of inertia. As airloads and flutter enter the model considerations, the complexity of the dimensional analysis grows.

6-2.6 ICING TUNNELS AND ICING MOCK-UPS

Icing tunnel tests allow evaluation of systems under icing conditions and permit optimization of the design prior to flight. Icing conditions can be simulated in the tunnel at the desired flight or ground operating conditions. During these tests, electrical power density, hot airflow, hot air temperature requirements, bleed air requirements, and anti-icing fluid requirements for ice protection of various aerodynamic shapes, such as airfoils, air induction systems, and windshields

Test conditions on air vehicle engine air induction systems should reflect the downwash characteristics and effects obtainable with the particular air vehicle configuration. Tests on components (in the laboratory or in flight) are conducted over the full spectrum of icing condition parameters (particularly temperature and liquid water content) to ensure that (1) engine performance requirements are met, (2) downwash impingement does not introduce special problems, and (3) no hot spots exist that could cause system failure. Cold spots that may permit ice accretions, which detach and cause engine damage, also are evaluated.

Generally, an acceptance test duration of 30 min with full performance compliance is required at each condition. To minimize the possibility of damage, preliminary, short-duration tests usually are conducted to perform visual checkout prior to the acceptance test.

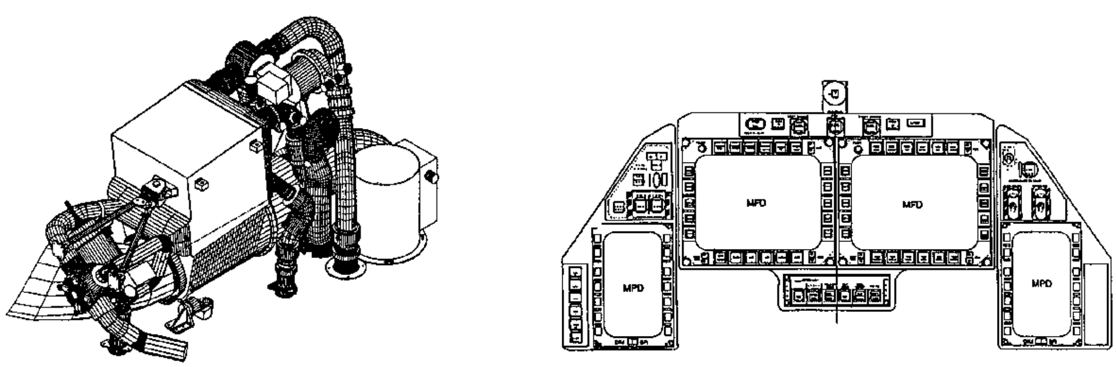
Heat transfer characteristics of the windshield or canopy can be established at simulated flight conditions. Complete systems can be evaluated, and windshield wiping, washing, and defogging operations can be developed or demonstrated in the icing tunnel. Tests are conducted to evaluate whether or not visibility requirements across the airspeed and icing spectrum are met. In addition, tunnel tests can identify hot spots that can result from airflow stagnation and cause system failure. Table 6-2 provides a list of icing test facilities and their capabilities.

6-3 INERT PHYSICAL MOCK-UPS

Inert physical mock-ups include general reduced-scale models; fuselage mock-ups; flight crew stations mock-ups; and mission crew, passenger, and cargo area mock-ups. These models may be constructed from substitute materials, black boxes may be empty, and equipment shells or housing may be used. In addition, computer-aided engineering may be used to assess the physical interrelationships among system components. The impacts of layout on design evaluation and qualification include accessibility (for maintainability considerations), human factors, and entry and exit considerations. Fig. 6-2 shows typical physical models. Additional information for the construction of air vehicle and related system mock-ups for formal evaluation is contained in MIL-M-8650, *Mock-Ups, Aircraft, General Specification for* (Ref. 2).

6-3.1 GENERAL REDUCED-SCALE MODEL

A general reduced-scale model is a system model built to a reduced scale for use as an adjunct to general arrangement drawings. It facilitates the visualization of the physical arrangements and allows for early detection and correction of physical interference problems. In addition, it functions as a three-dimensional visual aid to assess general compartment arrangement, access, space and shape, and payload potential layout. In addition, the reduced-scale model can be used with other models and layouts to demonstrate its air and sea transportability. It provides an early answer to the question, "How does everything fit together?".



(A) Mock-Ups (B) Computer Aided Layouts

Figure 6-2. Inert Physical Models

TABLE 6-2. ICING TEST FACILITIES

FACILITY	SIZE, m (ft)	SPEED	MINIMUM TEMPERATURE, °C (°F)	LIQUID WATER CONTENT, g/m^3	DROPLET SIZE, μ m (μ in.)	TYPE*
NASA Lewis Research Center Cleveland, OH	1.83 × 2.74 (6 × 9)	0-240 kt	–28.9 (–20)	0 to 2	10 to 30 (394 to 1181)	1
Naval Air Propulsion Test Center Trenton, NJ	7.01 × 7.01 (23 × 23)	0 to Mach 0.9	–20 (–4)	1 to 2	15 to 25 (591 to 984)	1
Naval Air Propulsion Test Center Trenton, NJ	5.18 (17) diameter	0 to Mach 2.4	–20 (–4)	1 to 2	15 to 25 (591 to 984)	1
Naval Air Propulsion Test Center Trenton, NJ	4.42 (14.5) diameter	0 to Mach 2.4	–20 (–4)	1 to 2	15 to 25 (591 to 984)	1
Naval Air Propulsion Test Center Philadelphia, PA	0.61 (2) diameter	70 to 75 mph	–30 (–22)	0.1 to 3	15 to 50 (591 to 1968)	1
Lockheed, California Burbank, CA	0.76 × 1.22 (2.5 × 4.0)	50 to 186 kt	–21 (–5)	0.7 to 4	7 to 35 (276 to 1378)	1
Lockheed, CA Burbank, CA	0.76 × 0.76 (2.5 × 2.5)	50 to 210 kt	–18.9 (–2)	0.7 to 4	7 to 35 (276 to 1378)	1
The Boeing Company Seattle, WA	4.57 × 6.10 (15 × 20)	0 to 200 kt	–34.4 (–30)	down to 5	15 to 25 (591 to 984)	1
National Research Council of Ottawa Ontario, Canada	0.30 × 0.30 (1 × 1)	0 to Mach 0.9	–40 (–40)	0 to 3	15 to 60 (591 to 2362)	1
National Research Council of Ottawa Ontario, Canada	1.37 ×1.37 (4.5 × 4.5)	0 to 200 mph	–25 (–13)	0 to 3	15 to 60 (591 to 2362)	1
National Research Council of Ottawa Ontario, Canada	1.56 × 2.44 (5 × 8)	0 to 500 mph	–25 (–13)	0 to 3	30 to 60 (1181 to 2362)	1
National Research Council of Ottawa Ontario, Canada	16.75 × 3.05 (55 × 10)	hover	ambient	0 to 0.9	30 to 60 (1181 to 2362)	2
Eglin Air Force Base, FL	9.14 × 9.14 (30 × 30)	0	17.8 (0)	0.5 to 20	15 to 90 (591 to 3543)	4
C-130 Tanker, Wright-Patterson Air Force Base Dayton, OH	N/A	up to 150 kt	ambient	0.1 to 1.1	80 to 100 (3150 to 3937)	3
KC-135 Tanker, Wright-Patterson Air Force Base Dayton, OH	N/A	up to 500 kt	ambient	0.1 to 1.1	80 to 100 (3150 to 3937)	3
US Army Helicopter Icing Spray System (HISS), CH-47 Edwards Air Force Base, CA	N/A	up to 120 kt	ambient	0.1 to 1.1	80 to 100 (3150 to 3937)	3

*1 = icing tunnels and engine icing chambers
2 = natural icing spray rig
3 = tanker aircraft
4 = climatic hangar and icing spray rig

6-3.2 FUSELAGE MOCK-UP

The internal and external shape and size of the air vehicle mock-up duplicates the dimensions of the engineering design to permit assessment of general configuration suitability for loading and unloading of crew, troops, cargo, weapons, ammunition, and fuel; for vision obscurations; for performance of crew functions; and for postcrash escape. The maintainability features of the air vehicle with respect to component accessibility, adequacy of built-in work platforms, and ground crew requirements to perform scheduled and unscheduled maintenance can be demonstrated.

Other design features that can be demonstrated on the mock-up include accessibility to doors, the cargo compartment, and fueling locations. The operation of doors, windows, hatches, emergency exits, controls, and functional equipment such as retractable landing gear or retractable steps can also be demonstrated.

The mock-up is configured to allow actual installation of any equipment that will alter its exterior shape or size. Control surfaces, turrets, flexibly mounted equipment hoists, external auxiliary fuel stores, weapon racks, and battlefield illumination devices should be capable of traversing their full range of movement to allow for demonstration of clearance limits, weapon fire angle limits, and weapon handling clearance limits.

The mock-up incorporates all of the steps, ladders, handholds, access hatches, and work platforms defined in the air vehicle design. Environmental devices, such as windshield wipers and deicer boots, which may affect the external configuration of the air vehicle, are also part of the mock-up.

The fuselage mock-up includes the crew stations, passenger and/or cargo compartments, and equipment compartments. Doors, hatches, windows, escape areas, access ways, handgrips, steps, tie-down provisions, and jacking provisions are mocked up. The fuselage mock-up may be used to determine routing of items such as cables and lines. Access points for maintenance and repair of air vehicle equipment should be included in the mock-up.

The size and location of escape hatches and emergency provisions for crew and passengers can be mocked up. Photographs and motion films of a simulated emergency evacuation may be provided for a slow-speed evaluation of potential hazards to the occupants from controls, equipment, or structure. The mock-up should be flexible enough to allow evaluation of proposed and/or alternate installations prior to building the air vehicle

6-3.3 CREW STATIONS

Crew station modeling includes flight crew station mock-up and the modular reconfigurable flight crew station simulator. These are used to determine the acceptability of the design with respect to provisions necessary to perform the mission. The mission crew station and the passenger and cargo areas are described in subpar. 6-3.4.

6-3.3.1 Crew Station Mock-Up

Cockpit(s) should include flight controls, propulsion controls, controls for retractable landing gear, rotor brake controls, electrical consoles and controls, armament equipment and electronic controls, instruments and displays, navigation equipment, the oxygen subsystem, normal and emergency controls for canopy and/or door actuation (including jettisoning), and cockpit furnishings and equipment that includes mirrors, microphones, headphones, etc. Furnishings and equipment should duplicate the production articles as closely as possible in size, shape, and location. Actual safety belts, shoulder harnesses, parachutes, emergency kits, life rafts, seat pads, and back pads should be installed, when applicable. The eye position, seat reference point, and measurement techniques related to vision, controls, and displacements designed for the crew should be identified. Flight controls should be operable through their normal envelope, although they need not operate their respective rotors or surfaces. Control friction devices should be mocked up, and stops installed to limit all control movements to those anticipated for the actual air vehicle. The neutral positions of the cyclic control should be simulated. Control locks, when applicable, and means for adjusting the directional control and brake pedals should be included in the mock-up. Cockpit canopies (including framing), hatches, windows, etc., should be mocked up in sufficient detail that the overall field of view from the cockpit is depicted accurately. Provisions should be made for evaluators and test observers to stand outside the mock-up on each side of the cockpit on removable platforms and walkways.

To the extent possible, transparencies provided within the mock-up should be within the optical quality limits established for the air vehicle. Radii of curvature, thickness of panels, and framing widths for windshields and other transparencies in the cockpit should simulate those of the actual air vehicle. Adverse weather and/or night vision aids should be mocked up. Individual paper, cardboard, plastic, or metal dials representing all required instruments should be mocked up. The individual dials and panels as a whole should be capable of easy relocation. Extra panels with dials that also can be relocated easily should be provided apart from the mock-up. All furnishings and equipment essential to performing crew station tasks should be available in the mock-up for demonstration purposes.

6-3.3.2 Modular Reconfigurable Crew Station Simulator

This simulator provides a modular and readily reconfigurable physical layout for the purpose of evaluating various configurations. Physical layout is the emphasis for use of this simulator. Operational mock-ups provide additional insight into the crew/crew station interfaces through the evaluation of accessibility, operability, and often, functionality. Aitoff's equal area projection vision plots defined in MIL-STD-850, *Aircrew Station Vision Requirements for Military Aircraft*, (Ref. 3) provide a method of depicting the crew member's vision around the air vehicle from the normal eye position. Crew station simulators provide the initial basis for the preparation of the Aitoff plots. Section II of this chapter discusses crew station simulation further.

6-3.4 MISSION CREW, PASSENGER AND CARGO AREA

The mission crew, passenger, and cargo area mock-ups could be constructed to provide a representation of the physical layout of those areas. However, a computer-aided engineering (CAE) system or virtual prototype might be a more cost-effective substitute. Whatever approach is used should provide the means by which to determine available space, loading methods, and ease of ingress and egress.

6-3.5 COMPUTER-AIDED ENGINEERING SUBSTITUTION FOR MOCK-UPS

Computer-aided engineering systems enable a three-dimensional, solid geometry computer representation of a system. It offers the advantage of rapidly changing the viewing angle so the visual representations of the layout may be easily assessed. In addition, design changes can also be evaluated rapidly. It is essential that the CAE system be part of the configuration management system in order to represent the latest approved configuration. The present state of CAE systems allows a reduced need for physical mock-ups. CAE can be effectively used as a substitute for subsystem form and fit. Design information from CAE can be shared by all disciplines from conceptual design through production. Physical mock-ups may still be required when operational maintenance procedures have to be established and demonstrated or as otherwise determined during the design, development, and qualification process. Physical mock-ups are also used for functional subsystem mock-ups, which are discussed in par. 6-4.

6-4 FUNCTIONAL SUBSYSTEM MOCK-UPS

For the purpose of this handbook a functional subsystem mock-up is a dynamic test fixture or rig capable of performing bench-level development and preflight qualification testing. These mock-ups (test rigs) approximate many of the operational parameters, such as loads, temperatures, pressures, voltages, motions, and vibrations. This paragraph discusses the electrical system; pressure system; engine and drivetrain; rotor system; electronic system manager networks; targeting, fire control, armament and stores stations; landing gear; and lighting system mock-ups. Their use in the development, evaluation, and qualification process is that they are part of the incremental, step-by-step buildup of experience relative to the characteristics of the system. They provide substantiation of characteristics that are properties of the subsystem alone and can be used for subsystem integration verification. It is often necessary to include partial mock-up of structure and other interfacing system parts that represent critical limitations to overall system performance. Because of limitations on the functional subsystem mock-up, system integration verification and qualification of many subsystems can often be completed only on a ground test vehicle and during flight tests on the air vehicle. Additional information on mock-ups can be obtained in MIL-M-8650 (Ref. 2).

6-4.1 ELECTRICAL SYSTEM

The electrical system functional mock-up should be used for checking out electrical components, interfaces, software, and firmware and for conducting preliminary electromagnetic interference and compatibility checks. Types of data typically obtained from hot bench testing are listed in subpar. 4-8.6. A mock-up of the electrical system of an air vehicle should include the following:

1. Power generation and storage devices and associated equipment to include generators, alternators, batteries, voltage regulators, transformers, and inverters. Any cooling and/or lubricating systems to be used with these components should be included in the mock-up to include ducts, piping, tanks, and valves.

2. Electrical distribution and control including wiring, cabling, contactors, switches, circuit breakers, fuses, and meters. Critical wire runs (power feeders, electrically unprotected wires, and congested area wiring) should also be included in the mock-up. Wiring should be representative of the final unit so installation techniques and hardware can be evaluated.

3. All items of electronic equipment to include communication and navigation systems, data bus, bus controllers, processors, panels and console structure, antennas, masts, and lead-ins. Fig. 6-3 provides an example of an electrical system functional mock-up.

The electrical system functional mock-up is usually limited for qualification purposes by its inability to simulate fully environmental considerations, shielding effects, etc. Algorithms

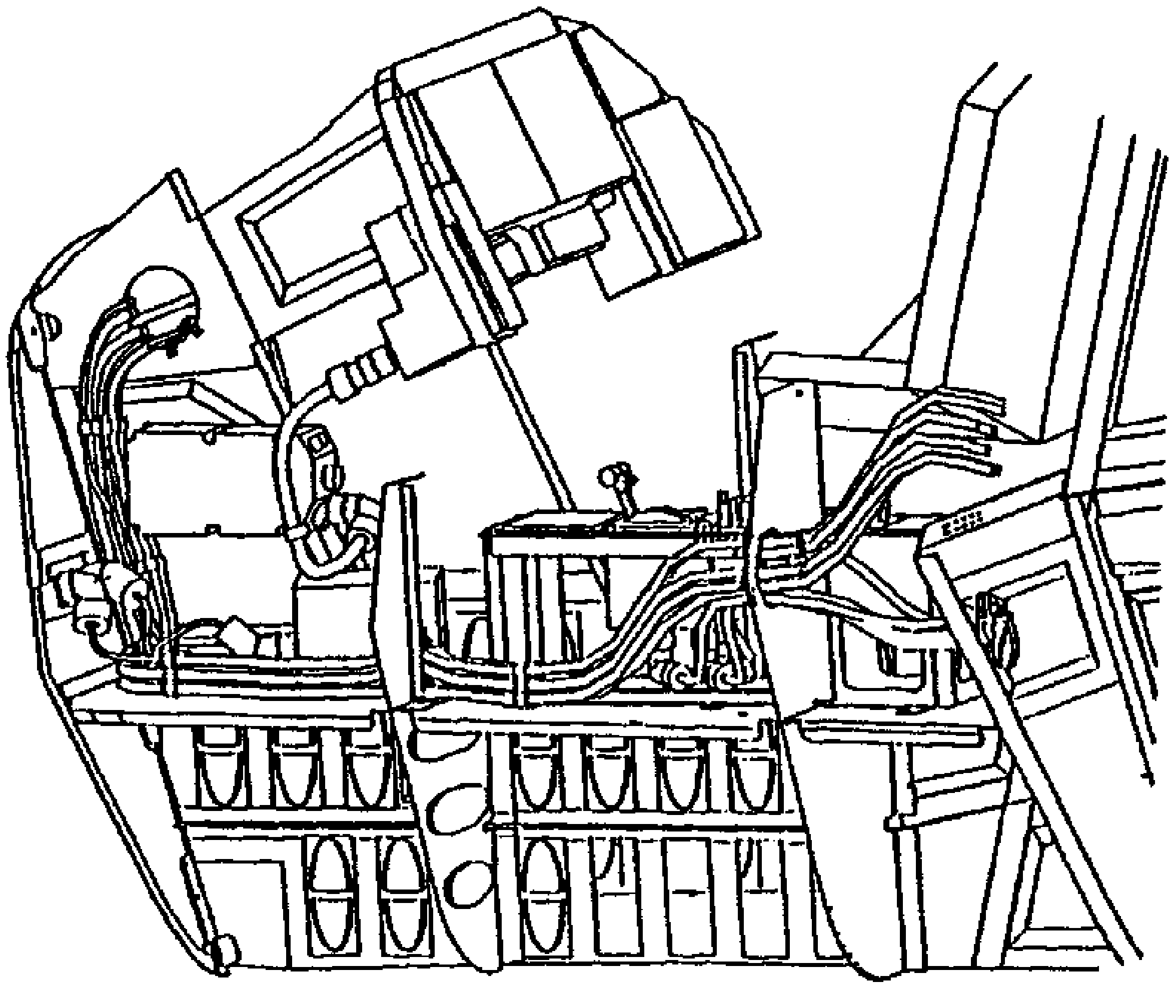


Figure 6-3. Electrical System Mock-Up

may not fully duplicate operational characteristics, etc. In addition, cost is often a major limitation.

6-4.2 PRESSURE SYSTEMS

Pressure systems include hydraulic systems, high-pressure pneumatic systems, and low-pressure pneumatic and vacuum systems. Pressure system mock-ups are intended to provide data and measurements leading to the determination that the pressure systems meet specification requirements. Qualification data that can be obtained from pressure system mock-ups include preflight data, pressure strength capabilities of vessels, fittings and tubings, and control logic.

6-4.2.1 Hydraulic System

A functional hydraulic system mock-up that is sufficient for dynamic test and preflight qualification of the system and its components should be fabricated. Major items of the hydraulic systems should be subjected to preflight qualification to demonstrate compliance with design and operational criteria. Functional mock-ups should be fabricated for all hydraulic subsystems, such as rotor and propeller controls, turrets, door actuators, landing gear, and weapons subsystems.

The mock-ups should incorporate actual hydraulic system components with associated plumbing including main and emergency pumps, reservoirs, accumulators, filters, controls, and sufficient piping to show clearances. The hydraulic plumbing should approximate actual air vehicle requirements in terms of lengths, diameters, bends, and fittings, i.e., “production-type” lines and hoses. Also hydraulic mock-ups should include the actuator controller and software (if any).

Limitations of the hydraulic subsystem mock-up for substantiation of qualification requirements include the inability to simulate all environmental factors, actual air vehicle hardware may not always be available, prototype hardware may not exactly duplicate performance characteristics, and cost of fabrication might limit exact duplication of physical characteristics. For example, seals might function very well on a test stand yet deteriorate rapidly in a dusty environment, and/or a simulated pressure source may not duplicate pressure fluctuations found in flight.

6-4.2.2 High-Pressure Pneumatic Systems

High-pressure pneumatic subsystems requiring qualification tests are of the airborne compressor-charged and ground-charged storage bottle types. Hot gas subsystems normally are not reusable (at least not without refurbishment) and are considered a “one-shot” operation. Thus verification is accomplished through qualification and acceptance testing on a component basis. Another high-pressure pneumatic source is a sealed gas storage bottle, which can be used as an emergency backup system, but this is also a “one-shot” operation.

Ground-charged air bottle subsystems are tested in the same manner as the airborne compressor-charged subsystem. To make the ground tests as realistic as possible, the test stand or apparatus should approximate actual air vehicle requirements in terms of lengths, diameters, bends, and fittings. The pneumatic subsystems should be properly lubricated, and all system components and attached linkages and mechanisms should be properly adjusted.

The mock-up should be adequate to determine whether

1. The various functions are accomplished satisfactorily.
2. The movement of all components is smooth and positive.
3. Relief valves, automatic devices used to terminate an operation, pressure controls, switches and signals, audible or other warning devices, and similar installations function as intended.
4. All indicating devices function and synchronize with the movement of the respective component, as specified.
5. The specified functioning pressures are controlled and not exceeded.Pressures may be obtained by normal system pressure gages, or electronic equipment, as applicable.
6. All tubing and fitting joints and component external seals are free from leaks.
7. All lines, fittings, and components are free from excessive movement and chafing.
8. There is full engagement of mechanical locks and catches.
9. The clearance for all moving parts throughout the entire range of movement is such that fouling of adjacent parts cannot occur.

10. All pneumatically operated doors and closures are flush with surrounding surfaces within limits specified.

11. Simulated normal flight operating conditions or any possible inadvertent operations will not cause system malfunctions.

12. Subsystems normally operated by the pneumatic system can be operated during an emergency.

A major limitation of the mock-up for qualification purposes is its inability to simulate environmental considerations such as vibrations and various climatic conditions. Also pressure spikes and fluctuations might vary considerably from actual airborne conditions.

6-4.2.3 Low-Pressure Pneumatic and Vacuum Systems

Low-pressure pneumatic and vacuum subsystems commonly are supplied by regulated bleed air from the engine compressor; however, this source could be simulated by some other means. The bleed air is normally at a very high temperature and pressure, and by necessity the ducting is insulated. If a high-pressure source is regulated to a lower pressure, the system should be capable of withstanding the higher pressure.

Extreme caution should be exercised by personnel handling these subsystems. Safety precautions should be outlined by the contractor.

A typical low-pressure pneumatic subsystem supplies pressure for an air-conditioning system, pressurizing a hydraulic reservoir, or any desired low-pressure pneumatic system. The bleed air pressure of the engine of the air vehicle should be regulated to the desired operating pressure with a pressure regulator. External electrical power and hydraulic power (for hydraulic-related subsystems) are required

The functional mock-up is useful for checking for leakage, pressure drops, relief valve cracking, reset pressures, etc. A major limitation of the mock-up for qualification purposes is its inability to simulate environmental considerations such as vibrations and various climatic conditions. Also pressure spike and fluctuations can vary considerably from actual airborne operations.

A typical vacuum subsystem test procedure and apparatus similar to that described for the low-pressure pneumatic subsystem may be used. Vacuum subsystem mock-ups are typically used to calibrate and qualify instruments and instrumentation subsystems. It is useful for checking for leaks. Also it is useful for checking proper operation of the directional gyros and attitude indicators. Mock-ups of this type are prone to leak and usually limited in their ability to simulate actual environmental conditions. Vacuum characteristics might vary considerably from the actual air vehicle operational characteristics. Operational characteristics might not be well-defined.

6-4.3 ENGINES AND DRIVETRAIN, FLUIDS, AND ACCESSORIES

6-4.3.1 Engine

A functional subsystem mock-up for an engine is a facility and test bed (rig) that includes all that is needed for development and preflight qualification of the engine and its components. An engine mock-up of this type usually consists of a concrete enclosure—called a cell or a blockhouse—for operating personnel and controls, engine mounting rig, engine controls, instrumentation, data recorders, fuel system and source, exhaust duct, noise suppressors or equivalent, power absorber, and safety devices. The test setup should be assembled so that all of the components are arranged in the proper spatial relationship. Accessories, such as particle separators (if any), should be installed to determine component arrangement and effects on the engine, external configuration, and performance. Instrumentation should be installed to measure pertinent parameters, such as compressor revolutions per minute (rpm), turbine rpm, pressures, lubricant temperature, flow rates, and torque. Components, such as reduction gearboxes, starters, starter generators, chip detectors, sensors, and oil coolers, also require unique test rigs and fixtures. These test rigs and fixtures are usually the property of the engine manufacturer or vendor furnishing the component. Typically, they may include a motor, pump, variable drive gearbox, fuel source, heat exchanger, load simulator, test instrumentation, gages, data recorders, and means for mounting the test article.

6-4.3.2 Drivetrain Assemblies and Components

A typical test bed (rig) for development and preflight qualification of drivetrain (transmission, gearboxes, bearings, couplings, shafts, etc.), fluids, and accessories may be either a regenerative-loop arrangement or an open-loop system. These test rigs are usually unique for every gearbox and transmission assembly. An open-loop rig requires full input power and a full power load absorber. The power absorber might be a water brake, dynamometer, or electric motor with suitable load banks, etc. The test rig is driven at normal operating speed by an electric motor, hydraulic motor(s), or other suitable prime mover. The regenerative loop captures part of the output power and feeds it back to the prime mover. Components, such as clutches, oil pumps, oil filters, and chip detectors, require unique test rigs and fixtures. These rigs and fixtures are usually the property of the vendor furnishing the component.

6-4.3.3 Engines and Drivetrain

Iron bird testing typically follows bench test. An iron bird, or propulsion system test bed, is used to concomitant testing of engines and drivetrain components. It is also used to evaluate the engine airframe interface, validate the control(s) design and installation(s), optimize the control functions, and evaluate maintainability. This test bed should include the entire propulsion and drive subsystem, such as rotor(s) or propeller(s), engine(s), auxiliary power units, transmission, and gearboxes. Also see par. 6-5 concerning the ground test vehicle.

The engine and drivetrain functional mock-up is useful for preflight qualification of engines, the drivetrain, bearings, gearboxes, couplings, etc. It is also useful for preflight qualification of engine components, fuel and oil systems, and other components. A secondary purpose could be maintainability and human factors evaluation if there were sufficient attention to detail. There are limitations. Typically, these types of mock-ups are not capable of simulating air inlet and exhaust pressures at all flight attitudes and velocities. Oscillatory and transient loads and vibrations cannot be exactly duplicated. Weapon exhaust flow is not easily duplicated on the ground and could affect both the engine and drivetrain.

6-4.4 ROTOR SYSTEM The functional subsystem mock-up requirements for rotor system mechanical rotor and controls, rotor and electronic controls, and whirl test articles are discussed in this subparagraph. Many modern-day air vehicles use some form of hydromechanical or electrohydraulic controls. Hydromechanical systems are discussed in subpar. 6-4.4.1, and electrohydraulic systems are included in subpar. 6-4.4.2.

6-4.4.1 Mechanical Rotor and Controls

Except for maintainability, human factors, and accessibility-related functions, which should be accomplished on a full-scale mock-up or preferably a computer-aided engineering substitute for mock-ups, other functional tests of rotor and controls should be accomplished on component-, assembly-, and/or system-level functional mock-ups. Rotor forces could be approximated by means of cams, electromagnetic devices, hydraulic force generators, and solenoids. Complex loading can be approximated via computer-controlled devices. Fatigue testing typically includes some form of the previously mentioned devices, yet seldom (if ever) is it accomplished on a total system basis. Representative portions of the control system often are tested on a subsystem basis with simulated loads and rates. Integrated hub and mechanical control system testing should be done on a control system test bed, whirl stand, power system integration test stand, or ground test vehicle, which is discussed in par. 6-5.

The control system test bed should include a complete rotor hub and control system. It should also include all provisions for controlling the rotor, i.e., the swash plate, control rods, pitch horns, mixing levers, bell cranks, hydraulic actuators, and other hydraulic components, as applicable. Gearboxes with appropriate shafting should be provided for mounting; however, the rotor does not have to turn during control system testing. Rotor blade root sections typically are used in lieu of the complete blade assembly; but the blades could be attached.

This functional mock-up could be used to check for adequate clearance throughout the full range of travel while under load. Proof loading, stick loading, and leak checking could be accomplished. Rotational testing is typically accomplished on a whirl stand; see subpar. 6-4-4.3. For those rotorcrafts requiring blade folding, either this mock-up or the whirl stand should be capable of demonstrating compatibility of rotor and hub components during the complex geometric manipulations generally associated with folding. Blade folding might be manual or might be powered by one of the available secondary power systems. The folding operation, security of locks, and functioning of the “SAFE-UNSAFE” indicator should be demonstrated with a mock-up that duplicates the exact motions of the blades. Actual components should be used in the power system.

A secondary purpose of the functional mock-up could be to check the adequacy of the design for visual inspection and maintenance accessibility. For example, oil-level sight gages and appropriate access doors should be located so that the doors are accessible and the gages can be seen when the doors are open.

Complexity and cost of the subsystem integration test stand, ground test vehicle, and power system integration test stands are major limitations. Simulated masses, forces, rates, displacements, etc., only approximate the actual operating environment. Power system integration test stands or tie-down testing is the best form of ground testing; however, these too only approximate the actual operating environments. Aerodynamic and aeroelastic characteristics cannot be fully duplicated and evaluated on the ground.

6-4.4.2 Rotor and Electronic Controls

The rotor and electronic control functional mock-up should incorporate many of the physical features of the mechanical and hydromechanical subsystem; however, it should also include electrical control devices, such as wires, sensors, motors, processors, and computers. Also see subpar. 6-4.5 for information on electronic system manager network mock-ups. A hydromechanical functional mock-up includes most of the required features that are addressed in subpar. 6-4.4.1. Rotors are rarely positioned directly by electric motors. Because of the large forces involved, such motors would be too large and heavy. For this reason, hydraulic actuators remain the preferred method to position rotor blades. Typically, they position the blades by placing forces on a swash-plate assembly that in turn moves pitch change links, blades, and rotor path. Gyroscopic effects are considered in the geometry. To set the position of the swash plate precisely, the hydraulic actuators are incorporated into a servomechanism containing an electronic (sometimes digital) compensation network, which steers the actuators to the correct position. Actuator position is measured by means of electronic sensors, such as linear variable differential transformers (LVDTs). The rotor and electronic control functional mock-up should incorporate these features.

Rotor forces, etc., can be simulated via the same means used for mechanical and hydromechanical subsystem functional mock-ups. This mock-up is useful for preflight qualification. In addition to the functions accomplished by rotor and mechanical mock-ups, limited software qualification is possible, although its effectiveness is limited by environmental effects. Also gains, rates, and loading can be approximated only during ground test controlling the movement of a hydraulic actuator assembly; see subpar. 6-4.5.

Flight control integration testing should be accomplished first and followed by power system integration testing. Computer and related software and firmware are tested by electronic simulation and bench test. Air vehicle tie-down testing or powered system integration test stands are the most complete means of ground testing. A power system integration test stand is sometimes called an iron bird. It duplicates most of the dynamic systems of the air vehicle, but it will not fly. Software can be verified during power system integration testing and flight testing. Actual operating conditions are approximated by this stand; however, aerodynamic and aeroelastic characteristics cannot be fully evaluated on the ground. The aforementioned testing is useful for preflight qualification. However, its effectiveness is limited by environmental effects.

Gains, rates, feedback loops, resonance conditions, etc., can only be estimated and approximated during ground testing. Optimization of gains, rates, and constants usually requires flight testing. Also electromagnetic vulnerability testing requires use of very specialized facilities. Subpar. 6-4.5 provides additional information concerning electronic control system functional mock-up requirements.

6-4.4.3 Whirl Test Article

Whirl testing subjects rotating aerodynamic components to their inertial and rotational forces. Although the operating conditions of rotors and propellers are similar in some respects, significant differences exist. Typically, whirl testing includes a tower approximately one rotor diameter in height, rotor hub and controls, electric motor, reduction gearbox, strain gages, load cells, track and balance devices, tachometer, means to measure deflection and angle of attack, hydraulic pump, actuators, safety barrier, and operations room. Whirl test rigs should be used for endurance testing, hover performance, aeroelastic stability testing, validation of nondimensional coefficients, and overspeed testing and to obtain data to update analytical models. Transition to hover and flight test is often based on good correlation between analytic predictions and wind tunnel and whirl test results. The test rig is limited to open-loop testing at low-wind conditions. Generally, only hover and in-ground-effect performance and stability testing can be accomplished.

In both rotors and propellers, a large amount of kinetic energy is in the assembly when it is rotating at operating speed. This makes a complete failure catastrophic. While this emphasizes the importance of qualification tests, it also makes these tests difficult and possibly hazardous to perform.

Rotor system whirl tests are conducted prior to the first flight of the rotorcraft. As a minimum, the aerodynamic calibration of main rotor static thrust performance and the stress and motion surveys over the design range of combinations of collective and cyclic pitch and rotor speed should be obtained. Fig. 6-4 shows a typical whirl test rig.

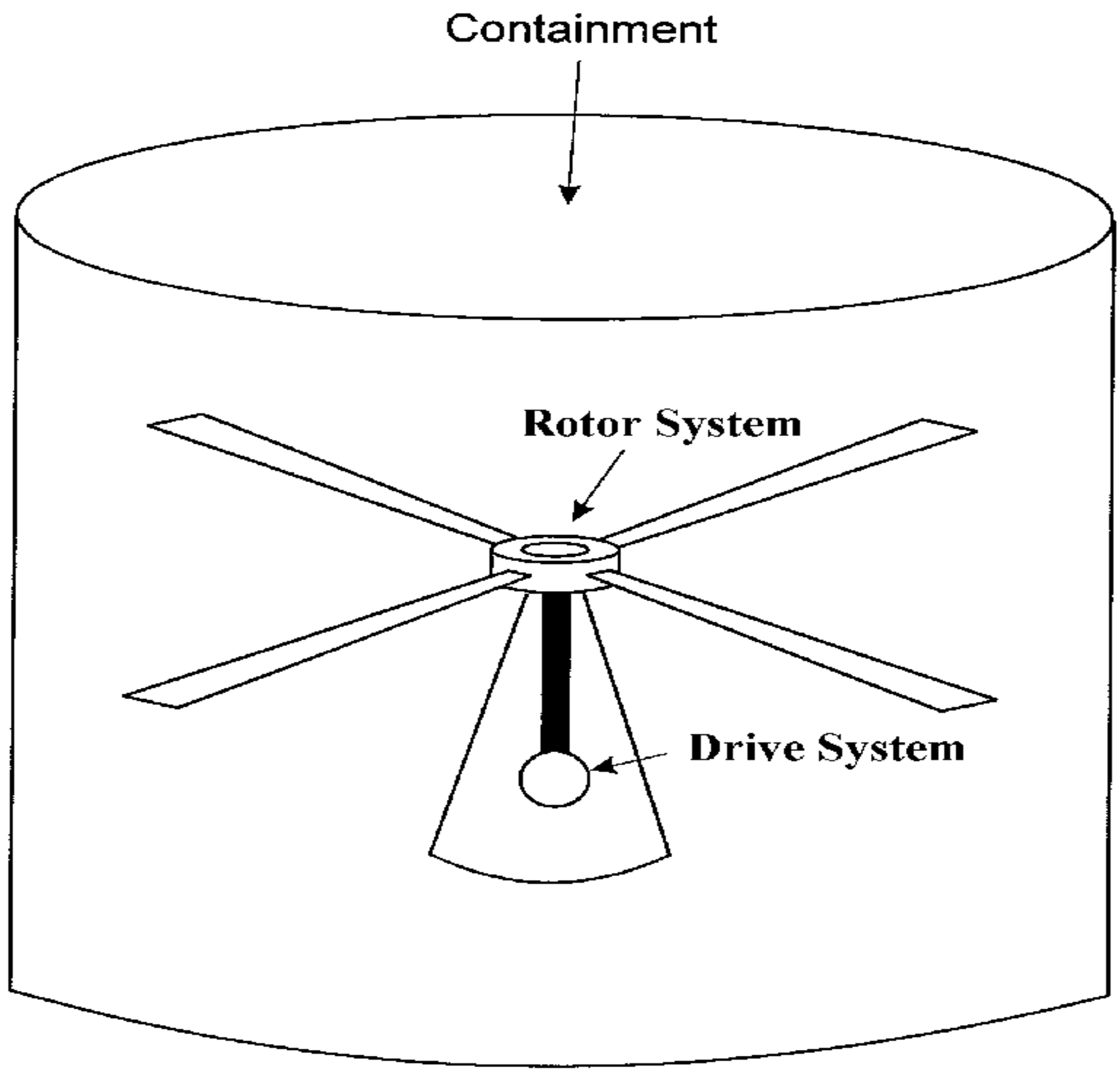


Figure 6-4. Whirl Test Rig

6-4.5 ELECTRONIC SYSTEM MANAGER NETWORKS

Electronic system manager network mock-ups consist of the processor hardware and software, memory, and input/output (I/O) devices. Since a functional mock-up of the electronic system manager must function with the same algorithms (coded into the software) and the same processor, the mock-up typically uses engineering development model hardware and preproduction software. As a result, functional mock-up tests approximate the same level of testing as test of the actual hardware. The data bus for functional mock-ups should satisfy the air vehicle system specification for data communication to the maximum extent possible. Information concerning typical requirements and concepts of operation may be found in Society of Automotive Engineers Standard AS 15531, *Digital Time Division Command/Response Multiplex Data Bus*, (Ref. 4).

The use of "clean" laboratory power and grounds, different physical arrangement of the component, shielding differences, and differences in cable lengths between the mock-up and the actual hardware may affect the validity of the mock-up results. Therefore, the mock-up should be as production representative as possible to reduce the impact of these variables.

6-4.5.1 General Control and Data Bus Networks

General control and data bus networks of mock-ups consist of the bus (i.e., the cable), the bus controller, remote terminals with their associated subsystem, and/or subsystems with embedded remote terminals, each with its associated software. Cable stubs are coupled to the bus through a coupling transformer or by direct connection to the bus and are coupled to the transmitter/receiver through an isolation transformer. The extent to which the mock-up hardware and software represent the actual system determines the applicability and limitations of the mock-up to provide valid qualification data. Control and data bus network hardware components, as well as component software, require qualification. A production representative control and data bus network may be used to provide qualification data. However, cost is a limiting factor to providing an adequate mock-up. Fig. 6-5 depicts a typical control and data bus network.

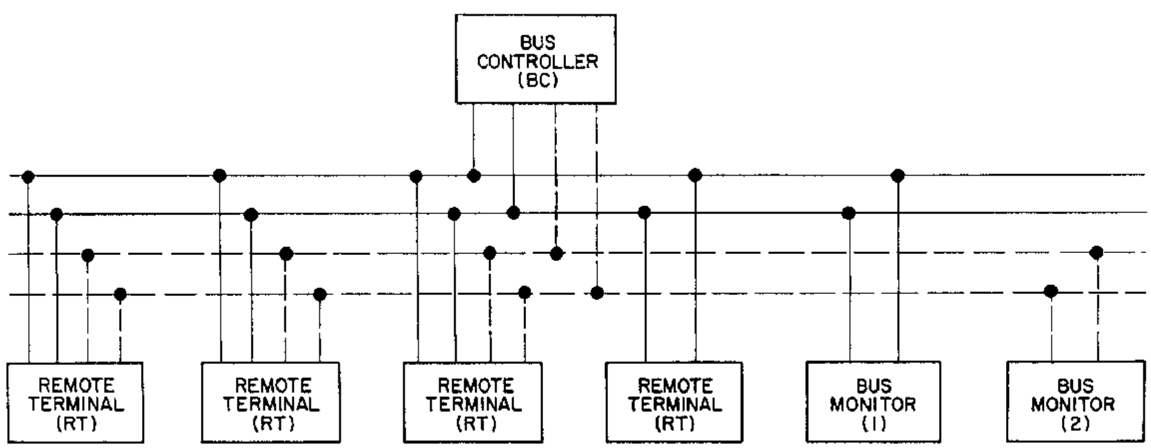


Figure 6-5. Control and Data Bus Networks

6-4.5.2 Electronic Flight Controls

Electronic flight control functional mock-ups could be of the analog, digital, or fly-by-light types. Older air vehicles typically used analog. Anytime a system is linear, i.e., it can be expressed in its entirety in the LaPlace "S" domain, analog construction is practical. However, the system might be more susceptible to noise. Fly-by-light systems are less susceptible to electromagnetic fields but more susceptible to temperature variations. Electronic flight control system mock-ups consist of position-sensing devices, actuators, the data/signal transfer medium (wire or fiber-optic cable), and processors. Except for system-specific hardware and possibly software, the functional mock-up is similar. The mock-up is used to determine that the system provides the appropriate control actuations for the given set of input conditions. Also see subpar. 6-4.4.2. The fact that the load forces on the system are simulated and not the actual loads produced on the air vehicle limits the utility of such a mock-up. All systems require some form of shielding. Digital and fly-by-light systems require qualification of software and hardware. Cost is a major limitation, especially with fly-by-light systems and mock-ups.

6-4.5.3 Integrated Cockpit Avionics Networks

An integrated cockpit avionics network mock-up consists of the system control, displays, processors, interconnecting cabling, and associated software. It is used to evaluate the integration of subsystem and system hardware and software. The mock-up should include as much production representative equipment and wiring as possible. In addition, human interface considerations and data entry procedures may be assessed. Cockpit avionics integration requires qualification of software as well as hardware and requires in-flight evaluations in addition to the mock-up assessments. Flight evaluations are required because the laboratory environment only approximates the real world. Also initial cost is a major limitation of avionics network mock-ups.

6-4.5.4 Electronic Engine Controls

The electronic engine controls mock-up allows assessment of performance characteristics of analog and digital engine controls ranging from supervisory to full authority electronic control systems. Engine control mock-ups may assign mechanical and sensor functions to the hardware mock-up or simulate them on a computer, which substitutes a mathematical model for actual hardware. The computer interfaces with the mock-up by means of mechanical, electronic, and fiber-optic signals whose characteristics are similar to those received and generated by the hardware being substituted. As a minimum, the mathematical model should encompass both the engine and the rotordrivetrain. It can vary in complexity and accuracy (even considering air vehicle free body influences during maneuvers), the degree of which depends on the amount of fidelity required to substantiate the control methodology for performance and behavior before proceeding to flight test.

6-4.6 TARGETING, FIRE CONTROL, ARMAMENT, AND STORES STATIONS

Target acquisition and fire control systems are typically modeled by computer simulation and then tested on a hot bench that includes all of the essential electronic components. Models should also be developed for safe separation, jettison, and gravity drop of weapons and stores. Also the targeting, fire control, armament, and stores station installation should be completely mocked up, including fixed and movable weapons and accessories; turrets; rockets, guided missiles, and accessories; fire control subsystems; internal or external stores as applicable (including racks, supports, shackles, sway bracing, ejectors, etc.); dummy armor plate and bullet-resistant glass; and hoisting provisions, as applicable. The target acquisition and weapons sighting systems should be fully functional. The fixed and movable weapons, turrets, and fire control equipment should permit the full range of movement. Particular attention should be given to showing all armament installations in such detail that clearances (both ground and structural) and physical arrangement can be readily checked. The arrangement should be such that loading and unloading of missiles, rockets, and gun ammunition and removal and installation of guns may be demonstrated. Missile- or rocket-launching mechanisms should be completely mocked up and capable of movement through the normal operating travel. The mock-up should provide field of fire mechanical stops and safety interlocks.

If armor protection is specified, the mock-up should include the armor protection of the engine(s), auxiliary power unit(s) (APU), controls, wiring, and liquid-carrying lines, as well as flight crew stations. These mock-ups may also be used for operational testingtraining and maintenance demonstrations.

The targeting, fire control, armament and stores functional mock-up should be used for checking out electrical components interface, software, firmware, human factors, and for preliminary electromagnetic and compatibility checks. Typically, the mock-up might be limited by its limited ability to duplicate operational environments. Algorithms and weapons simulators might not duplicate actual performance. Target simulation is only an approximation. Clean laboratory power and less than exact physical arrangement of wires, cables, etc., might influence the results.

6-4.7 LANDING GEAR

Many air vehicles use skid-type landing gear in lieu of wheel-type systems. The choice of skid- or wheel-type landing gear is based on operational needs, which include but are not limited to low observable requirements. Typically, skid-type landing gear is developed and tested by the airframe manufacturer. It is essential that skid drop-test fixtures duplicate (as nearly as possible) the mass properties and stiffness of the airframe. Wheel-type landing gear, especially the retractable type, is normally developed by specialty companies. These companies usually have extensive facilities and functional mock-ups, such as drop, braking, hydraulic, and dynamic test rigs. Functional mock-ups of this type should be capable of simulating loads, spring rates, mass properties, and stiffness at various lateral and longitudinal contact angles The mock-up of a fixed landing gear—including brakes, swiveling features, and accessories, such as floats and bear paws—should permit evaluation of accessibility to the air vehicle for personnel and cargo loading and unloading and of the effect of the gear on the maintainability of the air vehicle. Skid-type systems should include oleo struts, tow wheeling, etc. Several mock-ups may be needed to demonstrate high- and low-type gear, flotation gear, and ski-type systems.

Retractable landing gear mock-ups should demonstrate operation of the retraction mechanism (normal and emergency extension), fairing doors, and the positive lock provisions. Hydraulic and electrical retraction mechanisms should be fully functional. The kinematics of the retraction linkages should be operative in order to allow evaluation of possible interference with doors, hatches, or special exterior equipment while in any of the intermediate landing gear positions during the retraction or extension cycle. The mock-up should include representation of all equipment in the wheel well in order to determine possibleinterferences and environmental problems. The flexure of the lines and hoses for landing gear retraction, brakes, and drive power should be demonstrated in the mock-up. The addition of transparent panels to the mock-up structure aids in determination of the suitability of the wheels-stowed configuration and assist in determination of possible design faults.

An alternate means of supporting the mock-up at the static gross weight of ground position should be employed for air vehicles incorporating retractable landing gear. The size and shape of shock absorption devices are important in the evaluation of landing gear clearance and operation. However, simulation of the landing gear spring rate or load deflection characteristics may not be warranted or desired. Nevertheless, the mock-up has limited value for qualification (except for accessibility and maintainability) unless landing gear spring rates and load deflection characteristics can be approximated. Clearance under load cannot be evaluated, and aerodynamic and other environmental factors cannot be inexpensively duplicated.

6-4.8 LIGHTING MOCK-UP

A full-scale functional mock-up of the interior and exterior lighting should be constructed. All modern air vehicles having moving maps and flight instrumentation on processor-driven cockpit displays or multifunction displays should have these displays included in the lighting mock-up. Lighting and reflections should be compatible with light-amplifying devices.

A full-scale mock-up should be used for lighting inspection and may be employed for crew stations, passenger stations, cargo compartments, and equipment compartments. An actual air vehicle cockpit or cockpit section should be provided, when practical, for inspection of cockpit lighting. If an actual cockpit or cockpit section cannot be employed for the cockpit lighting mock-up, the cockpit may be simulated. The framing, windows, windshields, bulkheads, and other cockpit sections that are visible to the pilot and/or copilot should duplicate those of the production air vehicle. Soft metals, plastics, and wood suitably coated to represent the production article may be used. The contractor should develop an interior and exterior lighting system mock-up checklist. Particular attention should be paid to the electrical power provided to ensure that the power available to the mock-up does not exceed that of an actual air vehicle.

Light-amplifying devices, such as night vision goggles, laser protection glasses and visors, and optical sighting devices, should be available for evaluation of lighting. This functional mock-up should be used for preliminary human factors and night vision evaluations; therefore, it contributes to preflight qualification. See subpars. 6-4.8.1 and 6-4.8.2 for the qualification limitations of lighting mock-ups. Early detection of problems is essential.

6-4.8.1 Interior Lighting

Complete interior lighting, with glare shields, should be mocked up. Moving, processor driven, and other multifunction displays should be included so that evaluation of compatibility in terms of glare, reflections, night vision, etc., can be performed. These should be functional displays. Provisions should be made for viewing the mock-up in a completely darkened room or by simulating complete darkness in the mock-up. Either a darkened room or red goggles should be provided for at least a 30-min dark adaptation. Passage from the cockpit lighting mock-up to any other lighting mock-up station or compartment in the should not require readapting observers to darkness. The mock-up should be illuminated with all instrument lights operative and should be provided with equipment identical to that to be installed in the operational air vehicle. In the case of instruments and console controls, the equipment to be installed or similar equipment (not pasteups) should be used. If controls that energize indicator lights cannot be actuated in the mock-up, the indicator lights should be energized by switches external to the mock-up or by internal switches not normally used for mock-up inspection. Adjustable dimming should be provided for all lights to allow the light intensity to be varied for the evaluation of night operations and the effects of glare. An actual blade assembly or blade section movable through its normal arc of rotation may be used to permit representative rotor reflections to be evaluated.

Provision should be made for inspection of the actual air vehicle cockpit or cockpit mockup section in daylight (bright sunlight) to determine the adequacy of warning lights, caution lights, etc.

The mock-up should be used for preliminary qualification of lighting, instruments, and displays. Preliminary qualification should include an evaluation of night vision compatibility characteristics. Early detection of problems is important. The use of prototype hardware, simulated displays, nonfunctional displays, and simulated cockpit arrangements and the nonavailability of the various light-amplifying devices for evaluation purposes limit the use of the mock-up for preflight qualification. Environmental effects and reflection of the airframe are not easy to duplicate. Reflections from a simulated disk in lieu of a rotating hub and blade assembly will not produce the modulated reflections of a rotating system. Also a simulated disk or a simulated hub and rotor system is not apt to have the same reflective properties. Typically, reflections and the modulating effects of a turning hub and blade assembly have not resulted in significant lighting problems.

6-4.8.2 Exterior Lighting

The location of exterior lighting should be duplicated in the mock-up. Provision should be made by the contractor to view the exterior lighting mock-up in a reasonably darkened area. Provisions should also be made to view the effects of external lighting on cockpit interiors (glare, etc.). Navigation lights, formation lights, landing and taxi lights, anticollision beacons, and high-intensity strobe lights should be demonstrated for visibility, light intensity, and flash frequency at the required azimuths and elevation angles. Structural, antennae, and external stores interferences with lighting patterns may be determined and corrective measures taken either by relocating the light or moving the obstructing appendage on the airframe. (See subpar. 6-4.8.)

6-5 GROUND TEST VEHICLE

A typical ground test vehicle is a nonairworthy air vehicle, airframe, or major portion of an airframe, which is used as a functional mock-up and test rig. Figure 6-6 shows examples of a ground test vehicle. Also a fully operational air vehicle could be tied down and used as a ground test vehicle. ***CAUTION: The ground test vehicle should be analyzed and tested to ensure nonexistence of aeromechanical instabilities (ground resonance) and whirl mode instabilities. In addition, tie down of the air vehicle for this type of testing typically requires use of more than the normal parking tie down loads and hard points, and may require analysis of permissible tension loads on normally compression loaded fittings such as jacking points to react the projected force generated by the test conditions. Cargo hooks have been used as both a supplemental tie down fitting and for tethered hover testing in lieu of rigid tie down.*** The ground test vehicle integrates propulsion, engine airframe interface units, software, and the rotor mechanical, electrical, electronic, hydraulic, and pneumatic systems needed for flight. This functional mock-up might incorporate all of these parts. It is used for airframe structural testing and dynamic component and rotor system evaluations. It provides confidence in the mechanical and structural integrity of the design necessary prior to the first flight. It may also be used to test the endurance of the propulsion and drive system in a manner less costly than flight testing. The ground test vehicle is a part of the progression from handmade component and subsystem mock-ups to early prototype hardware built from computer-aided engineering and computer-aided manufacturing proof articles integrated into a production representative system.

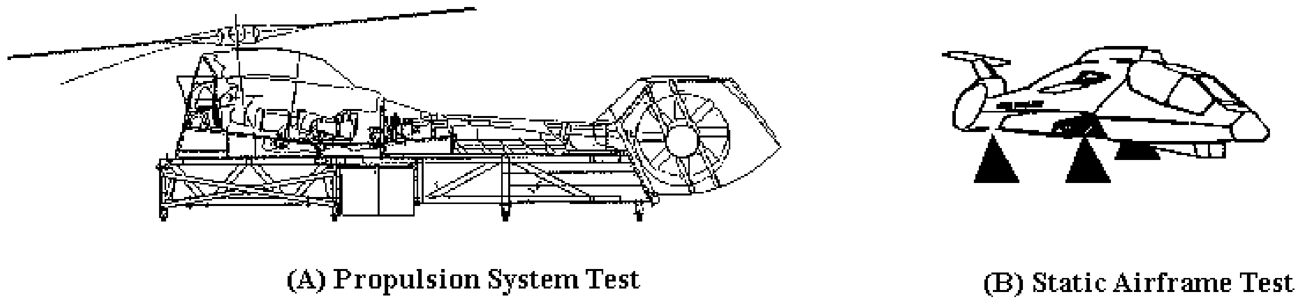


Figure 6-6. Ground Test Vehicle

6-6 MOCK-UP REVIEW AND APPROVAL

Mock-ups can be used to obtain an early determination of an actual air vehicle for service use. These mock-ups should provide a full representation of the physical arrangement with sufficient detail to permit checking compatibility with handling, maintaining, loading, and operating requirements for the air vehicle and its equipment. Also these mock-ups should be sufficient for checking crew and passenger stations, cargo and weapons provision, equipment arrangements, propulsion system installations, vision, clearance, lighting, personnel safety, etc. MIL-M-8650 (Ref. 2) provides additional information on planning mock-ups, mock-up reviews, scheduling and content of evaluations, and evaluators. Mock-up inspections are often accompanied by other visual data such as compartment layout drawings and air vehicle subsystem and hardware drawings, photographs, illustrations, an external vision plot illustrating the field of vision around the air vehicle from the crew's normal eye position per the Aitoff Equal Area projection vision plots defined in MIL-STD-850 (Ref. 3) and tabular photometric data from the lighting mock-up. Specific evaluation procedures should be established prior to an official mock-up demonstration to include definition of any objective scoring techniques and necessary tools or devices such as stopwatches, motion picture photographs, special lighting, and evaluation check sheets. For additional information relevant to evaluation, see MIL-H-46855, *Human Engineering Requirements for Military Systems, Equipment, and Facilities*, (Ref. 5).

Standardized design and mission suitability checklists are typically used to augment and/or provide guidelines for the evaluation of the mock-up. The inspection team should have sufficient time to review the mock-up, take measurements, review necessary criteria documents, and prepare comments prior to the critique. Mock-up review may include observing personnel representing the 5th percentile female through the 95th percentile male who are wearing Army flight clothing, arctic clothing, and survival equipment and performing mission functions, including ingress and egress, under night lighting conditions. Measurement of seat, panel, control, and other spatial relationships within the crew and passenger compartments may be evaluated.

An evaluation of the alternate uses of certain areas of the fuselage for various operational functions may be desirable, e.g., the operation of weapons from the doors or elsewhere through blisters or cutouts in the passenger compartment. The size of the hatches, particularly for the crew, may be strongly influenced by the access routes to the hatches within the crew compartment. Internal equipment obstruction should be evaluated together with the possibility of using the console, instrument panel, and seat bottoms or seat backs as steps to facilitate rapid egress from the compartment. Evaluation of the mock-up will identify any changes needed to assure that the emergency escape paths are not compromised by external fuselage projections, such as pitot heads or antennas, which might injure the personnel or impede their exit from the air vehicle.

A crashworthiness inspection should be conducted using the checklist in USAAVSCOM TR 89-D-22, *Aircraft Crash Survival Design Guide, Vol. I, Design Criteria and Check Bits*, (Ref. 6). The specifications, standards, and other documents referenced in the aircraft detail specification should be the criteria upon which judgments of contractual compliance are made. Design areas that do not comply with the detail specification or system description and other problem areas should be documented as either deficiencies or shortcomings on the form prescribed by the procuring activity. If it is practical, recommended design solutions to mock-up problem areas should be incorporated into the mock-up during the inspection.

If required, mock-up approval should be granted upon the contractor's compliance with the required changes and/or approved deviations, as specified by the procuring activity. The contractor should provide photographs of the approved mock-up. Table 6-3 provides a sample checklist for a seats and furnishings mock-up review.

TABLE 6-3. SAMPLE BASELINE CHECKLIST FOR SEATS AND FURNISHINGS

Crew Seats	1. Are the vertical and fore and aft adjustments accomplished separately (versus integrated operation)? 2. In what increments can the adjustment be made? 3. Where is the adjustment control located? 4. Is the location satisfactory? 5. Is the seat designed for the proper equipment? 6. Is the seat equipped with a correctly mounted inertial reel with a “stalock” feature? 7. Is there an indicator or reference point provided so that the crew can determine the correct eye level?
Passenger Accommodations	1. Are the passenger seats provided appropriate to the passengers to be carried? 2. Is adjustment provided for the seats? 3. Are satisfactory safety belts provided? 4. Are shoulder harnesses and inertial reels provided? 5. Are seats designed for the appropriate mission equipment? 6. If litters are provided, are the following satisfactory? a. Vertical distance between litters b. Height of topmost litter above an in-flight stable surface c. Aisle space between litters?

SECTION II

SIMULATIONS

6-7 INTRODUCTION

Simulations are the physical or mathematical emulation of characteristics of the physical equipment, its environment, events related to the equipment, or intelligence. The objective of a simulation is to reproduce certain aspects of the real world as part of the airworthiness qualification process. Qualification by simulation is desirable when the achievement of real-world situations is either prohibitively expensive, requires obsolescent time frames, or is dependent on remote or unpredictable natural occurrences. The qualification that is feasible to be performed through simulation is dependent upon how representative the simulation is of the actual system and its environment.

6-7.1 ABSTRACT EMULATION

Abstract emulation is used for concept exploration, design optimization, and tradeoff studies. It is necessary when economic and technological considerations render real-life measurements impractical, especially when prototype and test equipment do not exist and the technology to build it is not yet available. For example, air vehicle performance characteristic models allow assessment of a system over a wide variety of conditions for which actual measurements at each condition would not be practical.

Abstract emulation is the description, in mathematical terms, of the characteristics of a system. These system characteristics are described by means of equations (algebraic, geometric, statistical, and differential), logical rules, constraints, tabular data, graphs, and charts. The finished product, a model encompassingthese characteristics, is verified by using critical test cases strategically chosen to assess the ability of the model to predict the behavioral response of a system across all its different modes of operation, such as rolling, yawing, and pitching of an air vehicle. The model is considered satisfactory when its predictions are reasonable and agree with test data within tolerances proportional to the criticality of the prediction. Typical applications include preflight envelope exploration, test data analysis, and development of subsystem models that will be incorporated into larger models, such as battle engagement models.

6-7.2 PHYSICAL EMULATION

A physical emulation consists of a digital model adapted to output a specific response signal, equivalent control driver, or generate video to emulate an actual system, subsystem, or environmental characteristic. Physical emulations can be individual black boxes to emulate a specific subsystem interface or a computer that emulates the response and control signals of several components or subsystems simultaneously. These techniques are useful for assessing interface characteristics in the absence of the actual hardware. For example, in the course of developing a targeting and fire control system, the actual air vehicle electrical and control interfaces might be emulated using computer-generated signals until the actual air vehicle is available for interface and integration tests. Physical emulation “substitute parts” are also appropriate for functional subsystem mock-ups, flight simulators, and mission simulators. These physical emulations are used in those circumstances to save cost and make the simulation or mockup more effective or realistic.

6-8 SIMULATION BASES AND VALIDATION CRITERIA

This paragraph discusses various forms of simulations and representations of the physical characteristics that may be modeled mathematically. Simulations may be based on many different types of models, including tabular data, characteristic function, transfer function, statistical function or characteristic, and artificial intelligence. When all of these models are used, it is imperative that the underlying information and analysis techniques used to create the models are understood. Failure to do so will potentially result in the misapplication of the model and consequent invalid conclusions. Not only must these issues be thoroughly understood, but the models must have undergone thorough validation prior to their use. The criteria used to demonstrate validation should be established based on the type of model and the use of the model or simulation output.

6-8.1 TABULAR DATA MODELS

Tabular data models are simple models in which data are presented in a tabular manner. Standard atmosphere data are usually presented as a tabular data model. Given an altitude value, a simple table lookup provides information such as temperature, air pressure, density, speed of sound, and coefficient ofkinematic viscosity. Tabular data models are generally used where mathematical representation of that data is extremely complicated and/or requires large amounts of calculating capacity and time. This type of model is applicable in situations in which frequent and ready access to the data is required without the need to perform lengthy or difficult calculations. Engine performance data used in many flight simulators are examples of the uses for a tabular data model. This method of modeling is limited by the fact that the data are readily available only at the specific table values and data for intermediate values not tabulated must be obtained through interpolation. These models must be validated through systematic comparison of measured values at known points with the modeled values throughout the entire range of the model.

6-8.2 CHARACTERISTIC FUNCTION MODELS

Characteristic function models are developed through a process of fitting experimental data to a postulated mathematical representation of the data. Given a set of observations, it is sometimes convenient to reduce the amount of data to a model that depends on the values of observed parameters. An example of such an application might be the modeling of the pitching moment coefficient as a function of angle of attack. This is accomplished by “best fitting” the model to the data. The least squares method is most often used and can be applied to numerous models including straight-line, polynomial, and nonlinear models. It is also possible to develop confidence limits on the estimated model parameters. The validation process is further complicated if the calculated data are functions of multiple variables and the experimental process does not allow direct control of all variables simultaneously.

6-8.3 TRANSFER FUNCTION MODELS

Transfer function models are a subset of differential equation models used to model nonlinear physical devices. Complex devices tend to be described by nonlinear differential equations. Items in this category include aerodynamic, structural, thermodynamic, and electronic devices. Many nonlinear dynamic equation models must be solved by numerical computer simulation because exact closed form solution equations for them do not exist. When nonlinearities are insignificant, a system may be described by using linear differential equations. These can also be organized into dynamic equations; however, they can also be left in the order in which they appear in the system being modeled. Doing this, the particular elements (or equations) described by differential equations are organized into transfer functions. Transfer function models are used to analyze dynamic system characteristics. The transfer function of a continuous system is described in the S-plane by Laplace transforms. The transfer function of a system is the ratio of the Laplace transform of the time-varying input to the system and the Laplace transform of the time-varying output of the system. Thus, by applying the method used to find the inverse Laplace transform, system characteristics can be determined based on the transfer function and the Laplace transform of the input function. Transfer functions have the characteristic that for a system in series (The output of the first component becomes the input to the second component.), the transfer function of the system is the product of the transfer functions of the components. Since the process of taking the Laplace transform is a mathematical integration process and the inverse Laplace transform is a contour integral in the complex plane, these transformations can be readily performed digitally or by use of electronic analogs. Usually outputs from transfer function models include frequency response characteristics.

Sampled data systems (usually digital) use Z-plane analysis techniques, which are similar to (because they are derived from) Laplace transform techniques. These analysis methods apply to linear systems, and any significant deviation from the linear assumption by the real-world system negates the use of this approach.

6-8.4 STATISTICAL FUNCTION MODELS

Statistical function models are used to model data results that are stochastic (random) in nature. Random variables are variables whose value cannot be determined beforehand but whose behavior can be described in terms of statistical functions. The basic steps necessary to develop a statistical function model are to (1) gather data representing the random variable, (2) make a graphical representation of the data in terms of either their frequency distribution or their cumulative density function, (3) postulate a model that represents the data, (4) calculate the parameters of the postulated model, and (5) perform a goodness-of-fit test to determine how well the data fit the postulated model and calculated parameters. Statistical functions include the normal distribution, the exponential distribution, the uniform distribution, the gamma distribution, the beta distribution, the Weibull distribution, and the bivariate normal distribution. Special probability paper has been developed to assist in the graphical interpretation of statistical data. Data fitting a normal distribution, for example, would appear as a straight line on normal probability paper. Methods used to estimate function parameters include maximum likelihood estimators and method of moment estimators. Methods used to determine goodness of fit (which forms the basis for model validation) include the chi-square test and the Kolmogorov-Smirnov test.

6-8.4.1 Statistical Results

Statistical results are often assumed to follow a normal distribution (sometimes referred to as the bell-shaped curve). The two parameters defining this distribution are its mean and its standard deviation, which is sometimes referred to as sigma. These two parameters may be estimated from a sample by calculating the sample mean and sample standard deviation. The mean is a measure of the central tendency of the data, i.e., what is the most likely value of a random variable drawn from that population. The standard deviation is a measure of the dispersion of the data about their most likely or mean value. For a random variable drawn from a normal distribution, there is a 0.50 probability that it will fall below the mean, a 0.1587 probability that it will fall below the mean minus one sigma, and a 0.0013 probability that it will fall below the mean minus three times sigma. These are usually referred to as the average, expected minimum, and three-sigma values. Sometimes a five-sigma value (referred to as "Murphy's Law") may be calculated. This corresponds to a 0.0000002867 probability of occurrence. These values must be used with caution, especially at the extreme three- and five-sigma points because their validity depends on how well the true physical characteristics correspond to a normal distribution.

6-8.4.2 Monte Carlo Results

A Monte Carlo analysis shows how a system performs as configurations, topologies, and other parameters vary. It is necessary when a sensitivity analysis is impractical or when too many parameters (usually more than five) exist to sweep them, such that all combinations are represented (multidimensional sweep), while tabulating or plotting performance. The Monte Carlo analysis is useful for both measurements and optimization efforts. Because of its flexibility, it is a powerful tool useful to many disciplines. When the ultimate value or outcome of a parameter is a function of multiple stochastic variables combined in some form—additive, multiplicative, etc.—it is useful to develop a Monte Carlo simulation of the outcome. This may be necessary because the probability distribution of the combined variables cannot be derived in mathematical functional form. Generically, the Monte Carlo simulation method is based on using an algorithm that produces a pseudorandom number. A pseudorandom number is a number generated by a deterministic program that produces an apparently random sequence of numbers. This pseudorandom number, usually from a uniform distribution between 0 and 1, may then be converted to the desired distribution with appropriate parameters by using either transformation or rejection methods. Similarly produced random variables may then be combined according to the physical situation being modeled to produce a simulated result. This process is repeated a large number of times, and a statistical distribution of the system parameter may be determined. The number of simulation runs required to obtain valid data is a function of the variability of final result and the desired precision or confidence required of the simulation. As the scale of the simulation increases, the number of required simulation runs grows correspondingly. An example of the use of a Monte Carlo simulation would be to model the total error of a system based on the knowledge of the contribution of individual error sources.

6-8.5 ARTIFICIAL INTELLIGENCE (AI) MODELS

There are different classifications of artificial intelligence (AI) systems. One of the main applications is machine learning. An expert system makes use of machine learning. However, AI does not always involve machine learning. Hybrid systems use traditional procedures in conjunction with AI. See subpar. 6-8.7. AI expert systems are computer-based systems that use knowledge, facts, and reasoning techniques to solve problems that would normally require the abilities of human experts. These systems are usually based on rules or experience information about the behavior of a real-world situation. A rule might be of the form, "If condition *x* exists, condition *y* exists, and condition *z* exists, a likely result of these conditions is situation *b*.". A large body of such rules can be very quickly evaluated for a specific situation, and the expert system then arrives at likely conclusions concerning the situation. Expert systems are useful to state these rules formally and develop an experience base. As the number of rules to be processed becomes large, the processing time increases. This aspect may limit the applicability of the method when time-critical situations are involved. A properly developed expert system might be useful as a replacement for a human expert or to arrive at conclusions much more rapidly than a human. Rule-based expert system applications applicable to the airworthiness qualification include performance data analysis, event result prediction, and diagnostic aids.

Logical inference engines are subsets of an expert system. A logical inference engine attempts to find a pattern in cause and effect data. A patient teacher is a system that is initially tolerant of faulty output. Skillful opponent is an application from game theory. Artificial intelligence has not yet been applied to qualification at the system level. However, AI can and should be used for other work, such as battlefield and threat simulations, vulnerability analysis, survivability analysis, and logical modeling. See subpars. 6-10.5 and 6-11-3. An expert system is limited by the expertise built into the system; therefore, it should not be used for life or death decisions. More advanced computers should make more difficult and complex modeling possible.

6-8.6 NEURAL NETWORK MODELS

Neural network models are based on the principle that they gain knowledge through experience and develop a set of hidden rules, whereas expert systems operate on a set of formally stated rules. The neural network absorbs its experience as part of a training or learning process. These networks have been applied to speech recognition, pattern recognition (including target detection), and perception (color, brightness, and three-dimensional form). Validation is performed by comparison of model outputs with known real-world data. Performance may be quantified in terms of percent confidence or accuracy in the predicted results. The validation effort should include the search for inadequate or incorrect branches within this tree. A neural network is programmed by forcing the network to reproduce the response from some reference system. Both the neural network and the reference system are exercised at certain data points (or experiments) during which time the internal parameters of the network are tuned so that its outputs respond identically to the output of the reference system. The programming process scans and rescans the various data points until the neural network reproduces everything without further tuning. Hopefully, the tuning effort inherently captures (within the set of internal parameters) every degree of freedom of the reference system. If so, the neural network can accurately predict all responses of the reference system, even experiments not used during programming. However, if the network does not inherently contain a complete description of the reference system, the predicted responses will become less accurate as experiments deviate farther from the calibrating (programming) points. To be useful, a neural network must be able to respond accurately to signals that are "between" the programmed data points. Doing this, the network covers the complete range of interest, i.e., all of the relevant degrees of freedom. Examining between the data points (over the relevant degrees of freedom) should be a part of the validation effort. To achieve this goal, three issues should be considered. They are

1. All of the relevant character traits (degrees of freedom) of the reference system must be contained within the set of data points used for programming. A trait can be explicitly

demonstrated by a specific experiment (like an individual equation) or implied by the behavior across many data points (like a system of equations).

2. The neural network must have the topology (layout) and capacity to describe, store, and reproduce the degrees of freedom of the reference system.

3. The neural network must have the ability to extract implied information across many data points—similar to solving a system of equations. Also the neural network must contain all of the relevant degrees of freedom, even if they were not explicitly described in any one experiment. By doing this, the network absorbs the general rules of the reference system as it looks across the data points; therefore, it can respond accurately to data points that were not programmed explicitly.

6-8.7 COMPOSITE AND HYBRID BASES

The modeling tools of par. 6-8 may be combined to form composite or hybrid models of bases of data. For example, system characteristics may be measured in order to arrive at a statistical description of a system, which could then be used as the basis for a Monte Carlo simulation to model situations not measured in the original data collection process. As another example, the formally stated rules of an expert system could be combined with the learned rules of a neural network to arrive at a hybrid system that applies both techniques. This additional degree of abstraction compounds the validation process in that it presents a wider array of situations and conditions that must be assessed prior to concluding that the model yields valid results.

6-9 EMULATORS

6-9.1 INTRODUCTION

Emulators are designed to duplicate the behavior, properties, or performance of another system and are often used to generate inputs for other models and simulations. The aspect being emulated may be the system equipment, an environment, an event, or intelligence, as discussed in the subparagraphs that follow. A physical emulator tangibly interacts with the remainder of the system and effectively replaces the subsystem it emulates. Abstract emulators provide the information to assess what the interaction would be under specific conditions in order to allow system designers to predict what the interaction would be if the emulated situation were present. As discussed in subpars. 6-7.1 and 6-7.2, emulators may be either abstract or physical.

6-9.2 SYSTEM EQUIPMENT

As introduced in subpar. 6-7.2, system equipment emulation is used during development of a subsystem or component when it would not be practical or possible to duplicate all system interfaces. For example, during the course of temperature and vibration testing of a piece of electronic equipment, it may be necessary to emulate the signal inputs to and outputs of the system under test by using system equipment emulators for items such as controls and displays. The rationale for the use of equipment emulators at this stage of the qualification process is the impracticability of testing the entire system.

6-9.3 ENVIRONMENTS

Some environmental parameters may be critical to the qualification process, yet due to the nature of the environment, the qualification process may require the use of emulations.

Determination of qualification-critical environments should be done early in the development process. Table 6-4 provides a matrix of environments that may be emulated. Emulation of these environments is often necessary to evaluate performance in a controlled setting. The natural occurrence of these environments is often unpredictable and uncontrollable and therefore necessitates their emulation. In addition, environmental emulations are sometimes required due to cost limitations of conducting tests at remote sites.

6-9.4 EVENTS

As with emulation of environments, emulation of events is useful when the natural occurrence of an event is random and it is not practical to wait for its occurrence or when the occurrence of the event must be carefully timed in order to monitor the system response. For example, in order to assess the testability of a system, a failure event must occur that exercises the capabilities of the system. To wait for the natural occurrence of all possible failure events in order to determine testability, real-time performance would not be practical. The occurrence of failure events may be emulated through a process of fault insertion either physically or through appropriate stimulus of the system. Determination of the number and types of events to be emulated could be derived from a statistical modeling of the failure frequency of the emulated faulty component or through a Monte Carlo simulation. Use of statistical versus Monte Carlo models is discussed in subpars. 6-8.4.1 and 6-8.4.2. Event emulations must be validated for use in meeting qualification requirements. Validation issues include ensuring the correct statistical model is being used to represent the system being qualified. In addition, event emulations may not be totally satisfactory to meet all qualification requirements because certain events, which might actually occur naturally, would be avoided in an emulation environment. These would include events that could cause damaging secondary failures or would create a hazardous situation. Other simulated events include the occurrence of emergency conditions or actions by the enemy.

6-9.5 INTELLIGENCE

Intelligence emulation involves emulation of skills, judgment, knowledge, and applied doctrine. This type of emulation is one of the more complex types of emulations because of the difficulties involved in modeling human behavior.

This type of emulation may be used to represent the actions of a friendly or adversarial person in a larger simulated environment. This could be achieved using prerecorded scenarios, artificial intelligence, or neural networks. It would be useful in a qualification effort when assessments require consistent emulation of human activities. (See subpar. 6-8.5.) Validation of these emulations requires determination of the extent to which the emulation accurately represents the real world in relation to how it is intended to be used.

TABLE 6-4. EMULATED ENVIRONMENTS

ENVIRONMENT	PARAMETERS	MODEL BASIS	APPLICATIONS
Climate—Ambient	Altitude Temperature Pressure Humidity	System specifications, table of standard values for atmosphere and altitude, geodetic surveys, and climatic tables	Abstract or physical emulations, such as algorithms and software for use of aerodynamic performance
Climate—Local (within a system)	Temperature Pressure Humidity	System specification requirements and table of measured values	Abstract or physical emulations for thermodynamic analysis
Operational Signal Interface	Voltage Frequency Waveform Phase shift Impedance Protocol Physical qualities (Temperatures, Pressures, Rates, etc.)	Interface control specifications and measured values (input and output) by means of various sensors and actuators	Physical emulations of input and output commands to and from sensors and actuators, along with sensor and actuator dynamic response, accuracy, and authority
Operational Tolerance Inter-face	Measures of accuracy plus or minus, percent, amplitude, volts, amps, etc.	Signal definitions as determined from interface control specifications and measured values	Abstract or physical emulations, such as error assessments and firm-ware for subsystem testing
Operational Control Interface	Position Speed Temperature Pressure Accelerations On and off commands, etc.	From physical plant, available and measurable data as integrated into signal flow graphs, state diagrams, and block diagrams	Abstract or physical emulations of system to calculate stability and control margins, transient response, etc., for use in simulated performance testing
Spatial Location	Latitude Longitude Altitude Orientation	Geographic surveys, digital mapping, global positioning data, and coordinate system	Abstract or physical emulations for use in navigation and targeting models
Atmosphere—Ambient	Wind Turbulence Ice Fog	System specification requirements and table of measured values, meteorological statistics	Abstract or physical emulations for use in transient response calculations and simulated performance testing
Atmosphere—Aerodynamic	Temperature Pressure Density	System specifications, table of standard values for atmosphere and altitude, geodetic surveys, and climatic tables	Abstract or physical emulations such as algorithms and software for use of aerodynamic performance
Terrain Obstacles	Woods Mountains Swamps, etc.	System specifications, geodetic surveys, digital mapping, photographic maps	Abstract or physical emulations for use in simulated performance testing
Electromagnetic Field and Noise	Frequency Bandwidth Peak power Mean power, etc.	System specifications, intended operational environment, table of measured values	Abstract or physical emulations for use in design analysis and simulated performance testing
Smoke and Obscurants	Density Drift rate Type and length	System specifications, experimental results, tables of measured values	Abstract or physical emulations for use in simulated system performance

			testing

6-10 SIMULATORS

6-10.1 INTRODUCTION

A simulator is a physical model and simulation of a weapons system or piece of equipment that is not a prototype but which replicates some major aspects of the operation of the equipment. It may include elements of imbedded computer hardware and software associated with these operations or the environment immediately impacted by the equipment itself, but which is reactive only to the manipulation of the single piece of equipment. Simulators are intended to expose equipment developers, operators, and maintainers to specific aspects of system operation without the necessity of the actual system. Simulators may be used to evaluate and assess system characteristics as well as training.

6-10.2 MISSION EQUIPMENT

A mission equipment simulator is used to assess the operation and integration of the mission equipment of the air vehicle. For example, a mission simulator might include controls and displays, a target detection system, communication andavionic equipment, weapons, and navigation components. Such simulations are implemented by combining and integrating system equipment simulations with environmental simulations. As part of a qualification program, they provide the confidence that mission equipment integration issues have been properly addressed. Fig. 6-7 provides an example of a mission equipment simulator.

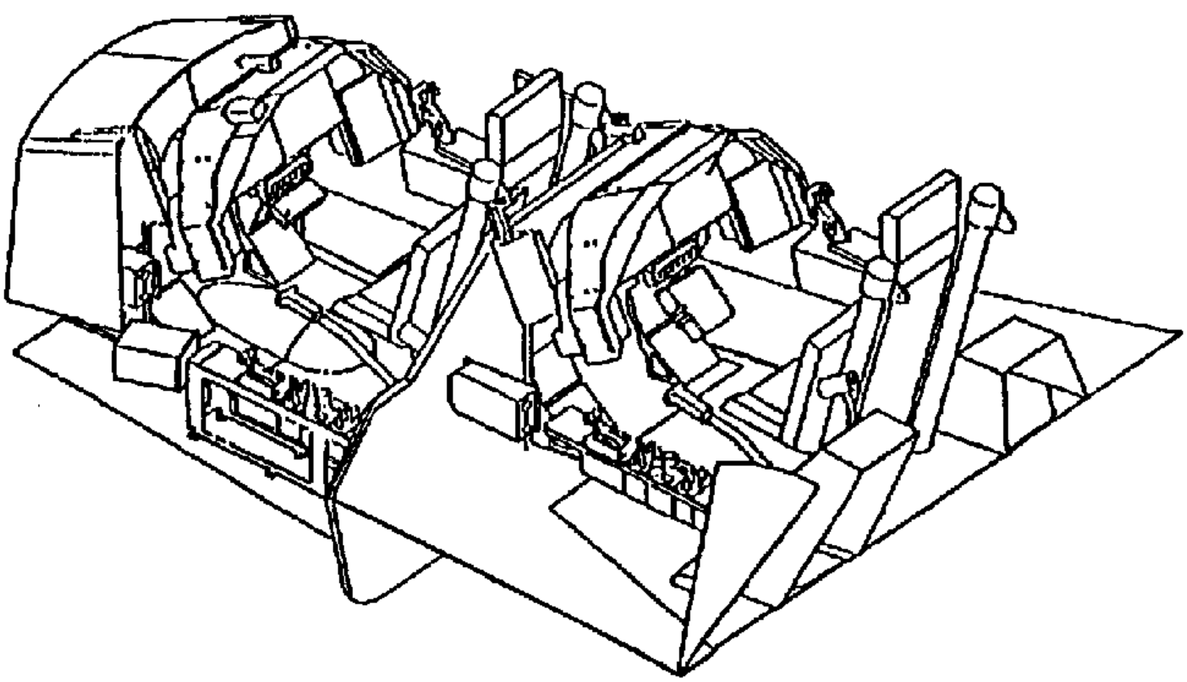


Figure 6-7. Mission Equipment Simulator

6-10.3 FLIGHT SIMULATORS

Flight simulations provide the flight crew with a moving platform and displays that react to their air vehicle control inputs in a manner similar to the actual air vehicle. The simulators incorporate system equipment simulation, environment simulation, and event simulation. Flight training simulators are used to provide procedural and flight training to pilots and therefore should replicate the total system to the maximum extent possible. Flight simulators may be used to evaluate the design of air vehicle handling qualities and system integration issues prior to building an actual airframe. It is important to understand the impact and limitations of motion and visual representations in these “fly-before-build” simulators. In addition, flight simulators may be used to evaluate flight envelope expansion impacts. In the qualification process they provide early indication of man-machine interface issues and thus provide another important element in the step-by-step buildup of confidence in the design. An example of a flight simulator is presented in Fig. 6-8.

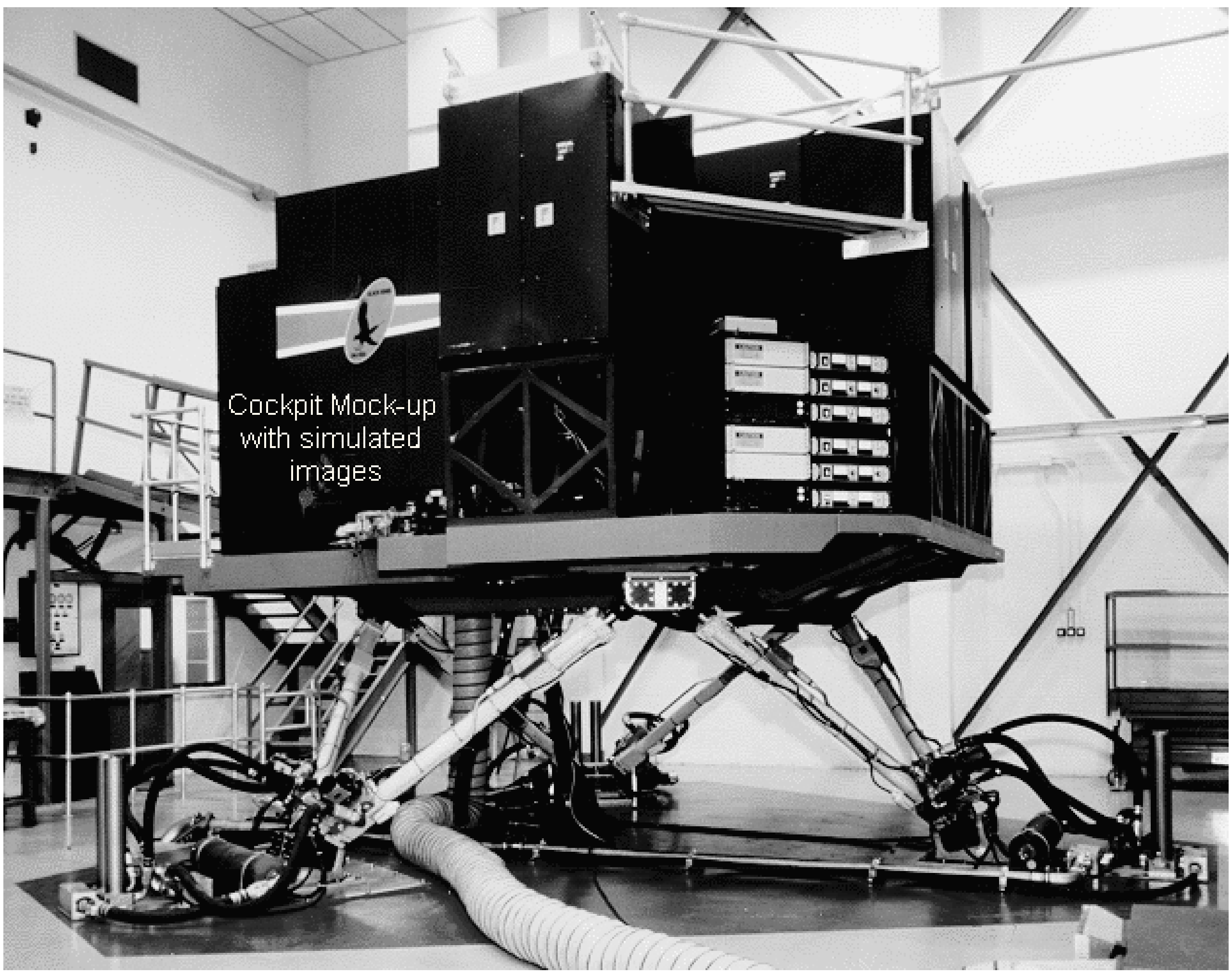


Figure 6-8. Flight Simulator

6-10.4 MISSION FLIGHT SIMULATORS

Mission flight simulators provide integration of air vehicle flight functions with mission equipment operation. As such, mission flight simulators should include accurate modeling and emulation of all subsystems in order to allow assessment of the proper achievement of mission functions, such as target engagement, in a fully simulated flight environment. Mission flight simulators should include the capability to conduct both air-to-ground and air-to-air missions. From such simulations early assessment of the impact of air vehicle handling and control characteristics on mission equipment performance, such as probability of hit or probability of kill, may be determined. Validation of a mission flight simulator is an extensive and time-consuming effort, which requires validation of all subsystem models including engine performance models, flight control law models, armament system fly-out models, etc.

6-10.5 BATTLE ENGAGEMENT SIMULATORS

Battle engagement simulators provide the added level of integration that comes from simulating the interactions of one or more friendly systems against one or more enemy systems. Such engagements might include air-to-ground, air-to-air, or ground-to-air situations. These engagements may occur simultaneously and with multiple air vehicle and ground force players. It is, therefore, important to assess the impact of parallel and sequential computations on the simulated results. Sequential computations can generally be accomplished more easily and at the least cost but may provide incorrect responses when multiple engagements are allowed. This combined arms battle may be controlled either semiautomatically or automatically by instructor personnel. Battle engagement simulators may include a network of several distributed mission simulators, as depicted in Fig. 6-9. High-level system parameters that go beyond traditional specification requirements may be assessed in this manner. These include loss exchange ratios and system exchange ratios.

Also the Defense Modeling and Simulation Office (DMSO) of the Advanced Research Projects Agency (ARPA) and the military services are in the processing of expanding the use of virtual prototypes. The battlefield distribution simulation-development (BDS-D) is an example of one development, which focuses on providing a war fighting assessment capability network using a soldier-in-the-loop virtual reality approach. See *Virtual Prototyping: Concept to Production* (Ref. 7) and *The Defense Modeling and Simulation Office (DMSO)* web site (Ref. 8).

6-11 SIMULATIONS AS SOFTWARE ENVIRONMENTS

Simulations can be used as part of the software engineering and test environments both without and in conjunction with actual system hardware. This paragraph describes simulation of the host, the host environment, the system environment, and embedded simulations. These simulations are often implemented using discrete event models.

6-11.1 HOST

The host is the processor that executes the subsystem or system software program. Often the host processor is simulated on a mainframe computer, which allows software development and system performance assessment prior to availability of the host processor hardware. The mainframe computer is programmed to simulate the planned host processor, and the simulation

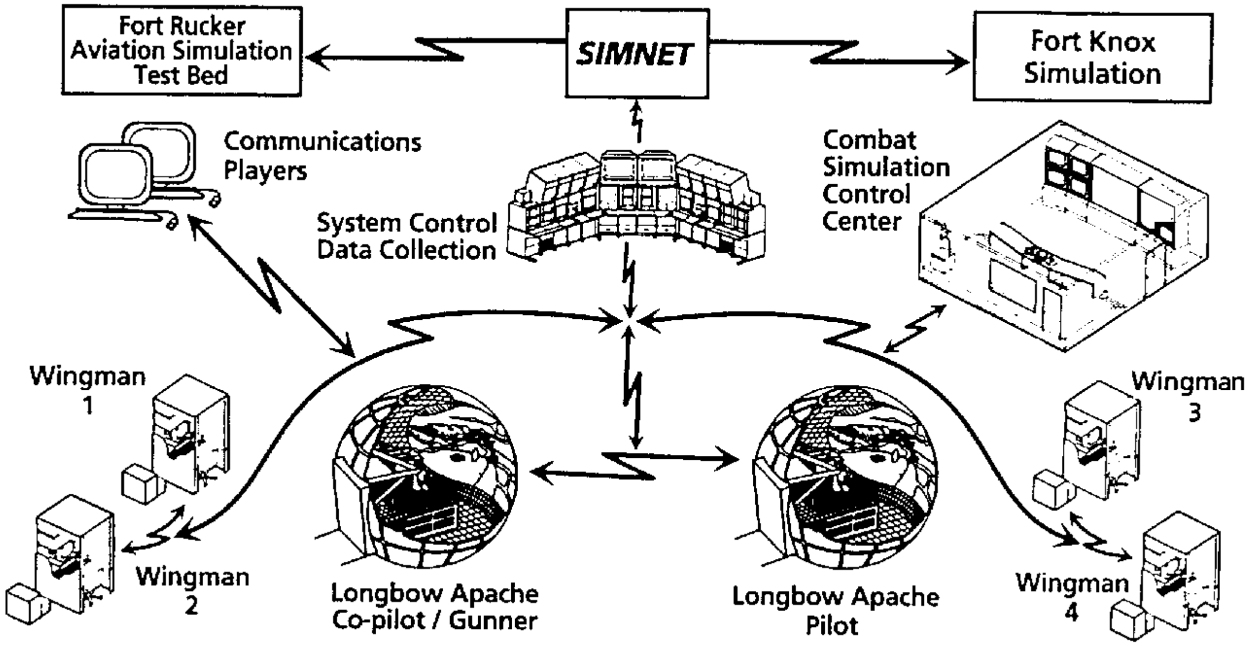


Figure 6-9. Battle Engagement Simulation

should allow assessment of throughput capacity, timing, and memory requirements. It also is useful because it provides interface compatibility with the host environment emulator. The simulation allows the user to display and modify simulation parameters, set breakpoints and control tracing, display simulation reports, perform simulation output analysis, and generate graphic displays at execution time. Queuing analysis techniques are often used in the simulation for the analysis of the host processor. The development of high-detail, large-scale simulation models can become very time-consuming to construct and maintain. When funds and schedule are limited, it may be more useful to develop small-scale models that allow high-level design decisions and would thus provide only preliminary preflight software qualification data.

6-11.2 HOST ENVIRONMENT

In addition to simulating the host processor, simulating the host environment may also be a useful development tool. The host environment includes all interface inputs and outputs, and the host environment simulation should replicate these interfaces and signal responses. These environment simulations may be used to test more than one host processor. The discussion in subpar. 6-11.1 concerning techniques, applicability, and qualification issues applies here as well.

6-11.3 SYSTEM ENVIRONMENT

System environment simulations are built from host simulations, host environment simulations, and operational environment simulations. (The intended host is the actual hardware that will ultimately execute the software in the air vehicle.) They allow assessment of the execution of software for the target architectures other than that of the host machines and thus allow testing of software design implementation. When properly implemented and validated, they can provide information that supports preflight software qualification. However, full qualification requires flight test.

6-11.4 EMBEDDED SIMULATIONS

Simulations may also be embedded in an operational system to provide unique capabilities to the operator and maintainer. Simulations that provide a training capability for exercising system functions, such as weapons firing without actually doing so, enable economical maintenance of proficiency. Embedded simulations may also include trajectory predictors, heads-up display (HUD) images, and virtual cockpit displays. With these, based on artificial intelligence or neural network techniques, a pilot's associate could provide recommendations that allow the pilot to perform rapid simulation assessments in a high-threat environment. Special care must be taken during validation and qualification of embedded simulations to ensure system performance is not degraded with the addition of training simulations. Another consideration is to provide positive indications and safety interlocks to prevent inadvertent weapons activation while in the training mode.

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LIST OF ACRONYMS

AI	=	Artificial Intelligence
APU(s)	=	Auxiliary Power Units
CAE	=	Computer-Aided Engineering
CAM	=	Computer-Aided Manufacturing
CFD	=	Computational Fluid Dynamics
FOD	=	Foreign Object Damage
HISS	=	Helicopter Icing Spray System
HUD	=	Heads Up Display
IO	=	Input-Output
PFD	=	Powered Force Models
PFM	=	Powered Force Models
TDT	=	Transonic Dynamics Tunnel
DMSC	=	Defense Modeling and Simulation Office
ARPA	=	Advanced Research Agency
BDSD	=	Battlefield Distribution Simulation Development

CHAPTER 7
COMPONENT QUALIFICATION

Component qualification requirements and procedures for specific component qualification tests are identified. Also identified are the component types that normally undergo component qualification

7-1 INTRODUCTION

The objective of component qualification is to ensure within reason that the components meet or exceed the specified performance. A component can be airworthy but not necessarily qualified. More often than not, components are not qualified prior to first flight. Early identification of operational suitability and performance deficiencies allows time for the development process to correct the deficiencies. Qualification tests should be performed on production or near production hardware. Performing component qualification at the component level may be the only practical level at which a certain performance characteristic can be demonstrated. This is particularly true for tests requiring the use of laboratory equipment that could not practically accommodate a subsystem or system. Except for flight safety parts (FSPs), component qualification facilitates parts standardization in that a qualified component may be used in other applications if it can be shown that the new application is sufficiently similar or equivalent to the application for which the part has been qualified.

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7-2 QUALIFICATION REQUIREMENTS

Component qualification requirements are based on the criticality of their application in a specific air vehicle design and on the anticipated environmental conditions to which the component will be subjected. The types of components and the types of component qualification tests that may be performed on these components are addressed in the subparagraphs that follow.

7-2.1 TYPES OF COMPONENTS

Components are usually grouped according to the general function of the components, the subsystem to which the components belong, or the functional application of the component. Table 7-1 presents typical functional-application-component-type groupingsalong with examples of components belonging to those groups. Components can be one piece or an assembly. For example, an oil pump assembly, bearing assembly, shaft assembly, gear assembly, and filter assembly are all components of a transmission assembly. A transmission assembly is a component of the transmission and drivetrain assembly.

7-2.2 TYPES OF TESTS

The types of component qualification tests to be discussed later in this chapter are functional tests, structural tests, endurance tests, and environmental tests. An introduction to these tests follows:

1. *Functional Tests*. Functional tests involve the demonstration of specified performance requirements and operational characteristics. Form, fit, and function should be validated.

2. *Structural Tests*. Structural tests demonstrate the structural integrity of a component prior to its installation in the air

TABLE 7-1. QUALIFICATION COMPONENT TYPES

COMPONENT	EXAMPLES
Structural (including dynamic components)	Rotor blades Driveshafts Castings Crew seats
Electromechanical	Generator (alternator) Fuel boost pump Oil cooler fan Rocket or missile launcher
Hydromechanical	Landing gear Oleo strut Flight control actuator Rotor brake Landing gear retraction cylinder
Mechanical	Rotor hub Transmission Overrunning clutch
Electrical	Voltage regulator Anti-icing and deicing element Generator Transformer-rectifier Circuit breaker
Avionic	Radio Intercom Mission computer Navigation equipment Control or display unit Stability or flight control system Weapons processor Armament interface unit

vehicle. Included are such items as castings that form part of the primary structure, armor components, fuel and oil tanks, and transparent areas. For critical dynamic components, determination of the service life based on fatigue loads is the basis for qualification.

3. *Endurance Tests*. Endurance tests show the life adequacy of components subject to wear and/or deterioration with use.

4. *Environmental Tests*. Environmental tests demonstrate that the equipment can be properly stored, operated, and maintained in the anticipated environmental conditions, including the electromagnetic environment.

7-2.3 COMPONENT QUALIFICATION MATRIX

The component qualification matrix provides a way to depict the components that will undergo component qualification and the specific qualification tests to which these components will be subjected. This matrix may be in two parts, one to show preinstallation qualification requirements and one to show preflight qualification requirements. Table 7-2 depicts the combinations of test types for the listed component types.

TABLE 7-2. MATRIX OF COMPONENT AND QUALIFICATION TYPES

	FUNCTIONAL QUALIFICATION TESTS*	STRUCTURAL QUALIFICATION TESTS	ENDURANCE AND SCREENING	ENVIRONMENTAL QUALIFICATION
Structural	1	1	2	
Electromechanical	1	1	2	2
Hydromechanical	1	1	2	
Mechanical	2	1	2	
Electrical	1		2	2
Avionic	2		2	2

*1 = preinstallation requirement
2 = preflight requirement

7-3 QUALIFICATION PROCEDURES

This paragraph describes the general procedures used for component qualification by discussing test specimens, test plans, test reports, qualification by similarity, and the special procedures applicable to flight safety parts.

7-3.1 TEST SPECIMENS

Each component to be tested should be of the production design and should meet design and acceptance criteria. The number of qualification specimens required is determined by the procuring activity (PA) based on the test or tests to be performed. For example, fatigue tests may require more test specimens than an environmental qualification. Use of a component in the qualification test that is not identical to the proposed production design should be approved by the PA.

In some cases preproduction tests will be required. The component configuration should be recorded, including all deviations from the proposed production configuration, in terms of material, process, or dimensions. If it is acceptable to the PA, significant changes may be incorporated into component design during the qualification test program as deficiencies are discovered. In these cases the component configuration used for each of the test specimens in each portion of the qualification test should be recorded. Once a final configuration is obtained, a rerun of some of the tests may be required by the PA. This is discussed further in par. 7-13.

If it is necessary to remove or replace any hardware on the test specimens during any of the tests, the reason for removal should be recorded with an accurate determination of the type of testing the replaced item has undergone. If the item replaced was a normal maintenance or overhaul item that was not expected to last the life of the test component, the qualification should proceed as planned. On the other hand, if the item replaced was one that normally should not fail in service, the design of the item should be reviewed and analysis made to determine whether redesign and retesting are necessary. Whenretesting is necessary to qualify a redesigned item, the amount of testing is dependent on the reasons of the original failure. If a complete retest is to be conducted using the same basic test component upon which the failure occurred, the chances for failure of some other item in the component undergoing qualification testing are increased, and this fact will be considered if other component part failures are encountered. Throughout development it is important to monitor component configuration and assess the impact of configuration changes on previously conducted qualification tests. If the changes are significant, it may be necessary to repeat certain portions of the qualification. In other instances it may be more practical to assess the impact of the changes during the course of subsystem- or system-level tests.

Validated models may be used as qualification specimens when it can be shown that they provide suitable representation of the actual component. An example of a potential application of a validated model is to replace expensive electronic equipment with ballast if the test requires only a correct weight and center of gravity for those items.

7-3.2 TEST PLANS

Test plans are prepared and submitted in accordance with the contract data requirements list (CDRL) for the components requiring qualification testing. These plans should state specifically the component design parameters to be monitored during the test, the number of specimens to be tested, the test to be conducted on each specimen, the duration and severity of each test, the procedure used to accomplish each test, and a test setup description and identification of the success or failure criteria should be included as appropriate. When environmental tests are a part of the qualification procedure, a functional test should be performed before, during, and after the environmental test to determine whether there has been any significant degradation in performance.

7-3.3 QUALIFICATION REPORTS

Qualification reports, submitted in accordance with the requirements of the CDRL, describe the procedures used to conduct component qualification and the conclusions of the component qualification. The reports are prepared for both qualification tests and qualification analyses. They describe the component and its application, its performance requirements, and the basis for the determination that the component has been successfully qualified. Qualification report formats are generally specified in a data item description (DID).

7-3.4 QUALIFICATION BY SIMILARITY

In some cases it is possible to use components in an air vehicle system that have been used on a previously qualified air vehicle. These systems or components may be used in their off-the-shelf configuration or with some minor modifications to make them compatible with the new model.

If an off-the-shelf product is used on the new air vehicle and the design requirements are the same as or less severe than the previous installation, the component is considered qualified, and no new tests are necessary. If the design requirements and/or operating conditions are more severe, requalification of the component is required. When required, requalification should address only those tests necessary to show that the component will perform adequately under the new requirements. Similarity alone cannot be used to qualify flight safety parts.

Category I similarity consists of those components used in a new design that are identical to components used in a previous design and have identical operational and environmental requirements. Category II similarity refers to components in a new design that have minor modifications to components used in previous designs and/or have similar operational and environmental requirements. Category III similarity applies to components that have been used in similar design applications by other contractors.

The method of qualification proposed by the contractor is subject to the approval of the procuring activity.

7-3.5 SPECIAL PROCEDURES FOR FLIGHT SAFETY PARTS

It is the policy of the US Army to acquire high-quality, proven, reliable, and safe flight safety parts. Flight safety parts that require engineering testing (fatigue, endurance, interchangeability, etc.) are procured only from sources whose part has met the engineering test requirements. In addition, a flight safety part must undergo an acceptable inspection, as indicated in Chapter 3. The processes used to identify and qualify FSPs are also described in Chapter 3. All inspection records should identify the specific FSPs and critical characteristics inspected and record the results of measurements and/or inspections, the date of inspection, the identity of the inspector, and the required inspection certification. When FSPs are required to be serialized, all operations and inspections affecting a critical characteristic should be traceable to the serialized item.

7-4 PARTS CONTROL PROGRAM

A parts control program(PCP) provides a means to reduce the proliferation of parts within the Department of Defense (DoD) by ensuring a new part is not designed if one already exists in the inventory that will meet the requirements. MIL-HDBK-402, *Guidelines for the Implementation of the DoD Parts Control Program*, (Ref. 1) provides assistance for implementation of a parts control program and contains the information considered necessary to tailor or streamline effectively the PCP requirements to suit specific acquisitions.

One of the advantages of using parts from a Qualified Products List (QPL) is that the testing for that part or component has already been performed; thus that cost need not be incurred again. However, it is necessary to determine the qualification level of the standard part and assess the degree to which the previously performed qualification testing satisfies the new requirements for the part. Partial requalification may be required to ensure that the part is fully compatible with the new application.

7-5 FUNCTIONAL QUALIFICATION TESTS

Functional qualification tests are discussed in this paragraph. Table 7-3 shows examples of functional tests and specifications for various component types.

TABLE 7-3. FUNCTIONAL QUALIFICATION TESTS

COMPONENT	FUNCTIONAL QUALIFICATION TEST	EXAMPLE* SPECIFICATION OR STANDARD
Fuel Pump	Flow rates, pressures	MIL-F-8615
Hydraulic Tubing	Strength, fittings	MIL-H-8775
Pneumatic Valves	Proper actuation at specified pressures	MIL-V-38398
Electrical Connectors	Insulation resistance, contact resistance and retention, EMI shielding, etc.	MIL-STD-1344

*Commercial standards and specifications suitable for the intended purpose should be used in lieu of the military standards and specifications. Otherwise, a waiver is required from the Milestone Decision Authority.

7-5.1 PURPOSE

The purpose of a functional qualification test is to demonstrate that the component complies with specification performance requirements. Functional qualification tests are performed to permit measurement of component performance parameters. The tests are conducted and documented so that each performance parameter or combination of parameters, as required, is exercised to its maximum capability.

7-5.2 DETAILED REQUIREMENTS

Detailed functional qualification test requirements are stated in the general specifications for the type of component being considered or are defined by the contractor based on subsystem specification requirements. Functional testing should be conducted under conditions that duplicate service conditions as closely as possible

7-6 STRUCTURAL QUALIFICATION TESTS

Structural integrity qualification requirements, static and fatigue loading requirements, special requirements of composite material structural testing, and crash resistance requirements are discussed in the subparagraphs that follow.

7-6.1 STRUCTURAL INTEGRITY PROGRAM

The contractor should be required to describe the program used to ensure that structural integrity receives attention from concept definition through design, testing, and operation of rotorcraft systems. . approach to achieving structural integrity throughout the life cycle is the Helicopter Structural Integrity Program (HSIP). The elements of the *Helicopter Structural Integrity Program (HSIP), Vol. I, Structural Test Requirements Specification*, (Ref. 2) are structural design criteria (which include materials and processes), analysis and test of design (fatigue integrity), structural integrity verification, and operational data acquisition and data management requirements (structural integrity maintenance) for rotorcraft. MIL-STD-1530, *Aircraft Structural Integrity Program, Airplane Requirements*, (Ref. 3) describes an equivalent structural integrity program for Air Force systems (called Aircraft Structural Program (ASIP)), with the addition of sonic effects.

Most contractors have a similar, although not identical, program to achieve structural integrity throughout the life cycle. Also the contractor should be encouraged to establish the philosophy for structural design of each load component as either a “fail-safe” or “safe-life” component. Neither the Army nor any contractors for the Army have ever qualified a component, subsystem, or system using the “total-life” concept. For additional information, see *Foundations of an Army Helicopter Structural Integrity Program* (Ref. 4). For additional information concerning composite materials, see subpar. 7-6.4 and ADS-35, *Composite Materials for Helicopters* (Ref. 5).

7-6.1.1 Structural Design

Detailed structural design criteria for the specific rotorcraft and components should be established by the contractor in accordance with the requirements of the specification. The specification typically contains design criteria for strength, damage tolerance, durability, flutter, vibration, weapons effects, etc. The contractor should convert these detail design criteria into actual limit load conditions. For additional information, see ADS-29, *Structural Design Criteria for Rotary Wing Aircraft* (Ref. 6) and MIL-STD-1530 (Ref. 3). Normally, the loads are related to structural design gross weight (SDGW) or maximum alternate gross weight (MAGW). These terms are defined in Ref. 4. Definitions of structural failure for metallic and nonmetallic components for both limit load and ultimate load tests are in HSIP, Vol. I. Material strengths should be based on MIL-HDBK-5, *Metallic Materials and Elements for Aerospace Vehicle Structures*, (Ref. 7) MIL-HDBK-17, *Plastic for Aerospace Vehicles, Part 1, Reinforced Plastics*, (Ref. 8) or other sources approved in advance by the PA. Typical other sources include coupon tests of composite materials for which no strength data are available.

Damage tolerance is defined by HSIP, Vol. I, (Ref. 2) and MIL-STD-1530 (Ref. 3) as the ability of a structure to resist failure due to the presence of flaws, cracks, or other damage for a specified period of unrepaired usage. Damage tolerance is typically achieved by means of redundant load paths, low stress levels, good fatigue characteristics, and slow crack propagation rates. Additional information on damage tolerance is included in *The Fundamentals of Aircraft Combat Survivability and Design* (Ref. 9).

Durability of the rotorcraft structure is defined by HSIP, Vol. I, as the ability of a structure to resist cracking (including stress corrosion and hydrogen-induced cracking), corrosion, thermal degradation, delamination, wear, and the effects of foreign object damage for a specified period of time.

The rotorcraft system specification and structural design criteria should address prevention of static and dynamic aeroelastic instabilities. However, static and dynamic aeroelastic instabilities cannot be addressed at the component level.

Detail structural criteria should include as a performance requirement that component natural frequencies w_n (as installed) should not be coincident with the forcing frequencies w_f of the rotorcraft. Analyses should show that structural components have been designed so that natural frequencies w_n are not coincident with forcing frequencies w_f (Ref. 10). Generally, a 10 percent frequency margin is required. As a minimum, flutter analyses for all lifting surfaces should be performed by the contractor to verify these tolerances, and stability testing should also be performed as required.

The contractor should analyze the effects of vibration on structural integrity. Vibration transmitted to the structure from the rotor systems should be treated as a superimposed load since Ref. 10 cites these vibrations as the cause of many structural cracks. Preliminary analyses are used later to compare with actual rotorcraft vibration to validate those analyses and update them as necessary.

Weapons effects as the result of operation of armament and blast loads should also be considered superimposed loads. These effects should be considered for loads imposed on the ground and in flight when weapons effects excitations could impact aeroelastic stability margins.

7-6.1.2 Fatigue Integrity

Detailed fatigue integrity criteria and procedures should be established by the contractor based on predicted component loadings. Typical methods of prediction may involve cumulative fatigue damage by Palmgren-Miner cycle-ratio summation theory or Manson's method, (Ref. 11) or other methods proposed by the contractor and approved by the procuring activity. Regardless of the methods used, the contractor should clearly quantify all assumptions used in fatigue life predictions and should submit the fatigue testing plans, procedures, and reports to the procuring activity for approval. These plans and procedures should include provisions for requalification of modified components.

The contractor should continuously monitor the status of fatigue-critical components to ensure that structural integrity is maintained. Ideally, this process should continue from design through the service life of all air vehicles until disposal. As a minimum, this continuous monitoring should take the form of failure analyses of defective fatigue critical components, comparison of assumed and actual flight spectrum loads, and updates to fatigue life predictions required by changes in service use (Ref. 10). Changes in service use are common for rotorcraft since military tactics, operational tempos, and missions may change drastically from development to operation of the systems.

This element of HSIP is similar to structural integrity maintenance with the exception of inspection intervals and procedures and individual rotorcraft tracking. The development of these topics is described in subpar. 7-6.1.4.

7-6.1.3 Structural Integrity Verification

The contractor should ensure that structural integrity of the rotorcraft is verified through tests and analyses prior to first flight and continuously throughout development. Component qualification tests and analyses include but are not limited to determining dynamic frequencies and modes, static strength, fatigue life, and damage tolerance. As mentioned previously, tests and/or analyses should be repeated for components modified as a result of unsuccessful testing.

Typically, first-flight structural integrity requirements include but are not limited to a static test to limit load for critical airframe components, landing gear drop test, ground modal survey and ground resonance shake tests, stress analyses, and a preliminary strength summary and operating restrictions report. As the development flight tests continue, actual flight load spectrum information may require revision of analyses and restrictions.

Following entry into service, additional flight load surveys may be performed as missions and tactics change. This situation is discussed in the following subparagraph.

7-6.1.4 Structural Integrity Maintenance

The contractor should define the means to ensure that the structural integrity of the rotorcraft can be maintained during its intended useful life. The methods used to accomplish this should include individual rotorcraft tracking, updates to flight loads, and failure analyses. Individual rotorcraft tracking can provide information useful to the prediction of structural flaws, determination of inspection intervals, and economic repair criteria. This tracking requires a data collection program that monitors rotorcraft individually throughout their lives. These data management systems should allow the procuring activity to identify flight safety parts (defined and explained in subpar. 3-13), and support surveillance testing of those parts, schedule overhauls, and manage the fleet; the data provided to the contractor should allow a designer to verify and substantiate the design (See Ref. 5.). As a minimum, the history of FSP should be tracked by their serial number. Tracking for each serially numbered component should involve the following information as a minimum:

1. Process, specifications, and materials used
2. Manufacturing inspection procedures
3. Service history
4. Failure data
5. Disposition information.

Additionally, fatigue lives, retirement lives, frequency of inspection, and inspection procedures may need revision once actual flight spectrum loads are identified and/or military tactics, operational tempos, and rotorcraft missions change. The contractor should identify to the procuring activity the significant changes in tactics, operational tempos, and rotorcraft missions that necessitate additional structural analyses and/or flight load surveys.

Failure and damage reports, such as Quality Deficiency Reports (QDRs), should be used to refine inspection intervals and procedures. To ensure that maintenance procedures are maintaining the required level of safety, the contractor should also maintain an active failure analysis and investigation program subject to approval by the procuring activity. This analysis and investigation program should allow the contractor to determine

1. The probable location of fatigue cracks
2. The rate of growth of fatigue cracks (rate of crack propagation *da*/*dN*)
3. The length of the crack at which the residual strength is no longer greater than expected loads (Ref. 12).

These data can be used to revise inspection procedures and intervals as needed.

7-6.2 STATIC LOADING

Static load testing should be performed to determine the load-carrying capacity of a structural member in a static condition. Static tests may be conducted to limit loads, ultimate loads, or failing loads. Limit load is the load or load factor that establishes a strength level for design of the rotorcraft; ultimate load is the limit load multiplied by the specified ultimate factor of safety, and failing load is the load at which failure of the structure occurs. A failing load test is advantageous when the location, type, or other details of failure or knowledge of the growth potential of the component is desired. Because a test to limit load is inherent in the other loading conditions, it is usually not specified for qualification unless it is important that the test specimen not be destroyed or unless a check for yielding is all that is desired. The static test of many components is conducted in conjunction with the static test of the airframe.

The main and tail rotor blades are tested for flapwise buckling or bending. Spar, nose cap, trailing edge, and box section components should be tested individually so that the strength properties and methods of failure can be determined.

Although fatigue is a critical aspect for rotor system dynamic components, static load tests furnish useful information on strength properties and load distribution. Examples of dynamic components that would undergo static loading tests are pitch links and arms, swash plates, drive links, fixed links, rotor hubs, masts, and pitch housings.

The basic test for flight control components is the proof load and operation test, which demonstrates that the systems will not deflect excessively, bind, or otherwise interfere with each other, with other components, or with the airframe while operated throughout the full range of travel and under design limit loads. The test also applies to the hydromechanical portions of the fly-by-wire systems. Both the pilot's and copilot's controls should be loaded and applied loads reacted at the blades and control surfaces. The controls should be cycled through their full range of travel with the limit loads applied, and the number of times cycled should be kept to a minimum because of the danger of low-cycle fatigue.

Rotor and control actuating cylinders should be subjected to proof pressure tests for leaks, loosening of components, and permanent deformation. In addition, limit and ultimate column loads, tension loads, and compression loads should be applied to the actuating cylinder at the output and inlet ports. Column load tests are accomplished with the cylinders in the most critical position. The actuators should be inspected for static and dynamic leakage after the limit load test.

Static testing of the transmission and gearbox housing should include ultimate load for critical nonflight (e.g., crash) conditions and failing load for the critical flight condition.

Class 1A castings, i.e., castings in which a single failure would cause loss of the rotorcraft, should be static tested to failure for critical loading conditions for which a casting factor of safety less than 1.33 is shown. Due to the unreliability of castings and the inherent scatter of casting test results, three casting specimens should be tested (usually the least acceptable ones), and a minimum casting factor of safety of 1.25 should be demonstrated at the ultimate load.

The performance requirements for crashworthy components (which include fluid system components) should be validated by statically and dynamically using the test methods of MIL-STD-1290, *Light Fixed and Rotary Wing Aircraft Crash Resistance*, (Ref. 13).

ADS-24, *Structural Demonstration*, (Ref. 14) provides useful information concerning demonstrating the structural performance requirements of the rotorcraft. The primary objective of the structural demonstration is to demonstrate the safe operation of the rotorcraft to the maximum attainable operating limits consistent with the structural design, i.e., a static test in the air. The demonstration is conducted after sufficient checkout and buildup flying has been conducted to give reasonable assurance of test completion.

ADS-29 provides useful information about establishing structural design criteria in terms of providing general design requirements, flight load conditions, ground loading conditions, and control system loads. The design criteria include maneuver conditions and flight procedures that may be used during the structural demonstration as part of the qualification process.

7-6.3 FATIGUE LOADING

A large number of rotorcraft components are fatigue critical. This means that their structural adequacy is based on a stated service life when subjected to repeating cycles of alternating load rather than on a positive margin of safety under critical static loads. Qualification of a fatigue-critical component requires determination of its service life, either finite or infinite, or demonstration of adequate fail-safe characteristics.

Fatigue testing should be performed on all critical, primary, structural, load-carrying components. The required testing should be sufficient to provide data adequate for service life determination or to demonstrate acceptable characteristics. Components to be tested include these:

1. *Main Rotor System*. In the main rotor system the components are obtained from the critical areas, the number of which is dependent on the rotor configuration. Critical-area components include the hub-to-mast attachment, actuators,swash plates, hub-to-blade root attachment, centrifugal tension-torsion strap, and a basic blade section. Additional areas of testing in the main rotor blade may be required due to concentrated mass areas, such as tip weights or antinode weights, which provide rapid change in section properties with resultant local stress concentrations. Each area of the

main rotor system should be considered thoroughly in the design stages and analyzed and identified to ensure the critical areas are included in the test program.

2. *Antitorque Rotor System.* This system is similar to the main rotor system, and the components selected for fatigue testing should be based on the identified critical areas. Fatigue testing should be conducted on the hub, blade root end, tension-torsion reaction system, and basic blade section.

3. *Main Rotor Control System.* Fatigue testing of the control system components forward of the boost system (if installed) usually is not required because such a system isolates the oscillatory loads that originate in the rotor system. Fatigue testing should be performed on all components from the boosters up to and including the pitch control arm. In the absence of a control boost system, all control system components subject to critical fatigue loading should be fatigue tested.

4. *Antitorque Rotor Control System.* This system is similar to the main rotor control system; fatigue testing should be performed on all components from the booster system to the pitch control arm or on all components subject to critical fatigue loading.

5. *Power Drive Systems.* Fatigue testing of the power train system components should be accomplished and should include the main rotor mast, transmission input shaft, antitorque rotor driveshaft, miscellaneous power takeoff shafts, and gear flanges.

6. *Transmission, Gearbox, and Associated Components.* Fatigue testing of the basic gearbox case, other critical gearbox housings, and their local supporting structure should be accomplished. Also qualification testing of gears, shafts, etc., typically includes but is not limited to fatigue testing at 125% of the normal rated torque while installed in the gearbox assembly. Usually, 10 million cycles at overload torque are accomplished.

7. *Engine Mount.* Any portions of the engine mounting system, including airframe-mounted attachments determined to be fatigue critical during the flight load survey, should be fatigue tested.

8. *Other Components.* Fatigue tests should be conducted on any other structural component for which fatigue loads are found to be critical. Attachments and mountings, such as those for horizontal and vertical stabilizers, landing gear, and armament, should be investigated during the flight load survey to determine the need for additional fatigue tests. Particular attention must be given to analytically identifying the mountings located in the antinode vicinity of the fundamental fuselage modes. Location of such mountings should then be confirmed by vibration test.

The laboratory fatigue test of rotorcraft components can be accomplished in various ways. The methods used most often are spectrum and S-N testing, i.e., testing that results in curves of stress versus number of cycles to failure. In spectrum fatigue testing, in-flight load conditions are reproduced as closely as possible. The relative magnitude and distribution of test loads should be based on measured flight loads. Because the flight load survey may not be completed when the fatigue test program is initiated, the first tests may be started with loading conditions based on computed loads or the flight loads measured on prototype hardware.

The test parts should be instrumented with strain gage locations identical to those used in flight test. Strain gages are not required if the test loads applied to the components can be verified with acceptable accuracy by other means. Oscillatory loads should be applied to each specimen in increments of the measured flight loads; the load distribution should be representative of all flight conditions. In some cases it may be necessary to superimpose gust loads on the fatigue loading spectrum.

The preferred method of fatigue testing is the S-N technique because service lives can be determined from S-N data for any load condition. Variables that significantly influence the test results, such as number of specimens, methods of applying loads, and data scatter limits, should be approved by the procuring activity.

Because spectrum testing involves reproducing in the laboratory load amplitude and frequency distributions directly proportional to those encountered in flight, it may be considered a more exact basis for the initial determination of service life. However, it is not possible to determine whether alteration of mission profiles or the frequency of alternate missions, or any other change in the air vehicle flight spectrum has an effect on the component service life without retesting in the altered spectrum. Therefore, spectrum testing, should be used only when specifically approved by the procuring activity.

Fatigue test specimens should be of production configuration and quality. The number of specimens to be tested should be proposed by the contractor and approved by the procuring activity.

Comparison of available fatigue test data with the effect of loading frequency on metallic materials indicates that tests conducted within a frequency range factor of 10 gives similar results. Test load frequency of application, therefore, should be kept within a factor of 10 of the normal operating frequency of application.

For the main rotor normal operating frequency (one per rev) is dependent on the rotor rotational speed and usually ranges from 4 to 8 Hz. The tail rotor frequency (also one per rev) usually is in the range of 15 to 30 Hz.

Each fatigue test setup has unique features based on the design of the air vehicle. For example, rotor system components may be subjected to four loads simultaneously: centrifugal force, flapwise bending, chordwise bending, and torsion. Loadings should be verified by analysis and by use of strain gages installed on the component, as appropriate. Force and moment distributions should be verified during testing and compared with design and flight distributions.

Most critical areas are located at joints or transitions. Strain gages, however, should be located in relatively uniform sections. Installations adjacent to joints and/or rapid transitions should be avoided because these local stress concentrations will influence the strain gage output and result in improper readout.

Use of stress analysis techniques such as stress coat, photo stress, and plastic models should be encouraged. These techniques are not used for detailed analysis but to determine rapidly the critical areas and approximate strain magnitudes. These critical areas can then be checked with appropriately located strain gages.

ADS-24 (Ref. 14) provides information useful to determining the structural demonstration criteria, and ADS-29 (Ref. 6) provides information useful to determining structural performance criteria for rotorcraft. The data obtained during this demonstration are used to verify that loads used in the structural analysis and static tests are not exceeded during flight and to substantiate fatigue life calculations.

7-6.4 COMPOSITE STRUCTURES

Structural testing of composite components is essentially the same as for metallic structures, except environmental factors and filament direction are of greater significance. Also, for each composite material to be used, the contractor should be required to determine the designallowables necessary to support the design and performance requirements of the contract. The contractor should be required to submit the properties data along with a summary of qualification test procedures, number of specimens, etc. If these properties are not known, the contractor should perform tests to determine the physical, mechanical, chemical, thermal, and electrical properties. Susceptibility to nuclear, biological, and chemical (NBC) agents and decontaminates should be part of chemical properties testing. ADS-35 (Ref. 5) provides additional information relevant to qualification testing of composite materials. Also see par. 7-14 through subpar. 7-14.4.

In fatigue testing of composite structures special care should be taken to select load application frequencies for laminated and bonded structures that ensure there is no excessive buildup of temperature leading to premature bond line failures.

7-6.5 CRASH RESISTANCE

Crash resistance tests are performed to demonstrate that systems are designed to prevent occupant fatalities and to minimize the number and severity of injuries during crash impacts. The procuring activity should define the performance and validation requirements for crashworthiness. MIL-STD-1290 (Ref. 13) provides relevant information. These criteria are usually specified for military rotorcraft but not for Federal-Aviation-Administration (FAA) -certified air vehicle. Crashworthiness of the systems that follow is validated by test:

1. Fluid fuel systems
2. Crew seats
3. Troop and passenger seats
4. Litter supports
5. Landing gears
6. Flammability tests of selected airframe and interior materials.

Tests and test methods include such items as static and dynamic tests on frangible devices, instrumented drop tests on landing gears to verify attenuation and loading strength characteristics, and rotorcraft system testing to verify analysis and substantiate system capability to prevent fatalities and minimize injuries.

7-7 FAA STRUCTURAL QUALIFICATION

This paragraph addresses the Federal Aviation Administration requirements for component structural testing and design of air vehicles. The agents of the FAA certify only that requirements have been satisfied.

7-7.1 STRUCTURE

The airworthiness standards of the FAA for aircraft, which are Parts 23 and 25 of Title 14 of the Code of Federal Regulations, (Refs. 15 and 16) establish strength requirements in terms of limit load (the maximum loads to be expected in service) and ultimate loads (limit loads multiplied by a prescribed factor of safety). These regulations require that compliance with the strength requirements be shown for each critical load condition. Structural analysis may be used only if the structure conforms to those for which experience has shown this method to be reliable. In other cases, substantiating load tests must be performed. Dynamic tests, including structural flight tests, are acceptable if the design load conditions have been simulated.

7-7.2 DESIGN AND CONSTRUCTION

Federal Aviation Administration airworthiness standards for design and construction of several categories of aircraft are included in Parts 23 and 25 of Title 14, Code of Federal Regulations (Refs. 15 and 16). These standards provide proof of strength requirements for various components. For wings, proof of strength must be accomplished by load tests or by combined structural analysis and load tests. For control surfaces, limit load tests are required. These tests must include the horn or fitting to which the control system is attached. For control systems, compliance with limit load requirements must be shown by tests in which

1. The direction of the test loads produces the most severe loading in the control system.
2. Each fitting, pulley, and bracket used in attaching the system to the main structure is included.

Compliance must be shown by analyses or individual load tests with the special factor requirements for control system joints subject to angular motion. For the landing gear, it must be shown that the limit load factors selected for design for takeoff and landing weights, respectively, will not be exceeded. Compliance must be shown by energy-absorption tests except that analysis based on tests conducted on a landing gear system with identical energy absorption characteristics may be used for increases in previously approved takeoff and landing weights. The landing gear may not fail but may yield in a test showing its reserved energy-absorption capacity simulating a descent velocity of 1.2 times the limit descent velocity if wing lift is equal to the weight of the air vehicle.

7-8 ENDURANCE AND SCREENING QUALIFICATION TESTS

Endurance tests and screening tests are discussed in the subparagraphs that follow.

7-8.1 ENDURANCE TESTING

Endurance tests are performed to demonstrate that wear resulting from normal use will not result in unacceptable performance degradation during a reasonable period of air vehicle operation. For this reason, formal qualification of the components of a new design is not begun until extensive prequalification tests have been completed satisfactorily.

Prequalification tests include investigation of abnormal operating conditions: overspeed, overtorque, oil out, and overpressure. Failure or excessive wear of shafts, bearings, seals, gears, impellers, armatures, and similar items during these tests is cause for design improvements and further testing. Prequalification testing of gearbox assemblies usually includes but is not limited to 200 hours of overstress testing at 125% of normal rated torque, during which time transient limits, overspeed, high temperature, and single-engine capabilities are typically demonstrated. See subpar. 7-6.3 for fatigue testing of gearboxes and related components.

Endurance testing for purposes of qualification usually includes 200 hours of operation while applying a loading profile representing a typical mission. This cycling is repeated throughout the course of the endurance test. Although it provides a good indication of component endurance characteristics, this test may not be able to duplicate adequately the types of interface problems that often cause failures at the system level. Therefore, special care should be used to evaluate such things as structural loads and deflections at critical interfaces.

7-8.2 SCREENING TESTS

Environmental stress screening (ESS) is conducted in order to precipitate and expose latent defects that may have been introduced in the manufacturing and assembly process. These tests are usually conducted on electrical and electronic parts, assemblies, and components in environmental chambers. The test items are subjected to temperature cycling and random vibration cycling. Specific test levels are established in order to provide the most effective screens within the design limits of the test item. The rationale for inducing failures is that if a failure of an item is impending, it is far less costly to uncover the failure in the laboratory environment at the part or component level than to incur a failure with the faulty component after installation in a higher level assembly or after fielding of the system. Because ESS is performed at environmental stress levels higher than those normally encountered, it is important that these stress levels be judiciously selected based on experience with similar components. Too low a level may not produce the desired screening level, whereas too high a level may cause adequately manufactured and assembled hardware to fail.

7-9 GENERAL PHYSICAL ENVIRONMENTS

Environmental qualification testing at the component level is discussed in the subparagraphs that follow. Environmental tests are usually performed in test chambers that expose the test item to a simulated environment singly or to a number of environments simultaneously. Table 7-4 presents the environments normally used for environmental testing and provides a brief purpose of each test. MIL-STD-810, *Environmental Test Methods and Engineering Guidelines*, (Ref. 17) provides a description of specific environmental test requirements and procedures. Specific test criteria contained in the standard may be cited as needed to validate performance. However, the contractor should not be required to comply with this standard in its entirety.

7-9.1 VIBRATION

Vibration testing is performed to identify the structural dynamic properties and to determine the resistance of a component to vibrational stresses expected in its shipment and operational environments. Vibrations can cause wire chaffing, loosening of fasteners, intermittent electrical contacts, touching and shorting of electrical parts, seal deformation, component fatigue, optical misalignment, cracking and rupturing, loosening of particles or parts that may become lodged in circuits or mechanisms, and excessive electrical noise. Vibration testing consists of mounting the test item to equipment that produces the required vibrational environment, exposing the item to a predetermined test level and duration and of operating the item as if it were in operational usage and verifying the ability of the item to function both during and after the test. This procedure is repeated for each of three orthogonal axes.

ADS-27, *Requirements for Rotorcraft Vibration Specifications, Modeling, and Testing*, (Ref. 18) and MIL-STD-810 (Ref. 17) provide methods for specifying, analyzing, and measuring air vehicle vibration environments. Applicable criteria can be used in a solicitation. Also the contractor could be required to propose a test that both duplicates the operational environment and demonstrates satisfactory performance of the component before and

TABLE 7-4. QUALIFICATION ENVIRONMENTS

ENVIRONMENT	PURPOSE
Temperature High temperature Low temperature Temperature shock	Determine the ability of the component to be operated and stored under hot and cold temperature conditions.
Acceleration	Assure that equipment can structurally withstand the expected forces due to acceleration without degradation during and following exposure.
Shock	Determine the ability of the component to withstand the infrequent, nonrepetitive shock of handling, transportation, and service.
Sand and Dust	Determine the ability of the component to be operated and stored in blowing sand and dust.
Gunfire	Determine the ability of the component to withstand and operate under gunfire vibration conditions.
Rain	Determine the effectiveness of protective covers or cases, the ability to perform in the rain. Determine equipment damage or performance degradation caused by the rain.
Humidity	Determine the resistance of the component to a warm, humid atmosphere.
Salt Fog	Determine the resistance of the component to an aqueous salt atmosphere.
Fungus	Assess the extent to which the component will support fungal growth or how fungal growth affects performance.
Icing and Freezing Rain	Demonstrate the ability of the component to operate properly in freezing rain, mist, or sea spray.
Low Pressure (Altitude)	Determine whether components can withstand and operate in a low-pressure environment, such as storage at high altitude, air shipment, and rapid decompression.
Solar Radiation (Sunshine)	Determine the effects of solar radiation on equipment, such as component expansion and contraction, and changes in strength and elasticity.
Vibration	Determine the ability of the component to function within the steady vibration environment to which it will be subjected during its operational life.
Explosive Atmosphere	Demonstrate the ability of equipment to operate in a flammable atmosphere without causing an explosion or to contain such a reaction.
Leakage (Immersion)	Determine whether an item designed to be watertight can be immersed without leaking into its container; determine other possible effects of immersion in water.
Temperature, Humidity, Vibration, and Altitude	Identify the failures that temperature, humidity, vibration, and altitude in combination can induce in electronic equipment.

after exposure. The test duration, amplitude, or both parameters (coincident) could be modified to accommodate reasonable test duration, but actual operational environment and component life must correlate.

7-9.2 TEMPERATURE

The purpose of high-temperature chamber tests is to determine whether components can be stored and operated under hot climatic conditions without experiencing physical damage or performance deterioration.

The purpose of low-temperature tests is to determine whether components can be stored, manipulated, and operated under low-temperature conditions without experiencing physical damage or performance deterioration.

Temperature shock tests are performed to determine whether materiel can withstand sudden changes in the temperature of the surrounding atmosphere without experiencing physical damage or performance deterioration.

High temperatures may temporarily or permanently impair the performance of components by changing the physical properties or dimensions of the material(s) composing them. Examples of problems that could occur as a result of high-temperature exposure are parts binding from differential expansion of dissimilar materials; lubricants becoming less viscous and joints losing lubrication; materials changing dimension either totally or selectively; packing, gaskets, seals, bearings, and shafts becoming distorted, binding, and failing causing mechanical or integrity failures; gaskets displaying permanent set; closure and sealing strips deteriorating; fixed-resistance resistors changing in value; electronic circuit stability varying with differences in temperature gradients and differential expansion of dissimilar materials; transformers and electromechanical components overheating; altering of operating and release margins of relays and magnetic or thermally activated devices; shortened operating life; solid pellets or grains separating; high internal pressures created within sealed cases; and discoloration, cracking, or crazing of organic materials.

Examples of problems that could occur as the result of exposure to cold are hardening and embrittlement of materials; binding of parts due to differential contraction of dissimilar materials and the different rates of expansion of different parts in response to temperature transients; loss of lubrication and lubrication flow due to increased viscosity; changes in electrical characteristics of electronic components, such as resistors and capacitors; changes in performance of transformers and electromechanical components; stiffening of shock mounts; cracking and crazing, embrittlement, change in impact strength, and reduced strength of materials; static fatigue of restrained glass; condensation and freezing of water; decrease in dexterity, hearing and vision impairment of personnel wearing protective clothing; and change in burning rates.

Sudden temperature changes can cause shattering of glass vials and optical equipment, binding or slackening of moving parts, changes in electronic components, electronic or mechanical failures due to rapid water or frost formation, cracking of solid pellets or grains in explosives, differential contraction or expansion of dissimilar metals, deformation or fracture of components, cracking of surface coatings, and leaking of sealed components.

Procedures for high-temperature storage tests consist of installing temperature sensors on, in, and around the test item and chamber; adjusting the temperature of the chamber to the initial test conditions; exposing the item to the specified temperature, time, and cycles; stabilizing the temperature after the last cycle; and conducting a visual and functional checkout of the item.

Procedures for low-temperature storage tests are similar to those described for high-temperature tests.

Procedures for high-temperature operational tests consist of placing the test item in the chamber in its operational configuration, exposing the item either at a constant temperature or a temperature cycle, operating the test item at the high-temperature level, and determining proper operation during and after exposure.

Procedures for low-temperature operational tests are similar to those described for the high-temperature tests except that they include tests of low-temperature manipulation (handling, disassembly, reassembly, and packing) by personnel clothed and equipped as they would be in a low-temperature tactical environment.

7-9.3 ACCELERATION

The purpose of acceleration tests is to assure that equipment can withstand the forces due to acceleration that are expected in the service environment and function without degradation during and following exposure to these forces. Forces induced by acceleration can cause structural deflections that interfere with equipment operation; permanent deformations and fractures that disable or destroy the equipment; broken fasteners and mounting hardware, which can then cause equipment to become loose projectiles, electronic circuit boards to short out and circuits to open up; inductances and capacitances to change values; relays to open or close; actuators and other mechanisms to bind; seals to leak; pressure and flow regulators to change value; pumps to cavitate; spools in servo valves to be displaced and cause erratic and dangerous control system response.

Acceleration tests are performed by placing the test item in either a centrifuge or on a powered sled on a track and subjecting it to the specified level of acceleration, operating it, and inspecting it after the exposure. The test is repeated so that item has been exposed in all six test directions—positive and negative direction of the three mutually perpendicular axes.

7-9.4 SHOCK

The purpose of shock testing is to assure that components can withstand the relatively infrequent, nonrepetitive shocks or transient vibrations encountered in handling, transportation, and service environments. Shock tests are also used to measure the fragility of a component so that packaging may be designed to protect it, if necessary, and to test the strength of devices that attach equipment to platforms which may be subjected to crash loads. Mechanical shocks excite equipment items to respond at both forced and natural frequencies. Among other things this response can cause failures due to increased or decreased friction or interference between parts, changes in dielectric strength, loss of insulation resistance, variations in magnetic and electrostatic field strength, permanent deformation due to overstress, and more rapid fatiguing of materials (low-cycle fatigue).

Shock tests may be classed as functional shock, equipment packaging shock, critical acceleration fragility shock, transit drop, crash hazard, bench handling, pyrotechnic shock, rail impact, and catapult launch and arrested landing. In each case the component is subjected to a series of shocks that represent the intended conditions. These tests are repeated for each of the three axes, and the ability of the equipment to withstand the test is recorded.

7-9.5 SAND AND DUST

The purpose of sand and dust testing is to

1. Ascertain the ability of equipment to resist the effects of dust particles that may penetrate into cracks, crevices, bearings, and joints

2. Determine whether materiel can be stored and operated under blowing sand conditions without experiencing degradation of its performance, effectiveness, reliability, and maintainability due to the abrasion (erosion) or clogging effects of sand particles.

Examples of problems that could occur as a result of exposure of materiel to blowing sand and dust are abrasion of surfaces, penetration of seals, erosion of surfaces, degradation of electrical circuits, clogging of openings and filters, physical interference with mating parts, fouling of moving parts, exothermal reaction (thermite effect) of clay particles (with aluminum oxide) at high temperatures that produces heat which could cause high-temperature corrosion and produce extremely hard, erosive particles.

Blowing sand and dust tests consist of mounting the component in an appropriate chamber; adjusting air velocity, temperature, and particle concentrations to specified levels; operating the items for the specified time period; and inspecting its condition after the test. Areas requiring careful inspection include bearings, grease seals, and lubricants.

7-9.6 GUNFIRE

The purpose of gunfire tests is to assure that the equipment mounted in an air vehicle with onboard guns can withstand the vibration environment caused by the overpressure pulses emitting from the gun muzzle as well as reactive recoil forces. Also the potential for corrosive damage to airframe and engine surfaces attributable to weapon emissions should be investigated. The vibration resulting from repetitive gun blast pulses might be as large as two orders of magnitude above normal flight vibration levels. Gunfire vibration might cause the structure and equipment to respond in a violent manner, and emissions might be ingested directly into the cockpit and engine. This response can cause intermittent electrical contact, catastrophic electrical failures, hydraulic malfunctions, structural fatigue failures, and a possibility of engine failure.

Gunfire tests consist of mounting the test item on a vibration shaker, operating the test item in accordance with its specifications, applying the vibration exposure in accordance with specified levels and durations, operating the item under the vibration exposure conditions, and repeating this process for each of three orthogonal axes.

7-9.7 RAIN

The purpose of rain (water intrusion) testing is to determine

1. The effectiveness of protective covers or cases in preventing the penetration of rain
2. The capability of the test item to satisfy its performance requirements during and after rain exposure
3. The physical deterioration of the test item caused by rain water.

In the atmosphere, rain interferes with or degrades radio communications, limits radar effectiveness, limits air vehicle operations by restricting visibility, damages air vehicles in flight, affects artillery and missile launching, degrades or negates optical surveillance, decreases the effectiveness of personnel in exposed activities, causes some fuzes to function prematurely, and inhibits visibility through optical devices. On impact, rain erodes surfaces. After deposition, water degrades the strength of some materials, promotes corrosion of metals, deteriorates surface coatings, and can render electrical or electronic apparatus inoperative or dangerous. After penetration into containers, water causes malfunction of electrical equipment; may freeze inside equipment, which may cause delayed deterioration and malfunction by swelling or cracking of parts; causes high humidity, which can in time encourage corrosion and fungal growth; and causes slower burning of propellants.

Rain tests may be conducted in blowing rain conditions, drip conditions, or water tightness conditions. In each case the item is placed in an appropriate chamber, exposed to the specified test condition for the appropriate time, and operational checks and visual inspections are conducted during and after exposure.

7-9.8 HUMIDITY

The purpose of humidity tests is to determine the resistance of components to the effect of a warm, humid atmosphere. Typical problems that can result from such exposure are swelling of materials due to moisture absorption, loss of physical strength, changes in mechanical properties, degradation of electrical and thermal properties in insulating materials, electrical short circuits due to condensation, binding of moving parts due to corrosion or fouling of lubricants, oxidation and/or galvanic corrosion of metals, loss of plasticity, accelerated chemical reactions, chemical or electrochemical breakdown of organic surface coatings, deterioration of electrical components, degradation of image transmission through glass or plastic optical elements, absorption of moisture by explosives and propellants, accelerated biological activity, deterioration of hygroscopic materials.

Humidity tests involve placing the test item in an appropriate test chamber, adjusting the chamber to specified temperature and relative humidity conditions, cycling the chamber conditions through specified values, and conducting operational checkouts of the component both during and after the exposure.

7-9.9 FUNGUS

The purpose of fungus tests is to assess the extent to which the component will support fungal growth or how the fungal growth may affect performance or use of the component. Fungal growth impairs the functioning or use of equipment by changing its physical characteristics. This may be in the form of direct attack as the fungi break the material down and use it as food (products of natural origin are most susceptible to this attack) or indirect attack on materials. Damage from indirect attack includes

1. Fungal growth on surface deposits of dust, grease, perspiration, and other contaminants causes damage to the underlying material even though that material may be resistant to direct attack.
2. Metabolic waste products, i.e., organic acids, excreted by fungi, cause corrosion of metals, etching of glass, or staining or degrading of plastics and other materials.
3. The products of fungal growth or adjacent materials that are susceptible to direct attack come in contact with the resistant material.

In addition, fungal growth can cause physical interference with

1. Electronic and electrical systems by creating undesirable electrical conducting paths across insulation materials or may affect the electrical characteristics of critically adjusted electronic circuits
2. Optical systems by adversely affecting light transmission through the optical system, blocking delicate moving parts, and changing nonwetting surfaces to wetting surfaces with resulting loss in performance.

Lastly, fungal growth on equipment can cause physiological problems, e.g., allergies, or be so aesthetically unpleasant that users will be reluctant to use the equipment.

Fungus test procedures involve preparing fungi cultures, applying them to the test specimens and control specimens, incubating the test items for specified time periods, and inspecting them to determine the extent of fungus growth, if any.

7-9.10 ICING

The purpose of icing tests is to evaluate the effect of icing produced by freezing rain, mist, or sea spray on the operational capability of components. A buildup of ice occurs in three principal ways: from rain falling on an item whose temperature is below freezing, from freezing rain falling on an item at or near freezing, or from sea spray that coats equipment when temperatures are below freezing. Ice formation can result in the following problems:

1. Mechanical and vibrational problems from the uneven shedding of ice in rotating components
2. Binding moving parts together
3. Added weight to radar antennas, helicopter rotors, and other airframe components
4. Increased footing hazard
5. Interference with clearances between moving parts
6. Reduced airflow efficiency and sigificantly degraded aerodynamic characteristics of surfaces
7. Impeded visibility through windshields and optical devices
8. Affected transmission of electromagnetic radiation
9. Probability of damage from use of mechanical, manual, or chemical ice removal measures.

Icing test procedures involve stabilizing the test item at approximately 2°C (36°F), delivering a uniform spray of precooled water, lowering the chamber temperature to –10°C (14°F) and maintaining the spray until 6 mm (0.24 in.) of ice has accumulated, adjusting the chamber temperature to –6°C (21°F) for 2 to 6 h, operating the equipment, exercising integral ice removal methods, operating the system again, increasing the ice coating thickness to 13 mm (0.51 in.), and repeating the previous procedures while operating the equipment and its ice removal features.

7-9.11 SOLAR RADIATION (SUNSHINE)

The purpose of a solar radiation test is to determine the effects of solar radiation on equipment that may be exposed to sunshine during operation or unsheltered storage.

The heating effects of solar radiation differ from those of air at high temperature alone because the amount of heat absorbed or reflected depends on the roughness and color of the surface on which the radiation is incident. Some materials may also be susceptible to the solar radiation spectrum and intensity. Solar radiation effects include jamming or loosening of moving parts, weakening of solder joints and glued parts, change in strength and elasticity, loss of calibration or malfunction of linkage devices, loss of seal integrity, changes in electrical or electronic components, premature actuation of electrical contacts, fading of colors of color-coded components, changes in characteristics of elastomers and polymers, blistering and peeling of paints and other finishes, and softening of potting compounds.

Test procedures involve

1. Raising chamber air temperature to a specified level
2. Exposing the test item to continuous 24-h cycles of controlled, specified, simulated solar radiation and dry bulb temperature
3. Repeating the cycles a specified number of times
4. Conducting operational tests and visual inspections.

7-9.12 SALT FOG

Salt fog climatic chamber tests are performed to determine the resistance of equipment to the effects of an aqueous salt atmosphere. Methods to minimize corrosive effects using protective schemes or handling are described in ADS-13, *Air Vehicle Materials and Processes*, (Ref. 19).

The effects of exposure to an environment in which there is an aqueous salt atmosphere can be divided in three broad categories: corrosion effects, electrical effects, and physical effects. Corrosion effects include corrosion due to electrochemical reaction, accelerated stress corrosion, and formation of acidic or alkaline solutions following salt ionization in water. Electrical effects include impairment of electrical equipment due to salt deposits, production of conductive coatings, and corrosion of insulating materials and metals. Physical effects include binding of the moving parts of mechanical components and assemblies and blistering of paint due to electrolysis.

The salt fog test procedure involves adjusting the chamber temperature to 35°C (95°F) and conditioning the test item for at least 2 h. The item is then exposed to a continuous atomized solution of appropriate salt composition for a period of 48 h. The item is then stored in a standard ambient atmosphere for 48 h. At the end of the drying period, the test item is operated and results are documented.

Because of the limited duration of the salt fog exposure, the test is limited in predicting long-term resistance to corrosion and deterioration. Therefore, better test methods to determine corrosion susceptibility for a particular program or application are needed.

7-9.13 EXPLOSIVE ATMOSPHERE

The explosive atmosphere test is conducted to demonstrate the ability of a component to operate in flammable atmospheres without causing an explosion or to prove that a flame reaction occurring within an encased equipment will be contained and will not propagate outside the test item.

Low levels of energy discharge or electrical arc from devices as simple as pocket transistor radios can ignite mixtures of fuel vapor and air. A hot spot on the surface of a hermetically sealed, apparently inert equipment case can ignite fuel vapor and air mixtures. Fuel vapors in compartments can be ignited by a low-energy discharge such as a spark from a shorted flashlight cell or switch contacts.

For testing the operation of a component in an explosive environment, the test involves

1. Preparing the chamber for test
2. Sealing the chamber with the test item mounted inside
3. Raising the chamber temperature to a specified level
4. Adjusting the chamber air pressure to a specified level
5. Injecting the required quantity of *n*-hexane into the test chamber
6. Circulating the test atmosphere to allow for complete vaporization of fuel and development of a homogeneous mixture
7. Operating the test item
8. Increasing the air pressure slowly in the test chamber to simulate an altitude change
9. Checking the potential explosiveness of the air-vapor mixture by attempting to ignite the mixture with a spark-gap or glow plug ignition source
10. Documenting the results.

7-9.14 LEAKAGE (IMMERSION)

Leakage (immersion) tests are conducted to determine whether materiel is constructed to be immersed in water without leakage of the water into the enclosure.

Penetration (seepage) of water into equipment enclosures can result in problems, such as fouling of lubricants between moving parts, formation of electrically conductive bridges (which may cause electronic equipment to malfunction or become unsafe to operate), corrosion due to direct exposure to the water or the relatively high humidity levels caused by the water, and diminishment of the burning qualities of explosives, propellants, and fuels.

The immersion test procedure consists of

1. Opening and closing any doors, covers, etc., that would be opened during normal use to ensure that any seals are functioning properly and are not adhering to the sealing surfaces
2. Conditioning the test item as specified
3. Adjusting the immersion water temperature to the specified level
4. Closing all sealed areas and valves, immersing the test item in water so the uppermost point of the test item is 1 m below the surface of the water
5. Leaving the test item immersed for a specified period of time
6. Removing the item from the water
7. Opening seals and inspecting and operating the item
8. Recording the results.

7-9.15 LOW PRESSURE (ALTITUDE)

The purpose of the low-pressure (altitude) chamber tests is to determine whether materiel can withstand and operate in a low-pressure (altitude) environment. Typically, low-level tests are not intended to test equipment that is to be installed and operated in air vehicles that fly at high altitudes, above 4600 m (15,000 ft). The primary objectives of the low-pressure test are to determine whether the test item can be stored and operated at high ground sites, transported by air in its normal shipping configuration, and survive a rapid decompression.

7-9.16 TEMPERATURE, HUMIDITY, VIBRATION, AND ALTITUDE

Typically, US Army rotorcraft operate below 2100 m (7000 ft); however, many rotorcraft are capable of operating at 6100 m (20,000 ft) and more. Additionally, other US Army air vehicles might operate at 9800 m (32,000 ft) and more. Studies have shown that thermal effects, vibration, moisture, humidity, and in certain cases, altitude have the greatest effect on the life of aviation electronic equipment in the operational environment. Temperature, humidity, vibration, and altitude can interact to produce failures. Hence this test procedure involves application of the combination of temperature, humidity, altitude, and vibration environments to the test item.

7-10 ELECTROMAGNETIC ENVIRONMENTS

The term “electromagnetic environment effects (E^3)” is used to encompass adverse effects due to any source of electromagnetic energy on victim equipment either at the system, subsystem, or component level. Electromagnetic environment is defined as the power and distribution in various frequency ranges of the radiated or conducted electromagnetic emission levels that may be encountered by an equipment, subsystem, or system when performing its assigned mission. This paragraph describes electromagnetic environment tests consisting of electromagnetic interference (EMI) tests, electrostatic discharge (ESD) tests, nuclear electromagnetic pulse (NEMP) tests, lightning tests, and TEMPEST tests.

7-10.1 ELECTROMAGNETIC INTERFERENCE (EMI)

MIL-STD-461, *Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility*, (Ref. 20) can be used as a source of information to establish performance and related criteria for the control of electromagnetic emissions and susceptibility characteristics of electronic, electrical, and electromechanical equipment. An emission consists of electromagnetic energy propagated from a source by radiation or conduction. Electromagnetic susceptibility is the degree to which an equipment, subsystem, or system evidences undesired responses caused by the electromagnetic emissions (radiated or conducted) to which it is exposed.

The associated test document, MIL-STD-462, *Measurement of Electromagnetic Characteristics*, (Ref. 21) can be used as a source of information to establish test criteria needed to verify specified levels of emission and susceptibility. In general, for radiation emissions the tests consist of placing the test sample on a ground plane in a shielded room and operating the equipment throughout its operating modes. Antennas are placed in the room at specified distances either to detect the electromagnetic radiation or generate the electromagnetic radiation. Conducted radiation and susceptibility test procedures vary depending on the specific design requirement being tested. The most common problem in conducting EMI tests is to design test monitoring equipment that is not susceptible to the electromagnetic environment being tested. Fiber-optic links and cable isolation should be used to the maximum extent possible to limit these interferences. Transverse electromagnetic (TEM) cell chambers and reverberation chambers or a chamber that combines both radiation methods may be used for EMI tests. Criteria for using the chambers are discussed in ADS-37A-PRF, *Electromagnetic Environmental Effects (E^3) Performance and Verification Requirements*, (Ref. 22).

ADS-37A-PRF (Ref. 22) establishes the electromagnetic environmental effects performance and interface requirements for implementation at all stages of the life cycle of air vehicle systems and components. ADS-37A-PRF also establishes verification requirements.

7-10.2 ELECTROSTATIC DISCHARGE (ESD)

Equipment performance specifications should also include a requirement that solid-state devices within the equipment must not be susceptible to damage or upset from ESD due to handling of the equipment by operating or maintenance personnel. ESD testing is applicable to solid-state components, conductors, pins, and enclosures exposed during assembly or maintenance actions. ESD tests are intended to demonstrate compliance with this requirement by subjecting the equipment to a specified ESD and verifying that no damage has occurred. Such verification may be difficult because ESD may not cause an immediate failure of the solid-state device. Also embedded processing components are susceptible to ESD. The damage may significantly reduce the life of a component without being immediately detectable. Additional information and criteria are available in MIL-STD-883, *Test Methods and Procedures for Microelectronics*, (Ref. 23).

7-10.3 NUCLEAR ELECTROMAGNETIC PULSE (NEMP)

Electromagnetic pulse (EMP) is the broadband high-power effect encompassing the totality of a system as an antenna, such as would result from a nuclear burst. EMP susceptibility analysis should be conducted to determine that the system is capable of completing its mission in a nuclear EMP environment. The analysis should include the shielding effectiveness of the overall airframe, the shielding effectiveness of cable shielding, and the determination of the responses of electrical connections, including inputs, outputs, antennas, power, and spare pins of mission-essential equipment or functions. EMP tests are intended to demonstrate that a nuclear EMP will not cause permanent damage or hazardous temporary upset to flight-critical functions. Additional information on EMP test procedures is available in the Test Operating Procedures (TOP) 1-2-612, *Nuclear Environment Survivability*, (Ref. 24). (See subpar. 7-12.2 for additional information concerning survivability testing.)

7-10.4 LIGHTNING

Air vehicles are required to survive the direct and indirect effects of a severe lightning strike that either directly attaches to the air vehicle or occurs nearby. Specifically, the air vehicle and its subsystems and components should be designed to satisfy the performance criteria that follow:

1. Prevent hazardous, temporary upset and permanent damage to flight-critical subsystems and components
2. Prevent lightning ignition of fuel and ordnance
3. Prevent catastrophic structural damage to the air vehicle and associated flight-critical subsystems and components that would preclude safe return and landing of the air vehicle
4. Minimize upset and prevent permanent damage to mission-critical subsystems and components so that the mission may be completed.

Lightning tests are intended to demonstrate compliance with these requirements by subjecting components to specified sudden discharge of static electric potential that simulates a natural occurrence in the atmosphere. Typically, the contractor is responsible for the test. Information concerning lightning and lightning tests is included in MIL-STD-1795, *Lightning Protection of Aerospace Vehicles and Hardware*, (Ref. 25). Federal Aviation Administration airworthiness standards for lightning protection of various categories of air vehicles may be found in Parts 23, 25, 27, and 29 of the Code of Federal Regulations, Title 14, *Aeronautics and Space*, (Refs. 15, 16, 26, and 27).

7-10.5 TEMPEST

TEMPEST is a US National Security Agency program designed to provide standards for electronic equipment to protect sensitive data from electronic eavesdropping. The classification of TEMPEST work should be determined and handled in accordance with the DoD Contract Security Classification Specification (DD Form 254). An original DD Form 254, which sets forth the classification specifications or cites the classification guidance, is provided to the contractor as part of the solicitation and award of a contract that necessitates access to classified information. TEMPEST test facilities and testing should comply with the requirements of National COMSEC[*] Information Memorandum (NACSIM) 5100(RP-1), *Comprising Emanation Laboratory Test Requirements*

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[*]COMSEC = communications security

Electromagnetic (U), (Ref. 28) and other national security communications security instructions that might be specified in the contract. All personnel assigned to perform TEMPEST work must have a Government-granted final security clearance of SECRET. Typically, the provisions of National COMSEC/EMSEC Information Memorandum (NACSEM) 5112(RP-4), *Nonstop Evaluation Techniques* (U), (Ref. 29) apply to air vehicles at the subsystem level in regard to handling of classified data including hardware and software. NACSEM 5201, *TEMPEST Guidelines for Equipment/System Design* (U), (Ref. 30) and NACSEM 5203, *TEMPEST Guidelines for Facility Design and Red/Black Installations* (U), (Ref. 31) should be used for guidance. Typically, the contractor is required to prepare and submit a test plan for Government approval. The scope of the plan depends on the complexity of the program. After obtaining Government approval of the test plan, facility, and equipment, the contractor conducts the test according to the test plan and submits a TEMPEST report. The US Army Communications and Electronics Command typically evaluates the facility, equipment, test plan(s), and report(s). Additionally, data might be required for TEMPEST evaluation of facility and equipment. Instructions should be provided within the contract.

7-11 OPTICAL/ELECTRO-OPTICAL QUALIFICATION TESTS

The component qualification of optical/electro-optical systems is discussed in the subparagraphs that follow.

7-11.1 TARGETING SYSTEMS

Tests applicable to electro-optical targeting systems include boresight, focus, distortion, transmissibility, uniformity, contrast transfer function (CTF) and modulation transfer function (MTF) tests, minimum resolvable contrast (MRC), minimum resolvable temperature (MRT), and stabilization tests.

Boresight tests are performed to ensure that the optical alignment among the various sensor and designator subsystems of the targeting system is within specification requirements and that the internal boresighting equipment provides the required boresight accuracy. In addition, tests are performed to ensure that the system can retain its boresight during the specified mission duration. Boresight tests may be performed in the laboratory by presenting simulated targets to the various sensors through the use of collimators or in test ranges in which appropriately placed and instrumented targets are observed and designated.

Focus tests are performed to determine the capability of optical subsystem to focus a collimated light source at a desired point in the optical subsystem. Focus tests are performed to determine proper optical alignment and positioning of optical elements.

Distortion is a form of lens aberration that occurs when the magnification of an object line segment varies with its distance from the optical axis of the lens. If the image of a rectangle appears with its sides curved inward, the distortion is called positive, or pincushion, distortion. If the sides curve outward, it is called negative, or barrel, distortion. Distortion tests are performed to determine the extent of such aberrations in an optical subsystem by presenting the subsystem with rectangular targets and observing and quantifying the type and magnitude of distortion.

Transmissibility of optical devices is a measure of the amount of energy passing through the optical elements. Energy incident upon the optical device is attenuated either because it is absorbed by the element or scattered. Transmission of radiation is important because it determines the amount of energy available for detection at the sensor. Transmission is determined by performing radiometric measurements of optical elements.

Uniformity tests are performed to determine display characteristics. Uniformity is a measure of the system to produce equally bright images for equally bright targets at various positions on the display. These tests are performed by performing brightness measurements over the entire display under varying display conditions.

MRT is a laboratory measurement of the lowest temperature difference for a square-wave bar pattern that a thermal imaging subsystem will allow an observer to resolve. This threshold temperature difference is a function of the spatial frequency of the bar pattern. Spatial frequency is measured in cycles per milliradian in object space. MRT tests are normally performed at a given spatial frequency by presenting a bar target to the imaging subsystem and gradually increasing the temperature difference between the pattern and its background. The temperature value at which the observer can discern a modulation within the bar pattern image is recorded as the MRT for the specific spatial frequency. The test is repeated for other spatial frequencies of interest.

MRC is analogous to MRT except that it measures the lowest contrast difference that a system is able to resolve. MRC testing is performed similarly to MRT testing.

MTF is a measure of the resolution of an imaging subsystem. It is the sine-wave spatial frequency amplitude response of the subsystem and equals 1 for sufficiently low spatial frequencies. In general, MTF tests are performed by presenting the targeting sensor with a number of sinusoidally varying target patterns at various spatial frequencies and measuring the response of the subsystem. The usefulness of MTF tests is that the overall performance of an electro-optical system may be determined from the MTF characteristics of its individual components.

The CTF of a system is its square-wave spatial frequency amplitude response. The CTF is easier to measure because it is easier to produce a square-wave optical pattern than a sine-wave pattern. The CTF values of system components, however, cannot be directly combined to produce system-level performance information.

Stabilization tests are performed to determine the capability of the electro-optical system to meet its performance requirement in the specified vibration environments. Line-of-sight angular motion results in MTF degradation and in undesirable motion of the laser spot in systems incorporating laser designation. Stabilization tests are performed by placing the sensor on a shaker platform and measuring the resulting line-of-sight angular motions while being shaken and before and after being shaken.

7-11.2 PILOTAGE SYSTEMS

Pilotage electro-optical systems are similar to targeting electro-optical systems in terms of the types of performance parameters requiring component-level testing. Major differences are that pilotage systems may include special requirements for the detection of hazards, such as wires, poles, and other obstacles. Additionally, line-of-sight stabilization requirements are normally much less stringent for pilotage systems than for targeting systems.

7-12 SURVIVABILITY QUALIFICATION TESTS

This paragraph addresses ballistic, directed energy, nuclear, and NBC threat testing of systems, subsystems, components, and materials. All of these threats are capable of affecting mechanical, structural, electrical, and electronic components. Typical test requirements are summarized in subpars. 7-12.1 through 7-12.4. Additional information concerning ballistic hardening, analyses, and tests; directed energy threats, tests, and vulnerabilities; nuclear hardening, electromagnetic pulse, neutron fluence, total dose, peak gamma dose rate, thermal radiation, nuclear air blast, and demonstrations; and NBC analyses, tests, and demonstrations may be found in ADS-11, *Survivability Program, Rotary Wing* (Ref. 32).

7-12.1 BALLISTIC TESTS

Components, subsystems, and an air vehicle should be subjected to ballistic firing tests, controlled damage tests, and a vulnerability reduction demonstration as provided for in MIL-STD-2069, *Requirements for AircraftNonnuclear Survivability Program*, (Ref. 33). Typically, ballistic tests are performed by subjecting the specimens to impact by projectiles of a specified type at a specified velocity and orientation and by determining the capability of the specimen to prevent penetration in the case of protective materials, such as armor, or to retain its integrity in the case of structural components. In addition, component-level tests may be performed to determine the capability of components to operate safely after loss of lubrication, which may result from ballistic damage. Damage might also occur to flight-critical avionic systems and components, such as computers and processors. The contractor typically selects the components, subsystems, and air vehicle and specifies the proposed test program in the Airworthiness Qualification Specification (AQS).

7-12.2 DIRECTED ENERGY TESTS

For the purposes of this handbook, directed energy weapons are limited to battlefield lasers and the high-power microwave. The battlefield laser threats and related performance requirements usually are described in the system specification and may include several types of weapons. The directed energy hardness should be validated through component and subsystem tests. Demonstrations at the air vehicle system level would also be appropriate. The tests should be conducted on actual or simulated components (same material and design as the actual components) and on complete subsystems or portions thereof. The vulnerability reduction substantiation, verification, and demonstration tests should be integrated and piggybacked on endurance-, fatigue-, ballistic-, and failure-type test programs to the fullest extent possible.

7-12.3 NUCLEAR HARDENING TESTS

Nuclear hardening tests are concerned with radiation and blast effects, whereas NBC tests are concerned only with nuclear particles, bacteria, and chemicals. Selected flight- and mission-critical items should be subjected to electromagnetic pulse, neutron fluence, total dose, peak gamma dose rate, thermal radiation, and nuclear air blast. Typically, these environments are simulated. For additional information concerning electromagnetic pulse and its effects on electronic components, see subpar. 7-10.3. Also see ADS-11 (Ref. 32) for additional guidance.

7-12.4 NBC TESTS

Simulant tests should be performed to reproduce an NBC contamination environment relationship to the threat environment. If NBC surety material (actual agent) tests are necessary, test methods should be described and their relationship to the simulant test correlated. Any assumptions made in the interpretations of the NBC survivability criteria are usually identified in the test plan along with their impact on the test design, procedures, and results. Component live-agent tests of the NBC filter(s) should be conducted to verify the filter absorption capability at the maximum permissible concentration specified. Live agents are actual agents. Typically, tests should be performed on the basic materials and on them in their intended operating configuration to assure NBC contamination and decontamination survivability.

7-13 COMPONENT TEST-ANALYZE-FIX-TEST

The principles of test-analyze-fix-test (TAFT), sometimes referred to as test-analyze-and-fix (TAAF), are equally applicable at the component, subsystem, and system levels. The TAFT cycle consists of subjecting the component to its intended operating environment and operating it. As failures occur or performance deficiencies are identified, analyses are performed to determine the root cause, and corrective actions are developed and implemented. Testing is resumed to verify the effectiveness of the corrective action and to uncover any remaining deficiencies. This cycle is continued throughout the component qualification program. Schedule constraints may not always allow the testing to stop for each anomaly uncovered. This practice, however, can result in deferral of corrective action incorporation and increase program risk due to uncertainties concerning the effectiveness of the corrective actions. TAFT should be included in the Airworthiness Qualification Plan (AQP) and AQS to ensure early incorporation of corrective actions and elimination of weaknesses prior to production.

7-14 MATERIAL QUALIFICATION

The requirement to qualify materials as part of the airworthiness qualification process is discussed in the subparagraphs that follow. This requirement is especially important to the use of new materials, such as plastics and composite materials, or to applications of new materials.

7-14.1 STRUCTURAL ALLOWABLES

Material design allowables are those strength requirement properties of materials used in the design. For new materials and new material applications, design allowables are generally not available in widely published references and must be determined experimentally. When it is necessary to develop data for materials, the test materials and processes should be the same as those intended for use in the production air vehicle and should represent a minimum of three batches of material. The statistical significance of experimental data should be identified, and the effects of the following should be established:

1. The variation in material properties due to the variation allowed in the time, temperature, and pressure of the cure

cycle to be used for the final component must be established.

2. The degradation due to the combined effect of temperature and humidity should be established. An experimental knockdown factor may be determined to account for this effect. The method and criteria to determine an environmental factor should be approved by the procuring activity.

ADS-35 (Ref. 5) provides guidance to determine tensile, compressive, flexural, shear, fatigue, creep, damage tolerance, and bearing strength properties. The procedures described in this ADS are for the characterization of organic matrix composite materials and are generally in accordance with the guidelines in MIL-HDBK-17 (Ref. 8).

7-14.2 ENVIRONMENTAL RESISTANCE

Because of their potential susceptibility to external environmental factors, it is imperative that composite materials be tested to ensure that they can maintain their structural properties in their intended environment throughout their required life. The resistance of composite materials to the effects of moisture, solvents, cleaners, and air vehicle fluids is determined by immersing samples in the appropriate fluid for specified times and at specified temperatures followed by testing the physical characteristics, e.g., tensile strength and flexing endurance, of the samples. It is also necessary to determine the resistance of composite materials to the effects of nuclear blast, thermal energy, and radiation; biological agents; and chemical agents, as well as to any potential adverse effects of decontamination agents. The effects of naturally occurring environmental factors, such as solar radiation, acid rain, hydrocarbons, and other unexpected normal environments, through appropriate environmental resistance tests must also be determined.

7-14.3 SPECIAL PROPERTIES

New materials, such as composite materials, may have special properties that require testing and documentation prior to use. During the curing process, if undesirable curing products are generated, it is important to identify those products and their effects. Composite materials may undergo dimensional changes after manufacture due to not only the expected temperature effects but also other factors such as humidity conditions or age. Outgassing may have detrimental effects such as forming deposits on optical surfaces and degrading optical performance.

7-14.4 PROCESS DEFINITION AND CONTROL

Essential to establishing properties of materials are the procedures and processes used to produce the material and the fabrication processes to manufacture it into a final product. For this reason, it is imperative that material processes be defined and documented in the form of process specifications and that the processes be controlled through the appropriate quality assurance procedures. In the production of metallic materials, for example, processes that impact inherent properties include the critical temperatures and cooling rates necessary to achieve proper crystalline structure. During manufacture of composite materials, for example, curing process characteristics (temperature, pressure, and time) significantly impact material characteristics. Compound effects of both material production and manufacturing must also be addressed as part of process specifications. Examples include annealing before forming and hardness treatment after forming.

7-15 PROCESS QUALIFICATION

For performance-based procurements the contractor is totally responsible for the processes and controls needed to satisfy the performance requirements of the contract and specification. The US Army requires controls for military-unique processes and those associated with flight safety parts. Process qualification is the formal procedure used to document that a specifically defined manufacturing and fabrication process produces the required repeatable performance results regardless of the manufacturer. In general, the procedure for process qualification consists of documenting the process in the form of a process specification. Process specifications identify the equipment necessary to conduct the process, the required materials, the procedures and operations (both required and recommended), the certification requirements of operators or process techniques, and the quality assurance provisions. The process specification is then applied to the specific materials intended for use in the process. Finally, tests, inspections, and verifications are conducted to determine that the process has yielded acceptable results and conforms to the requirements of the specification.

Qualification by process qualification may also be applicable to the manufacture of microcircuits in which parts of differing performance characteristics are produced by a common process with only minor changes in their overall configuration. The benefit of such an approach is that it avoids the requirement to undergo sometimes costly qualification procedures when only minor changes are made to a class of components by a common process. The risk of such an approach is that at some point a significant departure in configuration may be made that would no longer meet the original qualification criteria.

7-16 SPARES AND REPAIR PARTS QUALIFICATION

The purpose of spare and repair parts qualification is to ensure that items procured for the purpose of supplying the repair inventory are suitable for their intended function. Except when parts have been determined to be fully competitive, all parts require some type of qualification, particularly if spare and repair parts are procured from a supplier different from the original supplier of the end item. Par. 3-12 provides special requirements applicable to parts covered by a Flight Safety Parts Program. (Also see ADS-39, *Substantiation Requirements for Alternate Manufacturing Source of HelicopterDrive System Components*, (Ref. 34).)

7-16.1 BUILD TO PRINT

Build to print refers to the process of manufacturing an item to the dimensions and processes requirements of the drawing. When an item is built to print from an alternate source, it is necessary to perform a formal review in order to demonstrate that the source has the technical capability to convert the print information into a conforming item. It may also be required of a vendor after a break in production or for the production of new lots. A first article test may also be required. Performance specifications at the spare part and higher assembly level are preferred.

7-16.2 SPECIFICATION CONTROL

An item procured under specification control should undergo qualification testing to demonstrate that the vendor is capable of correctly translating the specification requirements into hardware meeting performance parameters. A first article test forms the basis for this demonstration, and in addition to being performed on the first article produced, it may also be required of a vendor after a break for production or in the production of new lots.

7-16.3 SOURCE CONTROL

Source control items are items that can be procured only from an approved source. For source control items in-system qualification testing must be performed initially since source control implies that there are unknown and intangible performance characteristics that cannot be determined by testing the repair item in isolation from its next higher assembly. This situation is an undesirable one because it also presents diagnostic and repair problems in the field. A first article test forms the basis for this demonstration, and in addition to being performed on the first article produced, it may also be required of a vendor after a break in production or for the production of new lots.

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LIST OF ACRONYMS AND ABBREVIATIONS

USAATD		US Army Aviation Applied Technology Directorate, Fort Eustis VA.
AQS	=	Airworthiness Qualification Specification
ASIP	=	Aircraft Structural Integrity Program
CDRL	=	Contract Data Requirement List
CTF	=	Contrast Transfer Function
DID	=	Data Item Description
DoD	=	Department of Defense
E3	=	Electromagnetic Environment Effects
EMI	=	Electromagnetic Interference
EMP	=	Electromagnetic Pulse
FAA	=	Federal Aviation Administration
ESD	=	Electrostatic Discharge
ESS	=	Environmental Stress Screening
FSP	=	Flight Safety Part
HSIP	=	Helicopter Structural Integrity Program
MAGW	=	Maximum Alternate Gross Weight Pulse
MRC	=	Minimum Resolvable Contrast
MRT	=	Minimum Resolvable Temperature
MTF	=	Modulation Transfer Function
NBC	=	Nuclear, Biological, Chemical
NEMP	=	Nuclear Electromagnetic
PCP	=	Parts Control Program

QDR	=	Quality Deficiency Report
QPL	=	Qualified Products List
SDGW	=	Structural Design Gross Weight

CHAPTER 8
SUBSYSTEM QUALIFICATION

Subsystem qualification requirements and procedures for specific subsystem airworthiness qualification are identified. Also identified are subsystems that normally undergo subsystem qualification.

8-1 INTRODUCTION

The procedures used to establish and carry out subsystem qualification as part of an overall qualification program are presented in this chapter. The objective of subsystem qualification is to ensure, within reason, that the subsystem meets or exceeds the specified performance. A subsystem can be airworthy but not necessarily qualified. More often than not, subsystems are not qualified prior to first flight. Subsystem-level analyses and tests are used to assure adequate safety characteristics and also to support a preflight airworthiness determination. Early identification of operational suitability and performance deficiencies allows time for the development process to correct these deficiencies. Qualification tests should be performed on production or near-production hardware. Some requirements can be tested practically only at the subsystem level. In these cases subsystem-level qualification is used to demonstrate formal compliance with design and/or specification requirements. Subsystem test articles and various test environments are discussed in detail in the paragraphs that follow.

In general, test setups at the subsystem test level include bare bench, hot mock-up, palletized flight test, and surrogate host flight testing. Bare bench tests are tests in which the subsystem is assembled and interfaced functionally with its components. Their purpose is to determine that the subsystem components perform and interface functionally as intended. This setup is not necessarily representative of the positioning and environment of the actual hardware. Hot mock-ups constitute the next higher level of integration and representation of the actual subsystem configuration and actual environment. In this examination subsystem components are positioned relative to each other as they would be on the air vehicle. Iron bird and tied down air vehicle testing are forms of hot mock-ups. Environments are also representative of actual operation. Palletized flight testing is performed by integrating a subsystem (usually electronic or avionic) onto a pallet for ease of installation and removal from an air vehicle and performing flight testing to determine subsystem performance in an actual flight environment. Another method of flight testing at the subsystem level is to integrate a subsystem into a surrogate host, i.e., an air vehicle different from air vehicles for which the subsystem is ultimately intended. This might be necessary if the air vehicle is not available due to schedule or other programmatic issues. The surrogate host serves as the platform from which subsystem-level characteristics can be derived in a flight environment without the necessity for the actual air vehicle for which the subsystem is intended.

Subsystem-level tests may be performed to satisfy both survey and demonstration requirements. Surveys are used to obtain data to establish the performance capabilities of the subsystem or system. Demonstrations are used to provide data that show that a performance requirement has been met. Par. 2-4 provides further discussion of the differences between surveys and demonstrations.

Environmental and electromagnetic interference (EMI) qualification tests are normally performed at the component level. Chapter 7 provides discussion and guidance on performing these tests. In some cases it might also be desirable to perform tests at the subsystem level to account for factors such as interconnecting cables and the ground plane. Electromagnetic compatibility (EMC) and electromagnetic vulnerability (EMV) tests are always performed at the system level. Chapter 9 provides discussion and guidance on performing electromagnetic environment effects (E^3) tests.

8-2 ENGINE, TRANSMISSION, AND DRIVE SUBSYSTEM QUALIFICATION

The engine, transmission, and drive subsystem airworthiness and typical qualification test objectives are to demonstrate that these subsystems satisfy the performance and interface requirements of the air vehicle, detail, and airworthiness qualification specifications. The qualification requirements fall generally under the categories of efficient power output and transmission capability under specified operating conditions and at specified reliability levels.

Typical test objectives include the measurement and performance demonstration of horsepower, torque, specific fuel consumption, efficiency, and reliability. Specific parameters are discussed in the subparagraphs that follow.

Aeronautical Design Standard (ADS)-9, *Propulsion System Technical Data*, (Ref. 1) may be used as a source of information to determine the data needed to evaluate the contractor's capability to meet specified interface and performance requirements. The procuring activity (PA) may reference this ADS as a source of information but should not require compliance. The contractor is responsible for design. These data provide a basis for technical proposal presentations, for their evaluation, and for evaluation of analytic reports. The ADS prescribes that a general description of the overall propulsion subsystem should be submitted to define configuration, arrangement, and functional relationships. It requires the analysis of the rotorcraft drive subsystem's torsional stability showing both gain margin and phase margin throughout the operational envelope. It also requires air vehicle manufacturers to supply all installation performance losses including the total installed effect of the losses on engine performance. For the engine and auxiliary power unit (APU) starting subsystem, a detailed description is required and should include schematics to show component location and associated hardware used in the installation. Any special operating procedures should be defined and include both normal and extreme temperature cases. Required fuel subsystem data necessary to verify fuel system design are required as well. For propulsion system cooling, engine and APU compartment cooling analyses and transmission and gearbox cooling analyses are required. Additionally, data describing the exhaust and infrared (IR) suppressor subsystem; the engine air induction subsystem; the fire detection, extinguishing, and protection subsystem; the bleed air and pneumatic subsystem; the heating and cooling (environmental control) subsystems; the drive subsystem; and the APU are needed.

ADS-39, *Prequalification/Substantiation Requirements for Alternate Manufacturing Sources of Helicopter Drive System Components*, (Ref. 2) provides requirements for validating that drive system components procured from a source other than the initially qualified manufacturer of the component (an alternate source) satisfy specified performance and interface. ADS-39 (Ref. 2) requires the substantiation of the equivalence of the product to the original manufacturer's component in terms of service life, strength, durability, form, fit, and function. The process of prequalification of alternate sources includes dimensional substantiation, material substantiation, process substantiation, and manufacturing process control. Dimensional substantiation ensures that all drawing dimensions, limits, and tolerances are followed. Material substantiation requires that castings and forgings be procured only from sources that have been previously approved by the Government for each specific component. Process substantiation ensures that all processes used in the component fabrication are performed by sources that have been previously approved by the Government for each specific component. Processes consist of heat treatment, shot peening, finishing, coatings, plating, and all other processes used to manufacture the part. Manufacturing process control requires that a process sheet listing the sequence of operations, operation descriptions, parameters, inspection stations and criteria, and specific equipment used to produce the equipment be included in the inspection report and submitted to the procuring service. Upon approval of the process results, the process sheet, including all changes made during the substantiation effort, is classified as "frozen planning". Any proposed changes to the "frozen planning" must be submitted to the procuring service for approval. ADS-39 (Ref. 2) specifies, by air vehicle, the specific substantiation requirements for each drive subsystem component.

ADS-50-PRF, *Rotorcraft Propulsion Performance and Qualification Requirements and Guidelines*, (Ref. 3) establishes the general performance, interface, and related validation requirements for qualification of US Army rotorcraft propulsion subsystems. For the purposes of this ADS "propulsion subsystems" includes engine and auxiliary power unit installations and start, fire detection and extinguishing, drive, fuel, environmental control, and hydraulic subsystems. Specific performance requirements should be included in the contract and its related specifications.

Engineering evaluation tests required by the standard include

1. Customer bleed air
2. Engine heat rejection and oil cooling
3. Oil flow interruption test
4. Engine electrical power failure test
5. Engine vibration survey
6. Starting torque
7. Maintenance test
8. Verification of correction factors.

Preliminary Flight Rating Test (PFRT) requirements described in the standard include

1. Endurance test
2. Engine component tests
3. Altitude tests
4. Structural tests.

Qualification test requirements of the standard include

1. Endurance test
2. Engine component tests
3. Altitude tests
4. Engine environmental and ingestion tests
5. Engine characteristics and fuel tests
6. Structural tests.

US Navy MIL-E-8593, *General Specifications for Turboprop Aircraft*

Engine, (Ref. 4) US Air Force MIL-E-87231, *Turbojet and Turbofan Aircraft Engines*, (Ref. 5) are additional sources of information. A triservice performance specification will replace these documents.

8-2.1 ENGINE PERFORMANCE

The engine performance airworthiness and typical qualification test objectives substantiate that the engine subsystem and its installation into the airvehicle meet the performance requirements of the system specification.

ADS-25, *Engine Performance Data*, (Ref. 6) defines the required format for presentation of gas turbine engine performance characteristics, ratings, and performance data. ADS-25 (Ref. 6) requires that unless otherwise specified, engine performance characteristics are to be based on

1. A fuel having a lower heating value of 42,565 kJ/kg and otherwise conforming to MIL-T-5624, *Turbine Fuel, Aviation, Grades JP-4, JP-5, and JP-5/JP-8ST*, (Ref. 7) and oils conforming to MIL-L-23699, *Lubricating Oil, Aircraft Turbine Engine, Synthetic Base*, NATO Code #0-156, (Ref. 8) and MIL-H-7808, *Lubricating Oil, Aircraft Turbine Engine, Synthetic Base*, (Ref. 9).
2. US Standard Atmosphere, 1976 (geopotential altitude)
3. No inlet air distortion
4. An inlet pressure recovery of 100%
5. The designated exhaust pipe
6. No customer bleed air extraction
7. No accessory power extraction other than that required for continuous engine operation
8. The engine control subsystem specified for the engine and performance predicted on the tolerance of the control subsystem that produces the poorest performance.
9. A shaft power absorber with characteristics specified by the contractor.

ADS-25 (Ref. 6) indicates that performance ratings should be in accordance with Tables IA, IB, IIA, and IIB of AV-E-8593 (Ref. 10) and should be provided in the user's manual or engine specification. The first stage turbine rotor inlet conditions for each rating established at 1.2 km, pressure altitude static, 35°C (95°F) conditions should be constant for all atmospheric and Mach number conditions except when limited by fuel flow, compressor aerodynamics, or torque limits. The delivered shaft power and fuel consumption for 75% maximum continuous power at 70% of rated delivered shaft speed, 0.41 Mach number, 6.0-km standard conditions should be specified.

In addition, ADS-25 (Ref. 6) indicates that engine performance data should be presented in two forms: one in the form of standard atmosphere curves and the other, a computer program suitable for use with a digital computer. The computer program is required to be the primary and forms part of and is to be identified in the applicable engine specification. The performance data are required to cover the operating envelope of the engine.

ADS-26, *Engine Installation Data*, (Ref. 11) is an interface document that describes installation and interface information required for turboshaft engines. It addresses

1. Item diagrams
2. Interface definition including drawings and installation interfaces
3. Moments of inertia
4. Engine mounts
5. Ground handling mounts
6. Engine stiffness
7. Pads and drives

8. Engine surface temperature and heat rejection
9. Engine component limiting temperature
10. Air and gas leakage
11. Engine inlet air subsystem
12. Bleed air subsystem
13. Power absorber to engine interface characteristics.

There are numerous engine power rating conditions that apply to engine power determination. The maximum power of the engine is an operating condition at which the engine is capable of operating for at least an incremental time duration of 10 min. The intermediate power is an operating condition at which the engine is capable of operating for an incremental time duration of at least 30 min. The maximum continuous power is an operating condition at which the engine is capable of operating continuously. Delivered shaft power is the power delivered at the output shaft as measured by delivered torque and delivered shaft speed.

Engine performance measurements include engine power, torque, shaft speed, gas temperature, specific fuel consumption, surge margin, speed burst, speed chop, load burst, and load chop.

8-2.2 TRANSMISSION AND DRIVE PERFORMANCE

Transmission and drive subsystem performance and typical airworthiness and test objectives ensure that the specified air vehicle level and detailed performance requirements have been met. In addition, these tests should verify the interface of the subsystem and airframe, proper lubrication, gear meshing, etc., to ensure prior to flight test that the subsystem will perform as required without catastrophic failure.

Following the component-level bench testing of transmissions, gearboxes, gears, etc., described in Chapter 7, performance testing of the transmission and drive subsystem is typically accomplished on an iron bird or ground tied down vehicle. See subpar. 6-4.3 for a description of the test setups. Either the iron bird or tied down vehicle is suitable for testing the performance of the entire drive subsystem. The rotor subsystems are used to control torque, etc. For initial qualification of a subsystem or complex component, subsystem-level testing is required. Shafting, couplings, and bearings external to the main transmission(s) and other gearboxes, which constitute the mechanical interconnect between these subsystem components, are verified operationally in conjunction with the transmission and drivetrain subsystem. Subsystem-level vibration testing should be accomplished as described in subpar. 8-2.3. Compatibility of the engine, drivetrain, and airframe should be demonstrated both on the ground and in flight; see subpar. 9-3.1. Performance of engine and drivetrain controls should be demonstrated both on the ground and in flight; see subpar. 9-3.1.1. Typically, 50 h of pre-first flight testing are accomplished at the expected flight load spectrums. Also 400 rotor brake stops should be demonstrated. This is usually followed by 1450 h of reliability and endurance flight testing also at expected flight load spectrums. Periodic teardown inspections are typically required. The test program should also demonstrate that the overrunning clutch is capable of 200 engagements without adjustment and 2400 engagements without replacement. For information about vertical takeoff and landing air vehicles and short takeoff and landing air vehicles, see MIL-T-5955, *Transmission Systems, VTOL-STOL, General Requirements for*, (Ref. 12).

8-2.3 ENGINE, TRANSMISSION, AND DRIVE VIBRATION DETERMINATION

Typical engine, transmission, and drivetrain airworthiness and qualification test objectives include validation that performance requirements, such as critical speeds, operational and design limit misalignment, and resonance frequencies, etc., have all been satisfied. Also included are validations that engine components and drivetrain natural frequencies are sufficiently removed from propeller frequencies, rotor and blade operational frequencies, weapons rates of fire, and starter-generator switching rates, etc. Typically, the contractor conducts a free vibratory test of the engine to obtain the frequency response characteristics, natural frequencies, and mode shapes. Special intake or exhaust duct configurations or other kits that significantly change engine mass and other characteristics are also investigated. Rotor subsystems, engine controls, and combustion subsystems all introduce lags that decrease the stability of the drivetrain. Torsional instabilities result in unwanted vibrations; hence the contractor should demonstrate by test that there are adequate gain and phase margins throughout the operational envelope. Objectively, stable gain margins should be available at frequencies corresponding to a phase angle of –180 deg and main rotor and tail rotor resonance at any operating condition. Stable phase margins, measured at the gain crossover frequency, should be demonstrated at all flight conditions. Also testing should demonstrate acceptable transient response characteristics and steady state error characteristics of the control subsystem. The contractor should propose a test plan to achieve these objectives. Typical measurements include frequencies, amplitudes, direction, pedal positions, collective positions, fuel flow, strains, and engine and rotor torque. Fig. 8-1 provides a typical format for the summary of propeller vibratory stress.

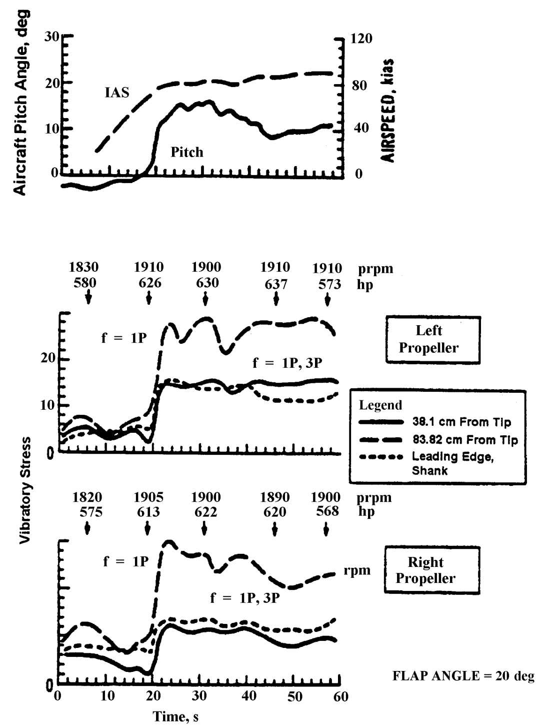

Figure 8-1 Propeller Vibratory Stress Survey Summary

8-2.4 ENGINE, TRANSMISSION, AND DRIVE ENDURANCE

The engine, transmission, and drive subsystem preflight airworthiness and typical qualification test objective is to substantiate that these subsystems can be operated at their required performance levels throughout the anticipated life of the subsystems without catastrophic failures. The endurance test setup should duplicate to the greatest extent possible the actual operating conditions and environment of the engine and drive subsystems. This setup should be essentially the same as the performance test setup described in subpar. 8-2.2. The extended time, or endurance, tests are usually based on anticipated flight spectrum conditions.

These tests are used not only to substantiate the life of the subsystem, but the results of these tests can also be used to establish limitations of the subsystems and to identify failure modes and inspection criteria.

Typical test measurements include the data necessary to establish and maintain the required test spectrum, such as engine and rotor torque, fuel flows, engine and rotor speeds, and frequencies and amplitudes of vibration levels. Endurance tests typically include specified inspection intervals to determine wear patterns and to inspect for indications of impending failure.

8-2.5 AUXILIARY POWER UNIT

The auxiliary power unit airworthiness and qualification test objective is to substantiate that the subsystem will satisfy specified performance requirements, such as performing reliably at the required power levels and under the required environmental conditions.

ADS-17, *Power Units: Aircraft Auxiliary Gas Turbine, Type IV*, (Ref. 13) provides general requirements for gas-turbine-type APU. Qualification requirements include a 200-h endurance test. The first 100 h of test should be conducted using fuel conforming to MIL-T-5624 (Ref. 7) Grade JP-4 and oil conforming to MIL-L-7808 (Ref. 9). The second 100 h should be conducted using fuel conforming to MIL-T-5624 (Ref. 7) Grade JP-5 and oil conforming to MIL-L-23699 (Ref. 8). An altitude test that consists of operation and air starting checks at selected conditions should be performed. Further, tests to demonstrate performance capability at low temperature and tests to demonstrate the use of emergency fuels are typically required. These tests should include starting capability and engine operating temperatures. Typical measurements for auxiliary power units made during these tests include speed, power, torque, and specific fuel consumption.

8-2.6 FIRE DETECTION AND EXTINGUISHING

The airworthiness and typical qualification test objective for the engine and auxiliary power unit mounted fire detection and suppression subsystem is to demonstrate ultimately that an engine or APU fire can be reliably detected and suppressed. Also some means should be provided by which to check the fire detection and suppression subsystem to assure its availability when needed.

Subpar. 9-3.6 provides a discussion of a system-level qualification requirement for fire detection and extinguishing.

The parameters to be assessed during qualification testing include but are not limited to sensor and suppression capability. The sensors should be capable of detecting a fire condition without initiating false alarms during normal operation. Fire suppression capabilities to be determined by test are the ability of the subsystem to provide fire extinguishing materials in sufficient quantity and at a sufficient rate to suppress the fire. The proper location of fire sensors and extinguishers must also be addressed.

8-3 FUEL SUBSYSTEM QUALIFICATION

The fuel subsystem includes all components whose primary function is to store, supply, sense, or control fuel in the air vehicle. The fuel subsystem airworthiness and typical qualification test objectives are to demonstrate the operating characteristics of the subsystem both on the ground and throughout the flight envelope. These objectives include but are not limited to the ability of the subsystem to store and distribute the fuel in a manner that allows achievement of air vehicle system-level requirements.

8-3.1 FUEL CAPACITIES

Typical qualification test objectives are to substantiate the fuel capacity and to determine usable and unusable fuel within the subsystem. The capacity of each internal and external tank should be determined and compared with specifications. The tanks should be filled with the air vehicle at its normal ground attitude.

Measurements include fuel capacity and the rate at which fuel can be delivered into the air vehicle's fuel subsystem, fuel probe accuracy, and center of gravity (CG) changes with fuel usage. Fuel tank capacity should include a measurement in gallons to fill the tank. In addition to the gallon measurement, fuel temperature and specific gravity should be taken before, during, and after the capacity check and should be used to determine fuel weight in pounds. Fuel quantity probe accuracy tests and calibration may be conducted during the fuel capacity test. Center of gravity tests should be conducted with the air vehicle positioned in the normal flight attitude. All available fuel should be removed from the air vehicle in 50-lb increments, and the CG recorded at each increment of fuel level.

8-3.2 REFUELING AND DEFUELING

The refueling and defueling airworthiness and typical qualification test objectives are to substantiate that the air vehicle can be safely fueled and defueled within the time requirements specified.

Refueling is normally accomplished using one of the following techniques: gravity refueling, pressure refueling, or suction refueling. Gravity refueling relies on the force of gravity to cause fuel to flow from its source to the air vehicle fuel subsystem. A pressure refueling system allows faster fueling by delivering the fuel from its source to the air vehicle fuel subsystem under pressure from the source. Suction fueling depends on the fueling subsystem of the air vehicle to suck fuel from its source into the air vehicle.

Defueling is typically accomplished on the ground and requires the use of ground support equipment. Gravity refueling and defueling rely on the force due to gravity to cause fuel to flow. This capability is needed at commercial airfields and in North Atlantic Treaty Organization (NATO) countries. There is a NATO standard nozzle. Pressure refueling is a term associated with closed circuit refueling. With closed circuit refueling there should be no vapor loss at the nozzle-to-receiver interface. Hot refueling, which is typically accomplished with engines running and rotor blades turning, is a form of pressure refueling. One objective of qualification testing is to demonstrate that pressure and hot refueling can be accomplished safely within the specified total elapsed time.

Testing should be conducted at incremental nozzle inlet pressures, and flow rates and service times should be measured and compared to the detail specification. Tests should also be conducted to verify the automatic shutoff function operates properly during refueling operations. Defueling should be conducted at the maximum discharge flow rate.

Measurements for refueling include fuel flow rates and pressures.

8-3.3 SLOSH AND VIBRATION

The slosh and vibration airworthiness and typical qualification test objective is to substantiate that air vehicle maneuvering will not cause adverse effects from fuel slosh and vibration. Slosh and vibration cause changes in the location of the fuel with a resultant change in the center of gravity of the air vehicle. Significant deviations in center of gravity should be controlled to prevent adverse impact on the dynamics of the air vehicle.

Measurements for slosh and vibration include the dynamics of air vehicle fuel under various air vehicle dynamic conditions. Measurements on the ground should include but are not limited to measurements of center of gravity changes with air vehicle attitude change. In-flight tests should include measurements of change in vibration levels and qualitative evaluation of changes in handling qualities during specified dynamic maneuvers.

8-3.4 FUEL SUPPLY AND FUEL TRANSFER

The fuel supply and transfer airworthiness and typical qualification test objective is to substantiate that the fuel subsystem is capable of supplying the engines with adequate fuel to sustain uninterrupted engine performance during all phases of air vehicle system operation.

Fuel may be supplied to the engine through suction, pressurization, or boost pumps. Suction-type fuel subsystems use the engine or other suction device to “suck” fuel out of the fuel tank. Pressurization-type fuel subsystems maintain pressure in the fuel tank and “push” fuel to the engines. Boost-pump-type subsystems push fuel to the engines but without pressurizing the tank. In addition, it might be necessary to transfer fuel from various storage locations on the air vehicle in flight. Fuel supply and transfer characteristics are typically measured in terms of fuel flow rates and pressures. Tests should be conducted at the full range of expected environmental conditions in order to assess the impact of fuel temperature and ambient pressure conditions on the performance of the fuel transfer subsystem. The effects of fuel boost pump and transfer pump failures should be determined by analyses and tests, if possible. Typically, a failure might result in a low flow rate or no fuel flow. The effects may vary for different fuel temperatures, ambient pressures, and air vehicle weights. Hence effects should be determined for the entire flight spectrum. Adverse effects might include engine surge, flameout, and instabilities in the engine control subsystem. The failure of a transfer pump might affect air vehicle stability and control.

8-3.5 FUEL SYSTEM CRASHWORTHINESS

The airworthiness and typical qualification test objective for crashworthy fuel subsystems is to demonstrate that the subsystem is capable of withstanding a forced landing or crash within specified limits of the installation without breaking loose, leaking, or resulting in fire. Additional objectives are to demonstrate adequacy of the rollover vent valves, self-sealing fuel lines and tanks, breakaway fuel lines and valves, and electrical components. Typically, fuel cells are drop tested from a specified height. Breakaway self-sealing valves and all frangible fittings are typically qualified on the basis of tests conducted at the component level and substantiated by qualification test reports, such as a breakaway self-sealing valve qualification test report. Test requirements and pass-fail criteria are usually specified in test plans that are prepared by the contracting authority (CA) and submitted for the approval of the PA. Required plans and reports should be defined in the statement of work and listed in the contract data requirements list (CDRL). Qualification should include structural, dynamic, and slosh and vibration analyses and testing. Also qualification includes functional analyses and testing of the fuel subsystem. Analyses and tests should be sufficient to demonstrate that the airframe and tanks are capable of reacting to all crash-related loads and forces associated with the overturning moment, etc. Analyses should start with a balanced free body diagram. Typical measurements include weights, forces, fuel pressure, and surges. For additional information refer to subpars. 8-3.6, 8-3.8, and 8-3.9. Also refer to Test Report (TR) 89-D-22E, *Aircraft Crash Survival Design Guide, Vol. 5, Aircraft Postcrash Survival*, (Ref. 14) and MIL-STD-1290, *Light Fixed and Rotary Wing Aircraft Crash Resistance*, (Ref. 15). Other requirements might be specified in the contract, which must be followed.

8-3.6 INERTING SYSTEMS

The inerting subsystems airworthiness and typical qualification test objective is to substantiate that the subsystems can be purged of fuel concentrations to allow for safe maintenance operations. Inerting subsystems include application of inert gas into the fuel subsystem to reduce the explosive atmosphere caused by fuel fumes.

Measurements for inerting subsystems include the capability of the subsystems to prevent the fuel subsystem from catastrophically exploding due to outside ignition. This is accomplished by measuring oxygen and/or hydrocarbon levels after inerting the subsystem. Subpar. 8-3.8 provides additional discussion of explosion protection.

8-3.7 AERIAL REFUEL

The airworthiness and typical qualification test objectives for aerial refueling subsystems are to demonstrate ultimately that the receiver air vehicle can rendezvous with tanker aircraft, join up, and safely transfer fuel from a variety of tanker aircraft and under a variety of environmental conditions. Thus qualification efforts are needed at both the subsystem and air vehicle system level. Also it should be possible to maintain weight and balance control throughout the fuel transfer operation. An automatic fuel management subsystem, fuel quantity gages, valves, and transfer pumps might be needed. Navigational aids and communications subsystems should be adequate for rendezvous. These subsystems and components might add to the overall qualification effort. Takeoffs and landings, slope landings, taxi operations, and in-flight operations should be demonstrated. Aerial refueling should be possible during daylight and darkness; aerial refueling with night vision goggles should be possible. Typically, qualification includes structural, dynamic, aeromechanical, aeroelastic, electrical, electromagnetic compatibility, and human factors analyses and testing. Also qualification includes functional analyses and testing of the aerial refueling subsystem. The ability to dissipate safely static and lightning-strike-related electricity should be analyzed and demonstrated. Crashworthiness of the host air vehicle should not be degraded. Flight operations typically include tanker day and night engagements and disengagements, day and night fuel transfer operations, and engagements and fuel transfer in light to moderate turbulence. Except for a single-engine receiver air vehicle, refueling should be possible with one engine in the receiver air vehicle inoperative. Aerial refueling is a multiservice operation. Much planning and coordination are normally needed to avoid costly delays. Typical measurements include electrical grounding, probe loads, vibrations, fuel pressures and surges, flow rates, temperatures, and weight. Other requirements may be specified in the contract.

8-3.8 EXPLOSION PROTECTION

Explosion protection includes all measures that are included in the air vehicle design to reduce the risk of explosion. This protection is provided through means such as ballistic tolerance to prevent fuel spillage, static electric charge prevention and lightning strike protection through use of proper grounding and material, and vent-drain features designed to prevent a buildup of explosive atmospheres. Also all electrically operated components should be properly grounded.

The explosion protection airworthiness and typical qualification test objective is to substantiate that these subsystems satisfy the performance requirements specified in the contract and Airworthiness Qualification Specification (AQS). Explosion protection systems assessments either provide the necessary protection or they do not. Test results are either go or no-go.

8-3.9 AUXILIARY FUEL

The US Army uses auxiliary fuel subsystems to enable its air vehicles to have greater range. These auxiliary fuel subsystems can be used for self-deployment and be removed later. The airworthiness and typical qualification test objectives for auxiliary fuel subsystems are essentially the same as those for the basic crashworthy fuel subsystem, which is discussed in subpar. 8-3.5. Auxiliary fuel tanks can be internally or externally mounted. Internally mounted tanks are usually mounted within the cabin and cargo area. These internally mounted tanks should be carefully vented to prevent fumes and vapors from entering the cabin and also to ensure vented fumes and fuel do not enter the engine and other critical areas. Also the vents should be properly sized to prevent tank overpressurization in the event of a high-level shutoff valve failure. Externally mounted tanks are usually mounted on pylons, which are jettisonable. External tanks should satisfy all aeromechanical, aeroelastic, and aerodynamic performance requirements. It should be possible to maintain weight and balance control throughout fuel transfer operations regardless of the type of tank and mounting. An automatic fuel management subsystem, fuel quantity gages, valves, and transfer pumps might be needed. These subsystems and components might add to the overall qualification effort. Thus qualification efforts are needed at both the subsystem and system level. Typically, qualification includes structural, dynamic, aeromechanical, aeroelastic, electrical, electromagnetic compatibility, and human factors analyses and testing. Also qualification includes functional analyses and testing of the auxiliary fuel subsystem. The ability to dissipate safely static and lightning-strike-related electricity should be analyzed and demonstrated. Airworthiness and crashworthiness of the host air vehicle should not be degraded. Typical measurements include weight, forces, vibrations, electrical grounding, fuel pressures and surges, fuel transfer rates, and temperatures. Other requirements may be specified in the contract and the AQS.

8-4 ROTOR, PROPELLER, AND PROPROTOR SUBSYSTEM QUALIFICATION

Rotor, propeller, and proprotor subsystem dynamics are difficult to predict accurately; therefore, qualification is often based on experimental results. The primary purpose of the qualification tests is to validate that structural performance requirements have been met.

This paragraph discusses the following rotor, propeller, and proprotor subsystem qualification testing:

1. Whirl testing
2. Aeroelastic stability and flutter wind tunnel testing

3. Flutter and lift and thrust performance wind tunnel testing
4. Antitorque subsystem performance tests.

Objectives and test descriptions are provided in the subparagraphs that follow.

8-4.1 WHIRL TESTING

The whirl testing airworthiness and typical qualification test objective is to assure that the rotor, propeller, and proprotor subsystems are qualified for installation on the air vehicle for ground and flight tests. Though aerodynamic excitations in test stands are not representative of flight, appropriate information can be learned about stress distributions, critical speed locations, and the boundary of incipient stall flutter. These tests also allow the aerodynamic calibration of main rotor static thrust performance, the stress and motion surveys over the design range of combinations of collective and cyclic pitch and rotor speed, and prove isolated rotor stability.

Rotor whirl towers are available at major contract facilities, such as Boeing Helicopter and Sikorsky Helicopter companies.

8-4.2 AEROELASTIC STABILITY AND FLUTTER

The terms "aeroelastic stability" and "flutter" are synonymous. Both aircraft and rotorcraft might experience flutter. Flutter is a self-exciting vibration. Airworthiness qualification and measurements for aeroelastic stability should not be accomplished at the subsystem level. Aeroelastic stability investigations and testing at the subsystem level are not recommended. The results of such testing are not conclusive. Aeroelastic stability qualification efforts should be accomplished at the air vehicle system level. See par. 9-5 for a discussion of dynamic stability at the system level. The air vehicle system level qualification effort should be accomplished in concert with the aeroelastic modeling effort discussed in subpar. 6-2.5.2.

8-4.3 LIFT AND THRUST PERFORMANCE

Lift is a term that is associated with wings and main rotor subassemblies. Thrust is a term that is usually associated with the propeller, tail rotor, and engine exhaust subsystem. Tilting the rotor produces a propulsive force analogous to thrust. Rotor lift and propulsive force can be directly measured in wind tunnels; however, it is not directly measurable on rotorcraft subsystems. Force models are discussed in subpar. 6-2.4. Typically, rotor subsystem flight performance is estimated based on rotorcraft system flight performance tests at known weights and speeds and with power required being the measured dependent variable. Wind tunnel testing is especially needed when there is concern about stability. (See subpar. 6-2.3.) Full-scale model facilities are available at the AMES Research Center, Moffett Field, CA. NASA/AMES has the biggest facility (24.4- × 36.6-m (80- × 120-ft)) available. NASA/AMES also has a 12.2- × 24.4-m (40- × 80-ft) facility and a reduced scale (2.1- × 3.0-m (7- × 10-ft)) wind tunnel. NASA Langley* has a 4.3- × 6.7-m (14- × 22-ft) reduced scale wind tunnel at its facility. Interference effects result from proximity of the main rotor blade to the fuselage and tail rotor. (See subpar. 6-2.5.1.) Also there are subsystem installation losses. Typical flight test instrumentations are a boom-mounted pitot-static subsystem, strain gages, accelerometers, and flapping angle potentiometers. Signals from the strain gages or other rotating transducers are

*Langley Air Force Base

typically transmitted to the recording instruments through slip rings. Many types of signal conditioning and calibration methods may be selected, as appropriate, to match the types of transducers and equipment available.

8-4.4 ANTITORQUE SUBSYSTEM

The antitorque subsystem counteracts the rotating forces tending to cause the single main rotor rotorcraft to rotate about the centerline of the main rotor mast. Antitorque subsystem types include open tail rotor, ducted tail rotor, and coanda thruster. Testing of antitorque subsystems should include, as a minimum, calibration of the static thrust performance and the stress and motion surveys over the design range of pedal position and required antitorque performance values.

8-4.4.1 Open Tail Rotor

The open tail rotor subsystem airworthiness and typical qualification test objective is to substantiate that this subsystem performs in accordance with specified requirements. The tail rotor subsystem is shaft driven from the main transmission through one or more intermediate tail rotor gearboxes. The purpose of these subsystem-level tests is to determine the ability of the subsystem to provide the necessary thrust.

Test measurements for the tail rotor antitorque subsystem includes the thrust, torque, and installation aerodynamic losses of the tail rotor subsystem. These parameters are usually determined by calculation from measurement input power and direct measurements of strain gages to determine output torque and thrust.

8-4.4.2 Ducted Tail Rotor

The ducted tail rotor airworthiness and typical qualification test objective is to substantiate that this subsystem meets the thrust and other performance requirements for satisfactory antitorque control. Ducted antitorque rotor subsystems are similar to open tail rotor subsystems in that they derive their power from the main transmission. They differ, however, in that they are shrouded as opposed to being open.

The primary measurements for the ducted antitorque subsystems are the rotor thrust and torque, and duct aerodynamic performance produced by the subsystem.

8-4.4.3 Coanda/Thruster Effect Antitorque Subsystems

The coanda/thruster effect antitorque subsystem airworthiness and typical qualification test objective is to substantiate that this subsystem meets the thrust and other performance requirements for satisfactory antitorque control. Coanda effect devices achieve their antitorque effect by using main rotor downwash flowing over an asymmetrical aerodynamic surface (essentially a wing section) with slot blowing positioned such that the lift resulting from the airflow provides an antitorque thrust. The subsystem is generally augmented by a thruster that provides maneuvering forces.

The primary performance measurement for coanda effect antitorque subsystems is again the thrust, coanda force, or torque produced. These parameters are usually determined by direct measurement of strain and calculation of forces and torques.

8-5 HYDRAULIC AND PNEUMATIC SUBSYSTEM QUALIFICATION

Hydraulic and pneumatic subsystem testing is necessary to qualify the installation, to verify the performance capability of the components operating together as a subsystem, and to demonstrate proof of compliance with interface requirements. This testing should follow component testing. Hydraulic applications primarily include flight control and utility functions. Flight control functions are considered to be flight critical and include servo control of cyclic pitch, collective pitch, and directional surfaces. Pneumatic applications may include such functions as engine starting, auxiliary utility subsystems, and emergency backups. Testing of hydraulic and pneumatic subsystems includes the common elements of determining pressures, temperatures, and flow rates.

8-5.1 HYDRAULIC SUBSYSTEM DEMONSTRATION

The hydraulic subsystem airworthiness and typical qualification test objective is to substantiate that the hydraulic subsystems will perform in accordance with their specified requirements.

The hydraulic subsystem should be simulated in mock-up; see Chapter 6. The mock-up should incorporate all hydraulic components and associated plumbing. Hydraulic plumbing should approximate actual air vehicle requirements in terms of lengths, diameters, bends, and fittings. Cyclic, collective, and directional control actuators should be installed with provisions to simulate both the no-load and load conditions. The mechanical linkages, levers, and cabling of the control system should be provided to allow inputs from the cyclic stick, collective lever, and tail rotor pedals. Since these control functions operate continuously and require synchronization and response, the test mock-up should include adequate instrumentation to record and display hydraulic fluid pressure, flow, and temperature at several locations. The mock-up should contain provisions to allow testing of armament and utility functions such as weapon turret azimuth and elevation, cargo hoist, doors and landing gear. Key points for monitoring pressure, temperature, and flow include

1. Reservoir bootstrap pressure
2. Reservoir return
3. Pump suction
4. Pump outlet
5. Branch circuit supply at using component
6. Branch circuit return at using component
7. Accumulator charge.

8-5.2 PNEUMATIC SUBSYSTEM DEMONSTRATION

The pneumatic airworthiness and typical qualification test objective is to substantiate that these subsystems will perform as specified within the required conditions.

The pneumatic subsystem test stand should simulate the actual subsystem installation. Also an iron bird or tied down air vehicle can be used as a test bed. All special test equipment should be installed and any approved modifications completed. The pneumatic subsystem should be properly lubricated and all components and attached linkages and mechanism should be properly adjusted. Testing should allow verification that

1. All specified functions are performed satisfactorily.
2. The movement of all components is smooth and positive.
3. Relief valves, automatic devices that terminate an operation, pressure controls, switches and signals, audible and other warning devices, and similar installations function as intended. Relief valves need not blow off but should not bypass air during normal operation of any component.
4. All indicating devices function and synchronize with the movement of the respective component as specified.

5. The specified functioning pressures are controlled and not exceeded. This may need to be determined at only one or at numerous locations in the subsystem, but should not receive major consideration at any point where unrealistic pressures are obtained on ground test compared with entirely different pressures in flight unless the unrealistic pressures will adversely affect the subsystems during operational use. Pressures may be obtained by normal pressure gages or electronic equipment as applicable.

6. All tubing and fitting joints and component external seals are free from leaks.

7. All lines, fittings, and components are free from excessive movement and chafing.

8. There is full engagement of mechanical locks and catches.

9. The clearance for all moving parts throughout the entire range of movement is such that fouling of adjacent parts cannot occur. Particular attention should be given to flexible connections to ensure that pinching or stretching does not occur.

10. All pneumatically operated doors and closures are flush with surrounding surfaces within the limits specified.

11. Simulated normal flight operating conditions, or any possible inadvertent operations, will not cause subsystem malfunctions.

12. Ambient temperatures are within permissible limits.

All emergency operations should be tested on all subsystems normally operated by the pneumatic subsystem or operated by the subsystem during the emergency. Each subsystem should be inspected for smooth, continuous operation during the changeover from normal to emergency operation.

8-5.3 CABIN PRESSURIZATION

The cabin pressurization airworthiness and typical qualification test objectives are to substantiate that the air vehicle cabin pressure and air quality can be maintained within the required limits.

Measurements for cabin pressurization subsystems include the ability to maintain specified pressure and provide the necessary air exchange to ensure a proper crew environment including temperature and air quality. Testing should provide data that demonstrate an adequate air supply for cooling and demonstrate that moisture does not condense within electronic components. Qualification testing should include testing to demonstrate the effects of decompression and indications of inadequate pressurization.

8-6 LANDING GEAR QUALIFICATION

The purpose of landing gear tests is to demonstrate the landing gear meets the specified performance and interface requirements, such as specified extend and retract times, normal and crash loads, low observables, and compatibility with flotation and skis (if applicable). Typical measurements for landing gear include energy absorption capacity and dynamic load characteristics of the landing gear.

Landing gear subsystem qualification tests include

1. Drop testing
2. Low- and high-speed testing
3. Breaking and brake lock testing
4. Floatation testing
5. Ski testing
6. Retraction and extension testing.

The purpose and objective of each of these tests are discussed in the subparagraphs that follow. (Also see subpar. 6-4.7.)

8-6.1 DROP TESTING

Drop tests of the landing gear and critical backup structure should demonstrate compliance with the air vehicle system specification and also show that the landing gear is capable of absorbing its prorated share of the crash energy according to the contractor's design and the requirements of the air vehicle structural design criteria. Normal load factor and the reserve energy absorption capacity of the landing gear should be demonstrated. Also capacity of the landing gear to land in sand (brownout condition) with some forward velocity should be demonstrated. Fore and aft loading are typically larger when landing in sand. These tests should be conducted to determine the dynamic load characteristics over a representative range of air vehicle weights, angles of attack, and sinking speeds, as applicable to the landing gear type. For wheel-type landing gear they should include sufficient wheel spinup to simulate critical wheel contact velocities. Relevant information concerning the conduct of drop test can be found in MIL-T-6053, *Tests Impact, Shock Absorber Landing Gear, Aircraft*, (Ref. 16). Specific sink speed, wheel speeds, and attitudes should be specified in the subsystem specification. In addition, the shock absorption performance of the gear should be evaluated with the initial metering configuration and with any changes that might improve overall landing performance characteristics. See ADS-29, *Structural Design Criteria for Rotary Wing Aircraft*, (Ref. 17) and ADS-36, *Rotary Wing Aircraft Crash Resistance*, (Ref. 18) for additional information. (Also see subpar. 6-4.7.)

Measurements for drop testing include the forces, velocities, and accelerations applied to the landing gear subsystem along the *x*-, *y*-, and *z*-axes and also measurement by means of strain gages, etc., of their impact on the structural components of the landing gear subsystem and supporting structure. Wheel speeds and attitudes should also be measured. Attitude is usually simulated by means of various inclined planes and wedges.

8-6.2 LOW- AND HIGH-SPEED TESTING

The low- and high-speed testing for landing gear airworthiness and typical qualification testing are conducted on wheeled landing gears to demonstrate the capability of the landing gear to meet the requirements of the landing performance and handling quality characteristics.

Measurements for low- and high-speed testing include loads and stresses imposed on the wheel housings and on the landing gear mounting assemblies at both high- and low-speed landing conditions.

8-6.3 BRAKING AND BRAKE LOCK TESTING

The braking and brake lock airworthiness and typical qualification test objective is to demonstrate that the braking subsystem satisfies performance requirements. The air vehicle should stop within specified limits, etc. In addition, the characteristics of the braking subsystem are assessed with the brakes in a locked condition.

Measurements for braking and brake lock testing include forces and stresses imposed on the landing gear, braking time, and braking distance. Braking data may be obtained in conjunction with the high- and low-speed testing described in subpar. 8-6.2. Braking capability adequate for both stopping and parking the air vehicle on a required slope should also be demonstrated.

8-6.4 FLOTATION TESTING

Flotation gear has been used successfully on rotorccraft and other air vehicles. Flotation gear is either fixed position or deployable. Deployable flotation gear should be capable of automatic inflation after water contact. Typical qualification test objectives and measurements are to validate water buoyancy, drop characteristics, stability and control characteristics at various sea states, stability and control with rotors turning and at rest, weight and balance limitations, effects on aerodynamic performance and aeroelastic qualities, water taxi capabilities, takeoff and landing characteristics with the subsystem installed, validation of adequate clearance for rotors or propellers at various centers of gravity and various sea states, maintainability, and electromagnetic compatibility if the flotation gear is squib activated. The effects of in-flight deployment should be investigated. Also effects on egress should be investigated. Typically, strain gages should be used to evaluate structural adequacy of points of attachment. Typical measurements are weight, buoyancy, drag characteristics, clearance, required power, voltage, stress at attachment points, and vibration characteristics.

8-6.5 SKI TESTING

Snow ski gear has been used successfully on rotorcraft and other air vehicles. US Army air vehicles must be capable of all-weather operation. Typical qualification test objectives and measurements are to validate footprint areas, buoyancy in snow, stability and control characteristics at various wind conditions, visibility in snow with rotors turning, weight and balance limitations, effects of aerodynamic performance and aeroelastic qualities, taxi capabilities under various snow conditions, takeoff and landing characteristics with the subsystem installed, validation of adequate clearance for rotors or propellers at various center of gravity positions, maintainability, and effects on in-flight performance. Typically, measurements should include weight, footprint area, structural adequacy of attachment points, vibration characteristics, ground and snow clearances, step height, and aerodynamic and aeroelastic characteristics.

8-6.6 RETRACTION AND EXTENSION TESTING

The retraction and extension airworthiness and typical qualification test objective is to demonstrate compliance with specified performance requirements, such as showing that the landing gear can be reliably extended and retracted under all anticipated flight conditions. The mechanical integrity of all structural members and actuation components is verified.

Measurements for retraction and extension testing include the actuator forces necessary to accomplish extension and retraction and the stresses imposed on the extension and retraction mechanism. These data are typically obtained through strain gage instrumentation. In addition, the time required for extension and retraction is assessed. Time measurements should include static extensions and retractions with the air vehicle on jacks on the ground and with aerodynamic loads in flight.

8-7 ELECTRICAL SUBSYSTEM

The purpose of airworthiness qualification testing is to demonstrate performance capabilities of the electrical subsystem including all of its components and interconnecting circuitry provided for the generation, regulation, storage, control, conversion, and distribution of electrical power. Also included is the embedded software. Typically, all equipment, devices, units, and subsystems that use electrical power should be either installed or emulated.

Both ground and flight testing are needed to demonstrate airworthiness and specification compliance. Ground tests should include all electrical subsystem performance tests and demonstrations that can be performed satisfactorily with the host air vehicle on the ground. Flight tests should include all of the performance tests and demonstrations that cannot be satisfactorily conducted on the ground. The contractor should demonstrate that

1. Operating temperatures of all electrical power and conversion equipment are within design limits.
2. The prime mover has adequate capacity to maintain rated generator loads and overload performance as specified by the contract.
3. Generation and conversion of adequate power from minimum ground idle to maximum engine speed.
4. Voltage regulation, frequency regulation, transient performance, and waveform of the alternating current (ac) subsystem satisfy the performance and interface characteristics of MIL-STD-704, *Aircraft Electric Power Characteristics*, (Ref. 19).
5. Voltage regulation and ripple voltage present in the direct current (dc) subsystem as measured at representative power input terminals of the utilization equipment satisfy the performance and interface requirements of MIL-STD-704 (Ref. 19).
6. Emergency power and alternate emergency electrical circuits are satisfactory for all flight conditions. This demonstration should include performance of the voltage regulator, frequency regulation, and waveform of the ac subsystem and the voltage regulation and ripple voltage content of the dc subsystem.
7. There is satisfactory performance of the fault protection subsystem and detection equipment under specific default conditions
8. The engine starting system is satisfactory.
9. The auxiliary power unit performs satisfactorily.
10. Accessibility for test, adjustment, and servicing is adequate. For information concerning this topic, see MIL-STD-7080, *Selection and Installation of Aircraft Electronic Equipment*, (Ref. 20).

8-7.1 ELECTRICAL POWER TESTING

The electrical power testing airworthiness and typical qualification test objective is to substantiate that these subsystems perform in accordance with their specified requirements at the subsystem level.

The electrical load imposed on the power subsystem by each individual electrical subsystem or unit should be measured and the total load on each electrical power subsystem determined. The subsystem or unit should be operated in all modes requiring maximum power. The power required is the steady state demand for the particular mode being considered. Primary power subsystem total load should include the input power to conversion equipment. The conversion (or secondary) power should be supplying its normal loads when its input power is determined.

The contractor should demonstrate that the design, operation, and performance of the primary electrical subsystem satisfies the requirements established by the detail specification and contract. Primary electrical power can be 115/208 V ac 3-phase 400 Hz, 270-V dc, or 28-V dc. The tests should demonstrate

1. Single generator operation and capability
2. Multiple generator operation and capability

3. Load equalization capability
4. Power transfer capability
5. Load transfer capability
6. Supervisory and control functions
7. Operational temperatures
8. Any special operational and design characteristics that may differ from other air vehicle models.

Also they should demonstrate that the primary electrical subsystem and utilization equipment satisfy the performance and interface characteristics of MIL-STD-704 (Ref. 19), including

1. Steady state voltage
2. Ripple amplitude
3. Ripple frequency components
4. Transient performance.

Conversion of secondary power is accomplished by transforming or converting the primary power to another type, usually 28-V dc. The contractor should demonstrate the design, control, and operational features of the conversion power subsystem by appropriate tests. Each individual load imposed on the conversion power subsystem should be measured and the total load on the conversion equipment determined.

Emergency and alternate power loads should be identified and individually measured. The total load on each emergency power source should be determined. Each dc load should be measured in terms of voltage input and amperes of current flow or watts consumed; each ac load should be measured in terms of phase-to-neutral input voltage, amperes of current flow, and either power factor (phase angle) or volt-amperes. It should be demonstrated that the available emergency power and the emergency circuits are satisfactory for all required flight operating conditions of the air vehicle. Emergency power should satisfy the performance and interface characteristics of MIL-STD-704 (Ref. 19) including voltage, frequency regulation, and waveform of an ac subsystem and voltage regulation and ripple voltage content of a dc subsystem. If the emergency dc source is a battery, adequacy of the battery to provide the required power to the emergency circuits for a specified time period at all ambient temperatures should be demonstrated.

A complete demonstration of the fault protection and detection capabilities of the electrical power subsystems should be performed and should include the following:

1. Individual load circuit protection
2. Circuit fault protection
3. Overvoltage protection
4. Undervoltage protection
5. Reverse current protection (CUT OUT)
6. Primary power failure detection
7. Secondary (conversion) power failure protection
8. Reversed polarity protection (dc)
9. Reversed phasing protection (ac)
10. External power protection.

A complete electrical installation environmental test should be conducted on prototype or early production air vehicles. This test should also include a test of the complete starter-generator subsystem. The capability and adequacy of the electrical starting subsystem and installed starting power sources of the air vehicle should be tested to demonstrate that the starting power capability meets the requirements of the detail specification at all ambient temperatures. Also a torsional test should be conducted to demonstrate that both the voltage control regulator frequency and starter driveshaft natural frequency are not coincident with the calculated torsional frequency of the starter-generator shaft. If the starter-generator has a super critical shaft, the contractor should demonstrate either by analysis or test that damping is sufficient to avoid the whirl mode. Typically, strain gage instrumentation is installed on the starter driveshaft so that both steady state and oscillatory torque values can be measured. A slip ring device might be needed on the starter shaft for signal transmittal. Oscillatory torque conditions typically exist in a complicated drive subsystem, such as the combination of the engine accessory drivetrain subsystem and the starter driveshaft subsystem. A reasonable maximum oscillatory torque limit is 10% of the starter pad maximum static torque limit.

Typical objectives of the flight test are to

1. Obtain the operating temperatures of electrical power-generating and conversion equipment for typical flight regimes and conditions
2. Demonstrate the adequacy of the electrical power and conversion equipment under actual flight conditions including but not limited to altitude
3. Demonstrate the capability of the prime mover to maintain the required generator loading
4. Determine the vibrational environment of each generator during flight conditions by monitoring each of the three axes of each starter-generator for vibrational amplitudes and frequencies.

Sufficient flights should be conducted and data obtained to demonstrate the performance and capabilities of the electrical subsystem in flight. The recorded data should be adequate to obtain time history plots. To satisfy these objectives, the following parameters are typically monitored and their values recorded by appropriate instrumentation through the flight regimes and altitudes of a typical mission and as required by the detail specification:

1. Speed of each engine in revolutions per minute (RPM)
2. Speed of each primary electrical power source (generator or alternator)
3. Operating temperatures of each primary electrical primary source
4. Vibrational amplitudes and frequencies on each of the three axes for each primary electrical power source
5. Voltage output of primary electrical power source
6. Current output of primary electrical power source
7. Frequency of primary source power if ac
8. Voltage output of conversion equipment
9. Current output of conversion equipment
10. Frequency of conversion power if ac
11. Operating temperatures of each conversion power source
12. Output voltage of each emergency (or alternate) power source
13. Output current of each emergency (or alternate) power source
14. Frequency of emergency power if ac
15. Operating temperatures of each emergency power source
16. Current supplied to each load circuit bus
17. Outside air temperature
18. Equipment compartment and, if required, individual component temperatures
19. Altitude
20. Airspeed
21. Pressurization of battery installation.

8-7.2 ELECTRICAL POWER ANALYSIS

MIL-E-7016, *Electrical Load and Power Source Capacity Aircraft, Analysis of*, (Ref. 21) provides guidance for preparation and submittal of the electrical load analysis. Typical requirements include wiring diagrams showing cable designations and length; a description of the electrical system operation during normal, emergency, and abort procedures; the load analysis showing all power requirements on the subsystem under flight conditions, and the data, methods, and instrumentation pertaining to the contractor's flight and ground evaluations of the capabilities of the entire electrical subsystem.

8-7.3 ELECTRICAL AND ELECTRONICS COOLING

Typical electrical and electronic cooling subsystem airworthiness and qualification requirements are to substantiate that these subsystems perform in accordance with their specified requirements at the air vehicle and subsystem levels. The test objectives are to demonstrate that the electrical and electronic cooling subsystems are capable of dissipating the heat generated and maintaining the temperature environment necessary for reliable system operation. Typical methods used to provide thermal relief to electronic equipment include the use of ram air effects, blown ambient air, or environmentally conditioned air. Judicious arrangement of electronic units in the avionics bays can greatly reduce cooling requirements.

Measurements for electrical and electronics cooling testing include cooling air mass flow rates and temperatures. If air conditioning or external cooling air is provided to the electronic equipment, the testing should include operation of the equipment with simulated failure of the conditioning equipment and blowers. Outside air temperature, cockpit ambient temperature, and compartment temperatures should be recorded as time histories. Temperature data should be obtained with the equipment operating and not operating to demonstrate that actual operating and storage temperatures do not exceed the equipment design limits.

8-8 AVIONICS— COMMUNICATIONS

The purpose of airworthiness qualification testing is to demonstrate that the air vehicle communication subsystems meet the performance and functional interface requirements specified in the contract. Radio equipment used primarily to transmit and receive information by voice or code is classified herein as communication equipment. This includes high-frequency (HF), very high-frequency/ amplitude modulation (VHF/AM), very high-frequency/frequency modulation (VHF/FM), ultrahigh-frequency/amplitude modulation (UHF/AM) radio function equipment, interphone equipment, and related antennas. Also included are applicable digital controls, secure communications subsystems, and identification friend or foe (IFF) equipment. All avionics should be bench tested in accordance with approved test procedures before being installed in the test air vehicle. See Chapter 7 for additional guidance concerning component testing. Typically, the contractor should make use of commercially available specifications that satisfy performance criteria of applicable military specifications. If commercially available specifications and standards are unsatisfactory, the contractor should prepare bench, preflight, and flight test procedures. These test specifications should include pass/fail criteria. Also "fail soft" functionality of integrated avionic configurations should be required and demonstrated; see par. 8-18. Further, these specifications should be submitted to the PA for approval. In some cases the use of military specifications, military standards, or aeronautical design standards might be specified by the contract.

The airworthiness qualification test ground station should be validated by the contractor and accepted by the contracting agency.

The type of ground station antenna, antenna ground plane, and height of all test station antennas should be stipulated in the test plan prepared by the contractor. The characteristics of the ground station transmitters and receivers should be detailed, particularly the power output of the transmitters and the sensitivity of the receivers. For performance testing of communication equipment, it is desirable to use the same type of receiver/transmitter for the ground test station as is being tested in the air vehicle.

Communication subsystem tests should be conducted on a production air vehicle, preferably the first. The host air vehicle used for airworthiness qualification of the subsystem should be fully configured as specified in the contract and the air vehicle detail specification. The tests should demonstrate that the installation is satisfactory and that the communication subsystem meets or exceeds minimum performance requirements as specified in the contract. Information concerning the avionics airworthiness qualification may be found in MIL-I-8700, *Installation and Test of Electronic Equipment in Aircraft, General Specification for*, (Ref. 22) and consists of both ground and flight tests.

Antenna subsystems should be tested both on the ground and in flight. An antenna subsystem is the complete interconnection of the antenna, the transmission line (coaxial cable and connectors), radome, and all parts that serve to match, tune, isolate, erect, interconnect and protect the subsystem. For additional information, see MIL-STD-877, *Antenna Subsystem, Airborne, Criteria for Design and Location of*, (Ref. 23). From the standpoint of operational performance, the entire air vehicle is an essential portion of the subsystem.

Avionics—communications subsystem tests are further subdivided into external communications tests and internal communications tests in the two subparagraphs that follow. TEMPEST requirements apply to avionics—communications subsystems. These requirements deal with the control of classified data in order to prevent the exploitation of these data by enemy threat subsystems. TEMPEST testing is used to demonstrate the extent to which these data have been protected from being inadvertently disclosed to an enemy.

8-8.1 EXTERNAL COMMUNICATIONS

The objective of airworthiness qualification testing is to demonstrate that the air vehicle external communication subsystems perform all of the specified functions in the manner required by the contract. Typical qualification test objectives are to validate reliable and satisfactory two-way communications at the required distances on at least 10 frequencies spaced across each frequency band in question. Omnidirectional capability is typically required. The airworthiness qualification ground test program consists of a basic preflight test plus those tests necessary to establish that the avionic subsystem installation is satisfactory for airworthiness qualification flight tests and for the subsystem maintainability requirements. As discussed in par. 8-8, a ground test procedure including rejection criteria for each communication set should be submitted to the procuring activity for approval. The air vehicle to be tested should be fully configured as specified by the contract and the air vehicle detail specification.

Airworthiness qualification ground test activities and measurements typically include

1. Visual inspection to ensure proper installation
2. Avionics and antenna bonding checks; for information concerning this topic, see MIL-B-5087, *Bonding, Electrical, and Lightning Protection for Aerospace Systems*, (Ref. 24)
3. Cooling checks
4. Radio frequency (RF), output power, and voltage standing wave radio (VSWR) measurements
5. Transmitter modulation checks
6. Other functional checks to assure proper operation
7. Assurance of maintainability.

The airworthiness qualification flight testing measurements typically include evaluations of antenna patterns, communication performance at required distances, vibration characteristics, temperature, and cooling characteristics during all flight regimes.

Ground and flight cooling tests should be conducted to determine the maximum obtainable compartment temperatures for each communication set during service conditions. If air-conditioning or external cooling air is provided to avionic equipment, the testing should include operation of the avionics with simulated failures of the air- conditioning equipment and blowers. In addition, the outside air temperature (OAT), cockpit ambient temperature, and the compartment temperature should be recorded as a time history. The latter should be recorded during an acceptable duty cycle of the communication set with the air vehicle stationed on a runway and with the equipment turned on and then off. The temperature readings are necessary to establish that the actual operating and storage temperatures of the air vehicle do not exceed the design limits of the communications set under test. Worst-case storage and operating temperature data should be determined by extrapolation of measured data to the required ambient condition. Extrapolated data can then be compared with the design limits.

Ground measurements of RF output power and VSWR should be accomplished at 10 frequencies equally spaced over each band of interest, which should be the same frequencies used during flight testing. These measurements should be taken as closely as possible to both the transmitter and the antenna in order to obtain the power loss of the transmission line, the VSWR at the antenna element, and the VSWR of the entire antenna subsystem. It is necessary to measure the power on all of the flight test frequencies for comparison of the maximum operating range with actual power output of the transmitter. The test qualifications should stipulate the VSWR requirements.

Transmitter modulation should be checked for specific tolerances by using a normal voice into each microphone for each control station. End-to-end checks should be used in the secure modes of operation.

Both ground and flight operational tests should be performed to demonstrate reliable and satisfactory two-way communications on all flight test frequencies equally spaced across the bands. These should be the same frequencies used for ground test measurements and antenna tests. Communication quality and signal strength should be recorded during both types of tests. The same ground station should be used for both ground and flight communication tests. If the communication subsystem contains retransmission capabilities, the retransmission performance, quality, and levels also should be determined.

Performance flight tests of communication equipment should include measurements of communication quality and signal strength over a specified range and altitude to demonstrate that reliable two-way communication can be maintained to all points of azimuth. Quality and signal strength levels may be described as follows:

1. *Quality*. Unreadable; barely readable; readable, occasionally difficult; readable, no difficulty; perfectly readable.

2. *Signal Strength*. Faint to very weak; weak to fair; fair to good; good to medium strong; strong to extra strong. Speech intelligibility by using phonetically balanced monosyllabic word lists and other similar techniques also should be measured. The contractor should define the test approach to be used.

Performance flight tests of information friend or foe equipment should include verification by ground-based IFF equipment of proper replies to all modes of operation (1, 2, 3/A, C, and 4) over a specified range and altitude to demonstrate that reliable interrogations and replies can be maintained to all points of azimuth.

Both ground and flight testing are typically required for antenna subsystems. Ground tests of antenna subsystems are limited by reflections and ground effects. However, tests, such as VSWR, electrical bonding, mutual interference, impedance, and limited operational tests, are typically required. Each antenna should be checked, as a minimum, at the low, middle, and high end of its operational range for compliance with the specified performance requirements.

Antenna patterns may be measured by flying a cloverleaf flight plan or by flying a flat 360-deg flight turn (circular pattern). The advantage of the cloverleaf flight plan is the radial accuracy of the different headings flown during the test. The disadvantage is that a signal null might exist between two of the selected headings and would not be detected. By flying a circular pattern, a continuous monitoring of the antenna signal can be accomplished. If the circular pattern is used, the diameter must be small compared with the distance to the measuring station. It is also important that the center of the air vehicle circle be maintained over a known geographical point. The altitude above the ground must be as low as is necessary to maintain line-of-sight and good signal reception. For airborne transmitter antennas the signal-receiving and -measuring equipment may be installed at the ground station. However, for antennas to be used with receivers, it may be necessary to install the signal-receiving and -measuring equipment on the air vehicle if the power handling capability of the antenna is less than the power output of the transmitter. The most desirable and informative antenna patterns are those plotted from continuously recorded data for the entire 360-deg turn. Maximum-range should be conducted to determine the outbound and inbound range of the communication subsystems.

Vibratory tests should be conducted on each component of the communication subsystem during typical operating conditions—startup, hover, takeoff, normal flight at several typical altitudes, landing, and shutdown—at two or more typical gross weights. The components to be tested will be instrumented for the vertical, longitudinal, and lateral planes. Rotorcraft vibration generally extends to lower frequencies and to greater amplitude at these lower frequencies than the vibration of other aircraft. Therefore, test results should be obtained at these lower frequencies to ascertain that the subsystem is compatible with the rotorcraft.

8-8.2 INTERNAL COMMUNICATIONS

The internal communication subsystem airworthiness and typical qualification test objectives are intended to demonstrate that the internal communication subsystem allows the crew members to communicate with each other adequately.

TEMPEST requirements apply to internal communication of classified information; see subpar.7-10.5. These requirements deal with suppression of radiated signals that might emanate from electronic equipment in order to prevent the exploitation of these signals by enemy threat subsystems. TEMPEST testing is used to determine the extent to which these undesirable emanations are radiating have been eliminated from the subsystem

Measurements for internal communication include adequate switching capability for varying modes of operation, signal levels, and noise levels. These measurements are conducted by the flight test crew and typically are qualitative in nature. The data should demonstrate reliable and satisfactory operation of internal communication. If a subsystem is digital, the output signal to bus should also be checked.

8-9 AVIONICS— NAVIGATION

The purpose of this airworthiness qualification testing is to demonstrate that the air vehicle navigation equipment performs all of its functions as specified in the contract. The tests required to qualify a navigation subsystem are typically an extension of those performed on communication subsystems. As such, the airworthiness qualification test ground station for navigation subsystems is also validated. In many cases the tests can be accomplished concurrently because the equipment performs both communication and navigation functions. Generally, however, navigation tests will be more quantitative than communication tests. Also a greater variety of signal sources and types of output is used in airborne navigation. This results in a greater variation in test procedures than is found among communication subsystems. Three types of tests to demonstrate thoroughly the qualification of an airborne navigation subsystem are bench, preflight, and flight tests.

Navigation subsystem tests should be conducted on a production air vehicle, preferably the first. The test air vehicle should be completely provisioned with all avionic equipment. The tests should demonstrate that the installation is satisfactory and that the avionics meet or exceed minimum performance requirements as specified in the contract. Navigation subsystems should be bench tested in accordance with an approved test procedure before being installed in the test air vehicle. See Chapter 7 for additional guidance concerning component testing. The typical criteria for avionics airworthiness qualification tests—both ground and flight tests—may be found in MIL-I-8700 (Ref. 22). Ground testing should also include measurement of VSWR performance, and maintainability. Flight testing should include evaluation of antenna patterns, ranges, subsystem performances, vibration characteristics, and cooling characteristics throughout all flight regimes.

Objectively, the contractor should make use of commercially available specifications that the satisfy performance criteria of applicable military specifications. If commercially available specifications and standards are unsatisfactory, the contractor should prepare its own bench, preflight, production flight avionic airworthiness qualification test procedures. These test specifications should include pass/fail criteria and should be submitted to the procuring activity for approval. The electrical power required by each navigation subsystem should be measured to verify power consumption and thereby partially evaluate the air vehicle power generation and distribution subsystem. In some cases the contract might require full compliance with military specifications. Comply with the contract.

Ground tests of navigation antenna subsystems are limited by reflections and ground effects. However, tests, such as electrical bonding, impedance, and limited operational tests, should be accomplished. In the case of navigation antennas, such as an automatic direction finding (ADF) sense antenna, impedance measurements are necessary to verify that proper matching has been accomplished. Each antenna should be checked, as a minimum, at the low, middle, and high end of its operational range for compliance with the specified performance requirements.

Vibratory tests should be conducted on each component of the navigation subsystem during typical operating conditions—startup, hover, takeoff, normal flight at several typical altitudes, landing, and shutdown—at two or more typical gross weights. The components to be tested will be instrumented for the vertical, longitudinal, and lateral planes. Rotorcraft vibration generally extends to lower frequencies and to greater amplitude at these lower frequencies than the vibration of other aircraft. Therefore, test results should also be obtained at these lower frequencies to ascertain that the subsystem is compatible with the rotorcraft.

Ground and flight tests should be conducted to determine the maximum obtainable compartment temperatures for each navigation set during service conditions. If air-conditioning or external cooling air is provided to avionic equipment, the testing should include operation of the avionics with simulated failures of the air-conditioning equipment and blowers. In addition, the outside air temperature, cockpit ambient temperature, and the compartment temperature should be recorded as a time history. The latter should be recorded during an acceptable duty cycle of the navigation set with the air vehicle stationed on a runway and with the equipment turned on and then off. The temperature readings are necessary to establish that the actual operating and storage temperatures of the air vehicle do not exceed the design limits of the communications set under test. Worst-case storage and operating temperature data should be determined by extrapolation of measured data to the required ambient condition. Extrapolated data can then be compared with the design limits.

TEMPEST requirements apply to any form of navigation equipment that both transmit and receive. These requirements deal with suppression of radiated signals that might emanate from electronic equipment in order to prevent exploitation of these signals by enemy threat subsystems. TEMPEST testing is used to determine the extent to which these undesirable emanations are radiating from the subsystem.

The subparagraphs that follow discuss avionic navigation subsystem qualification requirements. Navigation subsystems are subdivided into inertial, Doppler, global positioning system (GPS), and broadcast, and hybrid. Navigation subsystems and systems should always be flight tested in three dimensions.

8-9.1 INERTIAL NAVIGATION SYSTEMS

The inertial navigation airworthiness and typical qualification test objectives are to substantiate that these subsystems perform within the performance requirements of the specification.

Inertial navigation systems measure and integrate sensed accelerations of the air vehicle to derive position. Inertial systems must be initialized, i.e., they must be provided information about their starting location, each time power is applied in order to function.

Measurements for inertial navigation subsystems include position errors. Position error varies with distance traveled and time elapsed since initialization. These errors should be measured as a function of position and time to characterize subsystem performance.

TEMPEST is typically required for inertial systems if the inertial system is integrated into the weapon system in such a way that position data become classified and are transmitted over the data bus and between other air vehicles or ground stations.

8-9.2 DOPPLER NAVIGATION SYSTEMS

The Doppler navigation airworthiness and typical qualification test objectives are to substantiate that these subsystems perform within the performance requirements of the specifications. Doppler navigation subsystems operate on the principle that a reflected radio signal frequency is altered if a velocity difference exists between the source of the signal and the surface from which it is reflected.

Doppler subsystem position errors tend to vary as a function of straight line distance from the initialization point to the position being measured. Doppler accuracy is also affected by the characteristics of the surface from which the Doppler return signal is being reflected. Test data should, therefore, include information on the terrain over which the air vehicle is flying during testing. These data should also include an estimate of sea state when flying over water.

8-9.3 GLOBAL POSITIONING SYSTEMS (GPS)

The GPS navigation airworthiness and typical qualification test objectives are to substantiate that these subsystems perform in accordance with their specified requirements at the subsystem level. Additional test objectives are to substantiate the ability of the subsystem to acquire and track the GPS signals within the specific limits for specified navigational accuracy. The GPS operates on the principle that position can be very accurately calculated by receiving multiple signals from sources whose spatial, temporal, and signal characteristics are very accurately known. The signals being received by the host subsystem are radiated from multiple satellites. System errors tend to be affected by phenomena such as satellite positions, signal strength, and atmospheric conditions. The GPS accuracy is not driven by distance traveled or time of flight as is the case with the previous navigation subsystems.

8-9.4 BROADCAST NAVIGATION SYSTEMS

The airworthiness and typical test objectives of broadcast navigation subsystems are similar to those of communication subsystems. In many cases the tests can be accomplished concurrently because the equipment performs both communication and navigation functions. Generally, navigation tests should be more quantitative than communication tests. Also a greater variety of signal sources and types of outputs is used in airborne navigation. This might result in a greater variation in test procedures from subsystem to subsystem than is found among communication subsystems. Typically, three types of tests are required to demonstrate thoroughly the qualification of an airborne navigation system—bench, preflight, and flight. The bench tests are checks of the operational status of the subsystem components. The preflight tests are performed to assure proper installation. The ability of a subsystem to perform a particular mission can be determined only by flight test, which both simulates operational usage of the subsystem and allows collection of accurate performance data. Environmental tests also are required. Types of rotorcraft navigation subsystems to be considered include VHF omnidirectional range (VOR) receiving subsystems, low-frequency ADF subsystems, frequency modulation (FM) homing subsystems, gyromagnetic compass subsystems, tactical air navigation (TACAN) and distance-measuring equipment (DME), long-range navigation (LORAN), OMEGA (a low-frequency navigation subsystem used for long-range navigation), and instrument landing subsystems (ILS).

Typically, VOR qualification testing includes but is not limited to bearing accuracy (manual and automatic), to/from flag operation, warning flag operation, audio quality, and control. Bearing accuracy tests are typically performed with at least three simulated VOR bearings and on at least two frequencies in the 108.0- to 118.0-MHz range. Rotor modulation tests should be conducted over the entire operational range. Also electromagnetic interference and vulnerability testing should be conducted.

The ADF qualification testing includes but is not limited to sense antenna matching, reception using sense antennas, frequency accuracy, beat frequency oscillator operation, tune meter operation, manual loop operation aural null in manual mode, appropriate indication action in ADF mode. Flight testing typically includes ADF bearing accuracy with loop compensation, bearing accuracy without loop compensation, ADF performance flight test at range and altitude, and overstation passage accuracy. Bearing accuracy should be determined for relative bearings of 0 to 360 deg in steps not to exceed 30 deg. Range tests should be performed in all modes of the ADF set and on at least three different frequencies. Overstation passage tests should be run in the ADF mode. Also electromagnetic interference and vulnerability testing should be conducted.

Gyromagnetic and standby compass subsystem qualification testing typically includes but is not limited to operational checks and performance testing, compass swinging (compensation) procedures, synchronization, slaving, and warning flag operation. Compass swinging should be accomplished on a surveyed compass rose. See MIL-STD-765, *Compass Swinging, Aircraft, General Requirements for*, (Ref. 25) for additional information concerning establishing requirements.

Residual compass errors are typically recorded on compass calibration cards for display in the rotorcraft. Also electromagnetic interference and vulnerability testing should be conducted.

The TACAN/DME qualification testing includes but is not limited to bearing accuracy (azimuth angle), distance accuracy (slant range), maximum operating range, to/from indicator operation, course deviation indicator operation, audio quality, and control. Bearing and distance accuracy tests apply to TACAN operating in the air-to-ground mode and are typically performed with at least two TACAN ground stations. Distance accuracy tests are also performed in the air-to-air mode with two or more air vehicles equipped with TACAN equipment. Also electromagnetic interference and vulnerability testing should be conducted.

LORAN-C and OMEGA/VLF qualification testing includes but is not limited to the following:

1. A ground test to establish the functional performance of the receiver while installed in the air vehicle under normal conditions as well as in all degraded conditions under which the receiver is designed to operate

2. Electromagnetic interference and vulnerability testing prior to flight test

3. A flight test to characterize the performance of the receiver. This flight test should consist of a minimum of six separate way points geographically separate from each other and to the maximum extent possible over differing terrain. Each way point should be over a location that is established through aviation charts or other reliable means. At each way point the rotorcraft should establish a stationary hover. While maintaining the hover, the rotorcraft should execute a pedal turn, pausing every 30 deg as a minimum to record the displayed position as indicated by the receiver. These position records should be compared with the actual position of the air vehicle at each point and the data reduced in order to determine average error.

4. If formal instrument flight rules (IFR) certification of the LORAN-C subsystem is desired, demonstration of compliance with the requirements of Federal Aviation Administration (FAA) Advisory Circulars (ACs) 20-121, *Airworthiness Approval of Airborne LORAN-C Navigation Systems for Use in the US National Airspace System (NAS)*, (Ref. 26) and/or 20-130, *Airworthiness Approval of Multisensor Navigation Systems for Use in the US National Airspace System (NAS) and Alaska*, (Ref. 27) is required. If formal IFR certification of the OMEGA subsystem is desired, demonstration of compliance with the requirements of FAA ACs 20-101, *Airworthiness Approval of OMEGA/VLF Navigation Systems for the United States NAS and Alaska*, (Ref. 28) and/or 20-130 (Ref. 27) is required.

The ILS qualification testing includes but is not limited to localizer and glide slope position accuracy, warning flag operation, course deviation indicator operation, marker beacon operation, audio quality, and control. Also electromagnetic interference and vulnerability testing should be conducted.

8-9.5 HYBRID NAVIGATION SYSTEMS

Hybrid navigation subsystem airworthiness and qualification test objectives are to substantiate that these subsystems perform in accordance with their specified requirements at the subsystem level. Additional objectives are to substantiate subsystem reliability, navigational accuracy, and the ability of the subsystem to compensate for various abnormalities and errors. Hybrid subsystems combine two or more types of navigation subsystems to achieve better performance than separate subsystems are capable of, usually at combinations of lower cost and smaller size and decreased weight. Error characteristics of hybrid subsystems may be dependent on any combination of the following:

1. Time since initialization
2. Distance traveled
3. Atmospheric characteristics
4. Broadcast source characteristics including position relative to the air vehicle
5. Terrain conditions
6. Sea state if over water
7. Jamming and/or spoofing.

Test conditions must be specified differently, dependent upon the various subsystems that make up the hybrid subsystem. An advantage of hybrid subsystems is that they can usually be used in backup mode(s) when designed well. An example of this would be a Doppler/GPS subsystem that can operate in two backup modes: Doppler only when GPS is not available and GPS only when part or all of the Doppler subsystem is inoperable. Hybrid subsystems should be tested in each of their backup modes. The ADS-41, *Hybrid Navigation System Performance Flight Testing; Rotary-Wing Aircraft*, (Ref. 29) provides useful information concerning flight testing and evaluation of hybrid navigation subsystems.

8-10 CREW STATION DISPLAYS AND CONTROLS

The man/machine interface between crew station displays and controls is crucial to safe and proper subsystem operation. Improper design might adversely affect not only the operator's workload but also the safety characteristics of the subsystem. A properly designed crew station should consider the impact of human factors on crew efficiency and overall subsystem performance. The implementation and integration of mission equipment, controls and displays, lighting, and communications is instrumental to determining the efficiency and effectiveness of the overall weapon subsystem. For example, the lethality of a weapon may not be important if it cannot be delivered in a timely manner by the crew. The following paragraphs discuss specific aspects of these interfaces. (Also see subpar. 6-3.3.)

8-10.1 FLIGHT DISPLAYS

The airworthiness and typical qualification test objectives of the flight display subsystem are to substantiate that the flight displays satisfy all man/machine and environmental interface and performance requirements for safe operation during all required missions. The factors that establish flight-critical instrumentation allow the pilot to maintain control of the air vehicle safely during all situations. These include timing latency in the displays and integration of these displays within the cockpit. For example, requiring the pilot to move his head to operate essential equipment may cause pilot disorientation during operation under instrument meteorological conditions. Heads-up displays are an example of flight displays that usually contain flight-critical information. Flight-critical information usually includes, as a minimum, such information as air vehicle attitude, airspeed, and direction of flight.

Assessment of flight displays are primarily qualitative as to their functionality. In addition to the man/machine interface requirements, flight instruments are typically qualified as part of the various subsystems. Also electromagnetic interference requirements should be satisfied.

Par. 6-10 provides information on the use of modeling and simulation techniques to evaluate instrumentation characteristics.

8-10.2 FLIGHT CONTROLS

The flight controls subsystem airworthiness and typical qualification test objectives are to demonstrate that the air vehicle can be safely operated throughout its designated flight envelope. Human factors, such as control position extremes, location relative to pilot position, and flight controls switch locations and functions, should be evaluated.

Measurements for flight controls subsystems include the force required to activate the controls, the degree of feedback provided to the operator, and the maximum actuator rate at various load conditions. These measurements are generally obtained in conjunction with handling qualities testing.

Subpar. 6-3.3 provides information on the use of modeling and simulation techniques that may be used to evaluate flight controls.

8-10.3 COCKPIT AND INSTRUMENT LIGHTING

The cockpit and instrument lighting subsystem airworthiness and typical qualification test objectives are to demonstrate that the air vehicle and subsystems can be safely and effectively operated during night missions and with and without night aiding devices.

Measurements for cockpit and instrument lighting subsystems include brightness measurements and the degree to which brightness may be controlled and adjusted.

Subpar. 6-4.8 provides information regarding test setup and measurement.

ADS-23, *Lighting, Aircraft, Interior, AN/AVS-6 Aviators Night Vision Imaging System Compatibility*, (Ref. 30) provides relevant information concerning night vision goggle compatibility testing. Items to be verified include

1. Spectral radiant flux
2. Uniformity and balance
3. Brightness ratio
4. Dimming control
5. Veiling glare
6. Halo effect
7. Spectral reflections
8. Mode select switching
9. Priority of notice
10. Aircrew station signals
11. Internal surfaces and decals
12. Internal reflections
13. Power.

8-10.4 ELECTRONIC NETWORKS

The electronic network subsystem airworthiness and typical qualification test objectives substantiate that electronic-data-bus-controlled subsystems satisfy specification requirements and can be adequately controlled and operated.

Electronic networks provide a means for digital communications among various air vehicle subsystems. MIL-STD-1553, *Aircraft Internal Time Division Command/Response Multiplex Data Bus*, (Ref. 31) provides useful information for the data bus lines and interface electronic equipment. High-speed data buses should also be considered. MIL-HDBK-1553, *Multiplex Application Handbook*, (Ref. 32) provides useful information relevant to MIL-STD-1553 (Ref. 31) subsystems. Information concerning establishing interface requirements for interconnection and stores on air vehicles is contained in MIL-STD-1760, *Aircraft/Store Electrical Interconnection System*, (Ref. 33). Society of Automotive Engineers AS 4115, *Data Bus Systems Plan*, (Ref. 34) provides additional requirements for data bus testing.

Network control is a function of bus loading and latency. Data latency refers to the fact that a finite amount of time is required to transfer digital information from its source to its destination. The amount of time required is a function of the loading on the bus, i.e., the amount of bus traffic activity. Data latency results when the data reaching their destination is no longer valid or representative of the state of the system. Data latency effects may be modeled through simulations, such as time step simulations, to determine the latency effects on overall system performance.

Measurements for electronic network subsystems include but are not limited to data transfer and error rates and latency. These parameters are measured through the use of bus monitors while functioning all subsystems in an operational representative environment and duty cycle.

8-10.5 VOICE INTERACTIVE SUBSYSTEMS

The voice interactive subsystem airworthiness and typical qualification test objectives are to substantiate that the voice interactive system is capable of performing its intended function with all typical users.

Voice interactive systems provide the capability for the crew to control certain functions by issuing voice commands. This technique has the potential to reduce the crew's workload greatly. The critical characteristic of a voice interactive system is the capability to repeat consistently and accurately the appropriate response given a variety of individuals commanding the response.

Measurements for voice interactive subsystems include the size of the vocabulary of the system and the accuracy with which the subsystem is able to accept voice commands. In addition, the ability of the system to adapt to the voices of the total population of potential crew members should be evaluated.

8-10.6 MISSION EQUIPMENT PACKAGE COCKPIT INTEGRATION

The mission equipment package cockpit integration airworthiness and typical qualification test objectives are to demonstrate that all mission equipment has been integrated as needed to meet or exceed performance and interface requirements.

Measurements for mission equipment package cockpit integration is often qualitative in nature. A key item of interest is, "Can the crew member easily and consistently use a subsystem when required during all phases of operation?".

8-10.7 VISIBILITY

Aircrew visibility performance requirements should be provided in the air vehicle specification. Aircrew visibility, especially over the nose of the air vehicle, should not be restricted by the location of controls, consoles, and instrument panels. Also visibility should not be restricted by mounting and reinforcing strips that might be used to divide transparent areas. (See MIL-STD-850, *Aircrew Station Vision Requirements for* Military *Aircraft*, (Ref. 35) for additional information and guidance.)

Aitoff plots are a means of depicting the field of view from an air vehicle crew station. The plot depicts the limits of the field of view (in degrees from design eye position), and it is plotted onto a spherical plot. The contractor should demonstrate that the minimum angles of unobstructed vision illustrated in Fig. 8-2 and Fig. 8-3 are available to the pilot from the design eye position.

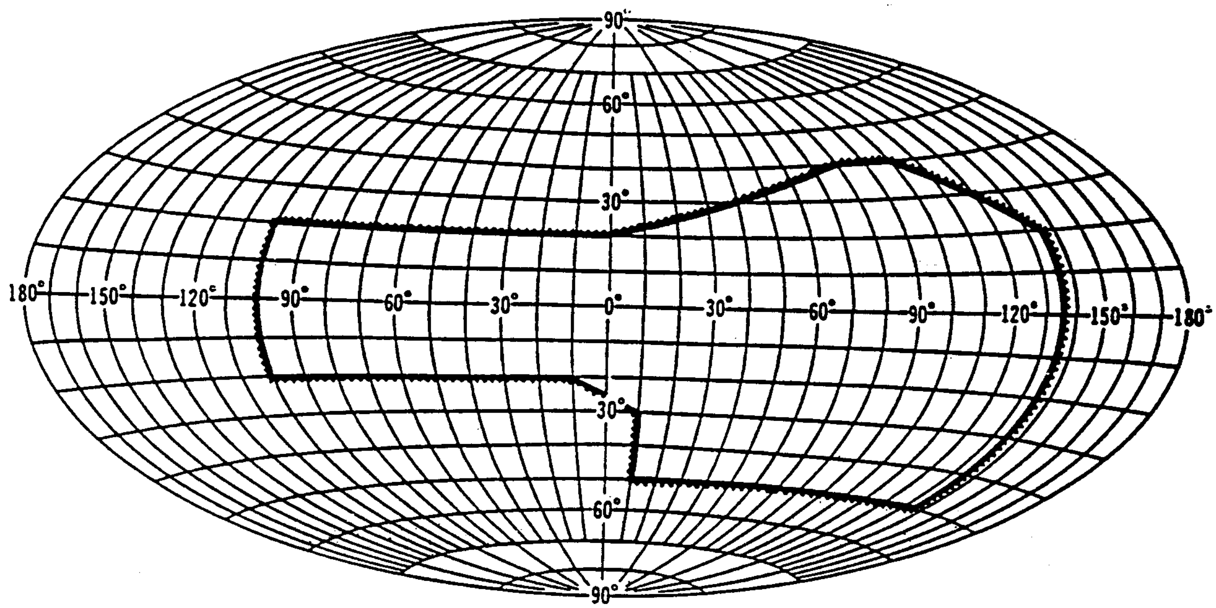

Figure 8-2 Side-by-side Helicopter Vision Plot

8-10.8 FLIGHT CREW VISIONICS

The flight crew visionics airworthiness and typical qualification test objectives are to demonstrate that the air vehicle can be safely operated using the visionics systems.

Targeting forward looking infrared (FLIR) subsystems have been adapted to provide the flight crew with visionics capability. The FLIR subsystem provides a visual representation of the thermal scene in front of the air vehicle. Such subsystems include helmet-mounted displays and imaging sensor slewing capability slaved to helmet motion. Human factors considerations and counter-countermeasures should be carefully assessed due to the critical nature of the man/machine interfaces involved in night pilotage by means of a visionics system. Slew rates of the helmet display and visual presentation of the visionics scene that is displayed to the pilot in relation to the real-world conditions are critical human factors concerns that relate to man-in-the-loop safe operation of the air vehicle.

Measurements for flight crew visionics include range and field-of-view capability of the subsystem and the degree to which the flight crew is able to perform the mission at night. Other considerations that determine mission performance capability is the subsystem image resolution contrast and the accuracy of the helmet position tracking.

8-10.9 PROPULSION CONTROLS

The propulsion controls airworthiness and typical qualification test objectives are to substantiate that the propulsion subsystem can be adequately controlled throughout the flight envelope. Propulsion control may be accomplished through the use of analog controls or digital controls. Digital control systems require qualification of the propulsion control system as well as qualification of the

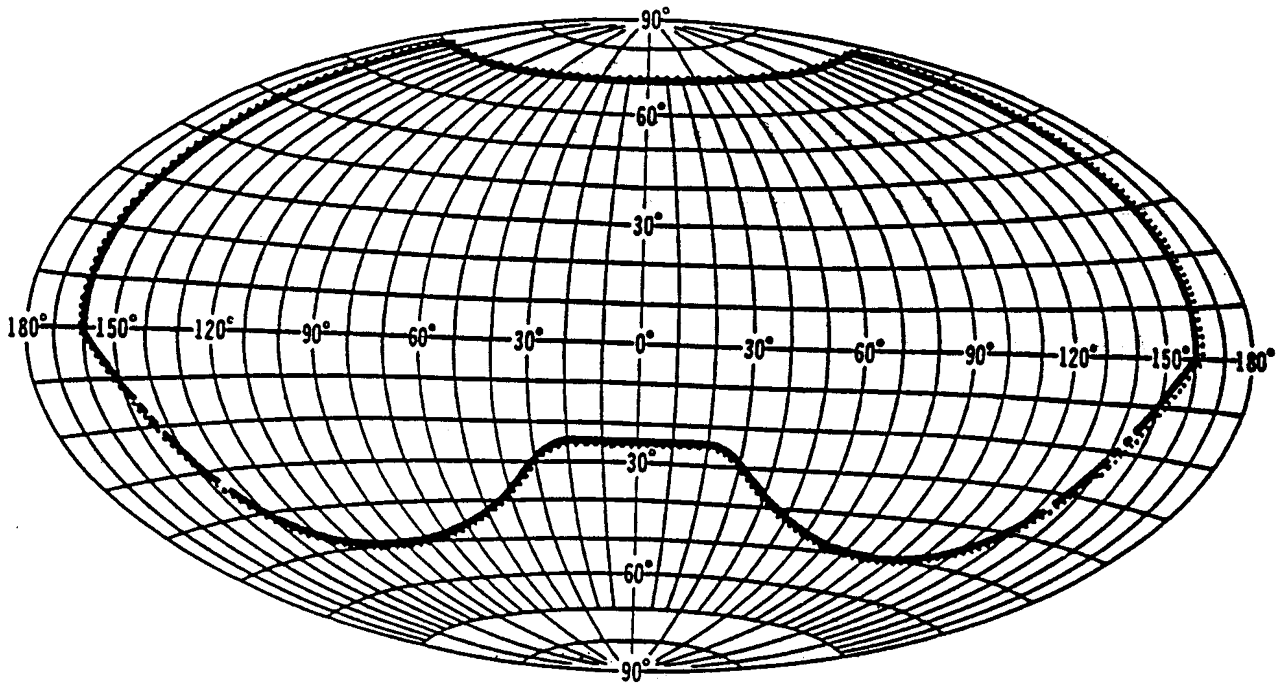

Figure 8-3 Single Pilot and Tandem Pilot Helicopter Vision Plot

software. Changes to the control software may also require requalification of the propulsion system. Qualification requirements increase as the authority of control increases. (See subpar. 6-4.5.4 for additional information.)

Measurements for propulsion controls include the force and response time necessary to accomplish propulsion control functions. These measurements should be taken during maneuvers and at the environmental conditions that represent the total flight envelope as closely as possible.

8-11 CREW STATION EQUIPMENT AND FURNISHINGS

The purpose of crew station equipment and furnishings airworthiness qualification testing is to demonstrate that all performance requirements of the air vehicle detail specification have been met and also that the crew can accomplish all functions necessary for the assigned missions. These qualification tests should also demonstrate the adequacy of personnel accommodations. A female aircrew in the 5th percentile in seated height and reach and a male aircrew in the 99th percentile in seated height and reach (Ref. 36) wearing the worst-case equipment and clothing—normally body armor and arctic clothing—should be able to perform all required functions when seated at each normal flight station with shoulder harness and seat belt fastened. See Chapter 6 for additional information and guidance.

MIL-STD-850 (Ref. 35) should be used for information concerning specifying aircrew station vision performance requirements for Army air vehicles. The particular air vehicles and mission requirements might necessitate external vision angles greater than those defined in MIL-STD-850 (Ref. 35) due to approaches over critical barriers, confined autorotations, etc. If greater angles are needed, they should be stated in the requirements portion of the contract. See subpar. 8-10.7 for additional information and guidance. The noise within the crew compartments should not exceed the maximum allowable performance defined in MIL-STD-1294, *Acoustical Noise Limits in Helicopters*, (Ref. 37) and MIL-A-8806, *Acoustical Noise Level in Aircraft, General Specification for*, (Ref. 38), as applicable. MIL-STD-1474, *Noise Limits for Military Materiel (Metric)*, (Ref. 39) also contains useful information concerning noise limits.

Evaluation of the seating and furnishings of the air vehicle should be accomplished insofar as is possible through detailed electronic mock-up evaluation; see Chapter 6. Satisfaction of all structural performance requirements should be demonstrated through engineering tests that involve stress analysis, laboratory test (shake table, etc.), and any destructive testing that might be needed. Further considerations to be evaluated are

1. Escape provisions
2. Comfort features
3. Restraint subsystem
4. Adjustment features
5. Passenger accommodations as they vary from pilot and crew accommodations
6. Protective armor, if applicable
7. NBC protection
8. Supplemental oxygen
9. Variable crew-mounted mission/survival equipment.

The crew seat subsystem should provide survivability from crash and ballistic threats. A variable energy attenuation feature should be incorporated to provide discrete adjustment for the Army aviator. Useful information may be found in MIL-S-58095, *Seat System, Crash-Resistance, Nonejection, Aircrew, General Specification for*, (Ref. 40). Additional information can be found in MIL-S-85510, *Seats Helicopter Cabin, Crashworthy, General Specifications for*, (Ref. 41). Protective armor should satisfy the requirements of MIL-STD-1288, *Aircrew Protection Requirements Nonnuclear Weapon Threat*, (Ref. 42). This is a military-specific requirement; however, a waiver is needed to cite this standard in a contract. Specific performance criteria should be included in the statement of work and specification. Unless otherwise specified by the PA, the seats for other aircraft should satisfy the requirements stated in Sections 25.561, 25.562, and 25.785 of Title 14, Code of Federal Regulations, Part 25, *Airworthiness Standards: Transport Category Airplanes*, (Ref. 43). Emergency escape and rescue design features should be tested and demonstrated. The PA should require emergency escape and rescue design criteria as specified in Technical Report (TR) 89-D-22A, *Aircraft Crash Survival Design Guide, Vol. 1, Design Criteria and Checklist*, (Ref. 44). However, for off-the-shelf, nondevelopmental aircraft the PA may be willing to accept aircraft and emergency escape and rescue design features that satisfy Title 14, Code of Federal Regulations, Part 23, *Airworthiness Standards: Normal Utility, Acrobatic, and Commuter Category Airplanes*, (Ref. 45); Part 25, *Airworthiness Standards: Transport Category Airplanes*, (Ref. 43); 14 CFR, Part 27, *Airworthiness Standards: Normal Category Rotorcraft*, (Ref. 46); and 14 CFR, Part 29, *Airworthiness Standards: Transport Category Rotorcraft*, (Ref. 47), as applicable to the type of air vehicle. All contractually required emergency escape and rescue design features should be demonstrated or tested. Satisfactory ingress and egress for crew members should be demonstrated. There should be minimum difficulty of movement and probability of damage to or fouling of equipment, clothing, etc. Doors and hatches should be tested. The possibility of damage or fouling of the equipment should be demonstrated to be remote. Personnel participating should wear the heaviest clothing and carry the maximum equipment consistent with the mission. Also the evacuation provisions that follow should be tested or demonstrated:

1. Simplicity (simplest escape mode consistent with safety and effectiveness)
2. Cutaway areas clearly marked
3. Evacuation aids, such as adequate handholds
4. Quick-opening doors and hatches, easily operated
5. Doors and hatches operable with either hand with no more than two distinct and different motions
6. Adequate survival equipment provided
7. Easy breakaway of cockpit and aircrew connections.

8-11.1 AVIATION LIFE SUPPORT EQUIPMENT (ALSE)

The US Army makes use of a variety of specialized ALSE such as nuclear biological, and chemical (NBC) filtration systems; chemical and biological (CB) protective masks; CB protective clothing; laser eye protection; personal armor; air bags; restraint subsystems; survival vests; personal weapons; water survival equipment; oxygen subsystem; helmets; and helmet visors for its personnel and air vehicles. The oxygen subsystem and the helmet subsystem are discussed in the subparagraphs that follow.

8-11.1.1 Oxygen System

An oxygen subsystem might be needed for high-altitude search and rescue missions, use in an NBC environment, or similar missions utilizing air vehicles with unpressurized cabins. See subpar. 8-11.5 for other ALSE considerations.

Typically, US Army oxygen subsystems are of the pressurized bottle (gaseous) type. As a minimum, oxygen-breathing provisions should be provided for the pilot and copilot positions. The PA should specify whether additional provisions might be needed for transport-type rotorcraft. The PA should require that the air vehicle contractor (AC) qualify the oxygen subsystem and pressurized bottles (if any). The bottles usually are wrapped with wire or another suitable material to help prevent and contain an explosion. The oxygen subsystem should satisfy the applicable performance requirements of US Air Force Guide Specification (AFGS) -87226, *Oxygen Systems, Aircraft, General Specification for*, (Ref. 48). Also MIL-D-8683, *Design and Installation of Gaseous Oxygen Systems in Aircraft, General Specification for*, (Ref. 49) contains useful information concerning defining performance and validation requirements for oxygen subsystems. Onboard oxygen subsystems that satisfy the requirements of MIL-D-85520, *Design and Installation of Onboard Oxygen Generating Systems in Aircraft, General Specification for*, (Ref. 50) have been successfully investigated and demonstrated on Army rotorcraft.

Basically, onboard oxygen-generating subsystems use filtered engine bleed air as an oxygen source. However, some engines do not have sufficient bleed air to satisfy this function. Many (but not all) US Army aircraft operate at higher altitudes and have pressurized cockpits. These aircraft should have an integrated gaseous oxygen subsystem that fulfills the supplemental oxygen requirements of Title 14, Code of Federal Regulations, Part 91, *General Operating and Flight Rules*, (Ref. 51). Subsystem outlets should be located at all seat locations including the toilet compartment. Demand-type, quick-donning oxygen masks compatible with the selected headset and meeting Technical Standard Order (TSO) 78, *Crew Member Demand Mask Oxygen*, (Ref. 52) and regulators meeting TSO-89, *Oxygen, Regulator Demand*, (Ref. 53) have typically been installed, one each for the pilot and copilot within arms reach. Passenger masks should be furnished at all other outlets. In the event of cabin depressurization, the oxygen subsystem capacity should be sufficient for the crew and all passengers to permit an emergency descent (15-min minimum required) from the highest Federal Aviation Administration (FAA) certifiable altitude to 3960 mm (13,000 ft) (or below). In addition, sufficient oxygen should be available to permit the pilot and copilot to breathe normal demand oxygen during the return flight.

Typically, qualification test objectives are to substantiate that the oxygen supply equipment meets specified performance requirements, satisfies the physiological needs of the crew and passengers for all expected operations, subsystem does not leak, pressure regulation and flow at each station are adequate, cleanliness of the subsystem is adequate, safety relief subsystems are available and fully functional, and retention mechanisms are structurally adequate. Specific requirements should be specified in the air vehicle specification and Airworthiness Qualification Specifications.

8.11.1.2 Helmets

Critical characteristics of helmet subsystems include but are not limited to weight and center of gravity location; adequate impact and noise protection; and compatibility with chemical and biological protective masks, laser protective shields, night vision goggles, the optic and helmet sight subsystem, and heads-up display subsystems. The PA usually requires use of the HGU56/P helmet. Typical qualification testing should include form, fit, and function testing, which includes human factors evaluations, vision plots, impact tests, proper alignment, validation of weight and center of gravity location, validation of adequate noise attenuation, adequacy of laser protection, and compatibility with other ALSE equipment. Measurements for helmets include mass characteristics, comfort, and degree of head protection provided by the helmet. See subpars. 8-11.2 and 8-11.5 for additional human factors and ALSE considerations.

8-11.2 HUMAN FACTORS

Human factors performance and validation requirements should be clearly specified in the air vehicle and airworthiness substantiation specifications. Ultimately, it is the contractor who is totally responsible for design and for meeting specified performance. The contractor's integrated system engineering process should address human engineering design criteria, principles and practices to achieve mission success and allow safe, reliable, and effective performance by operator, maintainer, and support personnel. Validation of human factors requirements is typically accomplished by human factors analysis, visibility plots, anthropometrics, and analysis of control locations. Virtual prototyping, etc., can be used as an alternative to nonfunctional mock-ups. ADS-30, *Human Engineering Requirements for Measurement* *of Operator Workload*, (Ref. 54) provides useful information for measurement of operator workload; however, it does not include the performance requirements. The contractor can develop and propose other means as needed to demonstrate compliance.

8-11.3 CREW STATION CRASHWORTHINESS

Crashworthiness encompasses all design features and characteristics intended to ensure crew protection in the event of a crash. Crashworthy seats provide protection to the crew member by absorbing energy. Typically, crew members are retained in their seats by a five point restraint belt system. Assemblies and components located within the crew station should be adequately retained during a crash to avoid their becoming projectiles. Helmets should be capable of withstanding specified impacts. Also devices such as air bags and the inflatable body and head restraint subsystem (IBAHRS) have been investigated. The IBAHRS is a crash-activated inflatable restraint subsystem. Also crew station equipment, seats, etc., should be adequately retained to minimize the potential for injury. Adequate clearance should be provided to avoid head and body injuries during sudden stops. Provisions and procedures for evacuation provide a means to minimize the effects of a crash. The adequacy of provisions and procedures for evacuation should be demonstrated.

8-11.4 FLIGHT DATA RECORDER

The flight data recorder airworthiness and typical qualification test objectives are to demonstrate that the subsystem reliably records specified parameters and is capable of withstanding crash conditions, such as those associated with deceleration forces and extreme temperature. The flight data recorder should withstand specified vibrations including but not limited to gunfire-related vibrations. Embedded software should be verified and validated. Adequate reliability and maintainability should be demonstrated. Measurements for flight data recorders include the parameters recorded, the accuracy of the data, and the total data-recording capacity. Typical parameters to be recorded are altitude, airspeed, pitch, roll, yaw, pitch rates, roll rates, yaw rates, rotor rpm, engine torque, and control positions. However, it is feasible to monitor a much larger number of parameters. The specification should define what parameters are to be recorded. Typically, at least a one-hour capacity should be provided for air vehicle parameters. Also crew member voice recording of not less than 30 min with overwrite capability should be provided.

8-11.5 ENVIRONMENTAL CONTROL

Cockpit and cabin climatic conditions may be controlled by a variety of cooling, heating, and filtration methods. However, operation within a nuclear, biological, and chemical environment requires specialized equipment. The NBC agents should either be kept out of the cockpit or the crew should wear protective clothing. Typically, protective clothing has been used to provide the necessary protection; however, this clothing tends to be uncomfortable and cannot be donned in flight. The US Army has been investigating and developing an aircrew microclimate conditioning subsystem as protection against heat stress when operating with NBC protective clothing. Its purpose is to regulate body core temperature. Also a cockpit overpressurization system might be used to help keep NBC contaminants out of the cockpit. The overpressurization subsystem should have the capacity to compensate for various forms of cockpit leakage.

Airworthiness and qualification test objectives typically are to demonstrate adequate space, power, weight, body core temperature, filtration, compatibility with other equipment, and a variety of human factors considerations.

Cabin heating, ventilating, and air-conditioning subsystems should satisfy the performance requirements of the rotorcraft detail specification. Information concerning ground and flight demonstrations can be found in MIL-H-18325, *Heating and Ventilating Systems, Aircraft, General Specification for*, (Ref. 55) and MIL-T-18606, *Test Procedures for Aircraft Environmental Systems*, (Ref. 56).

A crew environmental survey should be conducted. The objectives of this survey are to verify that the crew station environmental control subsystem (ECS) is adequate to control the cabin environment and also to assure minimum human performance degradation within the operating environment and mission flight profile of the rotorcraft. Typically, this is demonstrated by climatic hangar, ground, and flight tests, as appropriate. The suitability of the crew station environment should be verified under the extremes of the projected mission environment. Tests should be structured to give quantitative results whenever possible. Environmental parameters for crew stations are

1. Crew station surface and ambient temperature distribution
2. Airflow velocity, particularly at each passenger station
3. Air supply toxicity and contamination
4. Emergency smoke removal
5. Temperature and airflow measurement relative to defogging and deicing of crew station windshield and window areas
6. Wet-bulb temperature
7. Solar radiation black globe temperature
8. Dry-bulb temperature.

Items 6, 7, and 8 should be used to determine wet-bulb globe temperature (WBGT), which is the heat stress index preferred by the Army. The wet-bulb temperature is measured using only ambient convection for evaporation, and the dry-bulb temperature is measured with a shaded thermometer. The solar radiation black globe thermometer measures the temperature at the center of a 152-mm (6-in.) diameter copper sphere whose exterior surface has been painted flat black. Relevant information can be found in TB MED No. 507, *Occupational and Environmental Health Prevention, Treatment, and Control of Heat Injury*, (Ref. 57).

Climatic hangar tests of the rotorcraft crew compartment are conducted to determine the performance compliance of each environmental subsystem. Normal and extreme temperature ranges are evaluated at static sea-level conditions. Climatic conditions, including varying humidity levels, can be simulated at a temperature range of from –54° to 71°C (–65° to 160°F). Heavy and/or freezing rain can be simulated at the required temperature conditions to evaluate transparent area anti-icing, defrosting, defogging, and rain removal subsystems. The operating capability of all ECS equipment can be demonstrated in the Eglin Air Force Base, FL, climatic hangar at the required 71°C (160°F).

Defogging and anti-icing performance and time constraints and validation requirements should be specified in the air vehicle specification and AQS. Information concerning these requirements can be found in MIL-T-5842, *Transparent Areas on Aircraft Surfaces (Windshield and Canopies), Rain-Removing and Washing Systems for Defrosting, Deicing, Defogging,* *General Specification for*, (Ref. 58) and MIL-T-18607, *Thermal and Fluid Anti-Icing Systems and Equipment, Aircraft External Surfaces*, (Ref. 59) including a visual inspection of the general construction and serviceability of the subsystem. Prior to the installation of an anti-icing or deicing, defrosting, or defogging subsystem, the contractor should submit for approval by the procuring activity a report showing a schematic drawing of the proposed subsystems and all design data necessary to comply with the requirements. These data should be detailed and should show the methods used to arrive at the necessary capacity of the subsystems, an explanation or description of subsystem operation, the heat requirements, and the heat distribution and airflow considering various altitudes, conditions of flight and ground operation, and effect of personnel comfort as outlined in MIL-T-5842 (Ref. 58). The report should also include items, such as an outline of the type and location of the instrumentation, conditions of test, and methods of tests. The instrumentation should be adequate to determine heat flows through the area, to determine the dew point at each transparent area, and to ensure that any area will not be overheated. The windshield anti-icing tests typically consist of laboratory and flight tests. Information concerning these tests can be found in MIL-T-5842 (Ref. 58). The quantity of heat applied to the windshield should be checked in flight to ensure that the quantity required (determined during laboratory tests) actually is available. An accepted method used to determine heat flow is to measure the inside and outside surface temperatures of the transparent area and measure the effect of the OAT. If the thermal properties of the transparent area are known, the heat flow can be determined. The accuracy of this method depends upon the available temperature differential, the external heat transfer coefficient, the ice accumulation rate, and whether steady state conditions have been attained. When ducting is used in any part of the subsystem, it should be tested for flow rate, temperature drop, pressure drop, and duct leakage, and the methods and instrumentation used by the contractor should be outlined.

Compliance with the ECS requirements should be established during flight test operations. Certain ground tests not normally conducted at the climatic hangar at Eglin Air Force Base, FL, also should be performed. Testing to determine compartment contamination levels should be performed during ground operation with all engines operating and the air vehicle stationed at a wind heading most likely to ingest contaminants into the cabin air supply. Air samples should be collected with the doors and windows of the air vehicle closed and also with the doors and windows open or removed (if applicable). The standards and exposure criteria applicable to toxic fumes testing by the US Army are basically governed by Title 29, Code of Federal Regulations, Part 1910.1000, Subpart Z, *Toxic and Hazardous Substances, Air Contaminants, Permissible Exposure Limits*, (Ref. 60) and Department of Defense Instruction (DoDI) 6055.1, *DoD Occupational Safety and Health Program*, (Ref. 61). The Army Surgeon General (TSG) can specify alternative standards in place of the Federal Code where special considerations must be applied due in part to the character of the military exposure environment, which can differ materially from exposures experienced by other populations. For example, the transient nature of some military exposures when combined with the uncertainties of the synergistic effects of simultaneous exposure to several gases can provide for entirely different criteria than specified in the Federal

Code. Finally, there is the category of standards and criteria that is not only unique to the military environment but is also singular to military populations, such as the standard for exposure to carbon monoxide. Typically, the Army Surgeon General makes the final decision regarding acceptability of concentrations of measured contaminants.

Flight test operations should be conducted to evaluate the controllability and the capacity of each environmental control subsystem throughout the flight spectrum during weapons firing. Specifically, airflow velocity conditions at cruise altitudes should be established. Temperature control response characteristics should be determined by manually setting the temperature control adjustment above and below the design setting. Air vehicles equipped with combustion heaters should be tested at flight and atmospheric conditions that require intermittent or low output heating operations. The fail-safe characteristics of the environmental control subsystem should be demonstrated by simulating failures of the power source supplied to the temperature or airflow controls. Heating, cooling, and ventilation subsystem capacity should be verified by operating the air vehicle at the most critical design speed and altitude.

Heating subsystem flight tests should be conducted at night to eliminate solar effects; also there should be minimum electrical and personnel loads within the compartment. Air-conditioning and ventilation (cooling) tests should be conducted in conditions as close as possible to those on the outside design curve in Fig. 8-4 with solar radiation and simulated maximum personnel and electrical heat loads. Subsystem performance tests should be conducted with a minimum of 75% of the passenger and crew accommodations occupied during cooling tests and a maximum of 10% of the passenger accommodations occupied during heating tests. Instrumentation should be provided to determine the temperature distribution within all occupied spaces of the air vehicle, all electronic equipment bays, and all compartments. Instrumentation should be provided to determine the velocity of flow in all occupied compartments under all conditions.

Tests should be conducted to demonstrate satisfactory flight procedures for smoke removal. Also an investigation of the cleanliness of the air supplied to the cabin should be made by collecting air samples in an evacuated container and analyzing the contents in a laboratory. Sufficient samples should be obtained to cover all flight conditions under which contamination might exist. The moisture content of the air in both crew and passenger compartments also should be determined. Test personnel should be equipped with suitable masks during this program. Tests should be conducted to demonstrate safe and satisfactory performance of the subsystem and equipment under the following conditions:

1. Climb
2. Descent
3. Level flight
4. Maneuvering flight
5. Hover (in-ground effect (IGE) and out-of-ground effect (OGE)).

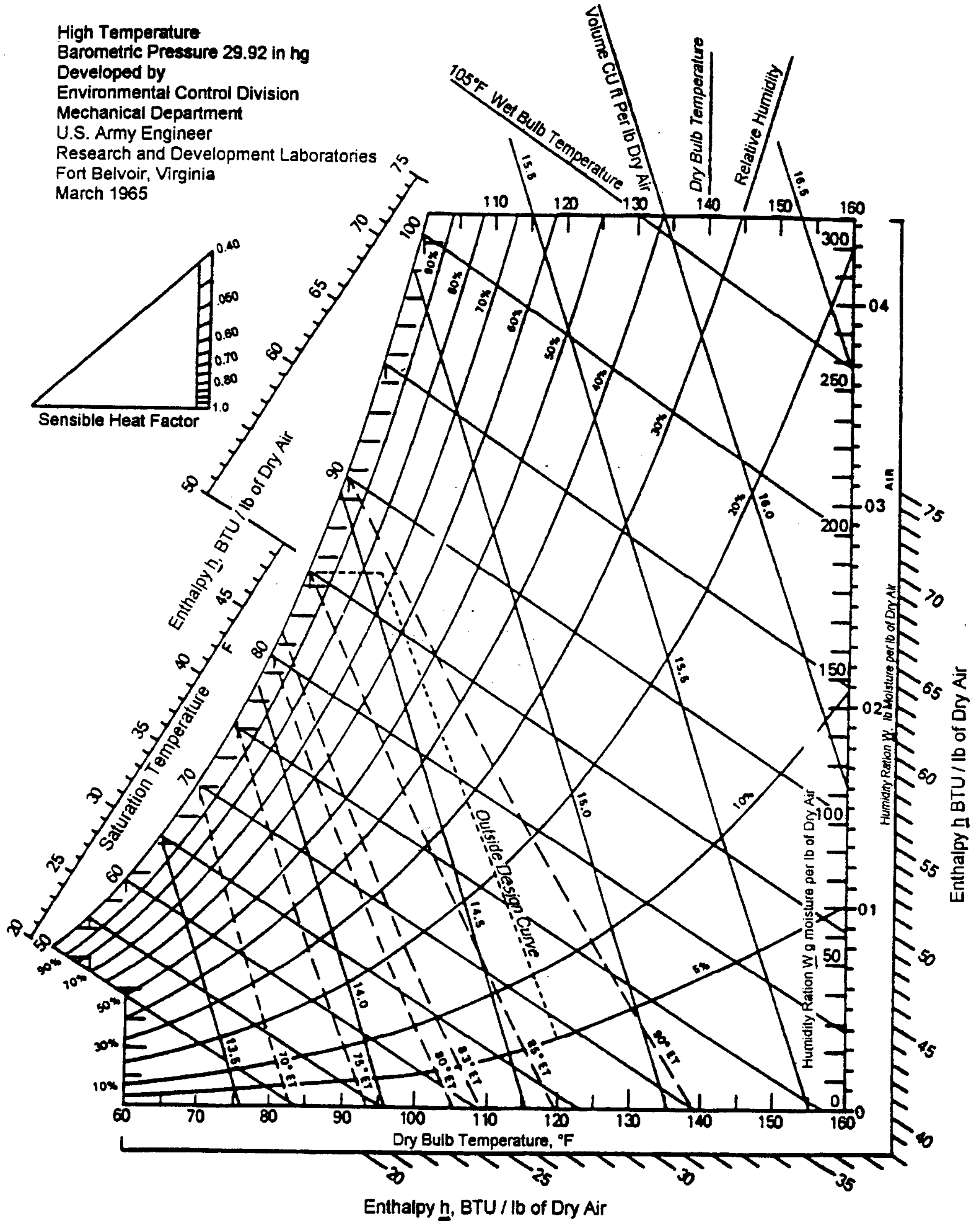

Fig. 8-4 U.S. Army Psychrometric Chart

Also contamination characteristics of the compartment air supply should be established during fueling, fuel jettison operations, and weapons firing. The air vehicle contractor usually prepares a plan in accordance with the CDRL. Also the air vehicle contractor usually collects air samples, performs analyses, and makes recommendations to the Government. Typically, air samples are analyzed for the following substances:

1. Ammonia (NH_3)
2. Carbon monoxide (CO)
3. Carbon dioxide (CO_2)
4. Nitric oxide (NO)
5. Nitrogen dioxide (NO_2)
6. Nitrogen (N_2)
7. Volatile organics.

The US Army Environmental Hygiene Agency is also capable of performing tests and analyzing the results. It has been recommended that air samples be compared to the more stringent of either the Occupational Safety and Health Administration (OSHA) permissible exposure limits (PEL) (Ref. 60) or the emergency and continuous exposure guidance levels (EEGLs) contained in Vols. 4 and 5 of the *Emergency and Continuous Exposure Guidance Levels for Selected Airborne Contaminants*prepared by the Committee on Toxicology (COT) of the National Research Council (Ref. 62). The COT EEGLs are recommended for use as criteria for the exposure of military personnel to toxic substances during military-unique situations or operations for which regulatory agencies have set no standard and typical 8-h per day workplace standards are not appropriate. The COT EEGL is a recommended exposure level at which Army personnel can continue to function and be unlikely to suffer irreversible effects.

The measurements that follow should be recorded during all ECS and ventilation subsystem tests:

1. Ground ambient dry-bulb temperature
2. Ground ambient wet-bulb temperature (ambient airflow)
3. Ground ambient globe temperature
4. Outside air temperature (in flight)
5. Dry-bulb temperature, pilot/copilot station at chest level
6. Wet-bulb temperature, pilot/copilot station at chest level
7. Globe temperature, pilot/copilot station at chest level
8. Air velocity, pilot/copilot station at foot level
9. Air velocity, pilot/copilot station at chest level
10. Air velocity, pilot/copilot station at head level
11. Temperatures of any surfaces in the crew station that feel hot to the touch from a cause other than solar radiation
12. Internal and external surface temperatures of the windshield measured at the top, middle, and bottom of the transparent area at centerline of pilot and copilot (deicing and defogging tests only)
13. Air velocity at each cooling or ventilation air discharge
14. Passenger compartment dry-bulb temperature
15. Passenger compartment wet-bulb temperature
16. Passenger compartment globe temperature.

8-11.6 TRANSPARENCY PROTECTION

Transparency protection is usually provided by a transparent wind screen. The wind screen should be capable of rain removal and should have adequate defog, defrost, and deice subsystems. Typically, heated air is used to clear the wind screen; however, electrically heated wind screen subsystems may also be used. The wind screen should have adequate clarity, freedom from distortion, abrasion resistance, and adequate field of vision and should provide ballistic and debris protection. The wind screen should be usable during both night and day. Also it should be usable with night vision goggles and related cockpit lighting. No material or construction should be used whose fracture would render the wind screen incapable of supporting the design limit load. For additional information refer to MIL-T-5842 (Ref. 58). Measurements for transparency protection include the degree of protection provided in terms of stopping specified types of projectiles and the optical characteristics of the transparency over its intended life.

8-12 PASSENGER FURNISHINGS

The passenger furnishings airworthiness and typical qualification test objectives are to substantiate that the passenger furnishings meet the requirements of the contract for safe operation during normal and emergency uses. Items that should be considered passenger furnishings include seats, restraints, ALSE, environmental control unit, communications, soundproofing, and fire-retardant materials. ALSE includes such varied items as first aid kits, flotation devices, oxygen systems, and other pilot survivability items.

Measurements for passenger furnishings include crash load attenuation provided by crew seats, acoustic attenuation of soundproofing, fire-retardant properties and placement of materials in the air vehicle, and capability of the environmental system to provide pilot comfort at the specified levels.

8-13 HOIST SUBSYSTEMS

Rescue and cargo hoist airworthiness and qualification tests should substantiate the load capacity and safety requirements for these subsystems. Data should be provided to demonstrate the capability of the hoists to operate throughout their intended flight envelope and at the required operating conditions. Specific requirements for rescue and cargo hoist qualification requirements are discussed in the subparagraphs that follow.

8-13.1 RESCUE HOIST

The rescue hoist airworthiness and typical qualification test objectives are to substantiate all of the various safety features as required by contract and also to demonstrate that the subsystem is capable of carrying the maximum rated load at 3 g's through a 60-deg cone angle. Also it should be demonstrated that the subsystem is not adversely affected by a specified electromagnetic field. The hoist should be capable of safely carrying the maximum rated load to the extremes of the applicable flight envelope. The demonstration should include operation of all control devices, antibacklash features, limit switches, and overload sensors used in the hoist subsystem. Quick-disconnect devices and cable cutters should be actuated at the most critical load conditions. Operating procedures defined in the operator's manual should be followed throughout the demonstration. The host rotorcraft and externally loaded rescue hoist should be flown at all conditions that are critical to strength, maneuverability, stability and control, and aeroelastic stability. Any other factors that are considered critical should also be demonstrated. The rescue hoist should also satisfy the various human factors performance requirements as specified in the contract.

Measurements include proof load, acceleration forces, quick-disconnect forces, and in-flight dynamic and aerodynamic forces.

8-13.2 CARGO HOIST

Airworthiness and qualification test objectives are to demonstrate that the subsystem can safely carry loads externally on the hoist to the extremes of the applicable flight envelope and also to demonstrate that the host rotorcraft is not adversely affected. The host rotorcraft and externally loaded cargo hoist should be flown at all conditions that are critical to strength, maneuverability, stability and control, and aeroelastic stability. Any other factors that are considered critical should also be demonstrated. The maximum hoist subsystem rated load is to be used for these tests unless a lesser load is more critical to dynamic stability.

The hoist subsystem should be demonstrated through a minimum of six operations at maximum rated capacity. The demonstrations are to cover all normal and emergency modes of operation, e.g., hydraulic, electrical, or manual. The hoist should be manipulated from each operator's station from which it can be operated.

A minimum of four load/speed combinations should be demonstrated to determine compliance with the rotorcraft detail specification. Speeds at minimum or zero load, 50%, 75%, and maximum rated load are typically used. The demonstration should include operation of all control devices, limit switches, and overload sensors used in the hoist subsystem. Quick-disconnect devices and cable cutters should be actuated at the most critical load conditions. Operating procedures defined in the operator's manual should be followed throughout the demonstration. Electroexplosive devices should be tested to validate adequate safety margins from inadvertent actuation; see subpars. 9-11.1 and 9-11.5.1.

Typically, the maximum rated load should be applied and the hoist installation tested at 2.5 g's throughout a 60-deg cone angle. Larger acceleration-related forces may be specified by the contract. Measurements include proof load, acceleration forces, quick-disconnect forces, and dynamic- and aerodynamic-related forces.

8-14 CARGO PROVISIONS

Typical internal cargo provisions include tie-downs, flooring, ramps, doors, winches, and cargo-handling rail-roller systems. External cargo provisions include cargo hooks and their associated hardware. Descriptions of internal and external cargo provisions and their airworthiness requirements are described in the subparagraphs that follow.

8-14.1 INTERNAL CARGO PROVISIONS

Typical qualification test objectives for internal cargo provisions are to confirm operational procedures and envelopes and assure subsystem compatibility. Proper operation of all tie-down fittings and devices should be demonstrated. Representative demonstration cargo should be made up and secured in the air vehicle using the procedures defined in the operator's manual. Particular emphasis should be placed on accessibility and ease of operation of tie-down provisions.

Qualification of individual components and subsystems, as required by their specifications, must have been completed before demonstration tests are begun. These tests, however, need not be repeated during the demonstration test. Strength test of attachment of cargo furnishings and fittings to the air vehicle structure should be completed prior to demonstration tests. Typically, these tests are accomplished by laboratory bench tests or on the static test air vehicle. Cargo tie-down provisions should be sufficient not only for flight but also for crash-landing conditions. Crashworthiness structural requirements are identified in the air vehicle specification or as emergency landing conditions in the FAA standards. Also it should be demonstrated that cargo-loading provisions maintain the air vehicle CG position within the approved limits and that CG movement associated with cargo airdrop is within limits.

Measurements for internal cargo provision include the capability to restrain the load in accordance with the air vehicle detail specification. A proof test of the cargo compartment floor to limit loads should be accomplished. Design limit loads, both distributed and concentrated, should be applied to walkways, treadways, and general cargo and passenger area floors. Also all conveyors and tracks installed in the air vehicle should be subjected to proof tests. Limit loads and concentrated loads should be applied, and the loads should be moved along the conveyor or track at maximum permissible speed. Proof tests also should be conducted at any other critical load/speed combination.

All cargo doors and ramps are typically demonstrated through six complete operations in the normal modes, i.e., manual, electrical, or hydraulic. Alternate modes or procedures to be followed in emergencies are typically demonstrated through one operation. Procedures contained within the operator's manual should be followed. Doors and ramps that are used as cargoways during loading and unloading operations should be subjected to proof tests at limit loads.

Also all cargo doors and ramps intended for airborne operation should be demonstrated in flight. The outer limits of the operational flight envelope of the cargo door and ramp should be demonstrated as well as any other critical points within the envelope. The demonstration should cover all normal modes of operation and the emergency procedures. Doors and ramps that can be blown off or otherwise ejected or lost from the air vehicle in an emergency need not be included in this demonstration. However, it should be demonstrated that door or ramp separation from the air vehicle does not result in additional hazards. Additional hazards might result from a separated object or debris striking the tail rotor or in adverse aerodynamic loading from the change in the aerodynamic configuration. All control devices including limit switches and overload sensors should be demonstrated. Changes in host air vehicle control forces, yaw rates, etc., should be measured.

8-14.2 EXTERNAL CARGO PROVISIONS

Typically cargo hooks are used for external cargo. The cargo hook subsystems should be demonstrated with the rotorcraft in flight. Automatic and semiautomatic hook engagements of a load should be made. All release modes including normal, automatic touchdown, manual ground, and emergency should be shown. Emergency release should be demonstrated during turns at the maximum allowable bank angle and speed and while carrying maximum rated loads. These tests may be carried out jointly with the test of the hoist subsystem.

Relatch features are to be operated, and proper operation of safety or warning devices, such as unlatched load beam indicator lights, should be verified. The demonstration should follow the procedures in the operator's manual.

External cargo provisions should be adequate for use with aerial recovery subsystems, such as those typically designed for recovery of disabled rotorcraft. Also these same provisions should be adequate for transportability of other high-mass items, such as trucks and cannons. Usually, objectives of qualification are to demonstrate that externally carried loads can be safely lifted, transported from one location to another, and let down. As such, qualification is needed at both the subsystem and system levels. Qualification efforts should include structural, dynamic, aeromechanical, aeroelastic, electrical, electromagnetic compatibility, human factors, and functional analyses and testing. Airworthiness and crashworthiness of the host air vehicle should not be degraded. Typical measurements include weight, sling loads, aerodynamic forces, vibrations, and airspeed. Specific performance requirements should be specified in the contract. The US Army Natick Research, Development, and Engineering Center is the proponent for external and sling loads. Therefore, any requirements should be coordinated through that organization.

8-15 LAVATORIES AND GALLEYS

The lavatories and galleys airworthiness and typical qualification test objectives are to demonstrate that personnel can safely operate and maintain these subsystems. Safety-critical items for lavatories and galleys should be evaluated to ensure there are no sharp corners and/or edges to cause injuries if turbulence is encountered and to ensure that the temperatures of items in the galley can be maintained at a safe level.

Measurements for lavatories and galleys include potable water and waste tank capacity, temperature control of galley heating ovens and hot plates, and human factors concerns.

8-16 TARGETING, ARMAMENT, AND FIRE CONTROL SUBSYSTEMS

The major elements of targeting, armament, and fire control subsystems include sensors, trackers, range finders, guns, rockets, missiles, and the associated electronic equipment necessary for integration and control. Targeting subsystems are designed to provide the flight crew with the capability to detect, acquire, track, range, and designate tactical targets. Targeting subsystems should be safe. Information concerning laser safety can be found in MIL-STD-1425, *Safety Design Requirements for Military Laserand Associated Equipment*, (Ref. 63). Also see subpar. 7-11.1.

Targeting, armament, and fire control subsystem performance are affected by target characteristics that must be specified in order for subsystem performance requirements and measurements to be meaningful. Target characteristic include information such as

1. Target type, e.g., tank, wheeled vehicle, etc.
2. Target size
3. Target-to-background contrast for visual sensors
4. Target-to-background temperature difference for thermal imaging sensors
5. Target radar cross section for radar subsystems
6. Target motion, velocity, and acceleration in directions along and perpendicular to the line of sight of the sensor
7. Target countermeasure characteristics such as foliage, nets, degree of defilade, obscurants, and others.

In addition to target characteristics, armament and fire control subsystem performance is tied to atmospheric conditions, which must also be specified in order for subsystem performance requirements and measurements to be meaningful. These atmospheric conditions and parameters include

1. Ambient pressure and temperature
2. Visibility conditions
3. Atmospheric attenuation at the specified wavelength for the sensor
4. Humidity conditions
5. Precipitation conditions (rain, snow, and sleet)
6. Atmospheric scintillation effects.

ADS-20, *Armament/Fire Control System Survey*, (Ref. 64) contains information about verifying the safety and performance of each armament fire control subsystem by means of ground and flight survey testing. Ground surveys are needed to determine airworthiness. Ground and flight surveys can be used to determine development status prior to formal qualification. These surveys usually encompass installation, ground checkout, ground firing, and preflight and flight testing of armament and fire control systems in the air vehicle. Typically, the following are tested:

1. Missile subsystems
2. Aerial rocket subsystems
3. Turreted gun subsystems
4. Target acquisition and designation subsystems
5. Fire control subsystem integration
6. Boresighting subsystems.

8-16.1 SENSORS

Sensors types include television subsystems, radars, thermal imaging subsystems, optical subsystems, and radar frequency interferometers. Sensor subsystems enable the operator to search visually for and acquire targets for both day and night engagements that are beyond the normal human visual capability.

The sensor airworthiness and typical qualification test objectives are to substantiate that these subsystems perform in accordance with their specified requirements.

Measurements for thermal imaging sensors include fields of view, modulation transfer function (MTF), system intensity transfer (SIT), minimum resolvable temperature (MRT) difference, optical or electronic noise, cross talk between detector elements, distortion, and noise equivalent temperature difference (NETD).

Measurements for television subsystems include fields of view, noise, automatic light control (ALC) performance, shading characteristics, screen blemishes, signal level, distortion, field-of-view alignment, and MTF.

Stabilization is a key parameter for both thermal imaging and television systems. The systems should be isolated from both rotor and airframe vibrations.

8-16.2 TRACKERS

Trackers allow for automatic maintenance of the sensor line of sight to the target regardless of the motion of the target or of the air vehicle within specified parameters.

The tracker airworthiness and typical qualification test objectives are to demonstrate that targets can be tracked throughout the required conditions.

Measurements for tracker qualification should include determination of the capability to track targets in various environmental conditions including clutter, obscurants, target multiplicity, and varying target spacing.

8-16.3 RANGE FINDERS

Range finders provide distance information between the target and the weapon platform. These data are used by the fire control computer to perform the fire control function. The airworthiness and typical qualification test objectives for range finders are the determination of performance parameters, such as maximum range capability, probability of single pulse detection, probability of single pulse false alarm, range finder accuracy, range finder resolution, and range precision.

The range finder airworthiness and typical qualification test objectives are to substantiate that the range finder accurately and consistently determines range under the specified conditions.

Measurements for range finders include output energy, interpulse period, pulse width, pulse-to-pulse time stability, pulse-to-pulse energy stability, beam divergence, and radiation outside the main beam. These measurements should be taken with various environmental conditions that include clutter, obscurants, target multiplicity, and varying target spacing.

8-16.4 ARMAMENT

Armament subsystem qualification is conducted to determine the ability of the weapon subsystem to satisfy performance requirements of the air vehicle and detail specifications. The armament subsystem should be configured as nearly as possible to the production installation. The test program should determine by measurements and demonstrations the following:

1. Accuracy

a. Subsystem boresighting accuracy and retetion

b. Round dispersion at the specified range(s)

c. Rocket and missile dispersion around target(s)

2. Arming and rearming time

3. Capability of operation under environmental stress from

a. Temperature

b. Salt fog

c. Sand and dust

d. Humidity

e. Rain

f. Vibration

g. Shock/bench handling shock

h. Blast overpressure

i. Icing

j. Fungus

k. Solar radiation

4. The effect of the subsystem on the environment such as

a. Toxic gases

b. Noise levels

c. Explosive atmosphere

5. System safety

a. Provisions for adequate safety devices for ground crew protection and in-flight operational safety

b. Jettison

c. Electromagnetic compatibility

d. Gun, rocket, and missile safe firing envelopes

e. Adequacy of armament inhibits, limits, and interrupts

6. Flight handling qualities and performance

7. Maintenance requirements and reliability.

Specific qualification tests that should be performed include but are not limited to the following:

1. Cockpit procedures testing, which includes switching, safety, and flight crew interactions

2. Subsystem controls, such as cockpit controls, switches, instruments, displays, and sights

3. Boresighting procedures should be demonstrated. Any special tools or devices required to accomplish boresighting should be used. Boresighting should be

rechecked periodically throughout the firing tests to determine the degree of boresight retention.

4. Procedures used to load and unload ammunition or stores should be demonstrated, as well as the safety procedures to be followed during the loading and unloading process. The time required to rearm should be determined and documented. Operational ground handling equipment should be used in the demonstration, and ground maintenance and troubleshooting procedures should be followed.

5. Armament firing tests should provide the following information:

a. Airframe response to pressure from the weapons and sonic energy pulses throughout the firing envelope of the weapons during both ground and flight operations

b. Recoil loads and airframe response to weapon rate of fire throughout the subsystem range of motion during both ground and flight operations

c. Cockpit noise levels

d. Electrical and hydraulic load on air vehicle subsystems from armament system operation

e. Gas accumulation in the cockpit, ingested into the engine, and in the vicinity of the weapon

f. Accuracy and boresight retention

g. Firing envelopes and clearances

h. Weapons debris does not degrade the air vehicle, tail rotor, engine, and externally mounted equipment.

6. Compatibility of the weapon subsystem within its anticipated environment, such as temperature-altitude, salt spray, vibration, dust, shock, blast, icing, and explosive atmosphere

7. Flash intensity tests to determine the effects on the crew, sensors, and cockpit lighting conditions should be assessed.

8. Clearance tests substantiating that there is no possibility of firing the weapons through the rotor path or propeller path in all possible weapon aiming and air vehicle flight conditions

9. "HERO" tests to demonstrate adequate safety margins from inadvertent detonation of electroexplosive devices.

Armament subsystem-level test objectives and measurements include determination of the following characteristics:

1. Turret or gun subsystem slew rates and position accuracy

2. External stores travel, slew rates, acceleration synchronization, and position accuracy with typical loads

3. Gun firing rates and ammunition belt loads.

MIL-H-8591, *Airborne Stores, Suspension Equipment and Aircraft-Store Interface (Carriage Phase); General Design Criteria for*, (Ref. 65) provides general structural and mechanical design criteria that can be used to establish performance requirements for airborne stores, suspension equipment, and their associated interfaces. A waiver is required to cite this specification. Provisions are included to promote cross-utilization and servicing capability among military air vehicles of all services of the Department of Defense and air vehicles of various NATO countries.

A program of static, dynamic, repeated load, environmental, wind tunnel, and other ground tests required for proof of structural and operational performance should be performed. Operational flight tests including carrier or shipboard suitability testing, if applicable, to demonstrate the structural and functional adequacy of the store should be performed.

8-16.5 FIRE CONTROL

The airworthiness and typical qualification test objectives for fire control subsystems include determination that the fire control subsystem provides the functions required for safe and effective operation of the armament subsystems.

The fire control subsystem provides the mechanism used to integrate all aspects related to target detection and to weapon subsystem aiming and firing. Typically, this function is provided by a fire control computer, which accepts information and control from the various fire control subsystems on the air vehicle and provides aiming, firing, and guidance information to the weapons.

Measurements for fire control subsystems include overall weapon firing accuracies in comparison to specified requirements. The accuracy measurements should include the data required to demonstrate the end-to-end compatibility of the weapons, sights, and targeting algorithms. These measurements should include recording of air vehicle position; weapons pointing data, such as azimuth, elevation, and range to target; and impact missed distances.

8-16.6 SENSOR FUSION

A sensor fusion subsystem is an integrated set of other subsystems that can be used to enhance targeting and piloting capabilities. Sensor fusion provides a means by which to combine target information automatically into the fusion processor from several sensors to determine whether or not an object is a target of interest. The objective is to provide increased target detection performance that would be available from any single sensor.

The airworthiness and typical qualification test objectives for sensor fusion include determination that system-level target detection performance requirements have been achieved as specified by the contract.

Measurements for sensor fusion include measurements and analysis of target detection probability and target false alarm rates. The analysis and measurements should take into account the target environment the subsystem is expected to encounter in actual operation. This includes target type, background conditions, and potential false targets in the scene. Technical performance testing of sensor fusion capabilities should be conducted on a controlled access range that has known surveyed targets. Environmental conditions including ambient light, temperature, humidity, and obscurant levels should be recorded.

8-16.7 SUBSYSTEM COUNTERMEASURE RESISTANCE

Sensor subsystems are susceptible to various countermeasure techniques intended to reduce their performance or in some cases destroy critical components and thereby render them ineffective. Countermeasure test requirements should be developed on the basis of the threats expected to be encountered by the fielded weapon system.

Countermeasures may be of the active or passive type. Active countermeasures include attempts to introduce intense sources of radiation into the sensor at the operating wavelength of the sensor. Tests and measurements should be made to determine the degree to which the sensor is able to operate either at specified performance levels or reduced levels in the presence of these countermeasure sources. The subsystem performance measurements are generally taken in a noncountermeasure environment, and the tests are repeated in a countermeasure environment to provide a direct comparison of the effectiveness of the specific countermeasure. In addition, measurements and assessments should be made of any damage to the equipment caused by the use of such sources. Of particular concern should be the protection of the operator from any potential injury caused by the use of the subsystem in a countermeasure threat environment.

Passive countermeasures include but are not limited to the use of decoys and techniques, such as camouflage, that make the target appear to be part of the clutter. Testing should be conducted at benign conditions (noncountermeasured) and with passive countermeasures to determine the effectiveness of the specific countermeasure against a given system or systems. Subsystem performance tests should be performed to assess the capability of the various sensors and any sensor fusion techniques to perform at their intended target detection probabilities in a passive countermeasure environment. The results will probably be classified.

8-17 SPECIAL MISSION AND NEW SUBSYSTEMS

Electronic countermeasure subsystems and electronic surveillance subsystems are examples of special mission and new subsystems. Electronic countermeasure subsystems are intended to reduce the performance of or defeat enemy electronic systems including communications and navigation equipment. Electronic countermeasure systems emit electronic radiation detrimental to the operation of enemy systems. Test measurements of such subsystems include power, frequency, and other characteristics of the emitted signals and comparing them with specification requirements. Passing criteria for these measurements are generally defined in terms of the amount of performance degradation to the targeted equipment caused by the countermeasure. The type of performance degradation and how that degradation can be determined are normally system dependent. It is also critical to assess the effects of such systems on other mission equipment installed on the test air vehicle and to determine any adverse impacts of the electronic countermeasure on friendly electronic systems.

8-17.1 ELECTRONIC/OPTICAL AREA SURVEILLANCE

The electronic/optical area surveillance airworthiness and typical qualification test objectives are to demonstrate that these subsystems perform to their required performance requirements and do not cause any adverse impacts to other installed subsystems. The demonstration should include not only substantiation of the performance capability of the subsystem being qualified but also performance monitoring of other subsystems to ensure their performance is not degraded. If the subsystem changes the exterior dimensions of the air vehicle, flight performance and handling qualities testing might be required to determine any changes caused by the installation of the electronic/optical subsystem. Other subsystems should also be monitored for potential electromagnetic interference.

Measurements for electronic area surveillance subsystems include frequency coverage, sensitivity, and data storage capacity. Measurements for optical area surveillance subsystems include field of view, resolution, and image capture and storage capability. The specific measurements for these subsystems and their pass criteria are usually subsystem dependent and should be specified by the procuring agency. These performance requirements and test results will probably be classified.

8-17.2 AERIAL DELIVERY SYSTEMS

An aerial delivery system is typically an airdrop subsystem, as compared with the cargo handling subsystem addressed in subpar. 8-14.1. Aerial delivery typically is not used with rotorcraft. Aerial delivery systems are usually palletized loads and involve the use of parachutes. Cargo is pushed or pulled from the aircraft. The US Army Natick Research, Development, and Engineering Center is responsible for qualification approval of air delivery hardware. The US Air Force normally accomplishes the in-flight demonstrations and qualification. All loads should be adequately restrained within the aircraft and should withstand all acceleration and crash-related loads specified for the aircraft. Typical objectives of qualification include the demonstrations that follow:

1. Specified aerial delivery loads can be installed in the specified type of aircraft.
2. Specified aerial delivery loads can be properly secured within the aircraft.
3. Tie-down provisions are adequate.
4. Aerial delivery loads and related tie-down provisions withstand all transportability-related loads.
5. Aerial delivery loads can be safely extracted from the aircraft.
6. Parachute loads are aerodynamically stable.
7. Rate of descent is adequate.
8. Aerial delivery loads are adequately cushioned for ground contact.

See MIL-STD-209, *Slinging and Tie-Down Provisions for Lifting and Tying Down Military Equipment*, (Ref. 66) for additional information. The contract should specify the actual performance requirements. Typical measurements include weight, size, clearance, rates, deployment loads, parachute loads, and impact loads.

8-17.3 ADDITIONAL WEAPONS

The additional weapons airworthiness and typical qualification test objectives are similar to those described in par. 8-16 for targeting, armament, and fire control subsystems. Flight performance and handling qualities testing may be required for additional weapons subsystems that are externally mounted. Test data should also be provided to demonstrate that the additional weapons subsystem does not cause a negative impact to other subsystems on the air vehicle.

Measurements for additional weapons include weapon accuracy and effectiveness measurements. These measurements should provide data to demonstrate total system integration and accuracy performance including detection, aiming, firing, and guidance as required.

8-18 FAULT TOLERANT SYSTEMS

Fault tolerant subsystems provide various degrees of redundancy in a subsystem in order to allow the subsystem to operate at either full or reduced capability in the event of a failure in one of its components. Fault tolerance may be achieved with either parallel redundancy or with path-switching methods. In a parallel redundant subsystem the redundant elements are capable of carrying out their function instantly upon the failure of a component without the necessity for any other intervention on the part of any other component of the subsystem. On the other hand, path-switching-type fault tolerant subsystems require some type of monitor to detect a failure has occurred and a switching device to switch to the backup component, subsystem, or system.

An example of a parallel redundant subsystem is a structural subsystem (such as a rotor blade retention subsystem made up of numerous individual elements) with multiple structural members arranged so that the failure of one (or perhaps more) element does not result in the failure of the subsystem. Demonstration of the capability of such a redundant subsystem can be achieved by intentionally failing individual structural elements and showing that the subsystem as a whole still provides the necessary structural integrity. Specific criteria must be established as to the number of structural elements that can fail before the subsystem can be considered no longer usable. In such a redundant subsystem it is important to be able to detect by inspection or through other means that an individual structural member failed so that appropriate repair or replacement action can be taken. Path-switching methods require that failure-sensing and switching elements be incorporated into the subsystem to allow for failure detection and appropriate switching to a backup subsystem. An example of an electrical or software subsystem providing path switching is a digital bus control subsystem that incorporates primary and backup bus controllers. Active software control devices monitor the proper operation of the primary bus controller and switch control to the backup controller if the primary controller fails. Critical to the proper operation of a fault tolerant system such as this is the reliability of the sensing and switching elements. In addition, the switching must occur in a sufficiently rapid manner so critical system functions are not disrupted.

8-19 SOFTWARE CONFIGURATION ITEMS AND EMBEDDED SOFTWARE INTEGRATION

The term “computer software configuration item” (CSCI), defined in MIL-STD-498, *Defense System Software Development*, (Ref. 67) applies to the computer software form of a configuration item as designated by a contracting agency. Basically, it refers to a collection of software source codes that constitute a configuration managed item. CSCIs are not necessarily measured or partitioned by any logical, functional, or physical constraints or requirements. They are frequently allocated in conjunction with the associated hardware configuration items (HWCI) on which they may reside or are executed.

The term “embedded integration” as it relates to qualification testing refers to verification of the performance of integrated hardware/software, which cannot otherwise be tested at the CSCI formal qualification test (FQT) level. Residence upon and integration with some form of computer resource device (firmware or hardware) allow the CSCI logic to perform the subsystem- or system-level functional operations.

Other than validating subsystem- or system-level performance, only verification at the interfaces can provide an intermediate test level of confidence beyond CSCI FQT. Refer to ADS-32, *Airborne Digital System Integration and Testing* (Ref. 68) for additional detailed guidance on this topic as it relates to airworthiness qualification.

8-19.1 SOFTWARE CONFIGURATION ITEMS

For qualification purposes, CSCIs typically must pass an FQT that involves formally testing approved and documented requirements in accordance with approved and documented test cases and then documenting the results. The three MIL-STD-498 (Ref. 67) data item descriptions (DIDs) used for the documents discussed in this subparagraph are DI-IPSC-81433, *Software Requirements Specification (SRS)*, (Ref. 69); DI-IPSC-81439, *Software Test Description (STD)*, (Ref. 70); and DI-IPSC-81440, *Software Test Report (STR)*, (Ref. 71).

CSCIs are built up from an aggregate of smaller logical parts. These parts are defined in MIL-STD-498 (Ref. 67). By definition, the smallest part that is a separately testable entity is the computer software unit (CSU). The computer software component (CSC) is defined as a distinct part of a CSCI and is made up of a collection of CSUs. Finally, the CSCI is made up of a collection of CSCs. CSU- and CSC-level tests are not considered qualification tests. They are documented in software development folders (SDF) as are their results and follow-up corrective actions. FQT is recognized as a qualification test for CSCIs but does not suffice for airworthiness qualification because it occurs prior to integration with hardware and subsystem- and system-level testing. Therefore, higher level testing should not only test software in the sense of how well the software has been implemented but also of how the system design and function operates to support successfully the subsystem- or system-level test objectives. Refer to ADS-32 (Ref. 68) for additional guidance on integration testing requirements affecting airworthiness qualification.

The requirements to be tested and validated for CSCI qualification purposes in FQT are those that are documented in DI-IPSC-81433 (Ref. 69). The procedures and final reports of FQT are documented in DI-IPSC-81439 (Ref. 70) and DI-IPSC-81440 (Ref. 71).

8-19.1.1 Software Requirements Specification

The SRS document is prepared on a per CSCI basis. The SRS contains the engineering and qualification requirements for a CSCI that should be tested during the FQT phase of software development. These requirements are essentially derived from the functions that are allocated in DI-IPSC-81432, *System/Subsystem Design Document (SSDD)*, (Ref. 72) and specified in DI-IPSC-81431, *System/Subsystem Specification (SSS)*, (Ref. 73), for accomplishment by software.

Each SRS requirement is independently testable at the CSCI level but not necessarily at lower or higher levels. The SRS should identify the requirements that follow:

1. Internal/external interfaces
2. Capabilities
3. Detailed data elements
4. Site/environment/installation-dependent data
5. Operational parameters
6. Sizing and timing specifics
7. Safety specifics
8. Design constraints
9. Security specifics
10. Human factors
11. Traceability
12. Quality specifics
13. Qualification methods.

8-19.1.2 SOFTWARE TEST DESCRIPTION

The STD document is prepared on a per CSCI basis. The STD contains the descriptions of the individual test cases that are used to validate performance against the SRS requirements to be tested during the FQT phase. The STD also describes pretest procedures, hardware preparation procedures, and software preparation procedures. Each SRS requirement has a corresponding STD test case. For each unique test case identifier, the STD should describe

1. The SRS requirement being tested
2. Assumptions and constraints
3. Detailed conditions for test case hardware/software initialization
4. Detailed procedures
5. Detailed inputs

6. Expected test outputs
7. Evaluation criteria.

8-19.1.3 SOFTWARE TEST REPORT

The STR document is prepared on a per CSCI basis. The STR is a permanent record of the results of the performance of FQT for a CSCI. The STR summarizes tests performed, results, hardware and software configurations used/tested, test conductors and witnesses, problems encountered, and backup test steps. The STR also identifies individual test cases, test case results, and rationale/impact of test case procedure deviations. For management purposes the STR provides evaluations of the CSCI, specific test results, CSCI deficiencies/ limitations/constraints, and recommendations for improvement of the CSCI design, operation, or testing thereof.

8-19.2 EMBEDDED SOFTWARE INTEGRATION

Once the software has passed the FQT phase, integration testing becomes an exercise in verifying subsystem- or system-level functionality. As much as is physically possible, each interface that is incorporated when a configuration item is integrated in the buildup of a subsystem or system should be tested to verify operation or data reliant on the functioning of that interface.

Software is integrated in many different ways and at many different levels; examples of these are developer to developer, CSU to CSU, CSU to CSC, CSC to CSC, CSC to CSCI, CSCI to CSCI, and CSCI to HWCI. These levels of integration are accomplished in many different ways from informal communication to informal internal interface documents to formally documented interfaces identified in interface requirements specifications (IRS), interface control documents (ICD), etc. Dependent upon the formality of the interface controls, qualification testing is usually limited to verification of the documented interfaces and performance validation at the integrated subsystem/system level.

8-19.2.1 Software/Hardware Integration

Software must be integrated with hardware to perform any usable function. Each step of the integration process should be followed by testing, preferably also regression testing, to assure that integration does not uncover unforeseen complications or introduce new problems. Regression testing includes the retesting of previously tested functions when a new function is added or a change is made. At the lower levels of integration, testing is informal and more reliant on the thoroughness of the developers. As levels of integration become higher and more formalized, testing should focus on verifying the documented interfaces and on successful accomplishment of subsystem- or system-level requirements.

8-19.2.2 Integration Test Requirements

The interface requirements that should be tested and validated in FQT are those that are documented in the DI-IPSC-81434, *Interface Requirements Specification (IRS)*, (Ref. 74). This DID specifies the requirements for all interfaces between one or more CSCIs and other configuration items or critical items. As stated previously, FQT is not a subsystem- or system-level test suitable for airworthiness qualification.

To assure the valid integration of software and hardware, several steps can be taken. First, the operating procedures that guide informal and formal integration and testing should be standardized and followed. During the development or modification of formal interfaces, documents such as the IRS and ICDs, strict overview, and control and participation by developers, integrators, testers, and users via an Interface Control

Working Group (ICWG) should occur. Technical reviewers should continually evaluate the correctness of interfaces for required data, defined types and limits, units, scaling factors, sources, destinations, timing requirements and impacts, fault tolerance of data, etc.

ADS-32 (Ref. 68) contains additional detailed guidance on the topic of integration test requirements as it relates to subsystem- or system-level airworthiness qualification.

8-20 TEST-ANALYZE-FIX-TEST (TAFT)

The results of subsystem level qualification testing form a part of the overall TAFT cycle in which performance or reliability issues uncovered during test are analyzed as to root cause, corrective actions are developed and implemented into the hardware or software, and the system is subjected to additional testing until it has been determined that the corrective action has adequately addressed the previously uncovered problem. This is part of a continuing process and may require that corrective actions be evaluated first by component-level tests prior to incorporation into subsystem-level testing. It may also be decided that incorporation of corrective action and retest may be performed with little additional risk at the system level. Typically the PA would approve TAFT decision, however, this is becoming a task allocated to Integrated Product Teams (IPT).

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CHAPTER 9

SYSTEM QUALIFICATION

System qualification requirements and procedures for specific system qualification tests are discussed.

9-0 LIST OF SYMBOLS

A	=	rotor disk area, m^2 (ft^2)
A_{GL}	=	above ground level
A_i	=	presented area of the *i*th component or subsystem, m^2 (ft^2)
A_{Vi}	=	vulnerable area of the *i*th component or subsystem, m^2 (ft^2)
C_P	=	power coefficient, dimensionless
C_T	=	coefficient of thrust, dimensionless
E_W	=	total weapon system effectiveness, dimensionless
N_g	=	gas producer turbine speed, rpm
N_p	=	power turbine speed, rpm
N_R	=	rotor speed, rpm
P_c	=	probability of classification as to correct type of target—hard or soft, wheeled or track
$P_{C\|D}$	=	probability of classification given detection by the threat as the correct type of target
P_D	=	probability of detection of a particular target
P_E	=	probability of engagement
$P_{E\|C}$	=	probability of engagement given classification
$P_{E\|D}$	=	probability of engagement given detection
P_H	=	probability of hit
$P_{H\|E}$	=	probability of hit given engagement
P_i	=	probability of damage per hit on the *i*th component or subsystem, dimensionless
P_K	=	probability of kill
$P_{K\|H}$	=	probability of kill given a hit
P_S	=	probability of survival, dimensionless
SP_t	=	shaft power, W (hp)
V_{CRUISE}	=	cruise speed, kt
V_D	=	design dive speed, kt
V_{DL}	=	design limit airspeed, kt
V_H	=	maximum level flight speed of engine(s) intermediate power rating or power transmission system continuous rating, whichever is less, kt
V_R	=	rotation airspeed, kt
V_{STALL}	=	stall airspeed, kt
V_T	=	true airspeed for each polar flown, kt
V_X	=	best angle of climb, deg
W_t	=	test weight, N (lbf)
B	=	sideslip angle, deg
θ	=	temperature ratio, dimensionless
μ	=	advance ratio, dimensionless
ρ	=	test air density, kg/m^3 ($slug/ft^3$)
φ	=	bank angle, deg
Ω_R	=	rotor tip speed, m/s (ft/s)

9-1 INTRODUCTION

As a minimum, during system qualification of the air vehicle, the air vehicle manufacturer will demonstrate compliance with the air vehicle system specification and the Airworthiness Qualification Specification (AQS) for the air vehicle. Also system qualification is typically required for modifications to a previously approved air vehicle. Among other things, this qualification should demonstrate that functional performance, safety, survivability, component life, and effectiveness measures are according to the contractual requirements. The AQS should be a complete integrated test plan for the system or modification describing the set of minimum analysis and testing requirements that satisfy all contractual provisions. The contractual requirement for submission of additional test plans, analyses, and reports for approval by the PA should be limited to demonstration of the primary airworthiness and critical performance criteria. Elements of the AQS are described in Appendix B.

An air vehicle can be airworthy but not necessarily qualified. Early identification of operational suitability and performance deficiencies allows time for the development process. One of the major objectives of this chapter is to define the airworthiness requirements that should be verified prior to any flight testing. Safety is a driving factor behind system qualification and should be continually assessed throughout the development program. System safety assessment includes the review of component level data and review of all system operations and performance to determine the likelihood of occurrence and the severity of failures or dangerous operations. Minimum flight prerequisites should be specified by the procuring activity (PA), and the air vehicle contractor (AC) should propose methods, techniques, procedures, and conditions to be used to obtain flight approval. United States (US) Army flight approval will normally be granted in the form of a Contractor Flight Release (CFR) or Airworthiness Release (AWR), described in Appendices C and D, respectively.

A flight release indicates that the PA considers the air vehicle to beairworthy; however, issuance of a flight release by the PA does not signify qualification. A Statement of Airworthiness Qualification (SAQ) should be issued when the PA has substantiated qualification according to the AQS. A SAQ might not be issued until an Airworthiness Qualification Substantiation Report (AQSR) has been issued to document item-by-item compliance with the AQS, waivers, and deviations. Issuance of the SAQ should coincide with type classification of Standard A. Also air vehicles for the US Army are acquired in a variety of ways. The Federal Aviation Administration (FAA) or some other agency might have engineering cognizance for some air vehicles. The agency having engineering cognizance is ultimately responsible for the airworthiness qualification of that air vehicle. For instance, the FAA issues an airworthiness certificate for air vehicles conforming to an approved type design. With the increased reliance on software for flight and fire control management, the scope of possible testing combinations becomes so prohibitively large that not all combinations can be flight tested in a realistic test program. Much of this testing might be done by simulation; see Chapter 6. Whenever possible, testing requirements should be tailored to use only the most critical combinations and should be approved by the PA.

System performance is a measure of how effectively all of the subsystems work together. This phase of testing should demonstrate the synergistic effects of the characteristics of the various subsystems.

Related subsystems that individually meet contractual requirements might not satisfy air vehicle system requirements due to the accumulation of errors. An example is the weapons subsystem, in which fire control errors, round-to-round dispersion, gun pointing error, air vehicle position error, etc., might combine to make gun accuracy unsatisfactory. Flight qualification testing should demonstrate these synergistic effects in a manner which is satisfactory to the PA.

Envelope expansion and other flight airworthiness determination tests should be conducted during the system qualification phase. Based on these tests, progressively less restrictive Contractor Flight Releases and Airworthiness Releases should be issued to allow further testing of the technical performance of the system. During all flight based on these tests, progressively less restrictive Contractor Flight Releases and Airworthiness Releases should be issued to allow further testing of the technical performance of the system. and ground testing, emphasis should be on safety and reduction of risk to an acceptable level consistent with continued ground and flight operations.

Component service life information should be gathered during this phase. These initial service lives should be used to schedule component replacements, services, and inspections. As additional information is gathered during the qualification program, component lives can be calculated based on actual air vehicle loads rather than estimated loads from analysis.

Proper planning of the full system testing program should preclude duplication of flight conditions for different tests. In many cases, flight conditions used for various tests are similar, and expanded instrumentation for one test may allow full or partial accomplishment of two or more test requirements during a single set of flights. In the planning phase the AC should identify to the PA tests that can be consolidated to use test facilities, time, and resources more efficiently.

Prior to these flight and ground tests, surveys and demonstrations should be used to identify critical conditions, flight regimes, and equipment malfunctions. When approved by the PA, surveys and demonstrations should be used as much as possible to reduce test time and resources. Par. 2-4 provides a more detailed discussion of the appropriate uses of surveys and demonstrations. Formal demonstrations are used to show the capability of the air vehicle to comply with the requirements of the detail specification. These demonstrations are usually performed through a test or series of tests.

9-2 STRUCTURAL INTEGRITY DEMONSTRATIONS

This paragraph describes the general demonstration procedures necessary to prove the structural integrityof the air vehicle. Successful demonstrations should ensure that the airframe design is structurally adequate, i.e., that it meets the specified requirements for dynamic frequencies and modes, static strength, fatigue life, damage tolerance, and crashworthiness. The contractor should provide a structural integrity program plan early in the design phase to coordinate all structural-integrity-related tasks to be met and maintained over the life cycle of the air vehicle. The subparagraphs that follow describe the typical qualification test objectives and measurements of the static tests, watertightness, weight and balance, and in-flight demonstrations as part of full-scale testing.

9-2.1 STATIC TEST PROGRAM

The static test program consists of a series of tests performed on a sample airframe to confirm that loads are distributed around the frame as predicted and that the frame can withstand loads equal to those calculated for the airframe during operation. The program should verify that load paths and stresses are as predicted such that the airframe will withstand the applied loading, and identify any poor structural design details to alleviate and prevent future structural safety or maintenance difficulties. The contractor should comply with the detail requirements for static tests as stated in the contract specifications. These requirements include the support of limit loads without yielding or exhibiting deformation that would affect the safe and functional operation of the air vehicle. Requirements also include the support of ultimate loads without failure for a prescribed length of time, e.g., minimum of 3 s. Crash loads and failing loads should also be demonstrated.

A loads analysis should be used to determine the magnitude and distribution of the significant static and dynamic loads the airframe might encounter when operating within the envelope established by the structural design criteria. This analysis is based on calculated flight loads, ground loads, power plant loads, control system loads, and the effect of weapon system loads on the airframe. Environmental strength degradation should be addressed by testing at elevated temperatures with moisture-saturated specimens or properly increasing loads to account for environmental effects. Test conditions should be selected from shear, moment, and torsion diagrams that are generated for each major load condition and analytical maximum strain predictions. The conditions that produce the most shear, moment, and/or torsion for a given structure or component should be demonstrated by test. Airframe sections should be tested to ultimate or failing loads. Miscellaneous airframe structures to be individually crash load tested should also be identified, e.g., landing gear, mounts, seats, stores, and fuel cells.

The static test article should be a complete airframe and should duplicate the structure of the flight article with the following exceptions:

1. The omission of items of fixed equipment and their support structure is permissible provided it does not significantly affect the load and stress distributions and the strength or deflection of the static test article. Items in this category include furnishings, electrical and hydraulic subsystems, and avionics.

2. The use of substitute parts and/or test fixtures is permitted provided they reproduce the effects of the parts from the standpoints of strength, stiffness, mass characteristics, and load transmittal. However, the structural integrity of the parts for which substitutes are made should be demonstrated by separate tests. Several items typically in this category are rotor subsystems, power plants and accessories, and transmission subsystems.

Deliberate manufacturing flaws and/or debonds to manufacturing limits as well as subsurface delaminations might also be introduced into the test article at critical areas, if appropriate. The static test article should be fully instrumented with load cells or load transducers, axial and shear strain gages, and deflection gages. The type, number, and location of instrumentation should be sufficient to determine that load paths and stresses are as predicted.

The instrumented test article should be incrementally loaded from no load to the limit, ultimate, and failing loads in prescribed increments. In each test required, all components critical to the pertinent design conditions should be tested and loaded simultaneously. The locations of the loading fixtures should be selected to provide the best fit for the overall desired shear, moment, and torsional distributions. Hard points and other natural load points can be selected in order to preclude overloading of any local structure. Prior to failing load tests, repairs of selected critical areas may be accomplished to verify the structural adequacy of the repairs as limit and ultimate loads are achieved. The failure conditions should be applied to the static test article after the completion of all ultimate tests. To ensure the detection of structural failures, the air vehicle structure should be inspected after each test load incremental application. The applied shear and bending loads, torsional moment distributions, strain gage readings, and exterior deflections after each increment in applied loading should also be recorded to establish the rate of deflection, strain, and permanent set.

In addition to substantiating static strength, the static test vehicle also should be used to substantiate fail-safe capability. The term “fail-safe”, as applied to an air vehicle or its members, means that the structure remaining or a portion of the original structure can sustain a percentage of its design load without catastrophic failure or excessive structural deformation following the initiation of any fracture or crack. Also to be fail-safe, a part has to have a failure mode that can be monitored or that can be found by inspection prior to total failure of the air vehicle. When a fail-safe design is provided by the use of redundant attachments and/or members, a percentage of redundancy should be agreed upon by the PA. The structure should be tested to the critical fail-safe loading condition by removing members or attachments to simulate failure and increasing the load levels. Typical measurements are weight, loads, torque, stress, strain, and frequencies. Cyclic and collective positions are also measured.

2.2 WATERTIGHTNESS

Watertightness performance requirements should be clearly specified in the air vehicle specification. Watertightness qualification tests are a series of ground tests and often flight tests used to demonstrate the capability of the air vehicle to prevent water intrusion into designated watertight areas. Detailed design requirements for air vehicle watertightness should be defined in the contract specifications and approved by the PA. Information concerning testing for watertightness and water control of air vehicles in rainy weather and during air vehicle washing can be found in MIL-W-6729, *Watertightness of Aircraft, General Specifications for,* (Ref. 1).

All areas of the air vehicle should be designated as watertight or nonwatertight. Areas containing equipment that may experience adverse effects from water intrusion, including corrosion, electrical discontinuity, or any other hazard related to air vehicle safety or mission capability should be designated watertight. Considerations for designation of watertight sections should include air vehicle cleaning procedures and all environmental conditions in stowed or flight configurations, including rain, wind, humidity, driven rain, salt spray, and mist. The design and qualification demonstrations should ensure that these areas remain free from external water intrusion, migration of water from other areas, and condensation. Areas in which the presence of water will not adversely affect equipment performance should be designated nonwatertight. The design and qualification demonstrations of the air vehicle should be such that any water that enters nonwatertight sections immediately flows to the air vehicle exterior or designated drainage area.

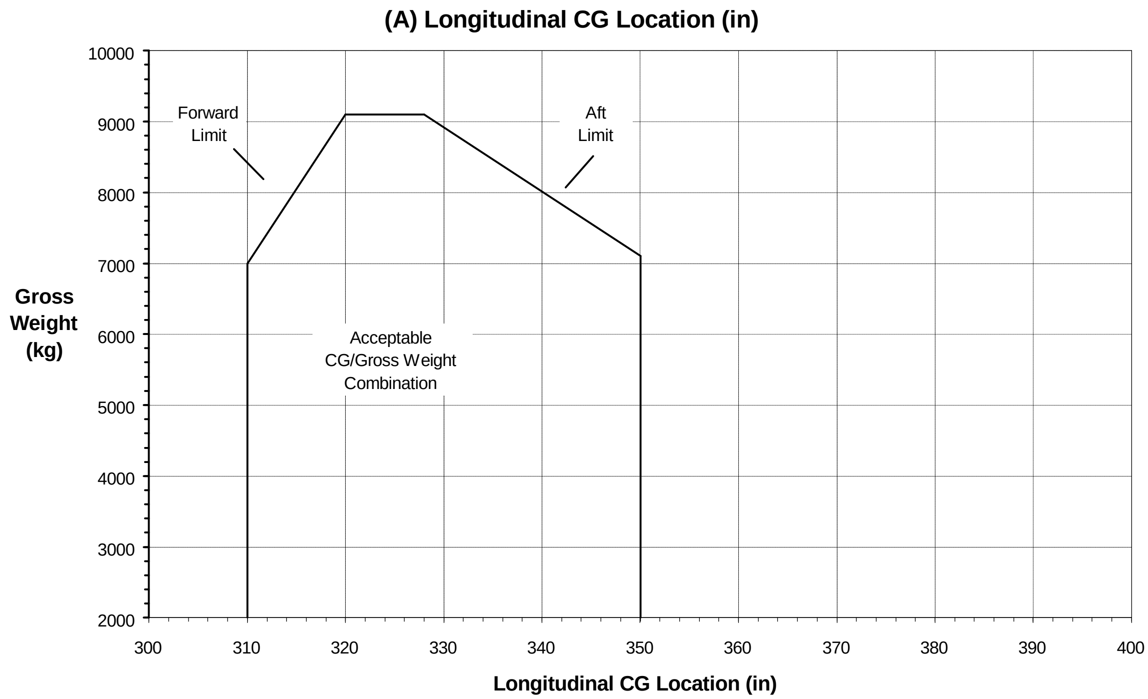
Watertightness qualification tests should be tailored to meet specific needs of the air vehicle. The test article should be complete, preflight inspected, configured for flight, and verified to be mission capable with all systems operating properly immediately prior to each specified test. As a minimum, the qualification demonstrations should include ground, ground with rainsoak, flight, and air vehicle cleaning tests. The ground and rainsoak tests should consist of a parked air vehicle subjected to a water spray system. The location, intensity, direction, and duration of the water spray should be specified in the qualification test plan. The test article should be flown in a heavy rain, as defined by the US Weather Service, for a specified time. During the flight test all compartments accessible in flight, such as cockpits and cabins, should be inspected for leaks around canopies, windshields, hatches, cockpit ventilators, and inspection or access doors. The test article should also be cleaned in accordance with the applicable cleaning procedures and checked for water intrusion during and immediately after the cleaning process.

Immediately following each qualification test the air vehicle should undergo an operational test and watertightness inspection. The air vehicle should be preflight checked, have the engines started, and be poststart checked to confirm all systems are operationally capable for flight and mission performance. Each malfunction should be assessed to determine whether it was caused by water intrusion or improper water control. Sections designated watertight should be inspected for water intrusion, water migration from other areas, and condensation. Nonwatertight sections should be inspected for any water accumulation.

9-2.3 WEIGHT AND BALANCE

Weight and balance limit determination and control are essential for safety and proper structural demonstration procedures. This allows for maximum flexibility in tactical operations and permits the rapid loading required for flight test maneuvers. Fig. 9-1 illustrates a typical center of gravity (CG) flight envelope showing a plot of weight vs CG location. The corresponding weight restrictions are shown with the lateral and longitudinal CG travel. CG limitations are usually implemented due to either controllability and handling quality issues or issues related to structural limitations. Strict adherence to weight control is required in the demonstration of test articles. The actual weights of test air vehicles and components should be verified for compliance with the design, gross, and alternate gross weights used in the structural analysis and load factor determination.

Some factors used to determine CG limits include available trim control motions, blade-flapping design limits, fatigue stresses in rotor head and blade components, and lateral and longitudinal stability requirements. Large CG offsets are balanced by small amounts of blade flapping, which increases the stresses on the blade, hub, and masts. The amount of flapping necessary to balance a large forward CG offset might become large enough to permit the blade to strike the tail boom or other fuselage structure. Other considerations include additional blade deflection occurring as a result of pilot control inputs, turbulence and/or gusts, and hard landings while testing at the maximum



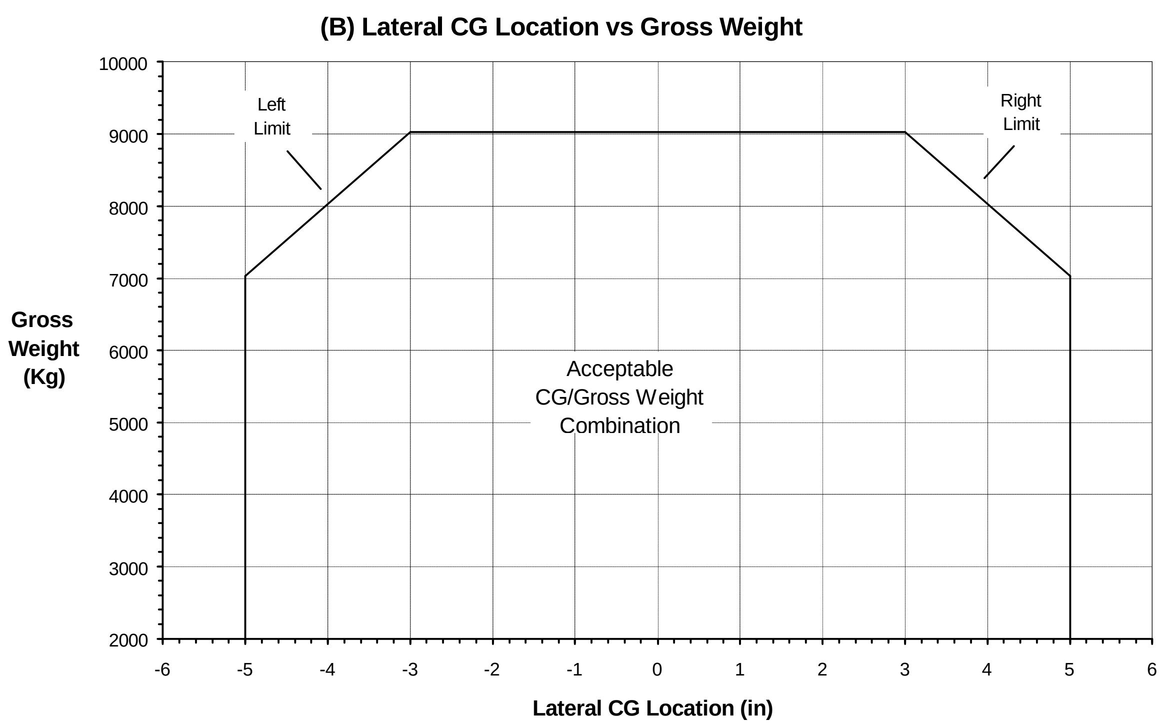


Figure 9-1 Flight CG Envelope

allowable forward CG position. The CG location also affects the longitudinal and lateral stability in forward flight. For a rotorcraft having a single-rotor, a forward CG should produce an increase in angle of attack, which produces an increase in rotor thrust and a stabilizing nose-down pitching moment about the CG. If the CG is behind the rotor shaft, the effect should be to produce a destabilizing, or nose-up, pitching moment. Alternate test configurations with external stores and equipment are destabilizing because they lower the CG and increase the instability of the rotorcraft. Rotorcraft with Tandem-rotors provide a wider range of CG without significantly affecting stability. CG limits on tandem-rotor rotorcraft are usually established for structural reasons.

Center of gravity location for aircraft with fixed wings affects not only the apparent stability but also might change the stall speed and stall characteristics and takeoff speed and takeoff characteristics. CG limits are established to ensure the pilot has control authority at the maximum limits.

Structural demonstrations are performed at the most critical weight and CG conditions. With the addition of instrumentation equipment, ballast, and representative component substitutions, it is essential that shape, mass, angular, and inertial properties are accurately resolved. The resulting load data from the structural demonstrations is used to determine safe operating and maintenance limits.

9-2.4 IN-FLIGHT LOADS

An in-flight structural test program is a substantiation of the airworthiness of the air vehicle and a formal demonstration of compliance with the structural requirements of the design specifications. The normal load factors are as specified or as limited by structural design and/or aerodynamics. The objectives of the tests are to

1. Demonstrate safe operation of the air vehicle up to the structural design envelope
2. Verify that in-flight loads used in the static and fatigue structural analysis and applied to the static test article and fatigue test specimens are not substantially different during operation of the air vehicle to the limits of the flight envelope.

The in-flight structural test typically involves flying the air vehicle in the primary mission configuration during typical flight maneuvers to record airframe and component loads data. The configuration of the test air vehicle should be identical to the proposed production air vehicle structure from the standpoint of both materials and tolerances. The addition of necessary ballast to attain specified CG locations and the installation of special test instrumentation typically are required during the tests. Demonstrations should be predominantly performed on the primary mission configuration at structural design gross weight. Additional demonstrations should also be conducted on alternate configurations, such as external stores or self-deployment at the maximum alternate gross weight. Dummy equipment having the proper shape, mass, and inertial properties may be used to simulate internally or externally mounted equipment. Any substitution or installation deviation should be approved by the PA.

The test air vehicle should have instrumentation that provides the capability to measure and record all parameters necessary to document the compliance with the demonstration requirements and to substantiate the structural integrity of the vehicle. Telemetering of critical parameters is essential because it provides instantaneous load information and thereby increases flight safety and expedites test progress. Considerations for instrumentation should include compatibility with existing Army equipment, a backup power source, redundant sources of data, crash protection, and data recovery. As a minimum, instrumentation should record control positions, control rate and sequence, performance parameters, and specific critical loads, stresses, and pressures. The complete instrumentation package should be tailored to fit the specific air vehicle within the designed weight and CG limitations.

The tests are conducted at the most critical combinations of gross weight, center of gravity, airspeed, altitude, load factor, rotor speed, and control motions. Considerations should be made for each of these parameters in the attainment of critical conditions for each test flight maneuver. The considerations should include but not be limited to

1. *Control Input*. More rapid control inputs usually generate higher loads, and the sequence of control inputs can affect loads significantly. Movement of the cyclic, collective, and directional controls (yoke and pedal for other aircraft) to the required displacements is limited in time. For example, control movement for Class I rotorcraft might be specified not to exceed 0.2 s. The controls should be held for the time required to obtain the specified load factor and should be returned in not more than the time required to the position for level, coordinated flight. Frequently, the maximum load factor is achieved by a sequence of cyclic and collective control displacement.

2. *Rotor Speed*. Rotor speed is the limit rotor speed, power on and off; the design minimum rotor speed, power on and off; and the design maximum rotor speed, power on and off. Forward airspeed and rotor speed combinations will be as limited by the transmission limit horsepower, engine power, drag, aeroelastic considerations, and any combination thereof.

3. *Weight and CG Location* The CG positions to be used for flight maneuvers should be the maximum forward, maximum aft, maximum lateral positions, maximum vertical positions, and any CG position within this range that produces a critical loading. Most test maneuvers should be conducted at basic design gross weight, design alternate gross weight, and/or maximum gross weight.

4. *Atmospheric Conditions* All flights should be conducted in smooth air unless specified by PA.

MIL-S-8698, *Structural Design Requirements, Helicopters,*(Ref. 2) and ADS-29, *Structural Design Criteria for Rotary Wing Aircraft,*(Ref. 3) define flight loading conditions and measurements for typical rotorcraft flight maneuvers. Title 14, Code of Federal Regulations (CFR), Part 23, *Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes,* (Ref. 4) and Title 14, CFR 25, *Airworthiness Standards: Transport Category Airplanes,*(Ref. 5) define flight loading conditions and measurements for typical aircraft maneuvers. Flight demonstrations may include symmetric pull-ups, pushovers, rolling pull-ups, dynamic yaws, sideslips, auto rotations, slope landings, hard landings, nap of the earth, and any specific combat maneuvers. Details of each test condition should be tailored to each air vehicle type and defined in the structural portion of an integrated test plan.

9-3 PROPULSION AND POWER DEMONSTRATIONS

The propulsion and power system demonstrations should be performed to demonstrate the operational and performance characteristics of the propulsion subsystem both on the ground and in flight. Demonstration of the adequacy of the entire propulsion and power system should include assurance of engine/airframe compatibility and proof of the suitability of the drive subsystem, the lubrication subsystem, the rotors, and the propellers.

Operation of a complete prototype propulsion subsystem will be the first integrated evaluation requirement. The test setup should be assembled so that all components are arranged in the proper spatial relationship. Instrumentation should be installed to measure pertinent parameters, such as pump speed (usually measured in revolutions per minute (RPM)), pressures, lubricant temperature, and flow rates. Following successful operation of the subsystem components in the bench tests, the subsystem performance should be evaluated in both ground and flight test vehicles; see Chapter 6. Additional measurements typically included during flight testing are transient rotor droop, rotor rpm, collective pitch position, pedal position, andtorques.

9-3.1 ENGINE/AIRFRAME COMPATIBILITY TESTS

Compatibility of the engine and airframe should be demonstrated during steady state and transient operation. Verification of compliance should be conducted analytically prior to ground testing. The contractor should conduct safety-of-flight evaluations on the ground test air vehicle to verify basic airworthiness and show equivalence to the iron bird test; see Chapters 7 and 8. The quantifiable information that follows should be obtained for ground and flight tests:

1. Controlled rotor run-up at various advance rates and engine acceleration and deceleration capabilities during power lever manipulations
2. Engine/drivetrain torsional oscillations while operating at various altitudes, gross weights, CG locations, airspeeds, main rotor speeds, and power demand sources
3. Electrical load transfers during ground operations and as engine and generating units are brought on- or off-line
4. Starts and restarts at altitude
5. Single- and dual-engine (if any) response characteristics throughout the air vehicle envelope while applying load demands from minimum to maximum power output at various rates
6. Simulated engine failures to demonstrate access to and stability at single-engine fuel control limiters
7. Adequacy of any engine failure detection or display system
8. Acceptable power turbine governing throughout the air vehicle envelope, during both steady and transient operations, delivered from flight controls and any automatic control devices
9. Effects on engine power regulation from the fuel management system, air induction and exhaust system, local atmospheric conditions, orvibratory environment
10. Accessibility and effectiveness of all propulsion control system field adjustments.

The most significant compatibility consideration is torsional stability. The essential engine/airframe compatibility requirement is to ensure that no self-sustaining torsional oscillations will occur. Therefore, the engine should dampen any torsional oscillations above a specified frequency, whereas the rotorcraft damping system should prevent excessive rotor shaft/transmission oscillations. For torsional stability purposes the engine/airframe response at the natural frequency of the rotor subsystem is of major concern. The damping or attenuation of perturbations at this frequency should be specified as a stability requirement.

Information about determining torsional stability requirements can be found in ADS-9, Propulsion System Technical Data, (Ref. 6). The torsional stability should be analyzed showing both gain margin and phase margin throughout the operational envelope. Representative open- and closed-loop Bode plots of the power turbine-speed governor loop should be included for worst-case gain margin and worst case phase margin conditions of gas generator speed, gross weight, airspeed, outside air temperature, etc. To evaluatetorsional stability, torsional system natural frequencies should be excited electronically through inputs to flight control actuators. Torsional system frequency response is then determined and analyzed to evaluate torsional stability.

9-3.1.1 Controls

Control demonstrationsshould be conducted on ground and flight test air vehicles. Flight tests may reveal instability not detected in the ground tests, and the engine/airframe system might be subjected to excitations at frequencies not encountered previously. Instrumentation and data collection should be conducted in the same manner for both ground and flight tests to verify stability.

Power lever control qualification includes testing of control positions, forces to move, and responsiveness. The engine power control or power turbine governor and the twist grip (if any) should be tested for loss of motion, required travel, required force, and time of any motor actuation response time. Limitations should be provided and verified for compliance by the PA. Instrumentation should include devices that indicate positions of control levers and measure the force applied to actuator linkages. Tests should be conducted for engine(s) off and engine(s) running conditions. Controls should also be included in the altitude restart demonstrations. Typical requirements for electromechanical, electronic, or electro-optic controls are defined in subpar. 9-15.4.

Engine gas generator acceleration and deceleration tests should be accomplished with and without air bleed and with automatic and manual engine power control. All tests using automatic engine power control should be run without moving the power-turbine governor beep switch to control engine output shaft speed. All power increase and decrease tests should be performed at the maximum acceleration fuel flow schedule and at the minimum deceleration fuel flow schedule. Operator methods used to increase or decrease power should be specified for each test. Data should be recorded to reveal governor transient response characteristics, torque overshoot or undershoot, transient droop or steady state droop, governor stability, and corrective actions. The tests should include power increases and decreases to specified power and torque limits. Flight tests should include test conditions conducted at incremental altitudes to a specified maximum.

Ground tests should be conducted to record the droop-compensation cam characteristics without actuation of the power-turbine speed beeper switch or control actuator. The steady state and transient droop characteristics should be obtained in flight for the range of collective pitch positions from full down to mid position and from mid position to maximum gearbox torque position. Flight tests should be conducted at two gross weights and at a preselected altitude range in specified increments. The change in rotor speed versus shaft horsepower should be verified for compliance.

Dynamic system/engine compatibility should be demonstrated at specified combinations of vehicle rotor speed and engine power settings. At each of these combinations the collective control should be cycled manually at the critical oscillation frequencies of the dynamic system and two frequencies within 0.1 Hz of critical on each side of critical. The response time of the test instrumentation for these tests should be specified, and data should be plotted as a time history.

Fig. 9-2 shows three examples of typical engine transient torque responses to a step demand for torque change. In the three examples, the torque rises to the demanded level in a relatively short time and then oscillates about that level at the natural frequency of the rotor system. One example shows a perturbation time history with a damping ratio of 0.11. This damping ratio is considered a design goal for engine response because the amplitude of the oscillation decays by more than half during the first cycle. The other two examples show a damping ratio of 0.064 and an undamped oscillation. Both of these examples illustrate unacceptable conditions. Fig. 9-3 shows the engine response time history and resulting data reduction of the transient engine torque and engine speed data. The damping ratio, frequency, and natural frequency are determined from the time history recordings as shown in Fig. 9-3.

9-3.1.2 Vibration

Vibration demonstrations should be conducted to determine the engine/airframe vibration environment in the rotorcraft. Information concerning this topic may be found in ADS-27, *Requirements for Rotorcraft Vibration Specifications, Modeling and Testing,*(Ref. 7). Modeling, ground tests, and flight tests are typically required to substantiate compliance with the vibration-related specifications.

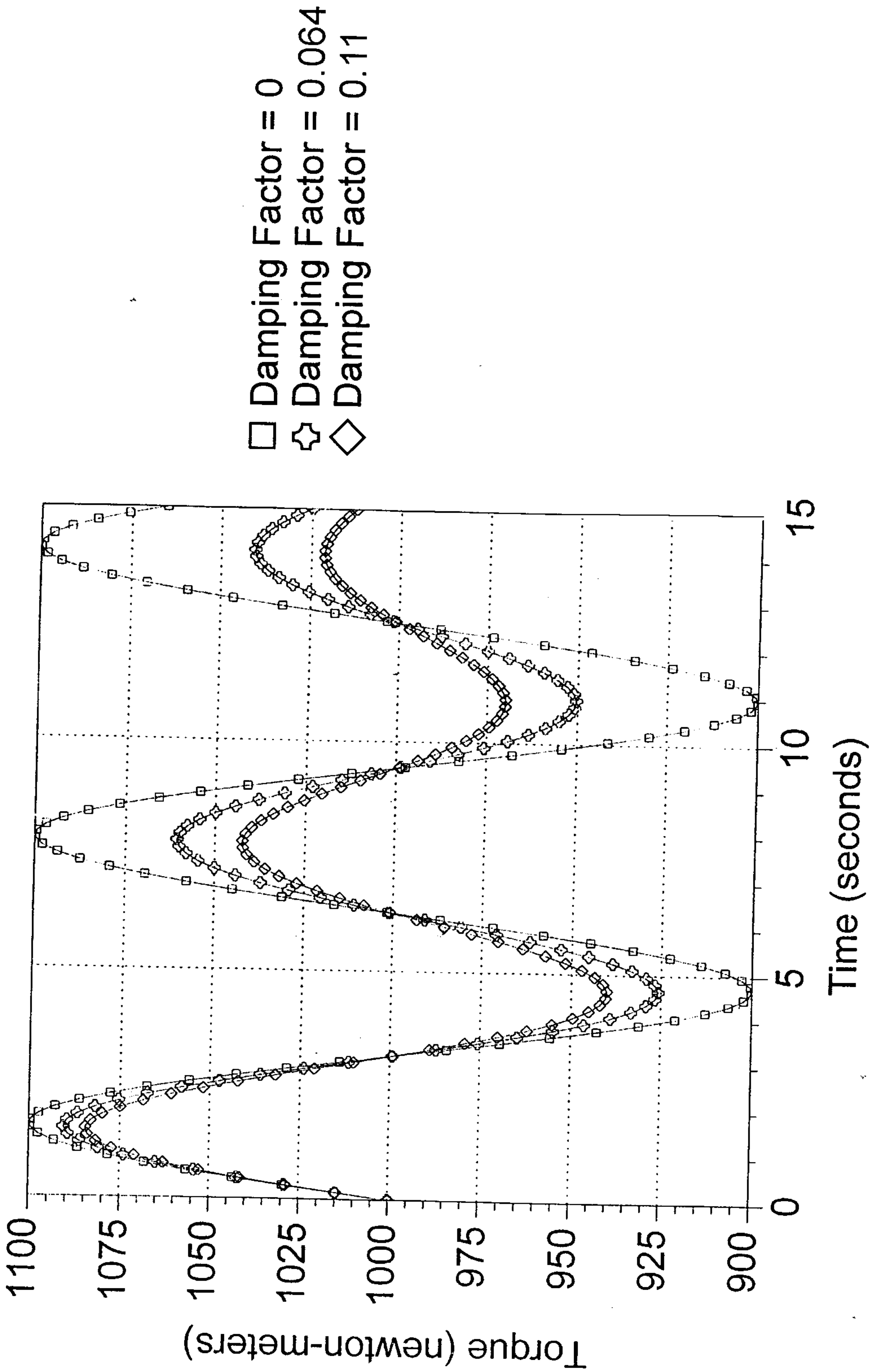
Initially, the engine manufacturer will derive modeling based on structural dynamic analysis and tests sufficient to calculate the engine bending frequencies with the engine installed on the airframe. The analytical engine compatibility modeling should be conducted with

1. The engine on the mounts and attached to a rigid structure
2. The engine on the mounts and attached to a compliant structure represented by a spring in each direction for which loads are reacted
3. The engine installation integrated with the rotorcraft dynamic model and the engine rigid body and flexible body modes defined.

A full-scale airframe shake test should also be conducted to

1. Determine the natural frequencies and other modal properties of the airframe and rotor support subsystem
2. Determine the major forced response mode shapes of the rotorcraft
3. Determine the transfer functions from force inputs at the rotor hub to the response at locations critical for vibration
4. Evaluate the effectiveness of any fixed system vibration control devices.

The engine manufacturer should define acceptable installation vibration limits by amplitude and applicable frequency for each sensor location. These vibration limits should reflect considerations of frequency of occurrence of vibration magnitudes that are representative of both steady state and transient flight conditions within a typical air vehicle mission. The test cell vibration



Source Adapted From AMCP 706-203

Figure 9-2 Transient Torque Response

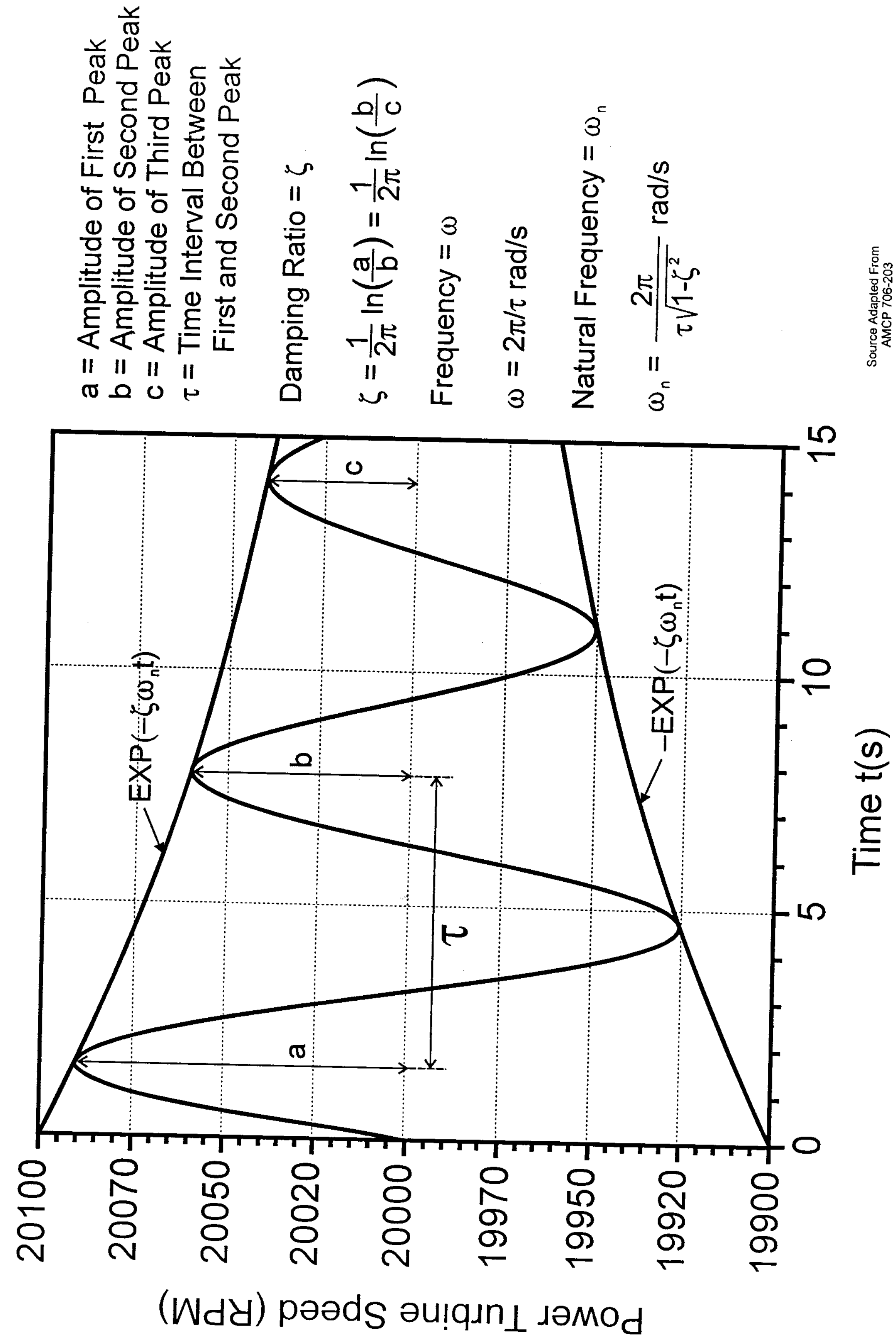


Figure 9-3 Damping Ratio and Frequency Analysis

limits for engine acceptance should be identified and compared with the installation vibration limits over the applicable frequency range. Instrumentation should include the necessary sensors and data acquisition system.

Ground tests should be conducted to record data for the most critical engine vibration conditions. Test conditions specified in the vibration survey should be the same for these demonstrations. The ground tests should be conducted for the final configuration at mission gross weight and at midrange CG unless otherwise specified.

Flight tests of the engine installation should cover specific extremes of the flight envelope that induce the highest vibrations. These tests should include the combinations of gross weight, CG, external stores, power, and flight conditions for which the air vehicle is to be qualified. The full spectrum may be flown with typical mission loading at a gross weight and CG configuration estimated to produce the highest engine vibrations. Data should be acquired at the normal, maximum, and minimum rotor speeds. The 20% of the total flight spectrum that produces the highest vibrations should then be repeated at three other gross weights and CG extremes. The effect of any special intake or exhaust duct configurations or other kits that change the engine vibratory characteristics should also be evaluated in the regimes producing the highest vibrations.

Aircraft controls such as propeller controls, thrustreversers, spoilers, etc., should be tested during ground and flight tests. 14 CFR Part 33 (Ref. 8) includes information for other aircraft engine testing requirements. Even though the aircraft is normally certified in accordance with Part 33 and 14 CFR Part 35 (Ref. 9), the US Army might supplement these requirements.

9-3.1.3 Starting

Engine-starting tests should be conducted to demonstrate the capability of the engine and its components to start within the flight envelope of the rotorcraft and to determine the adequacy of the engine shutdown and startup procedures. The ground and flight tests should be repeated a specified number of times to assure validity.

Ground tests should demonstrate compliance with component and system specification requirements, installation compatibility, and environmental engine-starting requirements. These tests should consist of two phases:

1. Initiation of the start cycle, noting start RPM, adequate voltage at exciter/vibrator, lightoff RPM within time limit, let-go RPM within time limit, engine torque/RPM, engine oil pressure, and exhaust gas temperature. Engine start performance is generally a measure of the capability to bring the engine to a stabilized idle speed within a given time and temperature limit. Fig. 9-4 illustrates an example data presentation for engine-starting characteristics plotted over start time.

2. Determination of

a. The number of consecutive start cycles without recharging orrepressurizing the starter subsystem power source.

b. The number of consecutive start cycles at not less than 10 dwell point temperatures equally spaced throughout an ambient operating envelope of–54 to 52°C (–65 to 125°F)

c. The maximum interval of time between the completion of one cycle and the beginning of the next cycle

d. The starter capabilities to motor the engine

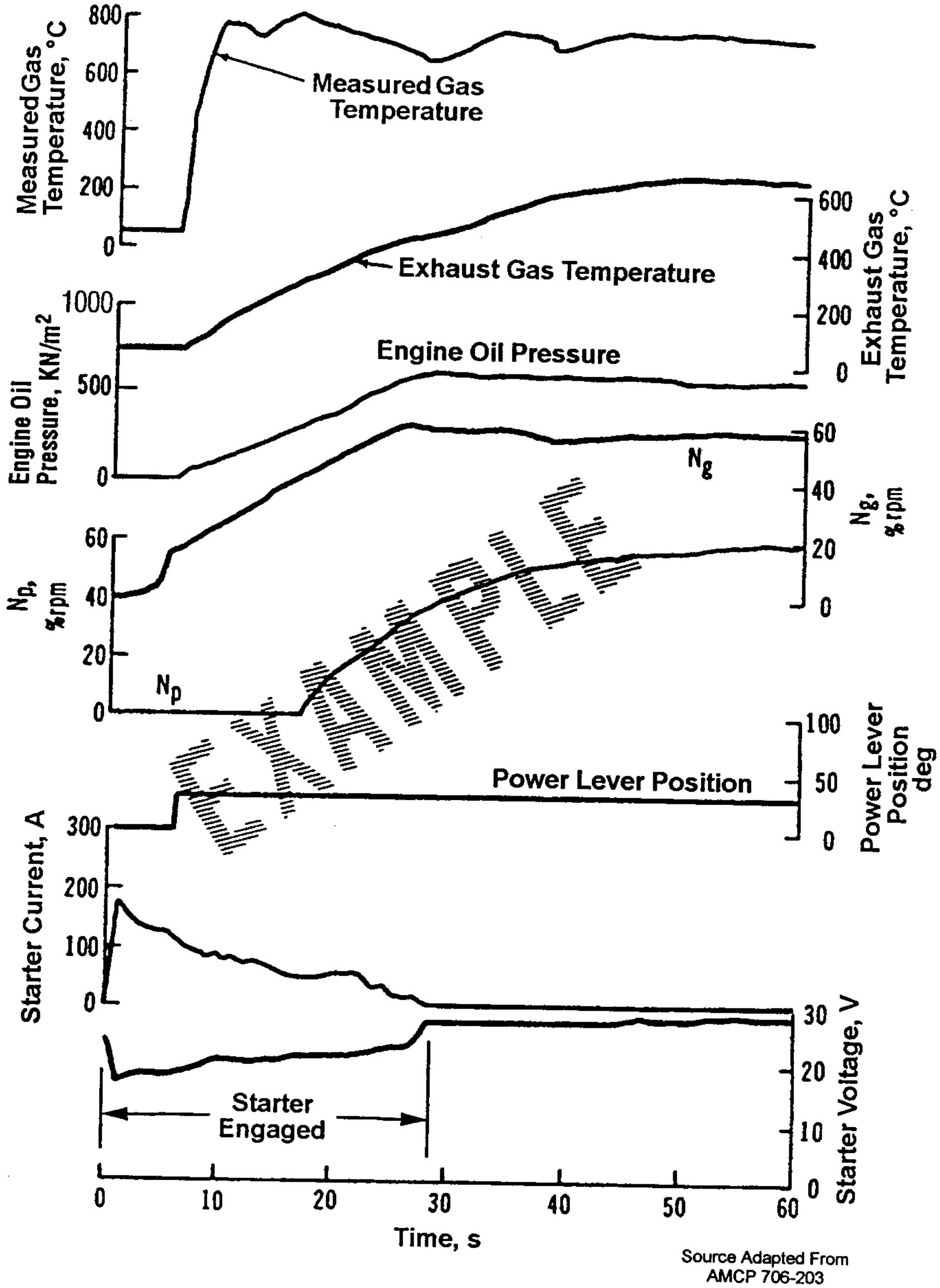


Figure 9-4 Engine-Starting Characteristics

e. The starter duty cycle for engine water wash and engine thermal stabilization. These test requirements should be performed at ambient temperature conditions as well as specified low- and/or high-temperature conditions. The engine-starting tests should also include requirements for using ground-assisted power, engine-cross-start capabilities, and any other start capabilities that are available for the system. Fig. 9-5 illustrates an example data presentation for starter performance using various power inputs and temperature conditions.

Flight tests should demonstrate altitude restarting capability, start performance variation with altitude, and the adequacy of the airborne engine shutdown and altitude restart procedures. Altitude restarts should be performed at a minimum of three altitudes from sea level to the specified service ceiling.

Instrumentation for starting tests is adequate to determine starter temperature, starter RPM, starter current or agent flow, starter terminal voltage or pressure, battery terminal voltage or pressure, time, voltage and current to exciter or vibrator, and torque output of starter.

9-3.2 PROPULSION SYSTEM TEMPERATURE TESTS

A propulsion system temperature demonstration should be conducted to determine the cooling characteristics of the air vehicle and engine-mounted components and structure under specified critical conditions. Temperature demonstrations may be conducted in conjunction with the propulsion system temperature survey, exhaust system survey, lubrication system cooling, and altitude test demonstrations. The contractor should conduct ground and flight tests to determine

1. Engine, transmission, and gearbox oil inlet and outlet temperatures

2. Temperatures of major engine components, structure, and related compartments

3. Temperatures of airframe-mounted accessories, airframe compartments, and areas affected by engine and/or auxiliary power unit and generator and/or blower exhaust impingement

4. Temperatures of the auxiliary power unit compartment and related components including associated air inlet and exhaust systems

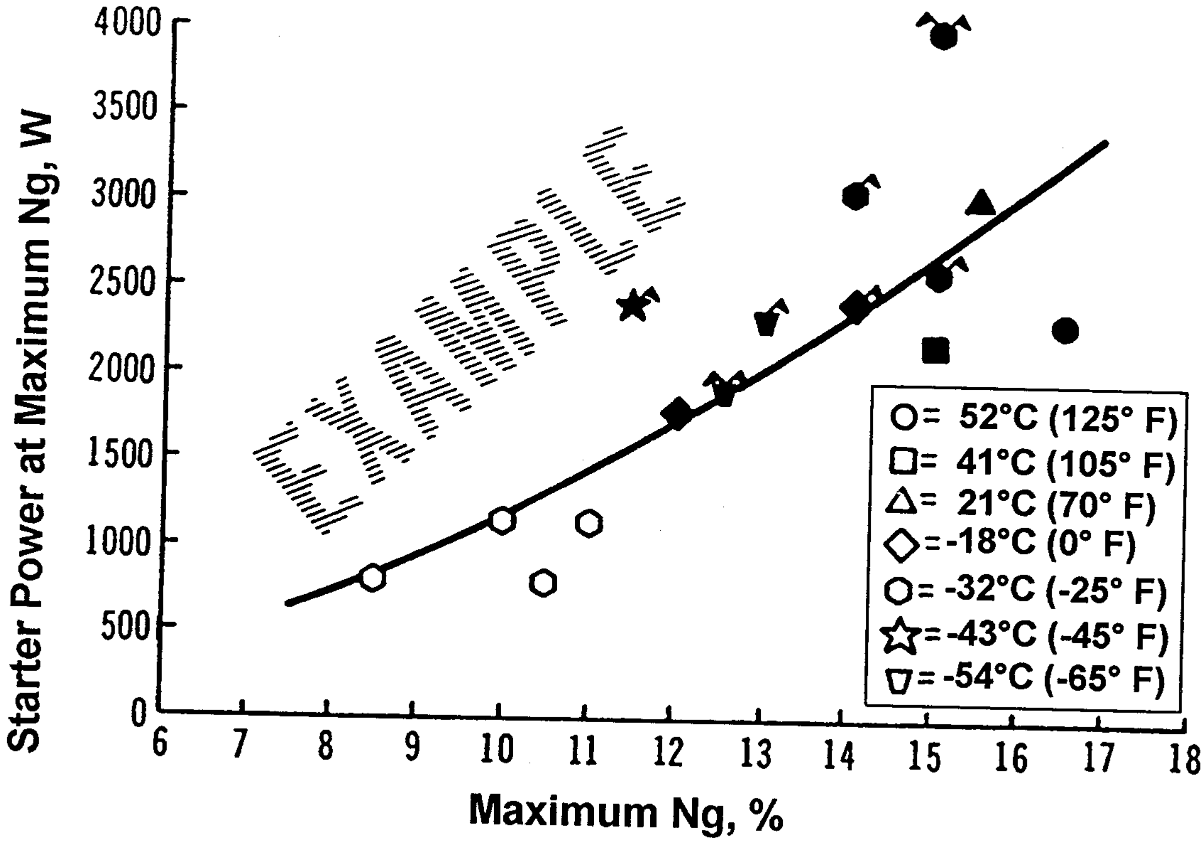
5. Heat exchanger inlet and outlet temperatures for both hot and cold fluids

6. Temperatures of infrared (IR) suppression system surfaces, structure, and related compartments.

A baseline IR-contrast signature of an unpowered (cold) air vehicle should be taken. This signature should be the reference used to determine hot-spot contributions. Measured spectral IR signature data of the unpowered air vehicle should be subtracted from the spectral signature of the powered air vehicle. The engine exhaust plume signature should be verified for compliance with the air vehicle and specification requirements.

Ground tests should be conducted at ambient conditions. The engines should be run for a specified time to allow temperatures to stabilize. Tests should be conducted under various conditions including ground idle, flight idle, 40% and 80% maximum continuous power, maximum continuous power, intermediate power, maximum power, and shutdown. Data should be recorded at established intervals through a specified time following engine shutdown.

Flight tests should be conducted at selected altitude intervals up to the service ceiling. The duration of each test should be sufficient to obtain temperature stabilization or the maximum time within design



Notes: 1. Shaded symbols indicate successful starts, open symbols indicate no start.

2. Single-flagged symbols indicate 21°C (70°F) battery used. Double-flagged symbols indicate auxilliary power unit used, and no flag indicates ambient-soaked battery used.

Source Adapted From
AMCP 706-203

Figure 9-5 Starter Performance

limitations. The level flight runs should include hover out-of-ground effect, hover in-ground effect, minimum power speed, maximum power, intermediate power, and maximum continuous power The test air vehicle should be instrumented with thermocouples and sensors placed in the required locations for adequate data collection. Pressure altitude, airspeed, engine RPM and torque, wind velocity and direction, and compartment airflow rates should be obtained in addition to the required temperature recordings. For all test conditions temperature data should be corrected to hot atmospheric conditions. Allowable operating temperature limits should be specified in the applicable air vehicle design specification or the engine/component manufacturer approved by the PA.

9-3.3 ENGINE AIR INDUCTION AND EXHAUST TESTS

The AC should conduct air induction and exhaust system demonstrations concentrating on the critical flight conditions and configurations identified during the engine air induction and exhaust system surveys. Test conditions include multiple combinations of gross weight, flight speed, flight path, altitude, temperature, power ratings, and intake and exhaust configurations. The AC should demonstrate induction and exhaust system losses and verify compliance with air vehicle and engine specifications.

The propulsion system air induction demonstration is conducted to demonstrate engine inlet pressure and temperature conditions and relate them to free-stream conditions. Engine inlet integration tests determine the compatibility and baseline engine performance influences of the air vehicle engine inlet including temperature and pressure distortion. The AC should conduct ground and flight tests to measure inlet and free-stream air temperatures and total and static pressures from which mean pressure and temperature variations across the engine inlet face can be determined. Inlet test regimes should include

1. Operation with engine anti-ice and/or deice subsystems on and off
2. Operation with the engine air induction subsystem in the normal, icing, or foreign object damage (FOD) bypass, and emergency bypass airflow modes
3. Operation in sideward and rearward flight
4. Operation in flight with varying sideslips
5. Operational characteristics of the inlet particle separator (IPS) and oil cooler subsystems with respect to engine inlet airflow and distribution
6. Demonstration of compliance with specified engine performance degradation from environmental ingestions.

The test engine will be subjected to specified bird, FOD, ice, sand, armament gas, and atmospheric water ingestions. Protection effectiveness of the inlet system against environmental ingestions should be specified by the PA.

Required instrumentation includes an instrumented inlet assembly on all engines to measure total pressure, static pressure, and total inlet temperature used to calculate inlet distortion.

The AC should demonstrate engine exhaust system characteristics during ground and flight tests to verify acceptable design practices and adequate safety of flight margins. The tests should determine the exhaust ejector effect on engine performance. The tests should also verify the IR signature suppression capability. Testing should demonstrate that the engine exhaust system meets or exceeds the hot metal and plume IR signature requirements.

The exhaust system test regimes should include

1. The effect of engine and auxiliary power unit (APU) exhaust flow characteristics on engine and APU performance
2. The effect on the exhaust characteristics resulting from convergence of various exhaust systems
3. The effect of suppressor exhaust impingement on aircraft or ground surfaces
4. The effect of exhaust flow characteristics on the performance of the IPS and engine and gearbox oil coolers.

9-3.4 HIGH-ALTITUDE CONDITIONS

Demonstrations of propulsion system performance affected by high-altitude conditions are conducted in conjunction with other qualification tests when appropriate. The engine should be subjected to altitude tests that consist of operation and air starting performance checks at selected conditions throughout the operating envelope specified in the engine specification. The test conditions should include the effects of power extraction, inlet recovery, bleed air extraction, and inlet distortion on engine performance and stability.

The control system and engine configuration should be calibrated prior to test initiation. The altitude tests should be accomplished using various specified oil and fuel grade combinations. Fuel temperature should be varied over a range sufficient to encompass all anticipated engine operating environments. Overall true root-mean-square (RMS) velocity measurements and acceleration spectrograms should be obtained for each velocity and acceleration sensor at the specified engine speed and power settings. The operating conditions selected will include at least the combination of the rated altitude(s) with the engine operating at the speed of maximum variation within the operating envelope.

Operation at each set of conditions will be of sufficient duration to stabilize the engine and to establish the performance and operating characteristics. Engine operation with the control system in control failure modes will be evaluated, and the effects on engine performance will be determined. The failure modes to be evaluated will be specified by the PA. Operation will be conducted to obtain the following data:

1. A sufficient number of altitude rating points will be selected for each altitude test condition in order to establish operating and performance characteristics. The effects of bleed air and power extraction for auxiliary engine-driven components on steady state performance will be determined at each specified test condition. The time elapsed versus engine speed, measured temperature, and fuel flow will be obtained for stability verification with the power setting at idle, maximum continuous, intermediate, and maximum.
2. The specified transient performance should be demonstrated at each rating condition. The effects of maximum bleed air and power extraction combinations on transient performance should also be determined.
3. Engine steady state and transient characteristics should be demonstrated at each test condition over the range of power settings with and without customer bleed air and power extraction.
4. Inlet airflow distortion limits and effect on transient operation and steady state performance should be demonstrated.
5. Engine in-flight starts and restarts
6. Altitude windmilling tests should be demonstrated.

Verification that the lubricating system should provide proper lubrication and operate without excessive loss of oil during windmilling operation should also be demonstrated.

9-3.5 LUBRICATION

The lubrication system demonstrations verify that the lubrication systems of the engines, transmission, and related gearboxes operate satisfactorily during critical ground and flight operations. The AC should demonstrate the adequacy of the lubrication system throughout the air vehicle flight envelope, including all attitudes within the operational flight envelope and maximum slope angles. Both steady state and transient attitudes should be demonstrated. Steady state demonstrations are limited to those attitudes sustainable by the air vehicle such as level flight, climb, and hover. Transient lubrication system demonstrations, which include quick turns, jump takeoffs, and high angle-of-bank decelerating turns, should be conducted at all attitudes up to the maneuvering limits of the air vehicle.

The test article should be an actual lubrication system as installed on the air vehicle. As a minimum, the following system-level information should be obtained:

1. Pressure measurements to evaluate line and component pressure drops and the effect on the subsystem operating characteristics
2. Dry lubrication pump priming characteristics and scavenge pump capability under all modes of operation
3. System lubricant quantity requirements and development of servicing instructions
4. Temperature measurements to establish the heat dissipation characteristics of the heat exchanger
5. Requirements of any onboard detection and diagnostic system and related sub components.
6. Chip detectors and fuzz burn-off sensors should be tested for specification compliance. The fuzz burn-off sensors should demonstrate the capability to include proper material detection and burn-off without indicating false alarms.
7. Satisfactory performance of the lubrication system after specified qualification and endurance tests.

Subsystem demonstrations should also be conducted to determine

1. Engine lubrication system quantity requirements
2. Quantity of usable oil
3. Oil reservoir expansion space
4. Oil reservoir servicing provisions
5. Oil reservoir level indication calibration
6. Oil reservoir pressure test
7. Low oil level warning operation
8. Oil vent system operation
9. Oil system bypass demonstration
10. Oil cooling demonstration.

9-3.6 FIRE DETECTION AND SUPPRESSION TESTS

The AC should functionally demonstrate, by using simulated fire sources, the installed fire detection system on the engines, APU, and in any internal weapons bay areas, when appropriate. The AC should demonstrate the adequacy of the fire-extinguishing system to meet system specification requirements as well as Federal Aviation Administration extinguishing agent requirements according to 14, Code of Federal Regulations (CFR), Part 29, *Airworthiness Standards: Transport Category Rotorcraft,*(Ref. 10); 14 CFR, Part 121, *Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft,*(Ref. 11); 14 CFR, Part 127, *Certification and Operations of Scheduled Air Carriers With Helicopters,*(Ref. 12);

and 14 CFR, Part 135, *Air Taxi Operators and Commercial Operators*,(Ref. 13). Tests should evaluate both main and reserve fire-extinguishing systems. All demonstrations should be consistent with the standards of the US Environmental Protection Agency.

MIL-F-7872, *Fire and Overheat Warning Systems, Continuous, Aircraft: Test and Installation of*,(Ref. 14) provides relevant information about determining performance, testing, and installation requirements of continuous-type fire and overheat warning systems for use in air vehicles. These systems are designed to use continuous lengths of heat-sensing elements connected to a monitoring device. These types of fire detection devices are usually installed in engine compartments and should be designed to withstand the normally high operating temperature of the environment without false alarms yet be sensitive enough to detect a fire quickly enough for a suppression system to be effective. MIL-F-23447, *Fire Warning Systems, Aircraft, Radiation Sensing Type; Test and Installation of,* (Ref. 15) provides relevant information about determining performance, testing, and installation requirements of radiation-sensing (surveillance-type) fire warning systems for use in air vehicle. Radiation-sensing fire detection devices are designed to produce an alarm signal when exposed to radiant energy (nonthermal) emitted by a flame. As designed and installed the system should prevent the occurrence of false fire warnings resulting from flight operations, environmental conditions, damage to components of the system, or loose connections. These fire detection systems should be demonstrated in specified environmental conditions and should record the corresponding response times. Flight demonstrations include verification that the system should not produce false alarms under various flight operating conditions. The actual ambient temperatures of the monitored spaces are also recorded during flight tests.

MIL-E-52031, *Extinguisher, Fire, Vaporizing Liquid: CF3BR; 2 3/4 Pound, With Bracket,* (Ref. 16) describes a one-time-usage, nonrefillable, handheld fire extinguisher and replacement cylinders containing 2 3/4 lb of monobromotrifluoromethane (CF3BR). These CF3BR extinguishers are being replaced by 2 1/2 lb CO2 portable bottles. Since the CF3BR extinguisher is such a common item, it might not be necessary to demonstrate discharge rates, etc. Evidence of previous qualification and demonstration typically will be acceptable. MIL-E-22285, *Extinguishing System, Fire, Aircraft, High-Rate-Discharge-Type, Installation and Test of*, (Ref. 17) describes the installation of high-rate-discharge-type fixed fire-extinguishing systems for engine spaces and other potential fire zones in air vehicles. These CF3BR extinguishers should eventually be replaced by HFC-125-CF3HF2 pentafluoroethane extinguishers. The fire-extinguishing systems are inspected for compliance with the system specifications. A pressure test of the system should be conducted to check the integrity of the tubing and fittings. The system should also be discharged under specified conditions; the duration of discharge should be timed to verify compliance.

Electroexplosive devices (EEDs), which are part of the fire suppression system, should be subjected to 20-dB safety margin testing; see subpar. 9-11.1.

9-3.7 TIE-DOWN TESTING

The total propulsion system including the engine and drive system, rotors, controls, antitorque system, APU, driven accessories, exhaust system, air induction system, and fuel systems should be subjected to demonstrations using either a test bed or the complete tied down rotorcraft. The amount of tie-down testing required is dependent on the testing completed on the ground test vehicle. The objective of the tie-down tests is to demonstrate the operational and performance characteristics of these systems and their associated interfaces. Tie-down testing demonstrates both hardware and software (if any). Also it verifies proper integration and operation of the systems prior to initial flight tests. The requirement for the tests is to demonstrate the absence of catastrophic failure modes and the fail-safe features of the dynamic components. The duration and scope of each test typically are specified by the AC and approved by the PA. As with all propulsion system qualification, tie-down tests should be conducted in conjunction with other required demonstrations whenever appropriate.

The tie-down tests should include shakedown, development, and systems enhancement testing on the tie-down test vehicle. During testing, degraded modes of operation should be demonstrated. Instrumentation should be installed to capture all necessary data adequately. Tests will include but not be limited to

1. Engine/airframe compatibility tests, including fuel control/flight control interactions, engine starts, rotor run-ups, steady state power governing, engine response performance, rotor management, and engine/airframe vibration characteristics
2. Fault insertion tests to verify adequate air vehicle behavior with loss of partial or complete authority of engine controls
3. Rotor/flight control stability checks at multiple speeds and power levels
4. Temperature margin on critical air vehicle components and related subsystems
5. Exhaust and IR suppressor operation with respect to structural integrity, cooling characteristics, vibration signature, and exhaust back pressure effects on the performance of the main engines, oil coolers, etc.
6. Fuel and lubrication system tests, compartment drainage, engine washing, and fire detection systems
7. Critical air vehicle stationary and rotating component parameters monitoring
8. Endurance tests as specified by the PA.

Postflight inspections and teardown should be performed to verify procedures, limitations, and adequacy of any modifications resulting from previous tests.

9-4 FLIGHT LOAD SURVEY

A flight load survey should be accomplished to obtain data that can be used to validate design loads or stresses for each flight condition in the maneuver spectrum defined for the air vehicle. These stress levels (mean plus oscillatory stress) should be measured for each gross weight, CG, airspeed, and altitude condition in the approved maneuver spectrum and should be used to predict component fatigue lives.

A typical rotorcraft maneuver spectrum for both scout/attack and cargo/utility rotorcraft is shown in Table 9-1, which is intended only as a sample. Component and airframe stresses should be measured for each of these maneuvers at a variety of mission gross weights and rotor speeds. In the example maneuver spectrum, the composite percentages shown for each maneuver would be used along with the measured stresses for that maneuver to determine accumulated stresses for components and airframes analytically over time. The addition of those weighted

TABLE 9-1. TYPICAL ROTORCRAFT MANEUVER SPECTRUM

EXAMPLE - Actual spectrum used should reflect aircraft's unique properties, current tactics and mission profiles.

	SCOUT/ATTACK DENSITY ALTITUDE, ft				CARGO/UTILITY DENSITY ALTITUDE, ft			
	0 to 4k	4 to 8k	> 8k		0 to 4k	4 to 8k	> 8k	
	PERCENT OF TIME				PERCENT OF TIME			
MANEUVER	40%	50%	10%	COMPOSITE*	40%	50%	10%	COMPOSITE*
Loiter A/S	20.55	19.86	18.31	19.98	18.55	17.76	17.51	18.05
Level Flight 0.6 VNE	0.83	1.68	1.61	1.33	1.53	2.88	2.71	2.32
Level Flight 0.7 VNE	1.14	1.33	0.98	1.22	1.94	1.93	1.78	1.92
Cruise 0.8 VNE	9.18	4.21	1.82	5.96	10.68	6.01	4.02	7.68
Cruise 0.9 VNE	30.42	18.71	13.03	22.83	29.42	17.71	12.23	21.85
High-Speed VNE	8.24	25.07	33.11	19.14	7.24	23.07	31.11	17.54
IGE Hover	1.54	**	**	1.54	2.64	**	**	2.64
OGE Hover	1.21			1.21	0.21			0.21
Flat Pitch	2.32			2.32	2.92			2.92
Normal Start	2.29			2.29	2.59			2.59
Normal Shutdown	1.19			1.19	1.29			1.29
IGE Turns	0.11			0.11	0.26			0.26
IGE Control Reversals	0.02			0.02	0.05			0.05
IGE Sideward Flight	0.03			0.03	0.08			0.08
IGE Rearward Flight	0.01			0.01	0.03			0.03
VTO to 40 ft and Accelerate	0.18			0.18	0.16			0.16
Normal Takeoff and Accleration	0.22			0.22	0.37			0.37
Rolling Takeoff and Acceleration	0.06			0.06	0.09			0.09
Twin Engine (TE) Roll-On Landing	0.08			0.08	0.11			0.11
TE Approach and Landing	0.38			0.38	0.48			0.48
Single Engine (SE) Approach and Landing	0.01			0.01	0.01			0.01
SE Approach With TE Recovery, IGE	0.01			0.01	0.01			0.01
TE Climb	3.00			3.00	4.36			4.36
SE Climb	0.03			0.03	0.04			0.04
Accel Climb A/S to Cruise	1.62			1.62	1.62			1.62
OGE Turns	2.99			2.99	1.99			1.99
OGE Control Reversals	0.09			0.09	0.06			0.06
Cyclic Pull-Ups	0.05			0.05	0.03			0.03
Decel to Descent A/S	2.02			2.02	2.02			2.02
TE Descent	4.84			4.84	4.84			4.84
SE Descent	0.05			0.05	0.05			0.05
TE to SE Transition in Climb	0.01			0.01	0.01			0.01
TE to SE Transition in Cruise	0.01			0.01	0.01			0.01
SE to TE Transition	0.01			0.01	0.01			0.01
Sling Load Takeoff					0.02			0.02
Sling Load Landing					0.02			0.02
Min Power Approach -Power, Recovery-IGE	0.35			0.35	0.45			0.45
Pirouette	0.01			0.01	0.01			0.01
Slope Landing	0.03			0.03	0.05			0.05
Rapid Acceleration	0.25			0.25	0.20			0.20
Rapid Deceleration	0.25			0.25	0.20			0.20
Pushover	0.17			0.17	0.17			0.17
Steep Dive	0.41			0.41	0.41			0.41
Shallow Dive	0.81			0.81	0.81			0.81
Pull-Up	0.86			0.86	0.86			0.86
High "g" Turns	0.96			0.96	0.66			0.66

*Composite spectrum to be used in life determination
**Values below this line are identical for all altitudes.

SE = single engine
TE = twin engine
A/S = airspeed
VNE = velocity not to exceed
VTO = vertical takeoff
IGE = in-ground effect
OGE = out-of-ground effect

stresses for each component should be used to predict the fatigue life of each component by the methods explained in Chapter 4 of AMCP 706-201, *Helicopter Engineering, Part One, Preliminary Design,* (Ref. 18). The fatigue lives of these components are used to establish the minimum component life.

Planning for the flight load survey will comply with the provisions of the approved AQS and should include but not be limited to

1. Tentative flight envelope, including design limit airspeed VDL, and gross weight and CG ranges
2. Ground and flight conditions to be examined
3. Planned instrumentation for the tests, to include structural monitoring, telemetry plans, and onboard recording
4. Data analysis and reporting procedures.

Results of the flight load survey tests may indicate that maneuvers included in the maneuver spectrum are not possible for certain altitudes, gross weights, etc. The results of the flight load survey document those findings.

9-4.1 MANEUVERS

Maneuvering flight is required to obtain flight load data at air vehicle limit conditions. Maneuvers performed during the flight load survey tests should encompass all normal operating limits anticipated for the air vehicle. Such limits will include but not be limited to mechanical subsystem limits, maximum gross weight, rotor speeds, operating altitudes, CG limits, and other applicable limits such as load factor, blade stall, vibration levels, and compressibility limits.

Flight conditions should include external and internal cargo operations for cargo and utility rotorcraft and armed configurations for scout and attack rotorcraft. The example maneuver spectrum for these two types of rotorcraft is shown in Table 9-1. Specific requirements for testing in various operational modes are covered in subpars. 9-4.1.1 through 9-4.1.5.

9-4.1.1 Air-to-Ground Scout/Attack

Once the actual maneuver spectrum to be used for flight load surveys has been established by the contractor and approved by the PA, the maneuvers typical of an air-to-ground scout/attack mission should be identified by the contractor. Typical maneuvers include mask-remask, jump takeoffs, decel-to-dash, and quick stop. Criteria used to initiate and complete the maneuver and data read options covered in subpar. 9-4.3 should be established by the AC and approved by the PA prior to testing. Consideration should be given to recording these loads sequentially with an appropriate delay to allow stabilization of the rotorcraft state. Once the rotorcraft state is stabilized, the next maneuver anticipated during this particular mission would be executed and loads recorded. All maneuvers would be executed in turn until testing is completed. Weapons firing in conjunction with maneuvers is desirable.

9-4.1.2 Cargo/Utility

Cargo/utility mission maneuvers and data requirements should be identified in the same manner used for the air-to-ground scout/attack mission, initiation and completion criteria established, and maneuvers should be conducted in a sequence similar to that ofsubpar. 9-4.1.1. Typical maneuvers are takeoffs, climbs, turns, cruising, and landings. Usually, these maneuvers are conducted at moderate to heavy weights. Also short-field takeoffs and landings should be considered.

9-4.1.3 Nap-of-Earth (NOE) Flight

Certain maneuvers listed in the approved maneuver spectrum are common to any rotorcraft performing NOE flight. Cyclic pull-ups immediately followed by pushovers are typical maneuvers. Also quick stops are included. These maneuvers and data read options are identified by the AC, and pilot techniques and descriptions of the maneuvers are approved by the PA prior to testing. NOE maneuvers should be flown in low-wind (less than 15 kt) conditions to reduce the environmental variability influence on the data.

9-4.1.4 Air-to-Air Combat

Some maneuvers listed in the approved maneuver spectrum might be executed differently by rotorcraft performing simulated air-to-air combat flights and might require different data read options. Typical maneuvers are pedal turns, pedal reversals, slips, pull-ups, pushovers, and the jinkings maneuver. These maneuvers and data read options should be identified by the AC, and pilot techniques and descriptions of the maneuvers should be approved by the PA prior to testing.

9-4.1.5 High-Altitude Surveillance

Maneuvers listed in the approved maneuver spectrum that are typical of high-altitude surveillance missions should be identified by the AC, and pilot techniques and descriptions of the maneuvers should be approved by the PA prior to testing. Typical operations are overgross takeoffs; slow climb to altitude; extended cruise; heavy, flat turns; and landings. Gust upsets are possible during this testing. Therefore, the AC should demonstrate prior to testing that the maneuvers planned are conservative enough to preclude any possibility of catastrophic failure due to gust upset.

9-4.2 TEST TECHNIQUES AND CONDITIONS

In the case of flight or CG envelope expansion, exceeding established pilot or control limitations, adverse weather operations, or special test techniques, maneuvers and conditions not covered by an existing Contractor Flight Release (CFR) or AWR; an updated CFR or AWR should be obtained following the procedures of Appendices C and D, respectively. If required by the PA, Government test witnessing might be required for such flights, and emerging flight load survey data might be required to obtain an updated CFR or AWR.

In-ground effect (IGE) maneuvers, such as NOE accelerations and quick stops, should generally start in low-wind conditions and accelerations should begin with a rapid application of power at a constant altitude. Normal rotor speed transients are permitted as long as the rotor speed can be stabilized at the desired value as soon as practicable. Accelerations should be terminated at airspeeds near 0.8 V_H; V_H is the maximum level flight speed at engine(s) intermediate power rating or power transmission system continuous rating, whichever is less.

Decelerations should be initiated at the same airspeed (near 0.8 V_H) by using the power required for that airspeed and should begin with a rapid cyclic flare and power reduction. Again, transient rotor speeds are permitted if stabilization is possible. Airspeed will be reduced farther at a constant altitude until a hover condition is attained.

Normal turns are entered from the desired trim airspeed and power. The turn is initiated with an approved roll rate and aft application of cyclic until a normal load factor of 1.4-1.5 g is obtained. For the test vehicle a visual “g” meter is used by the pilot. Roll out of the turn is performed by reversing the process. Any gunnery or special mission turn execution is performed according to the techniques and peak load factors approved by the PA.

Pullups and pushovers should be entered from the required airspeed and power. Cyclic control should be applied at the rate necessary to obtain load factors of 1.4 to 1.5 g for pullups and low or negative g acceleration to a level approved by the PA.

Autorotation should be entered at the desired trim airspeed and power. Entry should be performed according to the procedures approved by the PA, and descent should be stabilized at minimum rate of descent airspeed. Transition from autorotation to powered flight is the reverse of this procedure.

Control reversals and landing maneuvers should be conducted using procedures outlined in the test plan and approved by the PA.

For all maneuvers performed other than level flight, recording of data should be initiated during an initial stabilized condition, continued throughout the maneuver, and discontinued after a stabilized flight condition is once again attained.

9-4.3 LOAD MEASUREMENT

Components to be instrumented with load-sensing devices, i.e., strain gages, should be identified in the test plan and approved by the PA. These components will include but not be limited to

1. Main and tail rotor blades, propellers, and prop rotors
2. Rotor and propeller hubs
3. Main rotor, directional, and flight controls.

Location of strain gages is based on analysis of the predicted maximum strain and should be approved by the PA. The data read options to be used for each measurement are provided and justified by the AC. These read options may include

1. Read the maximum oscillatory and corresponding mean load recorded in the data record regardless of its location within the record.
2. Read the maximum positive or negative mean value and corresponding oscillatory value recorded in the record.
3. Read both the mean and oscillatory value applicable to each data record.
4. Read the mean value applicable to the data record.

Other performance parameters, such as airspeed, altitude, load factor, rotor speed, engine power, vibration levels, and control positions, should be measured to allow correlation of acceleration, load, or stress data with the maneuvers or operating conditions that produced them.

Loads and stresses in all critical dynamic components occurring during the maneuvers performed should be recorded using electronic recording techniques to allow a comprehensive analysis.

9-4.4 USAGE OF RESULTS

Once reduced, the flight load survey data should be used to establish a conservative estimate of critical component service lives; conservative is defined as underestimation of allowable service life. The AC use the methods of Chapter 4 of Ref. 18 to compute these service lives. Flight loads survey results should be reported in the structural demonstration report.

9-5 DYNAMIC STABILITY

Dynamic stability is an airworthiness criteria. The AC should demonstrate freedom from dynamic instabilities of the air vehicle throughout the operational envelope, including ground, shipboard, water, and airborne operations. Also aeroelastic and mechanical stability should be demonstrated in conjunction with any flight envelope expansion. These instabilities include but are not limited to unstable, self-excited vibrations that require no periodic force to maintain the vibration level. The AC should consider ground resonance for rotorcraft with lead-lag damper systems. Also the AC should consider aeroelastic (flutter) and mechanical stability for all air vehicles. Each of these areas is discussed in the subparagraphs that follow.

9-5.1 GROUND RESONANCE

When the frequency of the lead-lag motion of the rotor blades approaches the natural frequency of the landing gear spring system and inadequate damping is present, a violent, unstable oscillation called ground resonance can occur. Accordingly, all rotorcraft with lead-lag motion of the main rotor blades will demonstrate freedom from instability if the frequency of this mode is below or near operating rotor speed. A demonstration should also be required for the tied down configuration, if applicable.

The tests used to demonstrate freedom from this instability should include the most critical (as determined by correlated analysis) combinations of operational variables of the rotating and landing gear spring damping characteristics. The other parameters that should be evaluated include but are not limited to

1. Gear oleo servicing pressure variations
2. Percent airborne
3. Tire pressure
4. Slope landings
5. Stability augmentation system (SAS) on and off.

The AC should submit, as part of his AQS and dynamic stability testing, plans for ground resonance testing. These plans should identify excitation methods, gross weights and CG conditions to be used, methods for SAS-on and SAS-off testing, and methods of varying the parameters listed here. Provisions for motion picture and/or video coverage should be identified.

A test report should be submitted to the PA. The PA will specify the various plots of rotorcraft parameters versus rotor speed, and the test report should include those plots and a matrix of responses to those variables that clearly identifies the most critical combinations of those variables. See subpar. 9-5.3 for additional information.

9-5.2 BLADE FLUTTER

The terms aeroelastic stability and flutter are synonymous. Both rotorcraft and other aircraft might experience flutter. See subpar. 9-5.3 for additional information and guidance. Also see subpar. 6-2.5.2.

9-5.3 AEROELASTIC AND MECHANICAL STABILITY

The aeroelastic and mechanical stability airworthiness and qualification test objectives at the system level are to substantiate that main and tail rotor(s), propeller(s), proprotor(s), and fixed aerodynamic subsystem(s) have, when coupled to the airframe, adequate mechanical aeroelastic stability throughout the operational envelope, including ground, shipboard, water, and airborne operations. Ground operations should include all operating scenarios, such as rotor, propeller, or proprotor turning while tied down; rotor or proprotor coast down; run on landings and taxi operations. Shipboard operations with rotor, propeller, andproprotor turning with the air vehicle tied down, etc., should all be considered.

Aeroelastic stability analyses should be performed prior to flight. Rotating system analyses should use rotor,proprotor, or propeller rotating natural frequencies (edgewise, chordwise, and torsional) determined as a function of RPM from zero to 1.25 times normal operational rotor speed (Southwell plots) and verified by test. Fixed system analyses should use aerodynamic surface(s) natural frequencies determined for all operating configurations, i.e., wing stores, deployable surfaces, etc., and verified by test. Adequate stability margins are required and should be demonstrated for all operational combinations of rotor(s) RPM, airspeed, altitude, and load factor within the flight envelope.

Mechanical stability analyses should be performed prior to ground run. Mechanical stability is defined in this handbook to include ground resonance, drivetrain or torsional stability, and whirl mode stability. The analyses should consider all operational gross weight/center of gravity combinations (including the variation of longitudinal, lateral, vertical CG), temperature variation for temperatures ranging from –48° to 52°C (–55° to +125°F), and any two simultaneous, nonsimilar failures (i.e., simultaneous failure of one oleo and one lag damper, etc.). Adequate mechanical stability margins are required and should be demonstrated for all operational combinations of rotor(s) RPM, gross weight, CG, temperature, and simultaneous dual component failure.

Aeromechanical and aeroelastic stability should be demonstrated in conjunction with any flight envelope expansion. Stability test points typically required include

1. All corners of the flight envelope
2. Operations from various surfaces compatible with the use of the air vehicle at rotor speeds up to the maximum obtainable, including partial ground contact conditions (0 to 99% airborne)
3. A flare from autorotation at the maximum obtainable rotor speed
4. Other operating conditions identified as critical to stability.

Air vehicle configurations for these demonstrations should be shown by analysis and test to be most critical. At least three failure conditions identified as critical should also be demonstrated. Demonstration air vehicles should be equipped with a system capable of automatically exciting all relevant modes and with instrumentation capable of measuring the response of those modes.

14 CFR, Part 23, *Airworthiness Standards: Normal Utility, Acrobatic, and Commuter Category Airplanes,*(Ref. 4) and 14, CFR, Part 25, *Airworthiness Standards: Transport Category Airplanes,*(Ref. 5) should be used as a guide for required aircraft aeroelastic stability testing.

9-5.4 WING AND CONTROL SURFACE

For aircraft with fixed wings and tilt rotor aircraft, flight testing instrumentation should be used to monitor control positions and aircraft responses for evidence of loss and/or reversal of aileron or elevator control, wing and wing-aileron divergence, stabilizer-elevator divergence, and dynamic aeroelastic effects in which wing and control surface structures might be coupled with the rigid body response of the aircraft. This testing monitoring is normally conducted in conjunction with other testing. Planning for those tests should include a description of the monitoring instrumentation and methods that will measure these dynamic criterial. 14 CFR, Part 23, (Ref. 4) and 14 CFR, Part 25, (Ref. 5) allow freedom from flutter, control reversal, and divergence to be demonstrated by rational analysis if the analysis shows this freedom up to 1.2 times design dive speed V_D.

9-6 AERODYNAMIC DEMONSTRATION

The AC should conduct aerodynamic demonstrations and flight tests to verify level flight performance; rotorcraft, aircraft, and/or transition flight qualities for tilt-rotor aircraft; autorotation or unpowered glide and spin and stall characteristics; and takeoff, climb, landing, and hover performance. Collectively, these tests should have sufficient breadth of testing to provide data adequate to construct or modify the flight performance envelope section in the operator's manual. Each of these activities is covered separately in subparagraphs of this paragraph. These are typical AQS measures for both airworthiness and critical performance criteria. The methods, flight conditions and air vehicle limitations are typically proposed by the AV and incrementally authorized in the Contractor Flight Release by the PA.

9-6.1 FLIGHT PERFORMANCE TESTS

A flight performance survey and demonstration should be conducted by the AC to provide preliminary substantiation of flight performance and to provide data for inclusion in operator's manuals. The data collected and analyzed by the AC are important to validate the initial configuration. AMCP 706-204, *Engineering Design Handbook, Helicopter Performance Testing,* (Ref. 19) and Air Force Technical Report (AFTR) No. 6273, *Flight Test Engineering Handbook*,(Ref. 20) should be used as guides for data reduction and presentation.

9-6.1.1 Common

Common testing refers to tests that are common to rotorcraft and other aircraft. Flight test planning should identify the meteorological criteria for testing (calm, stable air), engine power measurement and propulsion system torque instrumentation, and calibration procedures for that instrumentation before, during, and after testing.

The AC should test and document level flight, climb, and engine performance, as required by the PA. Methods used for rotorcraft and vertical takeoff and landing (VTOL) aircraft are similar. 14 CFR, Part 33, *Airworthiness Standards: Aircraft Engines,* (Ref. 8) contains widely accepted methods used for engine testing that are applicable to a variety of air vehicle engines.

9-6.1.2 Aircraft

Performance testing for aircraft should use a widely accepted method for documentation, such as AFTR 6273, *Flight Test Engineering Handbook*,(Ref. 20). The principal purpose of aircraft with fixed wing flight performance testing is to determine lift versus drag for various configurations (flap setting, etc.) and flight conditions. A method used to accomplish this is included in Ref. 20. The lift versus drag data in combination with installed propeller (if so equipped) performance and installed engine performance can be used to calculate the following aircraft flight performance power required versus speed, power-limited speed, ceiling, climb rates, fuel flow, etc. Additional testing is required to measure specifically aircraft takeoff and landing performance, distance to clear obstacle, accelerate, stop distance, and landing distance. 14 CFR, Parts 23 and 25, (Refs. 4 and 5) contain requirements for climb with all engines operative or one engine inoperative and minimum control speed that are the design goals.

9-6.1.3 Rotorcraft

A widely accepted method used for testing level flight performance for rotorcraft includes the density-altitude/constant

$N_R/\sqrt{\theta}$ method. N_R is defined as rotor speed in rotations per minute, and θ is defined as the temperature ratio. This method is based on the fact that rotor performance can be uniquely described in nondimensional form with thrust and power coefficients C_T C_P, and advance ratio μ when the rotor advancing tip Mach number is constant for the range of nondimensional thrust coefficients C_T at each μ. Advance ratio μ is a nondimensional number representing rotorcraft speed divided by rotor tip speed.

Rotorcraft coefficient of thrust C_T is computed by

$$C_T = \frac{W_t}{\rho A \Omega_R^{\ 2}}, \text{ dimensionless} \quad (9\text{-}1)$$

where

W_t	=	test weight, N (lbf)
Ψ	=	test air density, kg/m^3 (slug/ft^3)
A	=	rotor disk area, m^2 (ft^2)
A_R	=	rotor tip speed, m/s (ft/s).

Rotor disk area and tip speed are fixed. By holding the relationship of test weight and air density constant (climbing as fuel is burned off), speed-power (μC_P) polars or plots can be obtained at various airspeeds for the same C_T. The testing will involve use of PA- and AC-determined values of C_T to define vehicle flight performance.

The power required for each data point is converted to the nondimensional power coefficient C_P, which in the SI is given by

$$C_P = \frac{SP_t}{\rho A \Omega_R^3}, \text{ dimensionless} \quad (9\text{-}2a)$$

and in the English system, is given by

$$C_p = \frac{550\,SP_t}{\rho A \Omega_R^3}, \text{ dimensionless} \quad (9\text{-}2b)$$

where

SP_t = shaft power, W (hp).

Finally the power coefficient is plotted against the advance ratio T, which in SI is given by

$$\mu = \frac{0.51444\,V_T}{\Omega_R}, \text{ dimensionless} \quad (9\text{-}3a)$$

and in the English system, is given by

$$\mu = \frac{1.6878\,V_T}{\Omega_R}, \text{ dimensionless} \quad (9\text{-}3b)$$

where

V_T = true airspeed for each polar flown, kt.

A cross plot can then be prepared by obtaining the appropriate values of C_T and C_P at constant values of advance ratio describing level flight performance power requirements.

Airspeeds for the best rate of climb, angle of climb, maximum rate of climb, and service ceiling should be established during climb tests. The AC should propose gross weights, power settings, density altitude ranges, and airspeeds to be used in the tests. The tests should be conducted so the effects of wind gradients (crosswind, reciprocal headings on successive data collection points) are minimized.

9-6.2 FLYING QUALITIES TESTS

The stability characteristics of air vehicles should be demonstrated by flight tests conducted in accordance with the provisions of subpars. 9-6.2.1 through

9-6.2.3 and the integrated flight test plan approved by the PA. The plan should include all of the gross weight, CG, altitude, and rotor or propeller speeds used in the testing. These tests should be conducted to establish or verify flying qualities requirements

9-6.2.1 Common

Common testing refers to testing that is common between rotorcraft and other aircraft. Common testing involves determination of static longitudinal, lateral, and directional stability and dynamic stability. However, methods used for the two types of air vehicles may differ greatly if an aircraft is qualified using 14 CFR, Parts 23 and 25, (Refs. 4 and 5) as a guide. MIL-F-8785, *Flying Qualities of Piloted Airplanes,* (Ref. 21) and ADS-33, Handling Qualities Requirements for Military Rotorcraft, (Ref. 22) both include the following:

1. Operational missions
2. Loadings
3. Moments and products of inertia
4. External stores
5. Configurations
6. Functional status
7. Definitions of service flight envelope (SFE) and operational flight envelope.

9-6.2.2 Aircraft

For aircraft with fixed wings a baseline configuration of weight (normally design gross weight), CG (normally forward and aft limits), propeller speed (normally design value), and altitude (preferably near sea level) should be chosen to conduct performance testing. Initially, the required testing should be conducted at these conditions, and configuration parameters should be varied singularly to the determine individual effects of parameter changes.

Stability derivatives are used to measure the flying qualities of the aircraft and can be obtained by using partial derivatives. As each parameter is varied, the partial derivative can be plotted against that parameter and used to imply compliance throughout the flight envelope. An example would be the partial derivative of airspeed with respect to longitudinal stick position against changing CG locations for the range of loadings evaluated. If external stores will be used, their effects on stability and control should be demonstrated.

The AC should identify the stability testing conditions to be used in the integrated flight test plan. If 14 CFR, Part 23, (Ref. 4) or 14 CFR, Part 25, (Ref. 5) is cited as the source for qualification requirements, the flight test plan should follow the guidance in those publications to determine the conditions to be used to evaluate stability of aircraft. These conditions include specific airspeeds, flap positions, landing gear status, and power settings for static longitudinal stability testing. Requirements cited in 14 CFR, Parts 23 and 25, (Refs. 4 and 5) are that the stick force curve have a stable slope for a range of airspeeds.

For static lateral and directional stability, the requirements are that stability be positive for specific ranges of airspeeds for three-control aircraft. For two-control (or simplified control) aircraft different requirements are cited including abandonment of controls for two minutes without assumption of dangerous attitudes or speeds.

Dynamic stability requirements involve testing for both short-period oscillations and combined lateral-directional (“Dutch Roll”) oscillations.

9-6.2.3 Rotorcraft

Performance testing, which is peculiar to rotorcraft, includes such testing as hover performance and handling qualities, vertical takeoffs, and slope landings. ADS-33 (Ref. 22) establishes the requirements for flying and ground handling qualities testing of Army rotorcraft. Use of this publication is meant to ensure that there are no limitations on flight safety or on mission capability due to deficiencies in flying qualities. Handling qualities are specified in terms of three levels, and the synergistic effect of several Level 2 areas could result in a Level 3 total rating (the lowest).

The AC should demonstrate flying qualities for rotorcraft. Information about this topic can be found in ADS-33 (Ref. 22).

9-6.3 TRANSITION FLIGHT QUALITIES TESTS

For air vehicles that can transition from vertical takeoff and landing (VTOL) or vertical/short takeoff and landing (V/STOL) (primarily rotorcraft) modes to fixed wing modes, the AC should conduct tests and demonstrations necessary to determine flying qualities during the transition operations.

In some cases two or more possible flight configurations might be possible at the same test conditions. An example could be flight at 90 kt and maximum gross weight that might be possible with the engine nacelles/thrust vectors in the VTOL mode (0 deg inclination to the vertical plane), in the fixed wing mode (90-deg inclination), or any inclination between those values.

The integrated flight test plan should, as a minimum, identify airspeeds, altitudes, propeller/proprotor speeds, thrust inclination for normal envelopes and for emergency envelopes with one-engine inoperative (OEI) operations, and gross weights to be tested for demonstrating transition flying qualities. Handling qualities and flight performance margins should be demonstrated to establish a transition flight envelope.

The tests and demonstrations should be documented in accordance with par. 9-6. Future revisions of ADS-33 (Ref. 22) may contain specific handling quality requirements for this mode of flight. Until then, MIL-F-83300, *Flying Qualities of Piloted V/STOL Aircraft,* (Ref. 23) should be used for this purpose.

9-6.4 AUTOROTATION OR UNPOWERED GLIDE

The AC should demonstrate the autorotation, or unpowered glide, characteristics of the rotocraft in accordance with the approved test plan. During this testing, safety of operators and ground crew members should be emphasized because establishment of limited power envelopes, such as the height-velocity (HV) envelope of Fig. 9-6, are among the most dangerous tests to be attempted.

9-6.4.1 Common

Common testing refers to testing that is common to rotorcraft and other aircraft. All air vehicles tested should demonstrate their rates of descent as a function of airspeed and altitude. The effects of the rate of descent on calibrated airspeed while the air vehicle is in unpowered descent should be established, and all data presented should be in operational terms such as impact on minimum rate of descent speed and stall speeds.

9-6.4.2 Aircraft

For aircraft with fixed wings the AC should establish parameters for unpowered glide. Typical parameters may include rates of descent at various airspeeds and altitudes, propeller speed and pitch limits, and other requirements of 14 CFR, Part 23 (Ref. 4) or Part 25 (Ref. 5).

9-6.4.3 Rotorcraft

The AC should demonstrate the autorotational performance of rotorcraft and should consider, as a minimum, four areas for evaluation. These areas are steady state autorotation performance, establishment of a height-velocity envelope, performance during partial power descents, and stability during autorotation entries.

Steady state autorotation performance should be established as a function of rotor speed, airspeed, density altitude, and gross weight. The envelope exploration, such as the sawtooth descent test technique, may be specified in the Contractor Flight Release. The sawtooth test method is a series of timed climbs and descents at varying airspeeds, through a given altitude band and alternating the climbs and descents. These tests should include performance at the most critical conditions for high and low rotor speed and rates of descent. Normally, the low-altitude, low-gross-weight condition should coincide with lower rotor speeds, and the high-altitude, high-gross-weight condition should be most conducive to rotor overspeed.

The HV envelope should be established by the AC using a method that minimizes actual hazard exposure and potential damage. One such method establishes this envelope by entry into autorotation at successively lower absolute altitudes for each airspeed tested. After an agreed-upon delay in reducing collective thrust, the rotorcraft should enter an autorotational descent, adjust airspeed in accordance with the approved integrated test plan, and land. The contractor should conclude testing at an airspeed at which some limiting condition, such as minimum airspeed attainable or maximum rate of descent, is encountered, and that airspeed and altitude should constitute a data point for establishment of the HV envelope. An example of this envelope is shown at Fig. 9-6. There are two upper boundaries in Fig. 9-6—one for low gross weight and one for high gross weight. Together with the lower boundary, the upper boundaries identify airspeed and altitude conditions that should be avoided. Complete failure while operating within those boundaries would probably result in damage to the rotorcraft and/or injury to occupants despite the best efforts of the pilot. In Fig. 9-6 a low-altitude, high-speed boundary is also shown that is an avoidance region for the same reasons.

Partial power descent performance should be established for multiengine rotorcraft as it is for the HV envelopes. These envelopes should identify the gross weights at which the rotorcraft cannot hover IGE after loss of one engine and any avoidance regions. Performance curves (power required versus airspeed and gross weight) for single-engine rotorcraft may be used to estimate partial power descent performance if a reduced power condition occurs.

The AC should also demonstrate that the rotorcraft has acceptable handling qualities and safe rotor decay characteristics following a power failure. The flight envelope used for this demonstration should involve all authorized flight conditions and gross weights . Entry procedures; delay times for collective pitch; and longitudinal,

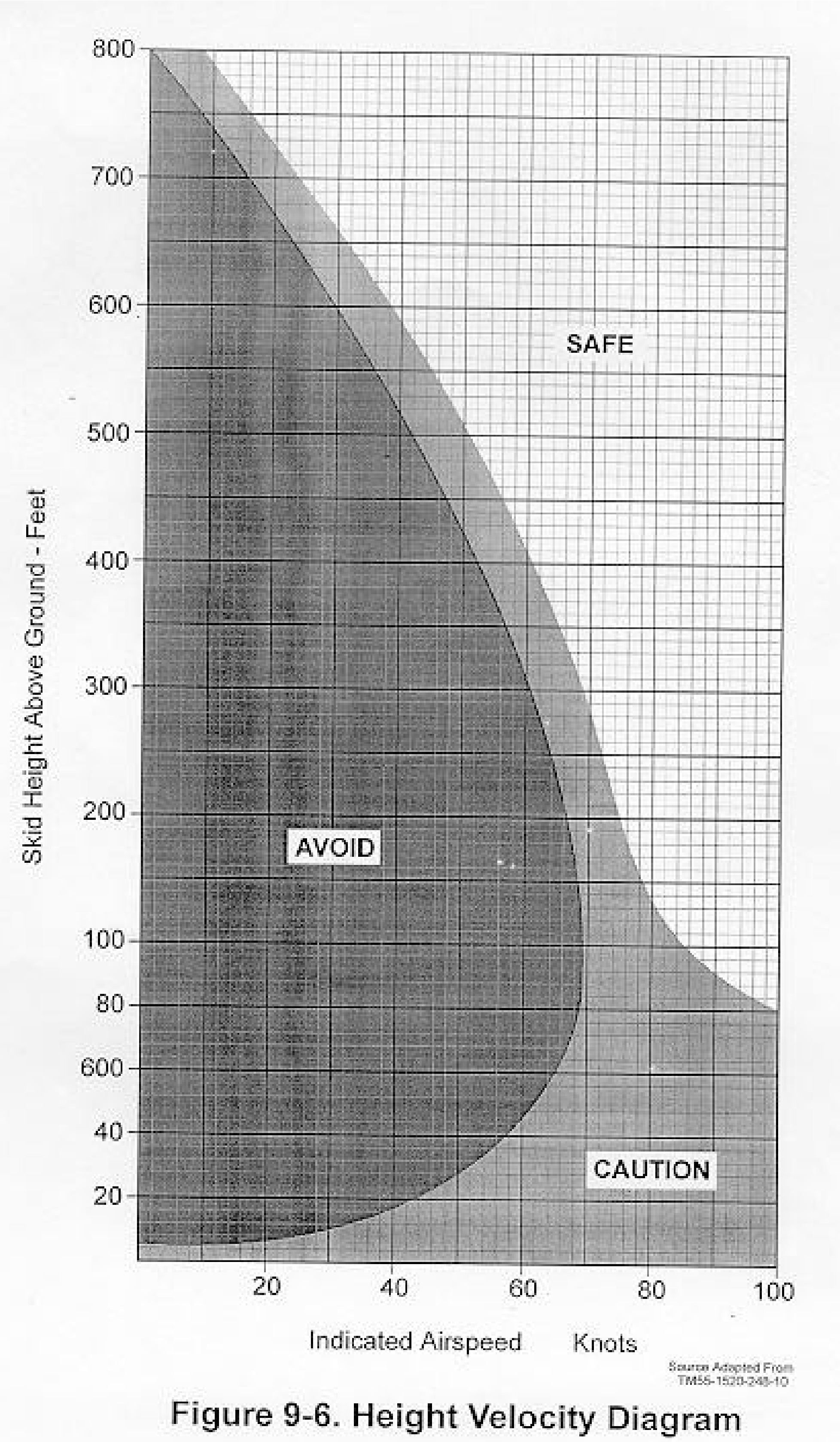


Figure 9-6. Height Velocity Diagram

lateral, and yaw control adjustment following power reduction should be in the flight test plan.

9-6.5 SPIN AND STALL CHARACTERISTICS

Spin and stall characteristics testing is conducted to determine theairworthy limit airspeeds at which the stalls and spins occur, indications to the pilot that the condition is about to occur, and the appropriate recovery response after the occurrence. If 14 CFR, Part 23, (Ref. 4) is adopted by the PA to specify spin and stall characteristics for aircraft, the AC should demonstrate that spin and stall characteristics are in accordance with the provisions ofsubpars. 23.201 through 23.221 of Ref. 4. Prior to initiation of testing, the AC should identify which category of criteria (normal, utility, or acrobatic) the AC intends to test against. The PA should specify exceptions to wing and cowl flap, landing gear, power, trim, and propeller criteria cited in 14 CFR, Part 23, (Ref. 4), if applicable. The PA should also specify or approve the contractor's proposed criteria for determining when an aircraft has encountered excessive loss of altitude, undue pitch-up, or uncontrollable tendency to spin.

If 14 CFR, Part 23, (Ref. 4) is not specified by the PA, the AC should develop a test plan to demonstrate recovery from stalls and spins. Demonstration of stall recovery should include recovery from the following types of stalls: wing-level stalls, turning flight stalls, accelerated stalls, and critical engine inoperative stalls. This test plan should follow the general guidelines of 14 CFR, Part 23, (Ref. 4), as applicable.

Regardless of the demonstration method, test results will be documented in accordance with par. 9-6.

9-6.6 TAKEOFF

Takeoff performance should be demonstrated with the aircraft at gross weights, altitudes, temperatures, configurations, engine power ratings, and CG locations approved by the PA. The purpose of these demonstrations is to determine takeoff distances required and obstacle clearance capabilities, to provide preliminary data for inclusion in technical manuals, and to verify specification compliance.

9-6.6.1 Common

Both aircraft and rotorcraft takeoff performance testing should demonstrate the runway or takeoff distance required to clear an obstacle of a set height (usually 15.2 m (50 ft). 14 CFR, Part 23, (Ref. 4) has set 10.7 m (35 ft) as the height for commuter category aircraft. This distance should be the horizontal distance measured from the point on or above the takeoff surface where the takeoff begins to the point along the takeoff path at which the required height above ground level (AGL) is reached.

For normal takeoffs the maneuver is similar for rotorcraft and other aircraft except for height above ground. Rotorcraft and other aircraft typically accelerate at a predetermined power setting to rotation airspeed VR,, rotate to a predetermined pitch angle, and accelerate to best angle of climb VX.. The means used to determine best angle of climb varies. Obstacle clearance capabilities should be calculated in advance for given ambient conditions. Loss of power implications should be considered. Rotorcraft-peculiar takeoff demonstrations are covered in subpar. 9-6.6.3.

Service ceilings should be determined by the AC for conditions with all engines operating and OEI formultiengined aircraft. The service ceiling is defined as the maximum pressure altitude at which a 30.5-m/min (100-ft/min) climb can be maintained for a given temperature, gross weight, and engine power setting.

Data should be collected to allow plots of rates of climb (R/C) versus torque change at various gross weights, configurations, and airspeeds approved by the PA.

9-6.6.2 Aircraft

14 CFR, Part 23,(Ref. 4) and Part 25 (Ref. 5) contain detailed requirements peculiar to aircraft takeoff and climb. These requirements should be used as a guide for demonstration of aircraft takeoff and climb characteristics. Tests should include crosswind takeoffs at the maximum allowable limits and aborted takeoff tests. Aircraft takeoff tests should also include tests to demonstrate the capability to maintain aircraft control during loss of thrust during the takeoff roll and loss of thrust after takeoff.

9-6.6.3 Rotorcraft

Rotorcraft takeoff demonstrations should include demonstrations of two other takeoff modes if required by the PA. These two modes are vertical takeoff and terrain flight takeoff.

Vertical takeoffs should be demonstrated for gross weights, altitudes, and temperatures specified by the PA. To perform this type of takeoff, the rotorcraft must have power in excess of that required to hover out of ground effect (OGE). Demonstration of required hover power is discussed in subpar. 9-6.8. Usually, these requirements are stated as a vertical rate of climb (VROC) at the specified gross weight and atmospheric conditions.

If specified by the PA, the AC should demonstrate terrain flight takeoffs. After verification that hover OGE is possible, these takeoffs begin from the normal takeoff position. However, a constant climb angle is used as the rotorcraft accelerates to specified obstacle clearance height. Once that height is reached, climb is discontinued, and the aircraft transitions to level terrain flight.

9-6.7 LANDING

The North Atlantic Treaty Organization (NATO) Advisory Group for Aeronautical Research and Development (AGARD) *Flight Test Manual, Volume 1, Performance,* (Ref. 24) defines landing as the process in which an aircraft is safely brought from a safe flight condition to a standstill. The AC should demonstrate landing performance according to the approved AQS using flight conditions and aircraft configurations approved by the PA. Information obtained during this testing should be used to establish emergency procedures for engine-out landing of multiengined aircraft.

9-6.7.1 Common

The AGARD *Flight Test Manual* stresses the steady, controlled nature of measurements such as rate of descent, angle of approach, and approach airspeed and the division of each landing test into air and ground run phases. The air phase encompasses all activities prior to touchdown, and the ground run phase begins when the aircraft touches down on the landing surface. The standard values or range of allowable values for measurements of airspeed, rate of descent, and/or angle of approach, combinations of gross weight, CG location, altitudes, and rotor or propeller speeds should be established before testing and incrementally explored .

Measurements that might vary from test to test include ground speed at obstacle height, ground speed at touchdown, air phase time, air phase distance, ground distance, wind speed, air temperature, and air pressure. When braking distance is of concern, the air vehicle should be equipped with a means to measure consistent application of braking force, such as a longitudinal accelerometer.

9-6.7.2 Aircraft

The landing airspeed chosen should be such that for aircraft airspeed is sufficiently above stall airspeed V_{STALL} to provide positive control and recovery in the event of an emergency, such as a single-engine failure on a multiengined aircraft. If 14 CFR, Part 23, (Ref. 4) or Part 25, (Ref. 5) is used as a basis for qualification, approach airspeed will be above 1.3 V_{STALL}.

Prior to testing, the standard approach technique should be established, and airspeeds and rates of descent or flight path angles typically are specified along with the data to be collected, collection methods, reduction techniques, and acceptable values for the landing parameters.

9-6.7.3 Rotorcraft

AMCP 706-204, *Helicopter Performance Testing*,(Ref. 19) contains detailed requirements for conducting rotorcraft landing performance tests. Traditional methods are covered that stress testing constant airspeeds throughout landing descent. Measurements include horizontal distance to clear a 15.2-m (50-ft) obstacle, rate of descent, and gear load at touchdown. Data reduction forms for these measurements are shown in Table 11-3 of AMCP 706-204 (Ref. 19). Any additional limitations, such as collective pitch limits or stability and control concerns, may also establish limits for minimum descent airspeed and will be documented by the AC.

For rotorcraft one constant landing airspeed may not be required. Subject to approval by the PA, an alternate method may be used in which the air phase is flown with a steady rate of descent or angle of approach with airspeed steadily decreasing to the approved value (zero for approach to hover). The information gained from use of this method can then be used to establish emergency procedures for rolling landings, such as minimum touchdown airspeed.

Vertical landing tests should be conducted to verify specification compliance. These tests should be conducted according to AMCP 706-204 (Ref. 19) and the approved AQS.

9-6.8 HOVER

Hover flight performance while a rotorcraft or VTOL aircraft is out of ground effect should be demonstrated by the AC. Also hover flight performance should be demonstrated in winds up to 45kt from any azimuth. Critical azimuth locations (if any) should be demonstrated and documented. The demonstration plan should detail methods, test gross weights, rotor speeds, and height above ground measuring techniques. Hover performance testing should be accomplished prior to landing performance testing according to AMCP 706-204.

The method described in subpar. 9-6.1.3 is an acceptable one to use to demonstrate hover flight performance. However, the importance of calm wind conditions, significant variation in gross weight and/or rotor speeds, and density altitudes should be stressed by the PA during test planning.

Height above ground is commonly measured by one of two techniques. The first technique involves use of a weighted, measured cord and a ground observer to talk the aircrew to the exact height. The second involves hovering at an exact height with the helicopter attached to a load cell on the ground. In this method, rotor thrust is equal to the helicopter weight plus load cell reading, allowing significant variations of C_T during one test flight.

Typical test results should include plots of C_T versus C_P for lines of constant height AGL and maximum hover gross weight versus pressure altitude along lines of constant temperature.

9-7 TOTAL SYSTEM VIBRATION TESTS

Total system vibration tests include ground vibration tests and flight vibration tests. Ground vibration tests are required to confirm that the mode shapes and natural frequencies of the airframe and rotor systems are consistent with earlier analyses. Normally, these analyses result in changes to the design configuration to ensure that helicopter modal frequencies do not coincide with the normal operating range of rotor speeds.

The flight vibration tests are conducted to determine whether vibration levels at crew and personnel stations are acceptable and to investigate vibration levels occurring at selected equipment locations. The vibratory requirements of ADS-27 (Ref. 7) typically apply.

As a minimum, the vibration testing plan should address the methods, conditions, configurations, data collection and analysis techniques, excitation means, schedules, relationships to previous vibration testing, firing tests, stability testing, and acceptance criteria.

Documentation of vibration tests should be according to par. 6 of ADS-27 and the approved AQS unless otherwise specified by the PA.

9-7.1 GROUND VIBRATION TESTS

The two primary types of ground vibration tests are airframe vibration (shake) tests and rotor system vibration tests needed to determine rotor blade and hub properties.

As early as possible in the development process, a full-scale airframe shake test should be conducted to confirm mode shapes and verify that natural frequencies of the airframe and rotor systems do not coincide with rotorcraft excitation frequencies during normal operations. Other purposes of the shake test are listed in ADS-27 (Ref. 7) as are the configurations to be tested and the requirement to repeat the testing using the final production configuration. For this test the mass of the main rotor blades should be simulated in the manner that based on analysis best represents the operating condition. Other airframe items should be installed in their normal operational position or a dynamically similar model of the item should be installed. The ground vibration test should be conducted with the rotorcraft completely suspended from the rotor hub(s) to simulate flight and with the critical gross weight on the landing gear and at intermediate conditions as needed. ADS-27 contains provisions that eliminate the requirement to have the critical gross weight on the landing gear.

Accelerometers are used to record responses to applied excitations. In the test plan the AC should identify accelerometer locations adequate to measure vertical, lateral, longitudinal, and torsional accelerations. Accelerometer locations should also be identified for external stores and for wings and empennages.

Shake tests should be conducted across a frequency range approved by the Government. Normally, this range should be from just above the natural frequency of the suspended helicopter to at least 50 Hz. Accelerometers and appropriate recording devices should be used to document responses to excitations by plotting single accelerometer readings, by unfiltered recording of all signals, or by plotting all accelerometer readings at frequencies of interest, such as main rotor frequencies. If testing at frequencies above 50 Hz is required, the AC should identify the techniques and methods to be used to interpret complex responses.

If ground resonance or mechanical instability is possible (lowest main rotor in-plane natural frequency at or below normal operating rotor speed), additional vibration testing should be performed to determine the effective hub mass, hub damping, and hub natural frequency. The aircraft should rest with all of its weight (not suspended) on a surface similar to the surface from which it will operate. Alternate landing gear configurations and representative tire or pneumatic float pressures should be tested for each landing condition. The effects of temperature on hub mass, damping, and natural frequency should be evaluated by using temperature ranges cited in the detailed aircraft specification. If temperature variations affect mechanical stability, the PA may require additional testing at the more critical temperature(s).

Prior to first flight, rotor system vibration testing needed to determine rotor blade and hub properties should be conducted. These tests are detailed in par. 5.2 of ADS-27 (Ref. 7) and include rotor blade and hub properties determination, control coupling, and rotor frequency tests. Nonrotating natural frequencies, both in and out of the plane of rotation (chordwise and flapwise), should be determined for all rotor blades. If applicable, the rotor blades should be mounted in the hub, which is suspended so that the vertical natural frequency of the suspended rotor system should be less than one-half of the calculated value of the lowest natural frequency being investigated. For these tests excitation may be applied to either the hub or a point on the blade appropriate to the mode under investigation. Plots of the computed coupled natural frequencies versus operating speed should be prepared in a similar manner to the typical plots shown in Fig. 9-7.

9-7.2 FLIGHT VIBRATION TESTS

An in-flight vibration survey of the air vehicle should be conducted by the AC. Information about defining vibration performance levels or intrusion indices at all crew and passenger stations can be found in ADS-27 (Ref. 7). Vertical, longitudinal, and lateral vibration levels should be measured with accelerometers located at stations that will realistically represent what occupants feel.

For rotorcraft, sensitivity to main and tail rotor out-of-balance and out-of-track conditions should be investigated. Vibratory surveys on new air vehicles should also include data collection on equipment outside the crew and passenger compartments. For a new air vehicle, vibration pickups will be installed along the fuselage, wings, empennage, and transmission or main rotor mounting.

ADS-27 defines four flight regions that should be tested for rotorcraft and tilt rotor aircraft vibration specification compliance. Region I consists of all steady flight conditions with load factors between 0.75 and 1.25 g and airspeeds from hover to cruise V_{CRUISE} and to the maximum rearward and sideward flight speeds while operating within the defined power-on rotor speed limits. Region II applies to all flight conditions outside Region I withdurations greater than 3 s, Region III applies to Region II flight conditions with durations less than 3 s, and Region IV applies only to tilt rotor aircraft. However, for tilt rotor aircraft operating in a rotorcraft mode or in

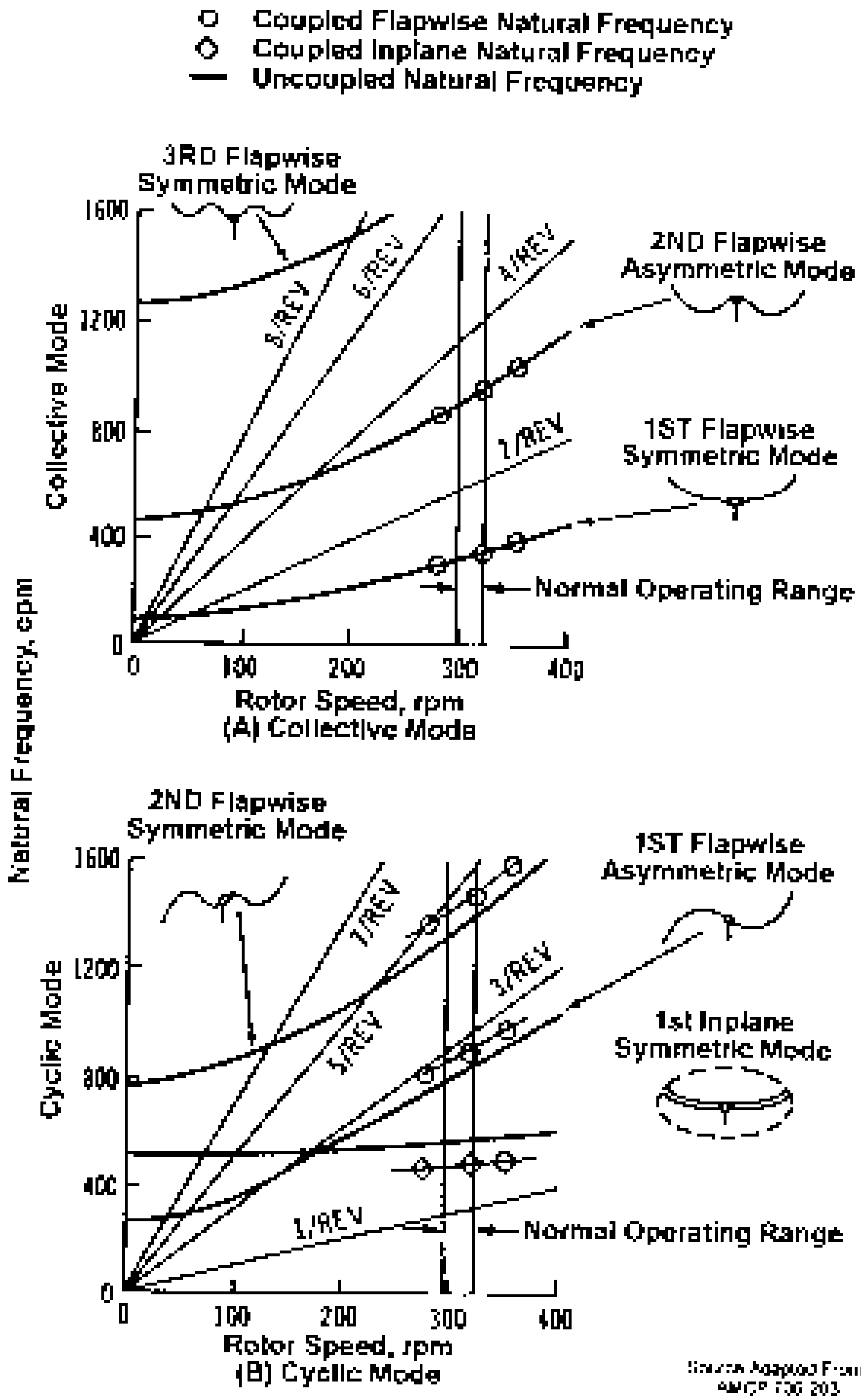


Figure 9-7 Typical Plots of Rotor Natural Frequency vs Operating Speed

transition between rotorcraft and aircraft with fixed wings, Regions I, II, and III requirements will apply, as appropriate.

Crew and personnel station vibration criteria for frequencies up to 60 Hz are identified in ADS-27 as are criteria for controls, instrument panels and displays, and weapons sighting devices. Additionally, ADS-27 identifies the requirement for new aircraft or aircraft undergoing major modification to incorporate onboard rotor vibration diagnostics systems. Demonstration and qualification of this onboard system is accomplished as part of the flight vibration surveys.

For aircraft the PA should specify in the Airworthiness Qualification Plan (AQP) flight vibration testing to be accomplished by the AC. The AC should define methods, conditions, analysis, and criteria for that testing in the AQS.

9-8 ACOUSTIC NOISE TESTS

Acoustic noise testing should establish an accurate definition of internal and external acoustic fields. Typically, it is a good idea to coordinate these test plans with the US Army Aeromedical Research Laboratory (USAARL) because this Laboratory is responsible for the review of data and input into health hazard assessments. These data are used to substantiate that specification noise requirements have been met. MIL-STD-1474, *Noise Limits for Military Materiel*, (Ref. 25) identifies the three types of noise criteria that may be used for limit noise exposure. These are hearing damage risk criteria (DRC), hearing conservation criteria, and materiel design standards. Of the three criteria materiel design standards provide specific noise limits to equipment designers and manufacturers that must not be exceeded if the materiel is to be acceptable to the PA.

Prior to acoustic noise testing the AC should have an acoustic noise survey that includes but is not limited to the external and internal noise conditions to be investigated, instrumentation and noise measurement requirements, test schedules, and data analysis requirements.

Measurements should be used to determine the acoustic environment with respect to established criteria. Such criteria include but are not limited to annoyance, distraction, speech interference, hearing damage, and external detectability.

9-8.1 INTERNAL NOISE TESTS

Internal noise testing should be conducted to obtain data that can be used to determine compliance with an established limit on the amount of noise permitted within the air vehicle. The limit may be based on hearing, speech communication requirements, effects on crew performance, and/or comfort level as specified by the PA. Information concerning these tests can be found in MIL-STD-1789, *Sound Pressure Levels in Aircraft*, (Ref. 26).

Since both the intensity and duration of noise contribute to noise exposure levels, noise intensity for all of the air vehicle operational modes should be determined. Used in conjunction with the time spent in each mode, sound levels for that mode can be used to calculate the noise exposure for a given mission profile.

For internal noise tests operational conditions that can be combined to form operational modes for testing include but are not limited to

1. Flight conditions analogous to the maneuvers of par. 9-4
2. Air vehicle configurations that affect noise attenuation, such as doors on or off and windows open or closed
3. Weapons firing status, active or inactive

4. Noise control means, such as soundproofing, installed or removed.

Minimum instrumentation requirements for internal noise tests should include but not be limited to

1. An instrumentation quality microphone or precision sound level meter (SLM) with free field and random incidence correction microphones
2. Calibration equipment for SLM to assure ±0.2-dB accuracy
3. Octave band analyzer (OBA) in accordance with American National Standards Institute (ANSI) Standard S1.11-86, *Octave Band and Fractional Octave Band Analog and Digital Filters, Specification for,* (Ref. 27)
4. Battery-operated tape recorder, if approved by PA
5. Environmental instruments, such as hygrometer and thermometer
6. Means to determine air vehicle altitude, velocity, power settings, and position of controls at the time of measurement
7. Signal cabling that will not generate spurious signals caused by vibration and electrical fields.

The AC should identify the internal noise criteria to be evaluated, instrumentation that will be used, methods of analysis and data reduction, and acceptable levels criterial.

9-8.2 EXTERNAL NOISE TESTS

External noise tests should be conducted to determine specification compliance, peak noise levels, spectral content, and sound directivity and should be sufficient to allow estimation of the probability of aural detection of the air vehicle. Another purpose of this test is to assess the damage risk criteria for ground personnel working in the air vehicle external noise field. Control of acoustic emissions is covered in subpar. 9-14.3.5.

Before testing begins the AC should identify the test site to be used. An idealized test site with a perfectly reflective plane surface may be used, or a site that simulates real-life conditions of terrain, ground cover, and weather may be chosen. Terrain should be uniform with a low sound-absorbing cover, and microphones should be positioned 1.5 m (4.92 ft) above the ground. In addition, the AC should identify methods for controlling extraneous ambient noise, and these methods should be used during testing.

The AC should select typical maneuvers from the maneuver spectrum discussed in par. 9-4 for external noise testing, and selected altitudes. As a minimum, these maneuvers should include IGE hover, flat pitch, and normal start and shutdown maneuvers in order to assess DRC for ground personnel.

The external noise tests should be conducted using equipment for noise data acquisition and analysis, for recording of meteorological data, and for electronic tracking, location, communication, and guidance of the air vehicle. Parameters to be measured include

1. Noise source strength and radiation
2. Temperature and wind velocity gradients and relative humidity
3. Scale and intensity of turbulence
4. Terrain geography and character and density of ground cover
5. Location of listening instruments.

The instrumentation used should include sufficient microphones, amplifiers, calibration equipment, electronic recording equipment, and time code generators to record the required parameters and correlate the recorded data with supporting data from other sources. The recording system should be able to record the frequency range of interest within 2 dB—usually 20 to 11,200 Hz. Time code generator outputs should be tied in with air vehicle position data, noise recordings, and possibly meteorological condition recordings. Layout, quantity, and spacing of microphones should be adequate to provide reasonable assurance that sideline noise characteristics are described and that unusual terrain or ground feature effects are considered.

During conduct of the testing, all noise data should be recorded for later laboratory analysis. The air vehicle should be flown at right angles to and over the center of the major axis of the microphone layout. These procedures and variations and piloting techniques, such as constant pitch flyovers, should be approved by the PA. Instrument calibration procedures should be documented.

Data analysis may involve the use of third-octave analyzers, narrow band analysis, pattern recognition devices, or a trained human ear. The methods used for data analysis and presentation including the use of automated and/or computerized hybrid analysis method integrating several analysis methods should be documented.

9-9 CLIMATIC LABORATORY TESTS

As part of the qualification tests, the entire air vehicle should be tested by operating the it (all systems including propulsion) in a climatic laboratory under controlled conditions that simulate as nearly as possible the operational conditions under which the air vehicle will operate. These conditions should be identified in the test plan, and should include but not be limited to temperature, shock, vibration, icing, sand and dust, and salt spray. Prior to qualification of the entire air vehicle, selected subsystems should be qualified in accordance with subpar. 6-2.6 for environments such as icing tunnels.

Climatic laboratory tests are essential to evaluating the effects of climatic conditions on

1. Airframe and dynamic component operation and strength
2. Engine operation and performance
3. Pilot capabilities
4. Operating characteristics of

a. Windshield, engine, and rotor system anti-icing, deicing, and defog systems (windshield clear and ready for flight within specified time)

b. Transmissions

c. Avionic and control subsystems including cooling

d. Auxiliary power units

e. Fuel, electrical, and hydraulic or pneudraulic subsystems

f. Heating, ventilating, and environmental control subsystems

g. Maintenance procedures

h. Handling and firing of external stores and weapons, if applicable.

Department of Defense (DoD) Directive 3200.11, *Major Range and Test Facility Base,* (Ref. 28) contains information on DoD test facilities available for all testing. The McKinley Climatic Laboratory, located at 3246th Test Wing, Eglin Air Force Base (AFB), FL, is the primary climatic laboratory used for this type of testing. Test planning for use of this laboratory must include a formal request by the PA to use the facility. Test planning by the AC is critical to the success of the climatic laboratory testing since the facility is heavily used and access is limited.

During the climatic laboratory testing, the air vehicle should be restrained by a system capable of absorbing maximum main rotor thrust or maximum propeller thrust. Exhaust gases from theAPUs and cabin heaters and cooling exhaust from electronic and electrical components should be vented outside the chamber if these exhausts will have a significant effect on laboratory ambient temperatures. Electrical load banks for the electrical system should be used to ensure maximum generating capacity is used.

In the test plan the AC should identify the time requirements for temperature “soak” (usually 48 h), preflight inspection, APU check, and systems checkout procedures to be used prior to climatic testing. The AC should also identify the test sequence(s) to be used after main engine(s) start and the simulated mission profile to be tested.

Once main engines are started, the testing should follow the approved test sequence and applicable mission profile. Conditions that produce cracks or fluid leaks should be noted as the air vehicle “flies” the simulated mission profile(s). If minor repairs are made and time permits, tests should be repeated to verify repairs.

The AC should identify the limitations of the climatic laboratory testing in the test report. These limitations typically include

1. Effects of tie-down systems on load paths and vibration characteristics
2. Changes in airflow around a rotorcraft operating at high-power IGE
3. For larger air vehicles the effect of high power settings on chamber ambient temperature.

Although the climatic laboratory tests are good indicators of performance in extreme environments, the climatic laboratory cannot simulate all of the possible environments to which the air vehicle will be exposed. Consequently, climatic laboratory tests should be followed by actual operational tests in natural environments.

9-10 ICING FLIGHT TESTS

Icing flight tests might be required to verify the operational capability of the air vehicle in flight conditions conducive to ice formation. Some specifications do not require this capability. The air vehicle may contain anti-icing or deicing equipment or a combination of the two. Some air vehicle subsystems and components require protection from the effects of ice formation due to the possibility of damage or performance degradation due to ice. See 14 CFR, Parts 25 (Ref. 5) and 33 (Ref. 18), and Advisory Circular 29-2, *Certification of Transport Category Rotorcraft,*(Ref. 29) for additional information. Consequently, the air vehicle specification and AQS might require that the operational capability of the entire air vehicle be demonstrated through actual and simulated flight in icing conditions.

Factors that influence the degree of icing include liquid water content, droplet size, surface temperature, altitude, and airspeed. However, consistent natural icing conditions are difficult to obtain. Conversely, simulated environments are highly dependent on ambient conditions such as temperature, wind velocity, and gust factor; therefore, it is also difficult to obtain consistent results.

Test plans should be submitted by the AC to demonstrate the following characteristics:

1. Increase in power required to maintain given flight conditions as a function of accreted ice thickness
2. Capability of the engine air induction system to maintain airflow for full engine power capability and ensure that ice ingestion does not occur
3. Capability of the windshield or windscreen system to maintain visibility requirements, preclusion of damage when anti-icing or deicing systems are used on dry windshield or windscreen

4. Air vehicle controllability

5. Heat transfer system performance of the anti-icing or deicing system(s)

6. Possibility of structural damage when ice is shed

7. Vibration levels during deicing system cycling

8. Proper operation of all ice protection system equipment and controls.

There are three types of tests to be conducted. Clear, dry air flight, simulated icing flight, and natural icing flight tests requirements are discussed in the subparagraphs that follow.

9-10.1 CLEAR, DRY AIR FLIGHT

Functional, safety, and performance characteristics of each ice protection system in the air vehicle should be demonstrated in specified conditions. Therefore, test procedures should consider the maximum operational capability of each system, its controls, and protective devices.

The effects of operating hot air systems on both the power consumed and conditions of protected surfaces should be determined at approved power conditions and altitudes. Additionally, approved power and airspeed conditions should be used to demonstrate electrothermal ice protection systems. Emphasis should be placed on determining electrical power requirements and availability. If freezing point depressant liquids are used, distribution and control of the liquids should be demonstrated.

The effects on unprotected surfaces may be simulated by attaching icing shapes and weights to those surfaces. During these tests, flutter and stall characteristics and the effects of those buildups on drag and mission range should be determined.

9-10.2 SIMULATED ICING FLIGHT

If required by the PA, flight in icing conditions might be required. There are various DoD icing spray systems (ISS), including the helicopter ISS (HISS). However, this equipment cannot normally duplicate natural icing conditions but is a valuable aid in obtaining pilot observations on visibility, control, and icing buildup during hover and low-speed maneuvers.

For rotorcraft rotor blades and aircraft or tilt rotor propellers, tests should be conducted throughout the ice condition spectrum to ensure correct operation, determine cycling time, determine impingement surface limits, and detect ice thickness. An optimum system should ensure that

1. No runback or refreezing of melted ice occurs.

2. The deiced accretion will not cause structural damage or loss of performance when shed.

3. Any cycling time requirements as a function of the rate of ice accretion are established.

4. Ice buildup and shedding do not introduce unacceptable levels of vibration.

The aircraft should also be tested with these subsystems off to determine the increased power required during given flight conditions as a function of accreted ice thickness.

9-10.3 NATURAL ICING FLIGHT

Unless otherwise specified in the contract, the AC should use Title 14 Code of Federal Regulations for guidance. 14 CFR, Part 25 (Ref. 5) should be used as guidance for aircraft icing qualification requirements. See Subpart 25.1093, *Air Induction Icing Protection*; Subpart 25.929, *Propeller Deicing;* Subpart 25.1403, *Wing Icing Detection Lights;* and Subpart 25.1419, *Ice Protection*. Also, unless otherwise stated in the specification, the AC should use 14 CFR, Part 33, (Ref. 8) for guidance, specifically Subpart 33.68, *Induction System Icing.* Advisory Circular 29-2 (Ref. 29) should be used as guidance for all rotorcraft. Natural atmospheric icing conditions differ from snow conditions. The PA might also require demonstration of the ability of the air vehicle to operate in falling or blowing snow; however, conditions for freezing water are not necessarily the same as those required for icing conditions.

The flight test program should progressively increase flight durations in snow conditions. Initially, short periods of flight should be conducted into icing clouds to obtain data on ice protection systems, power loss, and flying qualities. Flight time in icing conditions should be increased progressively to obtain full performance data. Extreme care should be exercised to ensure that excessive ice that would constitute an unacceptable hazard is not allowed to accumulate on the air vehicle during testing. Hazards to ground personnel, such as ice shedding during ground operations, should also be considered.

9-11 ELECTROMAGNETIC ENVIRONMENTAL EFFECTS (E3)

ADS-37-PRF, *Electromagnetic Environmental Effects (E^3) Performance and Verification Requirements*,(Ref. 30) should be used to establish subsystem- and system-level E^3 testing requirements for Army air vehicles. These testing requirements typically are driven by the expected operational electromagnetic environment (EME) and allowable E^3 effects established by the PA during the program preaward phase. System-level E^3 testing should consider the following areas:

1. Electromagnetic compatibility (EMC)
2. Electromagnetic vulnerability (EMV)
3. Lightning
4. Static electricity
5. Electromagnetic radiation hazards (RADHAZ)
6. TEMPEST.

The effects of nuclear electromagnetic pulse (NEMP), emissions control (EMCON), transient radiation effects on electronics (TREE), and directed energy weapons, such as high-power microwave (HPM), are discussed in par. 9-14.

ADS-37-PRF (Ref. 29) identifies the following four criticality types for evaluation of E^3 anomalies:

1. Flight critical
2. Flight essential
3. Mission critical
4. Mission essential.

Each anomaly identified during E^3 testing should be categorized into one of these criticality types.

An E^3 Requirements Board (E^3RB) or integrated product team, which typically is comprised of members from the program office, the user community, and the Aviation Research, Development, and Engineering Center, rules on categorization of equipment anomalies and determines which anomalies should be fixed and retested.

The subparagraphs that follow describe the requirements for system-level E^3 testing in greater detail.

9-11.1 ELECTROMAGNETIC COMPATIBILITY

The AC should conduct an intrasystem EMC test on a completely provisioned air vehicle (including ordnance) to demonstrate that the operation of one or more onboard subsystems or components does not result in degraded performance, unacceptable response, or malfunction of any onboard subsystem or component. Air vehicle subsystems and components should be exercised singly and jointly as they would be during typical mission scenarios. As a minimum, the AC should demonstrate acceptable performance characteristics during the following electromagnetic tests:

1. Ambient (background noise) measurement
2. Cross-talk (circuit isolation)
3. Receiver to receiver
4. Transmitter to receiver
5. Transmitter to active device
6. Transmitter to passive device*
7. Receiver to active device
8. Receiver to passive device*
9. Active device to passive device*
10. Active device to receiver
11. Electrical power system transients*
12. Electrical/electronic subsystem transients*
13. Simulated mission evaluation
14. Flight evaluation.

EMC testing should be conducted in an area of low ambient electromagnetic levels in order not to interfere with the test to be conducted. Electrical bonding measurements and functional testing of equipment should precede the EMC test to reduce risk of test failures or delays in testing. EMC effects with associated support systems, such as ground servicing equipment and ground support equipment (GSE), should also be considered during this testing. Additional testing methodology is provided by ADS-37-PRF (Ref. 30).

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*These tests should include 16.5-dB safety margin testing of electroexplosive devices, which should verify that EED bridge wire currents due to the (cumulative) induced energy from onboard and external equipment are at least 16.8 dB below the “no fire” current levels of the EEDS.

9-11.2 ELECTROMAGNETIC VULNERABILTY

With AC support the PA should conduct an intersystem EMV test on a completely provisioned air vehicle including ordnance less EEDs to determine any degraded performance, unacceptable response, or malfunction of any onboard subsystem or component when exposed to an electromagnetic environment external to the air vehicle. As a minimum, the air vehicle should be exposed to the worldwide EME defined in ADS-37-PRF (Ref. 30) and further defined by the air vehicle E^3RB during the program preaward phase. Air vehicle subsystems and components should be exercised singly and jointly as they would be during typical mission scenarios. When a test anomaly is discovered, an attempt should be made to isolate it to the susceptible subsystem or component, and as time allows, a potential fix should be determined. The test report should include vulnerability thresholds of the anomalies noted, frequencies, modulations, aspect angles of radiation, and other details of the test setup so that test conditions could be repeated at a later date to produce the same anomalies. EMV of the associated ground servicing equipment and ground support equipment should also be considered during this testing. A buildup approach in test levels should be used to minimize risk of damage to air vehicle. Additional testing methodology is provided by ADS-37-PRF (Ref. 30).

9-11.3 LIGHTNING

The AC should conduct and/or support a PA-conducted lightning protection survey and verification as provided for in subpars. 4.1.2 and 4.1.5 of MIL-STD-1795, *Lightning Protection of Aerospace Vehicles and Hardware*, (Ref. 31). Detailed testing methodologies may be found-in MIL-STD-

1757, *Lightning Qualification Test Techniques for Aerospace Vehicles and Hardware*, (Ref. 32) and ADS-37-PRF (Ref. 30). The types of tests that should be considered are addressed in the subparagraphs that follow.

9-11.3.1 Direct Effects Testing

A full-scale air vehicle generally should not be exposed to direct effects testing; rather, selected components should be tested based on an analysis of lightning attachment zones in conjunction with scale-model tests and/or other lightning test experience, including actual lightning strike statistics. Direct effects testing may be conducted either on coupons or samples of materials, such as those that characterize airframe skins, structural members or joints, and on full-scale production components that protrude into the airstream such as rotor blades, other airfoil tip areas, flight control linkage, weapons, antennas, sensors, and fuel systems, to name a few. Composite materials have replaced aluminum in secondary structures and in some cases, the primary structure. If the area inside the composite material is confined, the atmosphere inside the confined area could be superheated and cause an explosion. The pass-fail criteria, which should be established by the E^3RB during the program preaward phase, should be based on the ability to land safely, the ability to continue the mission, or to minimize the cost to repair.

9-11.3.2 Indirect Effects Testing

These types of tests may be conducted on a full-scale air vehicle with the goal of establishing the extent to which a direct strike to the air vehicle could couple unacceptable electrical voltage surges or transients into electrical or electronic subsystems installed in the air vehicle. A typical test involves the application of a high-level artificial lightning current between expected attachment points (See lightning strike zone analysis in MIL-STD-1795 (Ref. 31).) on the exterior of the air vehicle while resulting responses are monitored on the interior wiring. To minimize risk of damage to the air vehicle, test equipment, or to test personnel, the test should be conducted in incremental steps starting with minimum discernible induced current levels until the maximum applied threat level is attained. The pass-fail criteria should be based on induced transient data obtained during component electromagnetic interference testing (see subpar. 7-10.1).

9-11.3.3 Streamering Testing

The previously described lightning tests should also include a streamering test by which the exterior of the air vehicle or a mock-up portion of the air vehicle is subjected to a high-level electric field—a precursor to a possible lightning strike—to determine whether any arcing or sparking occurs to flight crew personnel, fuel vapors, ordnance, or flight-critical electrical or electronic equipment.

9-11.4 STATIC ELECTRICITY TESTING

The AC should conduct or support PA-conducted static electricity tests on a full-scale air vehicle. Testing should demonstrate

1. Ground personnel are not exposed to hazardous electrostatic discharges (ESD) during fueling, arming, and sling-load operations.
2. Precipitation static (P-Stat) is controlled in order not to degrade the performance of onboard electrical or electronic equipment.

9-11.5 RADIATION HAZARDS (RADHAZ)

The AC should conduct appropriate testing to demonstrate that the hazards of electromagnetic radiation to ordnance (HERO), the hazards of electromagnetic radiation to personnel (HERP), and the hazards of electromagnetic radiation to fuel (HERF) are sufficiently controlled in order not to endanger the air vehicle or its personnel or adversely impact mission performance.

9-11.5.1 HERO Testing

Information about the determination of HERO testing can be found in MIL-STD-1385, *Preclusion of Ordnance Hazards in Electromagnetic Fields, General Requirements for*, (Ref. 33) modified to a minimum of 20 O V/m to demonstrate that sufficient safety margin exists to preclude inadvertent ignition or dudding of ordnance EEDs due to the air vehicle external EME.

9-11.5.2 HERP Testing

HERP testing should be conducted to demonstrate that electromagnetic radiation hazards to onboard and ground personnel are controlled to appropriate levels. Electromagnetic radiation levels should comply with ANSI/IEEE C95.1-1991, IEEE *Standard for Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300GHz*, (Ref. 34) as implemented by Department of Defense Instruction (DoDI) 6055.11, *Protection of DoD Personnel From Exposure to Radio Frequency Radiation and Military Exempt Lasers*, (Ref. 35). Onboard emitters should be jointly exercised to the extent they would be during typical mission scenarios.

9-11.5.3 HERF Testing

HERF testing should be conducted to demonstrate that sufficient bonding, grounding, and shielding exist to preclude inadvertent ignition of fuel vapors onboard the air vehicle caused by onboard electromagnetic emitters as well as the EME. Onboard emitters should be exercised jointly to the extent they would be during typical mission scenarios.

9-11.6 TEMPEST Testing

The AC should conduct or support PA conducted TEMPEST testing in accordance with contractual requirements.

9-11.7 ANTENNA COUPLING

Antenna-to-antenna coupling should be analyzed as part of the intrasystem EMC testing. Analysis should cover areas exposed by history of known problems in previous programs and areas suspected by the contractor to be problem areas. Emphasis should be placed on determining the effects of active transmission through one antenna on passive systems or receivers of another system. For information concerning intrasystem EMC testing, see ADS-37-PRF (Ref. 30).

9-12 WEAPON SYSTEM EFFECTIVENESS TESTS

Army air vehicles that incorporate armament subsystems should be subjected to qualification to validate compliance with the air vehicle specification requirements. Those subsystems include but are not limited to missile, aerial rocket, turreted and fixed guns, target acquisition and/or designation hardware and software, fire control and integration hardware and software, and boresighting subsystems. Any weapons subsystem change that represents a significant departure from existing designs or that embodies major features not previously tested should be tested to demonstrate compliance with the guidance of this handbook and the system specification. However, prior to any ground and flight testing, the armament and fire control subsystems must go through laboratory and hot bench tests to validate critical component and software parameters, component fabrication, and subsystem and software integration. Time line requirements should be verified. Inhibit, limit, and interrupt analyses should be conducted to show that armaments are prohibited from interfering with one another and to show that armaments are inhibited from firing when firing constraints are exceeded.

In all cases safety should be paramount in evaluation and demonstration of weapons systems. For additional guidance concerning range safety, refer to AR 385-63 (Ref. 36) and related 385 series regulations. The Airworthiness Qualification Specification should describe the scope, test planning, testing, instrumentation and data analyses, and documentation requirements for weapons and fire control subsystems installed on an air vehicle. Ground testing of these subsystems should encompass all items requiring verification prior to flight testing. Flight testing should include all applicable testing types necessary to verify the armament/fire control subsystem design prior to any required formal demonstrations. See ADS-20, Armament/Fire Control System Survey, (Ref. 37) for additional information.

Ground tests should include but not be limited to

1. Armament and fire control operations
2. Armament and fire control boresight
3. Arming procedures
4. Ground firing tests
5. Displays and display resolution
6. Sensor switching
7. Target acquisition and designation sight (TADS)
8. Laser designators, range finders, and laser spot trackers (LSTs)
9. Cryogenic cooling
10. Fire control integration
11. Boresight systems
12. Electromagnetic compatibility
13. Environmental conditions.

Prior to first flight, ground tests using air vehicle power should be conducted on the air vehicle. The purposes of these tests are to validate critical air vehicle interfaces, ensure EMI/EMC compatibility, verify safety-of-flight critical features, and ensure functionality of all operational controls and modes. Flight testing should be performed to verify the design and its integration prior to actual firing of stores. Flight testing of the armament and fire control subsystems should be conducted within the design operational flight envelope (OFE) for rotorcraft or the limit maneuvering envelope (LME) for other aircraft. The OFE is defined in ADS-33 (Ref. 22) and the LME is defined in 14 CFR Part 23 (Ref. 4). These flight tests should include but not be limited to

1. Air vehicle flight performance
2. TADS pointing and day or night, navigation, and target handover capability
3. Laser ranging and designation
4. Effects of weapons firing on TADS
5. External stores jettison
6. Gun, missile, and rocket operation, range, clearance cones, boresight retention, and accuracy
7. Fire control installation
8. External stores
9. Weapon firing effects on engine(s).

Information concerning ground and flight tests can be found in ADS-20 (Ref. 37).

The weapons subsystems configuration for effectiveness testing should be as near as possible to the production installation, including all nonfunctioning elements of the subsystem. Weapons systems effectiveness tests against ground and air targets are covered in subpars. 9-12.1 and 9-12.2, respectively.

Effectiveness measures for each of the subsystems should be specified by the PA, and in some cases measures of effectiveness (MOEs) may be dependent on several subsystems. These MOEs are used to verify that the delivered or proposed system meets the user's operational requirements.

In most cases these MOEs measured individually might not verify the effectiveness of the armament and fire control subsystem. Even if all MOEs are in compliance with specifications, the interaction of several characteristics may result in an armament and fire control subsystem that does not satisfy the user's requirements when used against ground or air targets.

To be effective against any target, the armament and fire control subsystem should allow the pilot, gunner, and/or weapons system operator to detect, classify, engage, and strike targets in vulnerable areas at maximum standoff ranges. Typical MOEs for these functions include but are not limited to

1. Probability of detection $P_{\boldsymbol{D}}$ of a particular target
2. Probability of classification $P_{\boldsymbol{C}}$ as to the correct type of target—hard or soft, wheeled or tracked
3. Probability of engagement $P_{\boldsymbol{E}}$
4. Probability of hit $P_{\boldsymbol{H}}$
5. Probability of kill $P_{\boldsymbol{K}}$.

Many of these measures may be combined as conditional probabilities. Two examples are the probability of kill given a hit ($P_{\boldsymbol{K|H}}$) and the probability of engagement given detection ($P_{\boldsymbol{E|D}}$). Since the weapons system must detect, classify, engage, and hit the target to kill it, the total weapons system effectiveness $E_{\boldsymbol{W}}$ against a specific target at a given range using a specified armament subsystem can be expressed as:

$$E_W = P_D \cdot P_{C|D} \cdot P_{E|C} \cdot P_{H|E} \cdot P_{K|H}, \text{ dimensionless} \quad (9\text{-}4)$$

where

$P_{\boldsymbol{C|D}}$ = probability of classification given detection
$P_{\boldsymbol{E|C}}$ = probability of engagement given classification
$P_{\boldsymbol{H|E}}$ = probability of hit given engagement.

Prior to any weapons system effectiveness testing, the integrated test plan should include a systematic ground and air test program necessary to determine weapons system effectiveness. This plan should describe the test, analysis, or simulation used to demonstrate the MOEs previously described and/or other MOEs specified by the PA . The plan should also include provisions for demonstration of safing and arming procedures both on the ground and in flight and should describe testing to verify that loading and unloading procedures can be accomplished safely.

Full-mission simulators should be used to address the total mission environment, which includes training, battlefield tactics, and environmental conditions. The full-mission simulator should use cockpit systems that demonstrate the capabilities of the proposed concepts under test and have the capability for the air vehicle to detect airborne and surface targets and geographical features visually at ranges that are representative of actual flight.

Instrumentation and data analysis should be based on ADS-20 (Ref. 37), and included in the armament and fire control portion of an overall integrated test plan.

9-12.1 GROUND TARGETS

Target acquisition and designation systems qualification against targets should include data points that exercise the required ranges of air vehicle parameters, sensor modes of operation, target parameters, and meteorological conditions. See ADS-29 (Ref. 37) for additional information. Obscurants such as fog, haze, smoke, or light rain may reduce detection capability P_D at maximum weapon ranges. Clutter might reduce probability of detection, classification, and engagement of targets—P_D, P_C, and P_E, respectively. Effectiveness testing against ground targets should consider the effects of clutter and smoke and obscurants on MOEs such as reduced P_D, P_C, or P_E, and these results should be documented.

Moving targets or targets that change directions might reduce P_H for unguided weapons such as guns and rockets. For guided weapons the ability of the weapon subsystem to track the vulnerable areas of a target until round impact should be evaluated. Inability to track these areas might result in a miss or impact in other than a vulnerable area, which results in reduced P_H and P_K, respectively. The maneuvering required in unmasking might result in detection of the air vehicle or might preclude timely engagement of the ground target. Both of these conditions could allow the target to initiate evasive action or mask itself.

The effects of target motion and direction changes and unmasking maneuvering of the air vehicle on MOEs, such as P_E, P_H, and P_K, should be documented.

9-12.2 AIR TARGETS

The same considerations for ground target effectiveness should be used when weapons system effectiveness against air targets is evaluated. However, since air targets might have equal or superior maneuverability and comparable or superior armament and fire control subsystems, certain aspects of weapon system effectiveness testing become more important. The armament and fire control test planning should define the methods used to verify operational characteristics of weapons subsystems when used against air targets. These methods should be included as part of an overall integrated test plan. The operational characteristics are specified by the PA, and these tests, models, or simulations should use a firing envelope approved by the PA. Typical firing envelope parameters should include airspeed, maneuver load factors, and time to turn and engage off-axis targets. A safe launch envelope should be defined by analysis and actual firing.

Sensor gimbal limits and turreted gun azimuth and elevation limits are demonstrated throughout the firing envelope. Additionally, sensor and turret slew rates, accelerations, and position accuracies should be demonstrated throughout the firing envelope. The AC should demonstrate the proper function of limit switches, such as a gun-firing inhibit, when either the sensor or turreted gun is commanded to point or fire outside the established limits for position, slewing rate, or acceleration.

In addition to the probability MOEs (P_D, P_C, etc.), false alarm rates should be demonstrated when there is a requirement for engagement of air targets beyond visual range (BVR).

Handling qualities when firing armament should be evaluated. Particular emphasis should be placed on off-axis gun firing, maximum and minimum elevation or depression of turrets, and missile and rocket firing during uncoordinated flight. Emergency jettison of external armament stores should be demonstrated throughout a Government-approved flight envelope.

9-13 EXTERNAL STORES SEPARATION

Flight tests should be conducted to demonstrate the separation characteristics of all droppable external stores. Droppable external stores are defined as any item that is not an essential part of the basic air vehicle and is affixed to the airframe with provisions for quick release. Droppable external stores may include but are not limited to fuel tanks, weapons pods, rocket launchers, missile launchers or rails, bombs, mine dispensers, torpedoes, or pyrotechnic devices.

Satisfactory separation characteristics should be demonstrated for the minimum criteria that follow and other criteria that may be specified by the PA:

1. Immediate operation of the jettison device or operation within an allowable time period
2. No damage to the air vehicle during or following actuation of the jettison device
3. Jettison trajectory clear of the air vehicle and other stores
4. No inherent instability of the jettisoned store while in proximity to the air vehicle
5. No adverse or uncontrollable air vehicle reaction at the time of jettison
6. Stability and control characteristics after jettison consistent with ADS-33 (Ref. 22) for rotorcraft and tilt rotor aircraft and 14 CFR Parts 23 and 25 (Ref. 4 and 5) or other specified documents for aircraft
7. No unusual degradation of performance characteristics after jettison.

Jettison of all external stores should be demonstrated for sufficient combinations of flight conditions to establish and verify a jettison envelope for each type of external store configuration. Selective jettison of stores should be demonstrated for those conditions that may result in adverse operational characteristics of the air vehicle and the remaining external stores. Typically, safe jettison is almost always demonstrated by limited jettison tests in conjunction with extensive jettison analysis.

All jettisons use the release method provided. However, each secondary or redundant release system should be used once during these demonstrations. All system failures should also be shown not to affect adversely the air vehicle characteristics or the jettison capability of the remaining stores.

Flight conditions for jettison demonstrations should be planned and documented. All demonstrations should be conducted at the extreme or critical combinations of weight and both longitudinal and lateral CG locations within the air vehicle maneuver spectrum. When external stores have expendables, such as rockets and flares, separation is demonstrated with full, intermediate, and empty weights for the stores.

Jettison demonstrations should be performed at sufficient airspeeds to establish the airspeed restrictions for satisfactory separation characteristics and demonstrated at the power required for level flight and during autorotative flight or unpowered glide. The maximum and minimum airspeed limits for safe operations should be established. Demonstrations should be conducted at altitudes and attitudes consistent with normal operation of the air vehicle. If the attitudes of external stores with respect to the air vehicle are varied, the most critical attitude consistent with operational usage should be demonstrated.

The initial envelope of sideslip as a function of airspeed should be determined from the side force stability parameter $d\varphi/d\beta$ where φ is the bank angle and β is the sideslip angle, and the side force required to recognize uncoordinated flight. The side force stability parameter is obtained during stability and control testing as a function of calibrated airspeed. During initial testing, the side force required to recognize uncoordinated flight can be determined. This side force requirement fixes an equivalent bank angle, which, when applied to the side force stability parameter, yields a limit sideslip angle as a function of calibrated airspeed as shown in Fig. 9-8. This figure shows how to determine the initial jettison sideslip envelope limit that should be demonstrated.

Video recording should be used to document the separation characteristics of all external stores configurations. Still photography should be used to document the location, shape, and method of attachment of external stores and the damage to the air vehicle caused by jettison. In addition to video, jettison testing should include data acquisition systems that are similar in nature to those required for the flying qualities test of subpar. 9-6.2.

9-14 SURVIVABILITY

Department of the Army (DA) Pamphlet 71-3, *Operational Testing and Evaluation Methodology and Procedures Guide*, (Ref. 38) defines survivability as the degree to which a system is able to avoid or withstand a hostile environment without suffering abortive impairment of its effectiveness—its ability to accomplish its designated mission. DoD Regulation 5000.2, *Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated Information System (MAIS) Programs*,(Ref. 39) states that survivability considerations form the basis for sustaining operational effectiveness and war fighting capability in peacetime and at all levels of conflict (from low intensity to strategic nuclear) through acquisition of survivable systems, equipment, and support. Threats considered should include conventional; electronic; initial nuclear weapon effects; nuclear, biological, and chemical (NBC) contamination; advanced threats such as high-power microwave, kinetic energy weapons, and directed energy weapons, terrorism, and sabotage.

The AC is totally responsible for satisfying the survivability performance requirements. The means by which to satisfy these requirements should be determined by the AC and included in the overall program plan and AQS. ADS-11, *Survivability Program, Rotary Wing*, (Ref. 40) can be use as a source of information. The survival characteristics of the air vehicle should be optimized so that the system meets the requirements of the specification at the least cost. The tradeoff process includes examining and quantifying both the survival benefits and penalties associated with alternative survivability enhancement techniques.

DA Pamphlet 71-3 (Ref. 38) describes some of the measurements used to assess survivability. These measurements include vulnerability, susceptibility, and avoidance capabilities. ADS-11 (Ref. 40) provides a more detailed definition of the

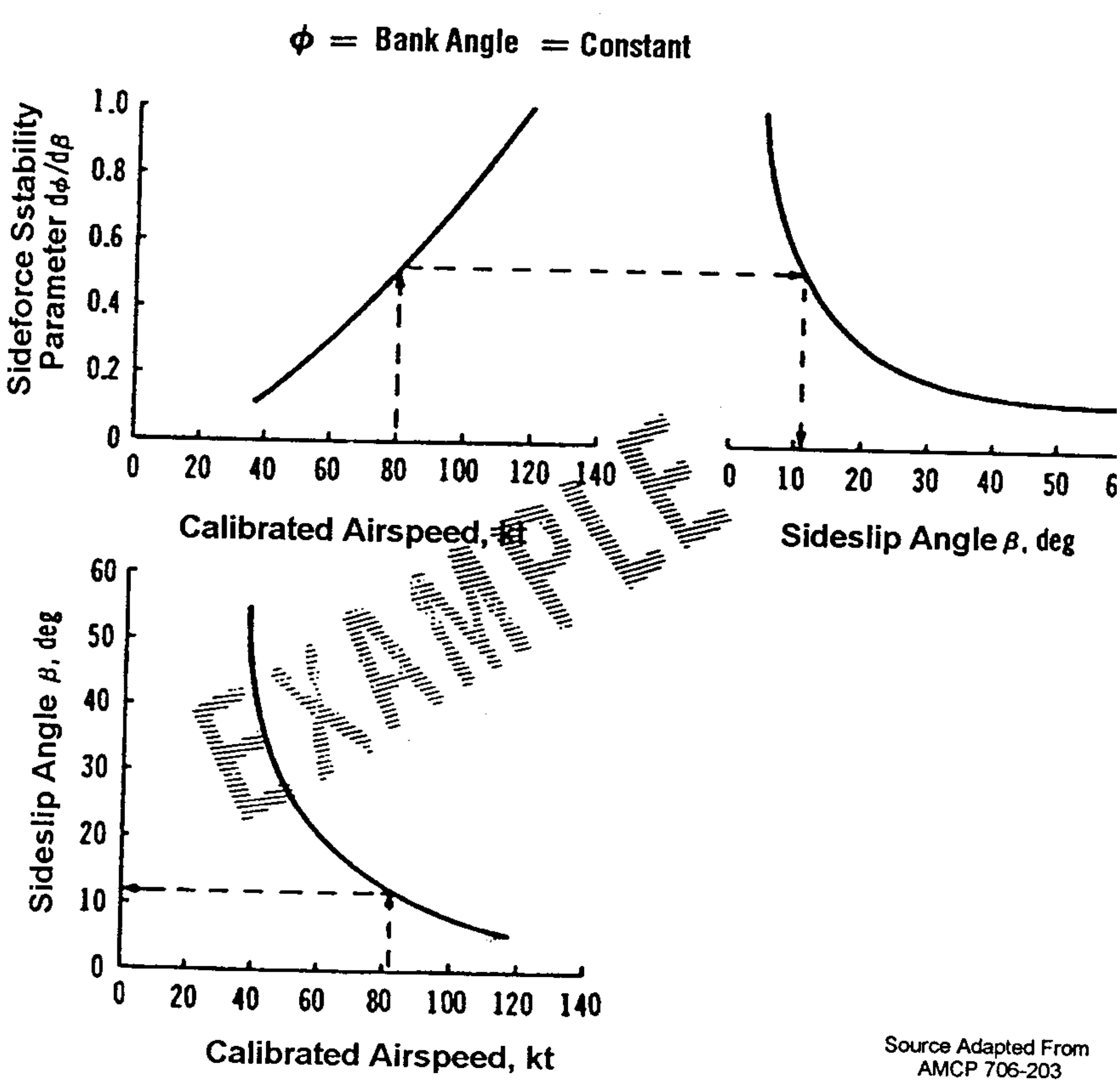


Figure 9-8 Jettison Envelope Calculation

ballistics, directed energy, nuclear, and NBC hardening; analyses; and test requirements as well as crashworthiness analyses and testing. DoD Regulation 5000.2 (Ref. 39) also includes provisions for survivability of mission-critical electronic equipment in an electronic countermeasures environment.

The probability of kill P_K is

$$P_K = P_D \cdot P_{C|D} \cdot P_{E|C} \cdot P_{H|E} \cdot P_{K|H},$$
dimensionless (9-5)

and the probability of survival Ps is

$$P_S = 1 - P_K, \text{ dimensionless} \quad (9\text{-}6)$$

where

P_D = probability of detection by a particular threat at the specified range
$P_{C|D}$ = probability of classification given detection by the threat as the correct type of target
$P_{E|C}$ = probability of engagement given classification
$P_{H|E}$ = probability of hit given engagement
$P_{K|H}$ = probability of kill given a hit.

If an acceptable value for probability of survival is 0.965, then individual values of 0.5 for the probabilities in Eq. 9-5 would satisfy the criteria

$$P_K = 0.5 * 0.5 * 0.5 * 0.5 * 0.5 = 0.03125$$

and

$$P_S = 1 - 0.03125 = 0.96875.$$

As can be seen from Eq. 9-5, if all of the probabilities start at 0.5, then an increase of 0.1 in any of these individual probabilities may be counteracted by a decrease of 0.0833 in another. P_S should be measured considering all of the combined effects because all factors are interdependent.

9-14.1 BALLISTIC SURVIVABILITY

DoD Regulation 5000.2 (Ref. 39) cites Title 10, United States Code, Section 2366, *"Major Systems and Munitions Programs: Survivability Testing and Lethality Testing Required Before Full-Scale Production"*, which requires live-fire testing of Acquisition Category I and II programs. Ballistic survivability testing is a major element necessary to satisfy this requirement. However, prior to any actual firing tests, analyses should be performed to the maximum extent possible to identify vulnerable components and subsystems in order to maximize the efficiency of live-fire testing.

Four elements of ballistic survivability testing are explained in the subparagraphs that follow. These elements are armor, ballistic-tolerant structure, positioning and separation of subsystems, and fuel ballistic protection. The testing to verify ballistic survivability should be identified in the Survivability Program Plan and should ensure that the air vehicle and crew can survive damage caused by specified threat munitions.

Threat projectile, impact location, obliquity, tumble, and striking velocity should be specified in test plans and should be recorded and reported for all firing tests. Information for this purpose can be found in ADS-11 (Ref. 40).

9-14.1.1 Armor

Several air vehicle components are both vulnerable to small arms fire and flight or mission essential. Armor is sometimes used to ensure that if these components are hit by small arms, mission accomplishment will not be precluded. Particularly vulnerable hardware includes engines, fuel cells, pumps and controls, hydraulic and/or pneudraulic components, transmissions, and control linkages and surfaces because they frequently cannot be masked by less critical components. However, use of armor should be minimized to prevent unacceptable performance degradation.

Prior to any survivability design or testing activities, the AC and PA should agree on the air vehicle damage measures to be applied. Typical measures are attrition, mission abort, and forced landing kills, as defined in MIL-STD-2089, *Aircraft Nonnuclear Survivability Terms*, (Ref. 41). Tradeoff analyses and cost-effectiveness analyses should also be performed. Information concerning these analyses can be found in subpars. 5.2.8 and 5.2.9 of MIL-STD-2069, *Requirements for Aircraft Nonnuclear Survivability Program*, (Ref. 42).

Information concerning ballistics vulnerability analyses, ballistic hardening, and ballistic testing can be found in ADS-11 (Ref. 40). Testing and analyses should be conducted against the threats identified in the system specification and/or AQS. Testing methods, munitions used, and passing criteria such as kill category, failure during damage tolerance testing, and $P_{K|H}$, should be identified in the test plan.

Compatibility of armor with operators and maintainers should be demonstrated. The AC should demonstrate that armor installed in its normal position does not interfere with critical operator or maintainer tasks.

9-14.1.2 Ballistic-Tolerant Structure

Components and structures designed to continue their functions after ballistic impact should be tested to determine their structural and functional characteristics after impact. These items should be identified by the AC. These components and structures should be subjected to postdamage testing. Information concerning this testing can be found in subpar. 5.2.1.2b of ADS-11. If battle damage assessment and repair (BDAR) is a requirement, such repairs should be tested to demonstrate specification compliance.

Degradation effects should be expressed in operational terms such as airspeed, "g" loads, angle of bank limits, and hours allowable after BDAR whenever possible.

9-14.1.3 Positioning and Separation of Subsystems

Positioning of components and subsystems can enhance survivability by reducing the vulnerable area of the air vehicle. Ballistic protection analysis is generally conducted by calculating the vulnerable area. The vulnerable area A_{Vi} for an individual component or subsystem is computed from

$$A_{Vi} = P_i A_i \text{, m}^2 \text{ (ft}^2\text{)} \quad (9\text{-}7)$$

where

A_{Vi} = vulnerable area of the *i*th component or subsystem, m^2 (ft^2)

P_i = probability of damage per hit on the *i*th component or subsystem, dimensionless

A_i = presented area of the *i*th component or subsystem, m^2 (ft^2).

Noncritical components or subsystems have no vulnerable areas by definition. Therefore, if critical components can be masked by noncritical components and thus require the round to pass through the noncritical component, P_i will be reduced, and this reduction will reduce A_{Vi}. In addition, P_i will be reduced when the critical component is placed behind ballistic-protective panels. Summation of vulnerable areas for critical components for a single shot provides the total air vehicle vulnerable area for that particular shot.

ADS-11 (Ref. 40) provides procedures the AC can use to describe ballistic survivability design features. Included are provisions for technical descriptions that show critical components and subsystems, presented or projected areas, substantiation of claimed invulnerabilities, and analysis and tabulation of vulnerable areas.

When redundant components are used and loss of one or more redundant components would not result in a loss of a critical function, physical separation of the redundant components lessens the probability of a single-shot kill.

Methods of validation and testing for the vulnerable areas should be planned and documented including the analysis, ballistic testing, and simulations to be used.

9-14.1.4 Fuel Ballistic Protection

Fuel system ballistic protection evaluation is usually performed by firing at the air vehicle, air vehicle mock-ups, or subsystem components. Information concerning fuel system testing including tanks, plumbing, surrounding airframe and protective features, and crash resistant fuel tanks can be found in ADS-11 (Ref. 40). Additional information concerning crashworthy fuel tanks can be found in MIL-T-27422, *Tank, Fuel, Crash Resistant, Aircraft,* (Ref. 43). Emphasis should be on self-sealing and fire suppression procedures. Fuel system test plans should define the location and number of shots, obliquity, type of seal allowed after firing, caliber of rounds, post shot inspection requirements, and fire suppression requirements. If fuel cell or ullage inerting, such as onboard inert-gas-generating system (OBIGGS), is used, procedures for testing such features should be included. Both passive and active fire suppression techniques, as defined in MIL-STD-2069 (Ref. 42), are demonstrated as applicable.

9-14.2 LASER SURVIVABILITY

Vulnerability of the air vehicle and crew to both low-energy and high-energy lasers (HEL) should be demonstrated by the AC when laser weapons are included among the specified threats. Techniques for laser vulnerability reduction often follow the same guidelines as ballistic vulnerability reduction, such as providing redundancy, separation, and burnthrough tolerance. The specified threat and operating conditions should be used to identify the operating frequencies, types, power levels, pulse rate and duration, beam size, power distribution, and slew rates to be tested. Primary emphasis should be on protection of aircrew vision and optical systems from the effects of low-energy lasers and protection of all systems and the air crew from the effects of HEL. Each of these areas is covered separately in the subparagraphs that follow. Also information concerning these areas is included in ADS-11 (Ref. 40).

9-14.2.1 Optical Countermeasures

Typically, optical countermeasures are intended to protect sensitive electro-optic mission equipment and aircrew vision from the effects of low-energy lasers. Such equipment might include canopy transparency and optical coatings and/or laser-protective visors. Analysis should be performed to identify vulnerable components, subsystems, and air crew positions in a manner similar to the ballistic vulnerability analyses. Information about performing this analysis can be found in ADS-11 (Ref. 40). Emphasis should be placed on determining the vulnerability of the aircrew to temporary or permanent blindness or other debilitating injury caused by lasers. Measurable parameters may include but not be limited to exposure times, ranges, frequencies, and power levels required to damage electro-optics or injure aircrews. Evaluation of the optical countermeasures should also include evaluation of visual impairment of the pilot while operating with these devices or systems during night flight and/or with environmental obscurations. Also see par. 9-17.

9-14.2.2 High-Energy Lasers

High-energy lasers can damage the air vehicle system by several damage mechanisms similar to ballistic damage and by low-level heating of large areas. For each threat and critical component or subsystem, analyses should be conducted by the AC to identify the particular damage mechanism. Information concerning these analyses can be found in ADS-11 (Ref. 40). Component and subsystem testing for high energy laser susceptibility should also be conducted. This testing should include tests on ground test vehicles, static test articles, air vehicle sections, or full-scale operational air vehicles. Laser systems used should be identical to the threats considered without scaling for test purposes. Laser characteristics, test conditions, configurations tested, and results of the tests should be documented. Also see par. 9-17.

9-14.3 SIGNATURE CONTROL

Signature control of IR, electromagnetic, visible, acoustic emissions and radar can be an effective way to enhance air vehicle survivability. Reduced signatures can mean lower P_{D}, $P_{C|D}$, $P_{E|D}$, and $P_{H|E}$. These signatures should be calculated by computer simulation or analysis but if required for specification compliance by the PA, they may be subject to verification by flight testing. With the exception of acoustic signatures, all signatures are dependent on detection of electromagnetic emissions or reflections in some portion of the electromagnetic spectrum.

If required by the PA, the results of signature testing should be used to calculate the survivability of the aircraft when facing specified threat systems.

9-14.3.1 Infrared

IR signature testing should be conducted to measure the system IR signature and to determine specification survivability parameters. Testing is normally conducted in three phases: ground operation, hovering operation, and a flyby. Calibration of test equipment should be accomplished prior to and after each test phase. Ground and hovering operations should be used to collect data to plot radiant intensities in specified IR wavelength bands. These radiant intensities, usually expressed in W/sr, can be used to determine acquisition and lock-on ranges for specified threats. Once these intensities have been determined, flyby operations against actual or simulated threat systems should be used to verify these ranges.

The test methods and conditions to be used should be identified. Aspect angles, altitudes, and slant ranges are typical conditions to be specified. Primary and secondary IR radiation sources should be identified during ground and hover operations by incremental azimuthal measurement of IR signature through a 360-deg rotation of the air vehicle. Typical sources may include engines, cooling fans, and solar radiation reflected from the airframe.

Flyby testing should be conducted while the air vehicle is using maximum continuous power. Flight grids should be established and documented. Flyby testing should be conducted using an actual or simulated missile threat system that can measure radiometric data.

Since engine and ambient temperatures, atmospheric conditions, and solar radiation may have a marked effect on IR signature, certain measurements are required during this testing. These measurements include but are not limited to

1. Engine parameters of measured gas temperature (MGT) and gas producer and power turbine speeds, N_g and N_p, respectively

2. Ambient temperature
3. Ambient pressure
4. Ambient humidity
5. Tailpipe or IR suppressor surface temperature
6. Pertinent fuselage temperatures affected by exhaust or secondary IR sources.

Data analysis techniques should be included in planning and documentation. As a minimum, measured spectral data should be compiled and the background data should be subtracted to obtain absolute signature data. The spectral data should be analyzed using computer analysis techniques to determine the acquisition and lock-on ranges of specified threat systems. Additionally, all parameters, such as MGT, temperature, and humidity, will be corrected to apply to the same atmospheric and aircraft conditions.

9-14.3.2 Radar Cross Section (RCS) and Signature

If required by the PA as part of the system specification, RCS signature control should be addressed by the AC in the testing program. Information concerning RCS reduction can be included in MIL-STD-2069 (Ref. 42). Analyses and testing should include the effects of external or mission stores on RCS. Primary measures may include but are not limited to jamming-to-signal (J/S) ratios for each aspect angle and threat combination required. The number and orientation of aspect angles, other test conditions, and the use of scale model tests should be planned and documented. Full-scale air vehicle or model tests should be used to obtain test results to verify specification compliance.

The minimum test conditions to be specified should consider air vehicle use, area of operations, probability of encountering each type of enemy radar, and mission profile(s). Using these conditions, the AC should identify the radar frequencies to be used, type of electrical and flight tests, maximum acceptable reflectivity, and reflectivity standard. These conditions should be identified along with hovering altitudes used or in the case of an aircraft, which cannot hover, heights and distances to be flown in a multilegged cloverleaf pattern. All test results should be reduced to decibels, which then can be referenced directly to the agreed-upon reflectivity standard. Typical standards include the sphere, the corner reflector, and the flat plate.

9-14.3.3 Electromagnetic Emission

Certain communication and navigation electronic subsystems might reveal the presence or aid in classification and engagement of an air vehicle. Such systems include but are not limited to onboard radar, Doppler navigation systems (DNS), radar altimeters, and communication subsystems. When these subsystems are used indiscriminately, the probabilities of detection, classification, and engagement (P_D, P_C, and P_E, respectively) may be increased.

Testing should involve assessment of P_D, P_C, and P_E for specified threats or threat simulators at various ranges. If emissions control is a requirement, these tests should be conducted in normal and EMCON mode. Maneuvering flight should be conducted during the tests if maneuvers can be shown to effect P_D, P_C, and P_E.

9-14.3.4 Visible Emission

If reduction of visible emissions is a specification requirement, the AC should demonstrate that visible emissions are at levels which comply with the system specification. Typical measures of visible signature are luminance and chromaticity. Luminance is defined as the luminous intensity of a surface in a given direction per unit of projected area, and chromaticity is the quality of color characterized by its dominant or complementary wavelength and purity taken together. Luminance may involve reflected light, such as sunlight glinting off canopy surfaces, or luminance of cockpit displays to outside observers. Normally, chromaticity requirements are satisfied by paint or paint schemes that blend with the surrounding terrain.

The testing methods, measurement techniques, and criteria used to measure visible emissions should be identified by the AC and approved by the PA.

9-14.3.5 Acoustic Emission

Acoustic signatures are the unique sound characteristics of the air vehicle that can be used for detection purposes. Par. 9-8.2 discusses air vehicle external noise testing. However, acoustic detectability depends on more than acoustical factors. A site that simulates real-life conditions of terrain, ground cover, and weather should be chosen. If the planned external noise tests conditions are the same, then combined tests may be proposed. Acoustic testing measures the frequency ranges and decibel levels produced by the air vehicle during specified maneuvering flight.

Microphones should be positioned 1.5 m (4.92 ft) above the ground for ground detection testing and near the tops of vegetation for testing overforested terrain. In addition, the AC should identify and use methods to control extraneous ambient noise, such as noise from rustling leaves.

The AC should select typical maneuvers from the maneuver spectrum discussed in par. 9-4 , altitudes, and piloting procedures to be used for acoustical emissions testing.

The acoustical emissions testing should be conducted using equipment of par. 9-8 for noise data acquisition and analysis, recording of meteorological data, and electronic tracking, location, communication, and guidance of the air vehicle. Parameters to be measured include

1. Temperature and wind velocity gradients and relative humidity
2. Scale and intensity of turbulence
3. Terrain geography and character and density of ground cover
4. Location of listening instruments.

Instrumentation used includes sufficient microphones, amplifiers, calibration equipment, electronic recording equipment, and time code generators to record the required parameters. The recording system will be able to record within 2 dB the frequency range of interest—usually 20 to 11,200 Hz. Time code generator outputs should be tied in with air vehicle position data, noise recordings, and possibly meteorological condition recordings. Layout, quantity, and spacing of microphones should be adequate to provide reasonable assurance that sideline noise characteristics are described and that unusual terrain or ground feature effects are considered.

During conduct of the testing, all acoustical emissions data should be recorded for later laboratory analysis. The air vehicle should be flown at right angles to and over the center of the major axis of the microphone layout. These procedures and variations, and instrument calibration procedures should be documented.

Data analysis techniques may be similar to the analysis techniques used to conduct external noise test. However, the methods used for data analysis and presentation should be identified.

9-14.4 MANEUVERABILITY

An air vehicle that can perform nap-of-the-earth (NOE) flight can reduce P_D for all radar and infrared guided weapons. Additionally, NOE flight shortens possible engagement time lines for unguided small arms threats. Thus maneuverability of the air vehicle system enhances P_S.

Once detected, a highly maneuverable air vehicle can reduce $P_{C|D}$ and $P_{E|C}$ and in some cases $P_{H|E}$ by executing evasive maneuvers. Par. 9-6 contains a detailed discussion of the aerodynamic demonstration requirements including the establishment of flying qualities.

The minimum maneuvers used to evaluate the maneuverability effects on survivability should be specified by the PA and should be used to verify air vehicle survivability equipment (ASE) effectiveness testing described in subpar. 9-14.5. Additional maneuvers may be identified by the AC.

Typical measures of effectiveness for maneuverability may include reduction in probabilities of detection, classification, engagement, and hit—P_D, P_C, P_E, and P_H, respectively.

9-14.5 AIRCRAFT SURVIVABILITY EQUIPMENT (ASE)

ASE basically can be categorized as threat sensors and countermeasures. Examples of ASE are IR jammers, radar jammers, radar warning receivers, and decoys. Additional survivability features that can aid defeat of threats by using the electromagnetic spectrum include low reflective paint and IR exhaust suppressors. Only the first four examples are described here.

IR jammers are intense IR sources that operate from the fuel or electrical power and confuse or decoy threat IR guided missile systems. When used in conjunction with low reflective paint and IR exhaust suppressors, these jammers jam all known threat IR missile systems.

Radar jammers are receiver-transmitters that detect both pulse and continuous wave (CW) illuminator radars and transmit jamming signals that prevent proper operation of enemy radar. Pulse illuminator radar jammers are designed to respond to the most critical threat weapons systems anticipated to be encountered by attack rotorcraft in a hostile environment, whereas CW radar jammers protect against surface-to-air missiles (SAM) and airborne intercept missiles (AIM).

Radar warning receivers also are designed to provide warning of pulse and CW illuminator radars before the air vehicle arrives in detection range. Additionally, there are missile approach detectors that detect the approach of IR guided missiles.

Decoys take the form of flares dispensed to confuse or mislead IR guided missiles and chaff dispensed from canisters or cartridges, which prevent radar-controlled air defense weapons from locating, hitting, and destroying the air vehicle dispensing chaff.

The AC should plan to conduct ASE effectiveness testing including use of the threat systems or simulators to be provided by the PA. Prior to testing ASE, the AC should establish the baseline susceptibility or vulnerability of the air vehicle to specified threat weapons systems when not using ASE. This should be done initially by analysis and verified by flight test using controlled maneuvers, altitudes, and air vehicle configurations. Typical measures are $P_{C|D}$, $P_{E|C}$, and possibly an analytical determination of $P_{H|E}$ without use of ASE. Threat systems or threat simulators should be used to establish the baseline characteristics and to perform effectiveness testing.

Once the baseline characteristics are established, the AC should repeat the flights and testing necessary to determine the reduction in susceptibility or vulnerability (increase in survivability) due to the use of

ASE. The AC should also document any limitations, such as electrical power, maneuvering, or range, brought about by use of ASE.

9-14.6 NUCLEAR, BIOLOGICAL, CHEMICAL (NBC)

Nuclear, biological, and chemical contamination survivability is defined as the capability of a system and its crew to withstand an NBC-contaminated environment and relevant decontamination without losing the ability to accomplish the assigned mission. NBC contamination survivability and testing should not be required unless it is reflected in the Operational Requirements Document (ORD) and Test and Evaluation Master Plan (TEMP) (Ref. 39). If a system requires NBC survivability, the AC should address each environment in an integrated test plan for the system. If required by the PA, contamination and decontamination survivability should be demonstrated for both short-term and long-term effects on materiel and personnel. Testing should also determine the degradation in operator performance due to operation in an NBC environment. A typical measure of effectiveness may be the percent of critical operator tasks successfully completed while wearing individual protection equipment (IPE) with a goal of 100%.

The total system should also be tested to determine the degree to which design features, such as cockpit overpressure and sealing, filtration systems, and hybrid collective protection equipment (HCPE) enhance NBC survivability of the operators. Information concerning these topics can be found in ADS-11 (Ref. 40).

9-14.7 DIRECT NUCLEAR EFFECTS

Nuclear survivability is defined as the capability of a system to accomplish its mission during and/or after exposure to a nuclear environment. Survivability may be achieved by a number of methods including but not limited to proliferation, redundancy, avoidance, reconstitution, deception, and hardening. Proliferation and platform redundancy are probably not viable options for relatively expensive and complex aviation systems. Avoidance and deception are tactical and/or strategic considerations. Thus hardening and subsystem redundancy are the only probable technical means by which to improve nuclear survivability for Army aviation systems.

Nuclear hardness is defined as a quantitative description of the resistance of a system or component to malfunction (temporary and permanent) and/or degraded performance induced by a nuclear threat environment. Hardness is measured by resistance to physical quantities such as overpressure, peak velocities, energy absorbed, and electrical stress. Damage mechanisms to be considered include blast, thermal, and initial radiation effects, and transient radiation effects on electronics (TREE).

Hardness requirements should be specified in the air vehicle specification, and validation requirements should be specified in the AQS. As a minimum, mission critical electronic equipment should be tested to verify survivability when exposed to high-altitude electromagnetic pulse (HEMP). Information concerning performing nuclear hardening analyses and testing for components and complete systems can be found in ADS-11 (Ref. 40).

9-14.8 CRASHWORTHINESS

The AC should demonstrate by analysis and testing the crashworthiness of the air vehicle. Normally, analyses are acceptable in lieu of actual tests, except at the component level. Structural crashworthiness, crew and passenger retention, injurious environment, postcrash fire potential, and evacuation should be the main considerations.

Appendix I of ADS-11 (Ref. 40) contains rating criteria for these areas as well as details of how the evaluation is performed. If required by the AQS, crashworthiness testing may be performed by the PA and AC. Details of that testing are included in subpar. 11-6.2. Data from AC testing should be used to reduce required Government testing.

9-15 AVIONICS— CONTROLS

The fundamental classification of flight control systems should be based upon whether control is automatic or manual. Whether control forces are transmitted through mechanical linkage, electrical wires, or fiber-optic cables does not greatly influence the task of flight control system qualification at the system level. The level of safety associated with manual or primary flight controls is established through proper design, analysis, and qualification of the individual components. Also software design and qualification begin at the unit level. These are then followed by proper integration of the components and software (if any) and tested on functional mock-ups and, finally, installation and test on an air vehicle. For safety reasons it is not feasible to demonstrate fault tolerance of primary control components during flight. These types of tests should be accomplished at the subsystem level and demonstrated in a mock-up and simulator. Other system level tests, such as electrical and electromagnetic environmental effects testing, are typically required regardless of control type (except for purely mechanical and hydromechanical systems) but become more critical when electrical and/or electronic controls gain greater authority. Many air vehicle control systems use some form of electrohydraulic actuators. As previously implied, system-level testing is an incremental buildup process; one objective of which is to validate design requirements. Flight test evaluation and qualification of the flight control system is typically a handling qualities, aeroelastic qualities, human factors, performance, reliability, and vulnerability evaluation. Qualification testing typically ends with user tests that include an evaluation of logistic characteristics. Mission capabilities are typically evaluated. The AQS should define the requirements for qualification. For the purposes of this handbook, there are six types of systems: fly-by-wire/fly-by-light systems, stability augmentation systems (SAS), autopilots, engine controls, instrument landing systems, and unmanned aerial vehicle (UAV) systems. With the exception of UAV systems, all systems perform the functions of providing pilot assistance through automatic or semiautomatic flight path control, or they automatically control airframe responses to disturbances. These functions are included in the definition of automatic flight control systems (AFCS) used in MIL-F-9490, *Flight Control Systems— Design, Installation, and Test of Piloted Aircraft, General Specification for,* (Ref. 44). MIL-F-9490 should be used as a guide to performing portions of the AQS and test plans for the AFCS. Specific requirements should be specified in the contract.

MIL-F-9490 contains AFCS operational state definitions, allowable degradations for AFCS component failures, and other testing information. These degradation levels should be used to determine the fail-safe and fail-degraded test requirements for the AFCS. Fail-safe systems testing should specify the minimum operational state allowable, e.g., State III minimum safe operation, whereas fail-degraded testing may allow a defined number of state degradations, e.g., no more than two states lower after failure.

Testing of those systems should be complementary to design and analysis activities. When the PA determines that AC analyses of AFCS is sufficient to ensure compliance with specifications, testing should not be required. Information concerning analysis requirements is included in par. 4.2 of MIL-F-9490 (Ref. 44).

Vulnerability performance requirements should be specified in the air vehicle specification. Validation requirements should be specified in the AQS. Primary testing should involve function, degree of pilot assistance, and vulnerabilities to natural environments, adverse events of nature, induced environments, onboard failure of other systems, maintenance error, flight crew error, and enemy actions. Information concerning these topics can be found in MIL-F-9490 as are the requirements for test witnessing, acceptance testing, instrumentation, and test conditions.

9-15.1 FLY-BY-WIRE/FLY-BY-LIGHT SYSTEMS

As previously stated, whether control forces are transmitted by mechanical linkage or by electrical wires and fiber-optic cable does not greatly influence the task of flight control qualification. Fly-by-wire and fly-by-light flight control systems include subsystems in which linkage between the pilot's controls and the control surfaces or controlled mechanism is implemented with electrical signals carried by wire or light energy in fiber-optic cables.

Each of these systems should successfully complete required AQS testing. Environmental test and evaluation should be a significant part of qualification. For information concerning test and evaluation, see MIL-STD-461, *Requirements for the Control of Electromagnetic Emissions and Susceptibility*, (Ref. 45) and MIL-STD-810, *Environmental Test Methods and Engineering Guidelines*, (Ref. 46). Fiber-optic systems tend to be susceptible to higher temperatures, especially at high altitudes. Although fiber-optic cables are not susceptible to an electromagnetic field, transistorized terminals might be susceptible. Wires are less susceptible to temperature yet more susceptible to electromagnetic fields. EMI and EMV testing is essential. Typically, system leveling testing should include but not be limited to

1. System safety-of-flight testing (software and hardware)
2. Air vehicle ground tests
3. Air vehicle flight tests.

Flight testing should not commence until a Contractor Flight Release for the current configuration (including the software used) has been issued. An Airworthiness Release will be needed if a Government pilot is in command of the air vehicle. Typical measurements during testing may include but not be limited to

1. Transient power effects
2. Interchangeability
3. Time to override computer inputs
4. Computation time as a percent of that available
5. Memory used and protection features
6. Software scaling constants.

Details of these measurements including the instrumentation requirements for these measurements are contained in MIL-F-9490.

Engine controls are covered separately in subpar. 9-15.4.

9-15.2 STABILITY AUGMENTATION SYSTEMS

Stability augmentation functions include traditional stability augmentation systems (SAS) as well as command augmentation systems and attitude hold, heading hold, position hold, velocity hold, and altitude hold systems. For rotorcraft ADS-33 (Ref. 22) defines the typical requirements for these systems as well as the requirements for operation after failure of these systems. For aircraft 14 CFR, Parts 23 and 25, (Refs. 4 and 5) are the appropriate documents. Verification of these requirements should form a part of flight loads, dynamic stability, and flying qualities demonstrations. Analysis of failure rates for SAS failures should be used to identify which failures are likely to occur during flight. Among the results of the analyses should be an identification of the specific axes affected, indication(s) to the aircrew, and aircraft response after failure. A system safety risk assessment is typically required by the PA.

The AC should also demonstrate provisions for SAS override and/or disengagement and selective reengagement of single axis SAS by the aircrew. Maximum airspeeds for SAS-off flight, engagement procedures, and operating restrictions or limitations for the air vehicle typically are established by the AC.

9-15.3 AUTOPILOTS

Autopilot subsystems perform the functions of providing pilot assistance through automatic or semiautomatic flight path control. This assistance may be intended to perform single functions such as altitude (barometric or absolute), heading, or airspeed hold or might be as extensive as to allow full mission flight from takeoff through enroute portions to touchdown. Automatic navigation functions are generally provided by systems called flight directors. These systems provide outer loop control of air vehicle direction and altitude through use of navigation sensors. Requirements regarding performance and qualification of these systems are derived from the DoD Flight Information Publications (FLIP) and FAA regulations, as appropriate. Qualification of these systems is most efficiently undertaken during navigation demonstrations because flying qualities are not typically of issue. MIL-F-9490 (Ref. 44) provides additional guidance regarding the performance requirements of these systems.

Since these subsystems are critical to safety of flight, the AC should use extensive analyses and simulation to prove the concepts and flight control algorithms prior to initiating flight test. Flight testing should be according to a test plan approved by the PA and should follow the guidelines of either a CFR or AWR issued by the PA. Minimum obstacle clearance altitudes are specified in the CFR or AWR as are flight restrictions, such as acceptable weather conditions (both ceiling and visibility) for testing.

Typically, development of the autopilot flight control algorithms necessitates development flight test. In these instances proposed obstacle clearance altitudes should begin at a minimum safe altitude and should be progressively reduced throughout the development test to allow safe conduct of the tests.

Following development testing, qualification testing conditions, altitudes, normal and emergency procedures, and autopilot performance capabilities should be demonstrated in accordance with a test plan. Typically, the AC should demonstrate multimode flight path guidance and crew override capabilities. Unless otherwise specified, automatic heading, altitude hold, attitude hold, velocity hold, and airspeed control should be demonstrated. Both qualitative and quantitative performance limits should be included. Reporting of qualification test results should be in sufficient detail to allow these characteristics and procedures to be included in operator's manuals.

9-15.4 ENGINE CONTROLS

Engine controls may involve mechanical linkages, electronic or fiber-optic components, and may be integrated with fire and flight control hardware and software. Electronic digital control systems allow more flexibility in providing load anticipation for a wide variety of situations. However, they are more difficult to evaluate and document due to the increased variables that affect engine and rotor governing. Critical characteristics of analog-to-digital and optical-to-digital conversions include frequency response, control loop time delays, and E^3 effects. The differences between qualification of electronic controls vs manual controls resides primarily at the component and subsystem levels. ADS-33 (Ref. 22) addresses aircraft performance characteristics during specific failures.

Par. 9-3 covers transient torque response and power turbine speed damping and frequency analyses. Typically, the AC demonstrates engine transient response, control transient response to engine failure, manual mode operation (if applicable), load sharing (if applicable), collective pitch lever pumps, rotor speed governing (dual and single), and torque-limiting capabilities. These demonstrations are accomplished on a power system mock-up or tied down air vehicle. Par. 9-6 discusses aerodynamic demonstration flight-performance-substantiating testing that can be considered other measures of functional performance. Portions of pars. 10-2 and 10-4 concern the reliability and maintainability characteristics of air vehicle subsystems, which provide information on probable operator and maintainer errors and failure mode, effects, and criticality analyses (FMECAs). Pars. 9-7, 9-9, 9-10, and 9-11 discuss vibration testing, climatic laboratory testing, icing flight, electromagnetic vulnerability, lightning protection, and failure effects caused by other onboard failures related to vulnerabilities to induced and external environments. Par. 9-14 focuses on the survivability requirements for air vehicle subsystems. Successful accomplishment of this testing should at least partially satisfy the requirements for demonstration of function and degree of pilot assistance. Consequently, the AC should make every feasible effort to integrate engine control testing into other testing requirements to preclude duplication of effort.

9-15.5 INSTRUMENT LANDING SYSTEMS

The AC should demonstrate the capability of instrument landing systems to aid the pilot’s execution within specified limits of both precision and nonprecision approaches. Critical performance characteristics of the instrument landing system include altitude and position accuracy and failure or degradation detection. Instrument landing systems may include avionic and electronic systems designed to aid the aircrew’s performance of precision and both tactical and nontactical nonprecision approaches. An instrument landing system is basically a navigation subsystem that could have a flight control loop; hence objectives and measurements for a navigation subsystem apply in general. See par. 8-9. Also the flight control loop (if any) should be tested and qualified as discussed in this paragraph. Precision approach demonstration should involve glide path as well as ground track error measurements. If required by the PA, these error measurements should be correlated to cockpit indications and actual positions over the ground to determine the accuracy of the instrument landing system.

When coupled flight controls are incorporated, the AC plan to qualify the instrument landing system should include test procedures, limitations, minimum ceilings and visibilities, airspeeds, and recommended emergency procedures.

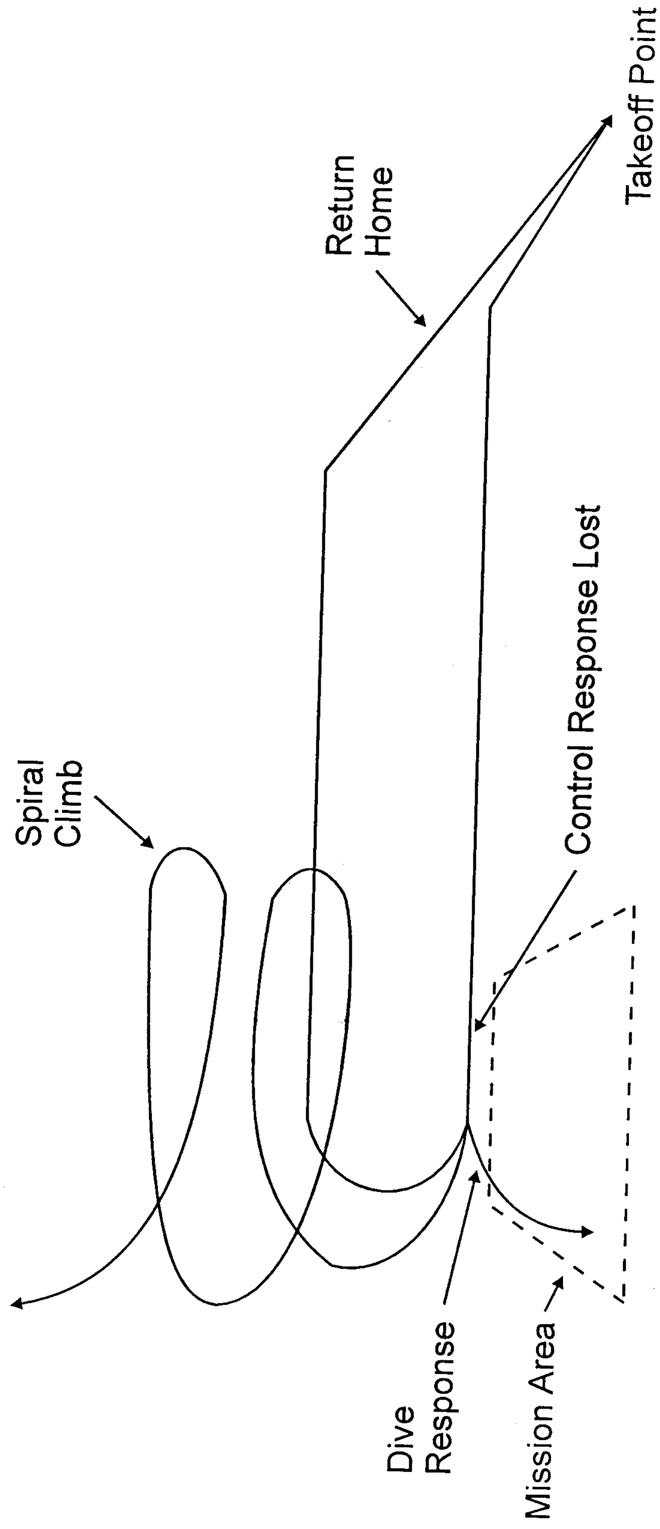
Part of the demonstration should involve degradation characteristics of the instrument landing system. A typical demonstration may be the indications to the pilot of loss of glide slope information, loss of power to instrument landing system components, and redundancy characteristics of the system.

If hybrid, integrated navigation systems, such as integrated global positioning system (GPS), inertial navigation system (INS), and Doppler navigation system, are identified for use in tactical approaches, the hierarchy of these systems should be identified, failure modes identified, and limitations established for degraded modes of operation.

9-15.6 UNMANNED AIR VEHICLE (UAV) SYSTEMS

There are two categories of unmanned air vehicles. Drone aircraft capable of manned flight is one category. Drone aircraft are used for a variety of purposes. In some cases they are used as targets. If capable of manned flight, all standard airworthiness objectives and measurements should apply. Also objectives and measurements of an unmanned air vehicle should apply. Another category is air vehicles that are not capable of manned flight. If the air vehicle is incapable of manned flight, only the objectives and measurements of the UAV will apply. Further, the objectives contained in DA PAM 73-1 (Ref. 38) might apply to either type of UAV. UAV flight control subsystems are controlled by remote operators or preprogrammed flight paths and algorithms. Hence an airworthiness release typically is not required; however, the need for some other type of release might be specified in the contract. Also the contract should specify who is responsible for ground and flight risks. A system safety risk assessment is typically required. Since no onboard human intervention is possible, the AC should demonstrate the ranges and effectiveness of the control data link, system reliability, navigation accuracy, and resistance to jamming, etc. The AC should also demonstrate by analysis, simulation, and fight test the response in the event of a loss of control response. Typical measurements are control response, position accuracies, fuel consumption, signal strength, etc. If control response is lost, typical actions would include either a power-on or power-off dive, a climb and return to takeoff point, or a spiraling climb. These actions are shown in Fig. 9-9.

If a malfunctioning control system is the cause of loss of control response, successful return to home base is unlikely, and a dive response may be the only feasible alternative. If the UAV is expendable, severely damaged, or unable to return to home base, a spiraling climb to clear airspace over the mission area and flight away from the mission area may be the chosen course of action. If maximum range is exceeded, a climb and return home might bring the UAV back into range where control can be regained.



Source: SDI

Figure 9-9 Unmanned Loss of Control Response

The AC should propose the procedures, algorithms, flight termination actions, and success criteria for UAV actions in the event of loss of control response. If required by the PA, flight test to demonstrate selected malfunctions may be required. Again since no onboard human intervention is possible, safety of ground personnel should be the primary concern during this testing, yet air traffic control is also an important issue. Demonstration of diagnostic and prognostic data links and flight termination hardware and software should ensure that

1. A flight termination condition is quickly and accurately identified
2. Initiation of the flight termination sequence has a very high probability of success, and the probability of flight termination is specified by the PA.

A typical measure of effectiveness may include the probability of failure detection, false alarms rates, probability of flight termination within a specified time period, etc.

9-16 TEST-ANALYZE-FIX-TEST (TAFT)

During the testing covered in this chapter, problems and malfunctions will undoubtedly occur. Once these events have occurred, failure analysis should be implemented to identify the root cause of the problems and any dependent malfunctions. Failure analysis should be used to identify fixes. The analysis is successful if it identifies the root cause of the malfunction. The AC should propose a fix in accordance with the terms of the contract. In the event that significant testing effected by the fix has already occurred, affected data points should be repeated. Also the PA should identify tests that should be repeated from the point of failure or from the beginning. An example of such tests may be a propulsion system endurance test that was not successfully completed due to a failure. Once the failure analysis is completed and the fix is implemented, the PA may require that the test be rerun completely. Other testing may allow continuation of the test from the point of failure with limited regression testing.

9-17 SAFETY

No hazardous or radioactive materials should be incorporated into an air vehicle unless the operational benefit outweighs the associated risks. Any such materials present well-defined potential hazards that should be thoroughly assessed and minimized. Also laser radiation hazards should be addressed. Information concerning laser radiation hazards can be found in MIL-STD-1425, *Safety Design Requirements for Military Laser and Associated Equipment,*(Ref. 47). Testing should be performed to ensure the hazards are well-defined and minimized.

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ABBREVIATIONS AND ACRONYMS

AC	=	air vehicle contractor
AFCS	=	automatic flight control system
AGARD	=	advisory group for aeronautical research and development
AGL	=	above ground level
AIM	=	airborne intercept missiles
ANSI	=	aerican national standards institute
APU	=	auxiliary power unit
AQP	=	airworthiness qualification specification
AQSR	=	airworthiness qualification substantiation report
ASE	=	aircraft survivability equipment
AWR	=	airworthiness release
BDAR	=	battle damage assessment and repair
BVR	=	beyond visual range
CAS	=	command augmentation system
CDRL	=	contract data requirements list
CF_3BR	=	monubromotriflurومethane
CFR	=	contractor flight release
CG	=	center of gravity
CW	=	continuous wave
C	=	centigrade
F	=	fahrenheit
DOD	=	department of defense
DNW	=	doppler navigation systems
DRC	=	damage-risk criteria
dB	=	decibel
E^3	=	electromagnetic environmental effects
E^3RB	=	E3 requirements board
EED	=	electroexplosive device
EMC	=	electromagnetic compatibility
EMCAB	=	electromagnetic compatibility advisory board
EMCON	=	emission control
EME	=	electromagnetic environment
EMI	=	electromagnetic interference
EMV	=	electromagnetic vulnerability
ESD	=	electrostatic discharges
FAA	=	federal aviation administration
FLIP	=	flight information ;publications
FMECA	=	failure modes, effects, and criticality analyses
FOD	=	foreign object damage
GPS	=	global positioning system
GSE	=	ground support equipment
HCPE	=	hybrid collective protection equipment

HEL	=	high energy lasers
HEMP	=	high altitude electromagnetic pulse
HERF	=	hazards of electromagnetic radiation to fuel
HERO	=	hazards of electromagnetic radiation to ordnance
HERP	=	hazards of electromagnetic radiation to personnel
HISS	=	helicopter icing spray systems
HFC-125-CF_3HF_2	=	pentafluoroethane
HPM	=	high power microwave
HV	=	height velocity
IEEE	=	institute of electrical and electronic engineers
IGE	=	in ground effect
INS	=	inertial navigation system
IPE	=	individual protection equipment
IPS	=	inlet particle separator
IR	=	infrared
ISS	=	icing spray systems
J/S	=	jamming-to-system
LST	=	laser spot tracker
MFE	=	limit maneuvering envelope
MGT	=	measured gas temperature
MOE	=	measures of effectiveness
NATO	=	north atlantic treaty organization
NBC	=	nuclear, biological, and chemical contamination
NEMP	=	nuclear electromagnetic pulse
NOE	=	nap-of-the-earth
OBA	=	octave band analyzer
OBIGGS	=	on-board inert gas generating system
OEI	=	one-engine inoperative
OFE	=	operational flight envelope
OGE	=	out of ground effect
P-stat	=	precipitation static
R/C	=	radar cross section
RPM	=	revolutions per minute
RMS	=	root mean square
SAM	=	surface-to-air missiles
SAQ	=	statement of airworthiness qualification
SAS	=	stability augmentation system
SFE	=	service flight envelope
SHP	=	shaft horsepower
SLM	=	sound level meter
TADS	=	target acquisition and designation sight
TREE	=	transient radiation effects on electronics
UAV	=	unmanned aerial vehicle
USAARL	=	us army aeromedical research laboratory
USACHPPM	=	us army center for health promotion and preventive medicine

USAEHA	=	us army environment hygiene agency
V/STOL	=	vertical/short take-off and landing
VROC	=	vertical rate-of-climb
VTOL	=	vertical take-off and landing
V_D	=	design dive speed
W/SR	=	radiant intensities

CHAPTER 10

OPERATIONAL READINESS QUALIFICATION

This chapter describes the airworthiness qualification issues related to reliability; operational readiness/ availability; maintainability; durability; warranties; training and trainers; transportability; manpower and personnel integration (MANPRINT); logistics; battle damage assessment and repair; corrosion prevention and control; rationalization, standardization, and interoperability (RSI); ship-based operation compatibility; ground support equipment; tie-downs; and moorings.

10-0 LIST OF SYMBOLS

d	=	discrimination ratio = Π_2/Π_1, dimensionless
F_N	=	number of failures, dimensionless
f	=	inherent failure rate, failures/h
MCTF	=	mean cycles to failure, cycles
MRBS	=	mean rounds between stoppage, rounds
MTBF	=	mean time between failures, h
MTBUMA	=	mean time between unscheduled maintenance actions, h
MTTR	=	mean time to repair, h
OR	=	operational readiness, dimensionless
OT	=	operating time, h
ST	=	standby time, h
TALDT	=	total administrative and logistics delay time, h
TCM	=	total corrective maintenance downtime, h
TPM	=	total preventive maintenance downtime, h
TTR	=	time to repair, h
t	=	number of accumulated test life units, dimensionless
I	=	producer's risk, probability that equipment with *MTBF* = Π_2 will be rejected
ϑ	=	consumer's risk = probability that equipment with *MTBF* = Π_1 will be accepted
Π_1	=	lower test *MTBF*, h
Π_2	=	upper test *MTBF*, h

10-1 INTRODUCTION

Operational availability, or readiness, can be defined as the proportion of time that a system either is operating or is capable of operating when used in a specific manner in a typical maintenance and supply environment. All calendar time in a specific period is considered in the calculation of this proportion. Elements of this calendar time include operating time *OT*, standby time *ST*, total corrective maintenance downtime *TCM*, total preventive maintenance downtime *TPM*, and total administrative and logistics delay time *TALDT*. Operational readiness *OR* is defined as follows:

$$OR = \frac{OT + ST}{OT + ST + TCM + TPM + TALDT}, \quad \text{dimensionless} \qquad (10\text{-}1)$$

The intent is to include all characteristics critical to field operations in the definition of operational readiness. Eq. 10-1 shows that operational readiness is improved primarily by reducing maintenance time and/or administrative delay times. Criteria objectives for measuring operational readiness and specific logistics functions should be based on obtaining the data necessary to establish the values of the variables in Eq. 10-1.

Airworthiness can be affected by the transition of a system from development to operational use, and care should be taken to ensure that any significant differences in readiness are identified early in the transition. During developmental testing, aviation systems are typically maintained by prime contractor personnel who have experience working with developmental systems. Prototype or developmental systems are limited in number; thus extensive company resources can be concentrated on maintenance and support of those systems. Additionally, developmental testing is generally conducted at fixed Government or contractor facilities without real exposure to field environments.

Once operational testing begins, contractor personnel supporting systems are replaced with typical operators and maintainers, usually personnel who have recently completed training on the systems. Operator and maintainer errors become more prevalent, environmental conditions vary, and logistics support is usually short of that enjoyed at contractor facilities.

As the systems complete operational testing and are fielded, the importance of these additional sources of *OR* detractors increases. The numbers of systems, locations of those systems, experience of operators and maintainers, and length of the logistic pipeline have significant airworthiness effects on the operation and maintenance of aviation systems in field environments.

10-2 RELIABILITY

Reliability requirements should be included in the request for proposals (RFPs) by specifying quantified reliability requirements and allowable uncertainties, failure definitions and thresholds, and life cycle conditions of use. Typically, these reliability performance requirements should be specified in the air vehicle specification. Also objective requirements for reliability predictions, reliability maintenance and support, and reliability testing can be included to support the assessment of risk in achieving quantitative reliability requirements and to support risk management efforts. The air vehicle contractor (AC) should be responsible for developing or selecting analysis and modeling tools. The RFPs should solicit adequate information to evaluate the source data, models, reasonableness of modeling assumptions, methods, results, risks, and uncertainties. The procuring activity (PA) should avoid citing by specification, standard, handbook, or language "how to" design, manufacture, or test for reliability.

The AC should determine the customer's requirements and product needs. The AC, working with the PA and customer, should include the activities necessary to ensure that the customer's requirements and product needs are fully understood and defined so that the detail design specification can be compiled. The AC should receive from the PA all available important usage and environmental condition information, such as how the product will be used, by whom, and where. The AC should make assumptions for use and environmental conditions not supplied by the customer and should make plans to verify these assumptions and measure or determine any unknowns. The AC should receive from the PA and customer a maintenance and servicing policy to consider during determination of reliability requirements. The AC should receive from the PA and customer product physical configurations and expected life time specification.

The AC should meet the customer's requirements and product needs. The AC should structure and follow a series of engineering activities that ensure the resulting product satisfies the customer's requirements and product needs with regard to product reliability.

The AC should adequately verify that the customer's requirements and product needs are met. The AC should include activities that assure the customer that the reliability requirements and product needs have been satisfied.

Failure definitions and life cycle conditions are necessary to define fully the quantitative reliability requirements. The extent to which failures and usage conditions are defined should be determined on an acquistion-specific basis.

Several types of reliability can be used. Inherent reliability includes only the effects of an item design and its application. The inherent reliability is often used during the design process to select optimum design components. Operational reliability includes the combined effects of design, quality, installation, environment, operation, maintenance, and repair and is used to predict or evaluate overall system performance in an operational environment. Mission reliability involves the probability of completing a specified mission profile or the mean life units between critical failures. Mission reliability is used to predict the ability of an item to perform its required functions for the duration of a specified mission profile. Flight reliability involves the probability that a flight-critical failure will not occur during a specified period of time. Flight reliability is often used to establish inspection criteria and time intervals for inspection, replacement, or other maintenance actions. General (maintenance significant) reliability involves the probability that a maintenance significant failure will not occur during a specified period or the probability the mean life units between a maintenance significant failure will be less than a given value. General reliability is often used to predict the maintenance man-hours and skill levels and logistics costs required to support a system.

The AC is totally responsible for the reliability of the air vehicle and for meeting performance requirements. The AC should be responsible for implementing methods such as failure reporting, analysis, and corrective action systems (FRACAS). The means to validate and demonstrate performance should be included as part of the contractor's integrated test plan. Useful information can be found in MIL-HDBK-781, *Reliability Testing for Engineering Development, Qualification, and Production*, (Ref. 1). Also, see MIL-STD-882, *System Safety Program Requirements*, (Ref. 2). System safety is one of the criticality denominators.

10-2.1 RELIABILITY MEASURES

Inherent failure rates (failures due to design or application) are normally expressed as failures during a predetermined number of life units. For flight hours failures would be expressed as failures per million flight hours. Thus inherent failure rate f and inherent mean time between failures $MTBF$ are related as follows:

$$MTBF = 1/f, \text{ h} \qquad (10\text{-}2)$$

Operational failure rates can be related to operational reliability parameters, such as mean time between unscheduled maintenance actions $MTBUMA$, mean rounds between stoppage *MRBS*, and mean cycles to failure *MCTF* in the same way.

Reliability estimates made on inherent failure rates are useful for planning purposes, for comparing alternatives, and for assessing proposed changes. When test and operational data become available, they are the basis for program decisions and actions and for revised reliability estimates. With appropriate adjustment, i.e., higher estimated failure rates to account for the operational environment stresses, inherent failure rates and *MTBF*s can be used to estimate operational failure rates and reliability.

10-2.2 FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

An analysis commonly used to develop source data for reliability is the failure mode, effects, and criticality analysis (FMECA). The FMECA documents probable failures in a system within specified ground rules, the effects of each failure on system operation, identification of single failure points, and ranking of each failure according to a severity classification or failure effect. The contractor should define the procedures that will be used to perform and document the FMECA. The failure identification and severity should be related to reliability measures, such as mission and flight reliability, i.e., a failure that is flight critical should be classified as more severe than one that may impact mission success. The FMECA is typically used by the contractor's reliability, maintainability, quality assurance, and other logistic engineers. Also it can be one of the sources used to determine flight safety parts. Relevant safety-related information can be found in MIL-STD-882, *System Safety Program Requirements*, (Ref. 2).

Although an FMECA may be important to the contractor's logistic support analysis process, the procuring activity might not require submittal of a formal report. It is recommended that an integrated product team be used to define the specific need and required format. If submittal of a formal report is required, it should be delivered in a format compatible with the computer system of the procuring agency. The analysis approach used for the FMECA may start at the highest indenture level and proceed through lower indenture levels (top-down) or at the part or assembly level and proceed through higher indenture levels (bottom-up). Both the bottom-up and top-down analysis methods are used to determine the effects of all postulated failure modes of the lower level components on the higher level component or system.

Each failure mode and item analyzed should have a severity classification assigned. Failures classified as Category I (catastrophic) or Category II (critical) are generally applicable to flight or mission reliability. All failures apply to other types of reliability cited in this paragraph. Since FMECA is a risk-reduction tool, the process is usually updated throughout the acquisition program to reflect additional data that become available. In this way, failure modes for items and interfaces should become progressively more defined through the time of qualification.

10-2.3 SAMPLE DATA COLLECTION

Three methods of data collection are used depending on the intensity of information required, objectives to be achieved, and cost. These methods include semicontrolled, controlled, and intensified data collection and are sometimes referred to as levels of data collection. All three data collection methods require the data collector(s) to record failure and repair data to a specified level depending on the requirement and use of the data. The Level

1 method, or semicontrolled, is the most economical and is used for low-intensity projects. Also, it is common for the maintainer of the equipment to act as data collector and record maintenance events and repairs. This method is best suited for fielded equipment that has completed the qualification process. The Level 2 method, controlled, is more expensive and is used for higher intensity projects. The Level 3 method, intensified, is the most expensive, detailed, and manpower-intensive method. Unbiased, test-dedicated data collectors must be trained in the use of the data collection system and in the maintenance of the equipment itself to be able to recognize tasks being performed by military or contractor maintenance personnel.

An agreed-upon methodology for reliability assessment is established before initiation of qualification tests. The test lengths necessary to demonstrate adequate reliability characteristics are statistically determined, and the required data elements are defined. Precautions should be taken to obtain unbiased data from the designated data collectors. Consideration should be given to equipment design, operating and maintaining personnel, and operating environments when test data are collected on equipment prototypes in the qualification process. Data collected on prototype designs may not provide valid representations of the fielded system if significant design changes are required. In addition, care should be taken when using data acquired from qualification units to ensure the stresses induced during the qualification tests do not adversely skew the reliability predictions due to premature failures caused by combined stresses not related to the anticipated usage spectrum. Proper confidence limits and statistical techniques are applied to estimate reliability in the fielded environment. These statistical techniques, including hypothesis testing and inference from reliability test data, are similar to those described insubpar. 10-2.5.2.

10-2.4 SCORING CONFERENCES

Scoring conferences might be used as a means to review and evaluate collected test and operational data to ensure the data are assembled into an accurate and manageable database for useful evaluation. The trend is toward the use of integrated product teams in a more continuous mode of evaluating developmental and operational test results. Also, in some cases, developmental and operational testing might be combined. The purposes of reliability, availability, and maintainability (RAM) scoring conferences are to establish a test database and to assure that a proper and consistent determination is made for categorizing (assigning classification and chargeability) test incidents against RAM requirements. Principal spokespersons are provided by the materiel developer proponent, the combat developer proponent, the operational evaluator, and the development evaluator. The development tester and the operational tester each provide a representative to scoring conferences who serves in an advisory role, and the logistician is invited as an observer. When requested by the materiel developer spokesperson, contractors may participate to provide insight into the cause of a failure.

Scoring conference results are reached by majority decision of the principal spokespersons. These results include classification and chargeability of each RAM incident in the test database based on the approved failure definition/scoring criteria (FD/SC) and on the applicable minority (dissenting) opinions for each RAM incident.

10-2.5 RELIABILITY TESTING

As stated in par. 10-2, the PA should avoid citing by specification, standard, handbook, or language "how to" test for reliability; however, validation of environmental performance might still be specified. The fundamental purposes of reliability testing should be to demonstrate compliance with performance requirements and to improve the product. The three objectives of reliability testing are typically to disclose deficiencies in item design, material, and workmanship; provide measured reliability data; and determine compliance with quantitative reliability requirements. Four types of reliability tests are included in two categories. Environmental stress screening (ESS) and reliability growth test (RGT) are reliability engineering tests performed during the development and qualification phase and are designed to identify deficiencies and cause correction in the design process; these tests should be emphasized. Reliability qualification tests (RQT) and production reliability acceptance tests (PRAT) are reliability accounting tests and, given the emphasis on RGT and ESS, are limited to those necessary to provide reliability data and determine compliance with reliability requirements. Tasks associated with reliability engineering and accounting tests should be tailored based on program complexity, needs, and cost and should include only those tasks that provide maximum return on cost and schedule investment. Although experience plays a primary role in task selection, it should be supplemented by analysis and investigation.

The reliability test program typically includes establishing a failure reporting, analysis, and corrective action system (FRACAS); developing or selecting analysis and modeling tools; and defining the equipment to be tested and the number of items to be tested. Test conditions, duty cycles, and environmental, operational, and performance profiles should be defined prior to the start of the reliability testing program.

For ESS MIL-STD-810, *Environmental Test Methods and Engineering Guidelines*, (Ref. 3) describes the guidelines used to conduct environmental engineering tasks and test methods to determine the effects of natural and induced environments on air vehicles. Environmental testing is conducted to assure that military equipment is designed and tested for resistance to the environmental stresses it will encounter during its life. Environmental stress screening procedures are designed to be implemented so that early failures due to weak parts, workman defects, and other nonconformance anomalies can be identified and removed from the equipment. Also MIL-STD-810 (Ref. 3) provides test methods recommended to duplicate numerous types of environmental stresses, both natural and induced environments. During ESS and early in RGT overstress conditions may be applied to identify deficiencies. However, the final portions of RGT and all of the RQT and PRAT programs should use environmental conditions that simulate the operational environment as closely as possible.

RGT and RQT are discussed in subpars. 10-2.5.1 and 10-2.5.2, respectively.

10-2.5.1 Reliability Growth Test (RGT)

As defined by MIL-HDBK-189, *Reliability Growth Management*, (Ref. 4), reliability growth is the positive improvement in a reliability parameter over a period of time due to changes in product design or the manufacturing process. RGT is conducted to enhance system reliability through the identification, analysis, and correction of failures and verification of the effectiveness of the corrective action. MIL-HDBK-781 (Ref. 1) describes the elements of RGT. Typical application of RGT begins with prototype articles, continues through early production articles, and terminates upon demonstration that the reliability requirements of the system have been met.

MIL-HDBK-189 (Ref. 4) describes three essential elements needed to achieve reliability growth. These elements are detection of failure sources, problem identification and feedback, and redesign effort based on the identified problems. Problem correction may be a continuous process, or corrections may be held in abeyance and applied as "block" corrections. Each method of correction provides different reliability growth predictions as shown in Fig. 10-1.

Whatever method of correction is used, *MTBF* calculations are performed by dividing the number of accumulated test life units *t* by the accumulated failures. Section 4 of MIL-HDBK-781(Ref. 1) describes the two evaluation methods, Duane and AMSAA, used to evaluate confidence intervals, goodness of fit, and point estimates of *MTBF*.

Growth testing should emphasize performance monitoring, failure detection, failure analysis, and incorporation and verification of design corrections to prevent recurrence of failures. To enhance mission reliability, corrective action should be focused on mission-critical failure modes, and to enhance basic or inherent reliability, corrective action should be focused on the most frequent failure modes regardless of their mission criticality. These efforts should be balanced to meet predicted growth for both parameters.

10-2.5.2 Reliability Qualification Test (RQT)

The purpose of RQT is to demonstrate that the equipment design conforms to specified performance and reliability requirements under the specified combined environmental conditions. RQT testing is normally conducted on equipment that is representative of the approved production configuration and should be conducted in accordance with the reliability test procedures approved by the procuring activity. Depending on the qualification technique used, RQT is continued until an accept or reject decision has been reached or the total required test time has been completed.

For components or systems that have not been qualified, four types of tests can be used to demonstrate contract compliance with accept-reject criteria. These four types of tests are the probability ratio sequential test (PRST), both regular and short run (high risk); the fixed duration test; and the all-equipment reliability test. All are based on the assumption that the underlying distribution of times to failure is exponential. Guidelines and procedures for application of each test may be found in Section 4 of MIL-HDBK-781 (Ref. 1). RQT test planning should be based on the requirements established by the PA and should include the development of a graphically portrayed reliability growth planning curve to indicate what the reliability value should be at various points in the development program if conformance to the reliability requirement is to be achieved. Planning and evaluation should be based on predefined failure definitions and verifications, failure reporting

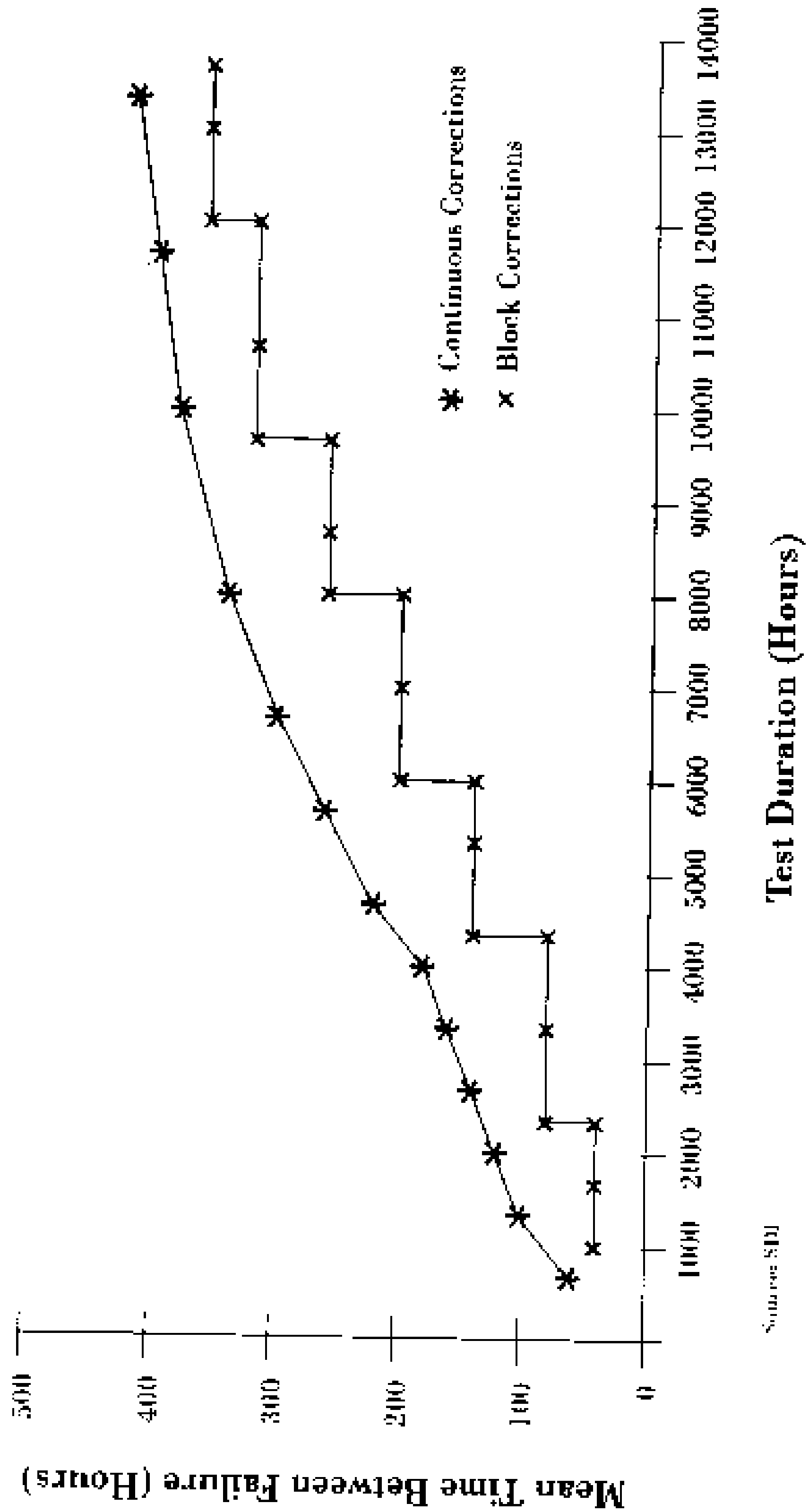


Figure 10-1 Typical Reliability Growth Test Results

procedures, and failure correction procedures.

The PA should specify lower test *MTBF* θ_1 and/or upper test *MTBF* θ_2. The ratio of upper to lower test *MTBF* is the discrimination ratio *d* and is a measure of the power of the test to reach a decision quickly. Higher values for *d* allow a quicker decision.

Acceptable decision risk also affects test planning and accumulated test hours. One type of decision risk is consumer's risk ß, the probability that equipment with *MTBF* equal to θ_1 will be accepted. Another type of decision risk is producer's risk α, the probability that equipment with *MTBF* equal to θ_2 will be rejected. Together with the discrimination ratio *d*, the tables of MIL-HDBK-781 (Ref. 1) relate to test duration (multiples of θ_1), *d*, α, ß, and acceptable and unacceptable numbers of failures for fixed duration test. This relationship is shown in Fig. 10-2. For fixed duration tests acceptable failures are equal to unacceptable failures minus one.

The same variables define the PRST accept-reject criteria. However, as shown in Fig. 10-3, acceptance or rejection is based upon the number of failures at a given test time falling outside the "Continue Test" range.

Each type of test—fixed duration versus PRST—has advantages and disadvantages, which are cited in Section 4 of MIL-HDBK-781 (Ref. 1).

10-2.5.3 System Endurance Tests

Endurance testing is conducted to demonstrate that the equipment has structural and functional life which is compatible with the system or subsystem life requirements. Endurance testing (sometimes called durability testing) may include a normal test, an overload (oroverstress) test, and a mission profile cycling test, which duplicates or approximates the conditions expected during service. Requirements for endurance testing, correction and retest of failures occurring during endurance testing, requirements for failure reporting and corrective action system reporting, and passing criteria should be as specified by the PA.

10-3 OPERATIONAL READINESS/AVAILABILITY

Eq. 10-1 defines operational readiness *OR* as

$$OR = \frac{OT + ST}{OT + ST + TCM + TPM + TALDT}, \quad \text{dimensionless} \qquad (10\text{-}1)$$

Operational readiness and operational availability are generally used interchangeably and are used to describe the expected percentage of total time a piece of equipment can be expected to be available for use for its intended purpose. As can be seen from this relationship, detractors from operational readiness include total corrective maintenance downtime *TCM*, total preventive maintenance downtime *TPM*, and total administrative and logistic delay time *TALDT*. Analysis of operational readiness includes determination of the value of each variable in Eq. 10-1, the positive and negative effects of each variable (or characteristic), and the areas where improvement can most likely occur.

Reliability characteristics of a system—mean time between failure and mean time between unscheduled maintenance actions—affect operational readiness because each event—failure or

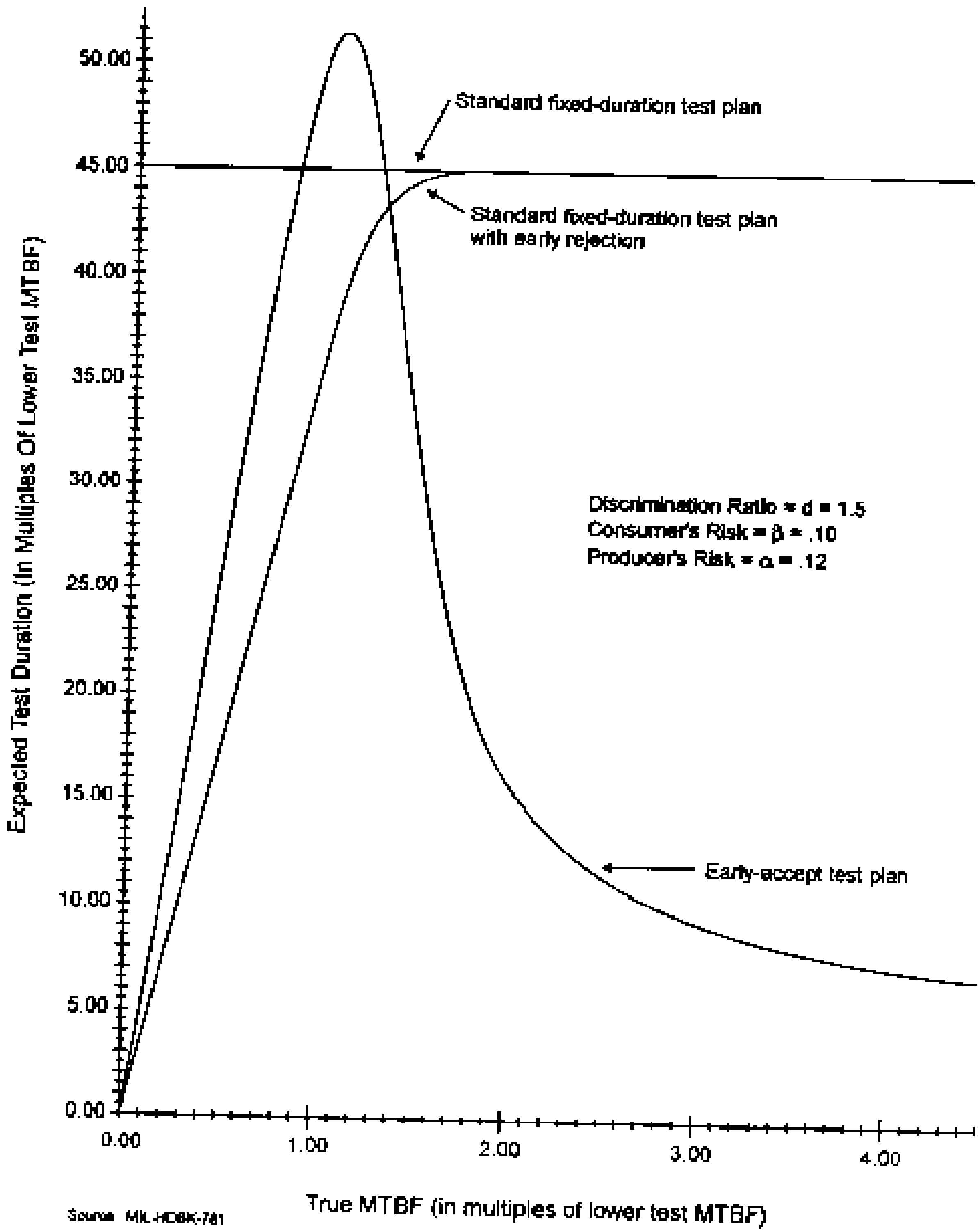


Figure 10-2 Typical Fixed Duration Reliability Test Plan

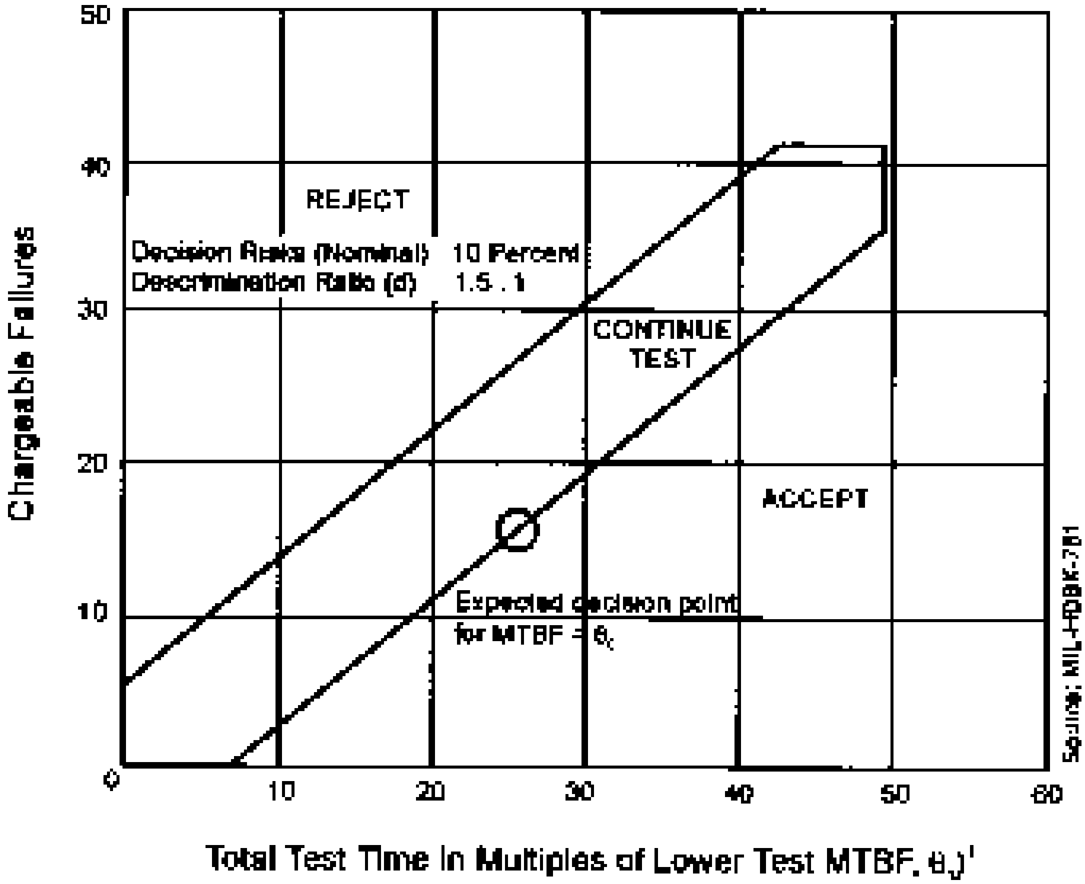


Figure 10-3 Typical Probability Ratio Seqential Test Plan

unscheduled maintenance action (UMA)—has an associated time to repair *TTR* and total administrative and logistic delay time *TALDT*. This effect is evidenced in the proportion of *TCM*. Maintainability characteristics are reflected in both *TCM* and *TPM* by the *TTR* and time to complete scheduled maintenance inspections. Logistic (principally supply support) characteristics are reflected in *TALDT* due to delays in obtaining spare and repair parts but may include delays in obtaining test equipment and/or tools.

Reduction of the proportion of *TCM*, *TPM*, and *TALDT* to total calendar time is essential to maintaining high *OR*. Therefore, the objectives of operational readiness qualification are to demonstrate that reliability (*MTBF* and *MTBUMA*), maintainability (mean time to repair (*MTTR*) and scheduled inspection downtime), and logistics parameters (*TALDT*) are sufficient to allow required operational readiness of the system. These reliability, maintainability, and logistics factors should be demonstrated to the specified levels of confidence.

10-4 MAINTAINABILITY

Maintainability is a characteristic of equipment that is expressed as the probability an item will be retained in or restored to a specified condition within a given period of time when the maintenance is performed in accordance with prescribed procedures and resources. Achievement of the required level of maintainability should be demonstrated in accordance with the prime contractor's approved maintainability plan.

The PA provides the prime contractor with the operational information necessary to establish the maintenance and support concept. This information also provides the basis of the quantitative maintainability requirements for the rotorcraft or aircraft. This information includes but is not limited to

1. Operating hours per unit calendar time
2. Operational readiness and mission success objectives
3. Downtime or availability constraints
4. Mobility requirements
5. Self-sufficiency constraints
6. Manpower, skill, and support constraints
7. Reaction time requirements
8. Operational environment
9. Number and location of operational sites
10. Number of operational systems per site
11. Deployment schedule.

The individual elements of maintainability are evaluated to determine which detract from operational readiness.

Two such elements are ease of disassembly and ease of assembly. For repair actions involving disassembly and reassembly, these two elements usually comprise the main portions of time to repair *TTR*. Given appropriately trained personnel with sufficient skill levels, if disassembly or reassembly is difficult or prone to maintenance error, corrective maintenance time (CMT) will be excessive.

Mean time to repair is also another important element of maintainability. The *MTTR* is defined as the elapsed clock times to repair specific classes of deficiencies divided by the number of deficiencies. Difficult, time-consuming repairs that are frequently required will drive MTTR to excessive values. Assuming that no corrective actions are concurrent, *MTTR* can be used to determine *TCM* indirectly according to the following relationship:

$$TCM = \frac{OT * MTTR}{MTBF} = F_N * MTTR, \text{ h} \qquad (10\text{-}3)$$

where

F_N = number of failures, dimensionless.

Improperly trained personnel or personnel with skill levels that are too low will also increase *MTTR* and thus *TCM*. Therefore, *MTTR*, skills, and training levels of personnel are maintainability elements that should be evaluated for aviation systems.

The maintenance level—unit, direct support (DS), general support (GS), or depot—responsible for each repair action should also be evaluated. Actions that are incorrectly designated as unit maintenance but require higher skill levels or additional support equipment not available in an organization increase *MTTR*, and there is a corresponding increase in *TCM*. Maintenance levels for PA-selected repair actions are evaluated as part of the contractor's maintainability program.

Inadequate support equipment used to detect, isolate, and/or diagnose faults also affect *MTTR*. Detection of faults that have not occurred (“false alarms”) increases the maintenance burden on the units. Failure to detect faults that exist can have airworthiness impacts since a problem has occurred but has not been identified by onboard detection and diagnostic equipment. Isolation or diagnosis to an ambiguity group (one of several components) increases repair times over the *TTR* for faults isolated to one component. Requirements for fault detection, isolation, and diagnosis are established by the PA, and the effectiveness of onboard and off-system diagnostic equipment and suitcase testers (portable test sets) should be evaluated using a PA-approved maintenance task sampling plan. Relevant information can be found in MIL-HDBK-471, *Maintainability Demonstration*, (Ref. 5). Faults or simulated faults are inserted into the system during the maintainability demonstration to determine whether the test equipment, maintenance procedures, and maintainer training are adequate to detect, isolate, and repair the fault properly. A failure mode and effects analysis (FMEA) should be applied to the functional level at which maintenance is to be performed to determine the failure modes or faults (open, short, etc.) that result in occurrence of the maintenance task of interest. Diagnostic procedures, test equipment, and repair procedures should be demonstrated by military personnel to confirm the adequacy of procedures, equipment, and training to achieve the contractual maintainability requirements.

Evaluation of maintainability elements is performed via statistical analysis of collected data. Relevant information can be found in MIL-HDBK-470, *Maintainability Program for Systems and Equipment*, (Ref. 6).

Maintainability testing should be conducted under conditions that are as realistic as possible to the anticipated environment and conditions for the system under test. This should include the presence of spares, tools, test and support equipment, technical publications, and personnel as anticipated for fielding. Fault insertions and simulated failures should be as realistic as possible but should not be used when the normal procedures could result in extensive damage to the equipment being tested.

10-4.1 PHYSICAL TEARDOWN AND MAINTAINABILITY DEMONSTRATION

Prior to fabrication of airworthy prototypes, mock-ups can provide a means to evaluate the accessibility of components for inspection and maintenance. Physical teardown of repairable components can also provide valuable maintainability information. Computer-aided engineering (CAE) substitutes are replacing inert physical mock-ups. Virtual prototypes are capable of a degree of functional realism that is comparable to a physical mock-up. Major subsystem components, wiring, cables, tubing, piping, and structural members should be mocked up to demonstrate accessibility. Electronic mock-ups should allow three-dimensional analysis for physical size, access, and clearances. Necessary changes identified during this analysis should be incorporated into the production configuration.

Physical teardown should be performed by the contractor using customer-defined facilities, tools, publications, and parts. The results of this physical teardown should be compared to predicted values, and corrective actions for design, procedures, tools, or parts are implemented as required by the PA.

10-4.2 TECHNICAL MANUAL VALIDATION

Technical manuals should be validated for technical adequacy and accuracy of repair parts and illustrated parts breakdowns; scheduled and unscheduled maintenance requirements; servicing requirements; troubleshooting; suitability of recommended tools; test, measurement, and diagnostic equipment (TMDE); and associated skill requirements. Typically, a tabletop review is accomplished on items such as checklists, schematics, wiring data, descriptive data, indexes, operational theory, basic issue items list, expendable supplies and materials, and the correlation of the maintenance manuals and the repair parts and tool lists. Hard copy maintenance manuals are validated for tasks selected by the PA. This selection might involve all maintenance tasks at each maintenance level. These evaluations are performed using typical user personnel.

If a video disk or onboard diagnostics will be used for the system, the same type of validation applies. Also ease of use, reliability of the system under field conditions, and ease of update should be evaluated.

10-4.3 TESTABILITY

When effectiveness of built-in test (BIT) and external test systems is required, testability attributes should be demonstrated and evaluated. Typical measures include fault detection accuracy, fault isolation accuracy, ambiguity level, and false alarm rates at each maintenance level. Also, typical procedures for these demonstrations are included in the addendum to MIL-HDBK-471 (Ref. 5).

10-5 DURABILITY

Durability can be defined as the probability that an item will successfully survive to its projected life, overhaul point, or rebuild point without a durability failure. A durability failure is a malfunction that precludes further operation of the item and is great enough in cost, safety, or time to preclude restoration, so the item must be replaced or rebuilt. Durability performance requirements should be specified in the air vehicle specification.

Typical measures include part life at replacement, time between overhauls (TBO), shelf life, resistance to corrosion, mean time between critical failures (MTBCF), and mean cycles to failure (MCTF). These data should be used to assess the achievement of contractual durability requirements, under both the basic climatic conditions and the extreme climatic conditions cited in the operational mode summary/mission profile (OMS/MP). Additional uses include evaluation of the planned supply support system and logistics-related durability factors.

Durability testing typically consists of a normal test, an overload test, and a mission profile cycling test, which duplicates or approximates the conditions expected in service. An integrated test program usually combines reliability and durability testing. Failures are evaluated, and corrective actions are incorporated into test items. If required by the PA, this information is documented in the Failure Reporting Analysis and Corrective Action System. The test is repeated, or at the option of the PA, the test may be completed and an additional run conducted to demonstrate that problems have been corrected.

Results of both technical test (TT) and initial operational test and evaluation (IOT&E) provide sufficient data to ensure that, with a high confidence level, the system meets contractual durability requirements and to assess achievement of each durability requirement according to the OMS/MP and under field support conditions.

10-6 WARRANTY

A warranty is defined as a promise or affirmation given by a contractor to the purchaser regarding the nature, usefulness, or condition of the supplies or services furnished under the contract. Warranties are acquired in accordance with the statutory requirements of 10 USC 2403, *Major Weapon Systems: Contractor Guarantees*, (Ref. 7) and regulatory requirements of FAR 46, *Quality Assurance, Subpart 7, Warranties*, (Ref. 8) and DFAR 246, *Quality Assurance, Subpart 7, Warranties*, (Ref. 9). AR 700-139, *Army Warranty Program Concepts and Policies*, (Ref. 10) assigns responsibilities, states acquisition policies, defines information requirements, covers fielding and execution procedures, and prescribes methods of compliance.

10-6.1 GENERAL PERFORMANCE WARRANTY

The purpose of warranties is to provide cost-effective and comprehensive coverage against failures of Government-procured items. Warranty performance measures are generally based on the number of items that fail to conform to the required performance standard at the required duration and the overall cost of the warranty compared to the expected cost of repair without a warranty. Warranty tailoring protects the Government from the costs and frequency of systemic failures and enacts responsive remedies for failures of significant operational impact. General performance warranties frequently use two basic concepts: expected failures and failure free.

1. The expected failure concept is based on the knowledge that the Government procures materiel to the minimum needs; therefore, any design will include expected failures. The contract supplier should not be liable for failures that are expected but should be held liable for failures that exceed the expected. The benefit from this concept is the initial contract warranty is provided with little or no cost since the Government requires remedies only for excessive failures. Procurement items adaptable to this concept include items that use contractor depot or intermediate contract support for maintenance.

2. The failure-free concept requires a period of failure-free use. Commercial and trade practice warranties are examples of this concept. Since failures may occur, the cost of the warranty normally includes the expense of repair or replacement that can be expected during the warranty term. The failure-free warranty may also be used when the reliability of an item is unknown or unspecified, such as for a nondevelopmental item.

Prior to negotiated procurement of an item warranty, a cost-effectiveness analysis is required to determine the value of the potential benefits received in comparison to the contract cost of the warranty plus the cost to the Government for administration and execution. This analysis is used to determine the value of the benefits, such as reduced maintenance or materiel cost, in comparison to the cost to the Government plus any readiness-related cost. Additional float quantities required, equipment downtime, or other productive time lost attributable to the exercise of the warranty incurs readiness-related costs.

Assessments are performed for warranties on an in-process and final payoff basis. Warranty benefit may differ depending on the procurement strategy. Nondevelopmental items may be well suited to a warranty program if that is the normal procedure used by the manufacturer. On the other hand, warranties may not be appropriate for low-cost items designed for discard. Warranty assessments should be used to determine warranty provisions and tasks for follow-on procurements and competitive resupply of the item or a similar item; and the overall effectiveness of the item warranty. The assessments also provide guidance to qualifying competitive resupply items. Qualification of warranted items should consider the cost and impact to the system of a warranted item. Generally, items with warranties may not require a full qualification test, but this is probably not appropriate for flight-critical items.

10-6.2 RELIABILITY IMPROVEMENT WARRANTY

A reliability improvement warranty (RIW) is a contractual commitment that provides the contractor with a financial inducement to improve a system in order to reduce repair or replacement costs and thus enhance field operational reliability. In an RIW the contractor may increase profits by introducing engineering changes that cost effectively reduce repair or replacement costs. The requirements of an RIW usually include a guarantee of a specified reliability level, and the contractor is obliged to upgrade all existing units at the his expense if reliability falls below the specified level. RIWs are generally applicable to systems that can provide reasonable cost savings but do not increase risk of significant mission failures if the reliability improvements cannot be obtained. Reliability measurements and analysis are conducted as described in par. 10-2.

10-7 TRAINING AND TRAINERS

AR 350-1, *Army Training*, (Ref. 11) defines training devices and simulators as tools used to reinforce job performance and to conserve service resources. Trainers that faithfully replicate actual hardware functions, arrangements, environments, and procedures allow safe, effective habit transfer from trainer to air vehicle or support systems and thereby minimize hardware training time and operator or maintainer errors (Ref. 6). These devices also provide a cost-effective and efficient method of providing a capability to train and test the ability to detect, diagnose, and repair failures without risk of damaging the actual system and system hardware. Trainers allow the simulation of situations and conditions that may not be economically or safely trained in any other way. Such trainers include but are not limited to synthetic flight trainers (also called flight simulators), built-in trainers, intelligent trainers, and combat evaluation trainers. No safety or health hazards are permissible in accordance with AR 602-2, *Manpower and Personnel Integration (MANPRINT) in the Materiel Acquisition Process*, (Ref. 12).

10-7.1 TRAINING

Operators and maintainers are required to perform numerous tasks as part of their duties. However, some of these tasks are identified as critical. DA PAM 71-3, *Operational Testing and Evaluation Methodology, A Procedures Guide*, (Ref. 13) identifies the percentage of critical tasks demonstrated as a measure of performance (MOP) for training. Using validated procedures, the soldier should demonstrate, or attempt to demonstrate, all critical maintenance and operator tasks. Individual and unit training through the direct support and general support maintenance level, training materiel, devices, and other aids are addressed. Training tasks that can be accomplished in training devices include but are not limited to flight crew coordination and system procedural task training and individual maintenance procedural training, such as diagnostic, and remove and replace tasks.

RAM factors used to assess training devices and trainers, which include qualitative reliability requirements, scheduled availability, and maintainability factors, can be found in MIL-T-23991, *Training Devices, Military; General Specification for* (Ref. 14). Other subjective measures are addressed in par. 10-9, "MANPRINT".

10-7.2 SYNTHETIC FLIGHT TRAINERS (FLIGHT SIMULATORS)

The percentage of critical operator tasks demonstrated is the accepted MOP. The primary purposes of synthetic flight trainers are to reduce cost through reduction of the required flight training hours and provision for a mechanism to train for emergency flight situations. Since the synthetic flight trainer is a simulation of actual flight, these trainers should be subjected to validation, verification, and accreditation (VV&A) mandated by Headquarters, Department of the Army (HQDA) policy. Through demonstration of synthetic flight trainer effectiveness in flight training, operator training effectiveness can be evaluated using fewer air vehicle and flight hours.

10-7.3 BUILT-IN TRAINER/TRAINING

A built-in trainer consists of auxiliary components added to an air vehicle or support system that allow the air vehicle to be used for training when not in use for operational or maintenance functions. The training is done via actual controls and displays to enhance the realism of the training scenario. Availability of appropriate built-in trainers involves the capability of air vehicles or support equipment to provide training to operators and maintainers during periods when maintenance or flight operations are not occurring. Using the air vehicle instead of cockpit procedure trainers eliminates the need for the cockpit procedure trainers. Also use of the actual air vehicle or support equipment ensures that layouts, functions, and procedures are identical to those for fielded systems. Availability of appropriate stimuli (e.g., simulated or actual threat warnings and responses, air vehicle systems information, and operator or maintainer actions) is critical to evaluation of the effectiveness of these trainers. Demonstrations of effectiveness for built-in trainers should include PA-required stimuli, systems responses, and operator or maintainer actions.

Trainer effectiveness should be demonstrated to show that the device is capable of replicating system functions, displays, and responses and should be tested to ensure the device is capable of being used to train the required tasks adequately. This type of demonstration and testing should be conducted by military users who are representative of the target audience intended to use the device. Trainer effectiveness of its intended function or functions is the primary prerequisite for qualification of the device for operational use.

10-7.4 INTELLIGENT TRAINERS

Artificial intelligence and expert systems used in trainers have primary goals of increasing the effectiveness of training and of reducing operator or maintainer workload. Expert systems may be as simple as automation of air vehicle maintenance troubleshooting charts or diagrams or as complex as using subject matter experts (SMEs) experiential data to identify the course of action with the greatest expectation of success. This success may be in the form of lowest number of man-hours or parts cost for maintenance or highest survivability in a combat or emergency situation. Artificial intelligence supplements expert systems by applying information that is not part of an experiential database in order to recommend a course of action.

Expert systems and artificial intelligence trainers should be subjected to VV&A by Government SMEs. Qualification of these devices includes determining that the device meets its requirements of performance and functionality. However, the device should also be assessed by the user to determine whether it can effectively be used to train its intended tasks adequately. Training effectiveness is generally measured by determining the level of competence of individuals after they have been trained on the device. These measures can include but are not limited to system knowledge, diagnostic capability, performance accuracy, and time required to perform a task.

10-7.5 COMBAT EVALUATION TRAINERS

Combat evaluation simulators are simulators or networks of simulators designed to replicate system performance of the simulated weapon system in a combat environment. These trainers are usually designed to replicate as closely as possible the capabilities of the system being trained as well as enemy and other friendly weapons systems. Combat evaluation systems can be used to predict or evaluate system effectiveness during development, and they can be used to evaluate unit effectiveness in employing the weapons system. In addition, these systems can be used to learn or develop new tactics, techniques, or procedures. Use of training devices for combat evaluation can overcome some of the obstacles to actual hardware evaluation. According to DA PAM 71-3 (Ref. 13), a major problem during the early stages of operational test and evaluation (OT&E) is insufficient available units to simulate the organizational relationships and interaction of the equipment with its operational environment. Data obtained during large force simulations can be used to extend test results and save considerable training resources and training costs. These trainers typically are used with other combined arms forces simulators (armor, artillery, etc.) to evaluate training.

Combat evaluation trainers should be subjected to VV&A by Government operational SMEs. Emphasis should be on verifying that critical unit mission performance replicates actual hardware performance capabilities and that constraints and limitations are identified.

10-8 TRANSPORTABILITY

The contract should provide minimal essential operational deployment information upon which specific transportability requirements are based. Specific requirements should be defined in the specification for the air vehicle. The AC should ensure that the systems, equipment, and munitions, including components and repair parts, are designed, engineered, and constructed so that required quantities can be moved efficiently by existing and planned transportation assets. Military Traffic Management Command (MTMC) requirements should be satisfied. All new air vehicles should be designed to be transportable in a given transport configuration and at a given weight that should be defined by the AC and approved by the PA. This needs to be accomplished early in the program. It should not be necessary to off-load fuel. Older air vehicles and nondevelopmental air vehicles typically have trouble satisfying transportability criteria. A load cap and some disassembly are often necessary. The US Army defers to the US Air Force in matters of air transportability. A detailed analysis should be performed to determine the specialized materials, tasks, tools, and equipment necessary to disassemble, transport, reassemble, and check out the air vehicle. The AC should define the means for packaging and tying down any assemblies and components that must be removed from the air vehicle to satisfy transportability criteria.

Information concerning development and shipment of materiel can be found in MIL-STD-1366, *Transportability Criteria*, (Ref. 15) and MTMCTEA Pamphlet 70-1, *Transportability for Better Strategic Mobility*, (Ref. 16). MIL-STD-1366 also covers dimensional and weight limitations for all modes of transport, slinging and tie-down provisions, containerization criteria, overloads, assembly and disassembly, air delivery, shelter criteria, and transportability testing. The transportation modes and the qualification criteria include but are not limited to the following:

1. *Self-Deployment (ferry flight)*. For qualification the air vehicle should meet specified requirements for ferrying including the total distance to be ferried, length of the longest leg, and the equipment and personnel required to be carried with the air vehicle. Maximum range, including auxiliary fuel provisions and aerial refueling capabilities, should also be demonstrated.

2. *Aerial Transport*. MIL-STD-1791, *Designing for Internal Aerial Delivery in Fixed-Wing Aircraft*, (Ref. 17) provides general design and performance guidance for the transport of military equipment in Air Mobility Command (AMC) cargo aircraft and long-range international Civil Reserve Air Fleet (CRAF) aircraft. The contract should specify transportability requirements. The air vehicle specification should include the required dimensional envelope, weight and balance limitations, and tie-down limitations as needed in its transportable mode for each type of transport vehicle. Typically, these air vehicles might have 1/4 to 3/4 of a tank of fuel. The AC should define the maximum gross weight and level of disassembly at which the air vehicle satisfies static load criteria for transport. Maximum allowable time for preparation, packaging, and on-loading should be specified in the contract. Also the maximum allowable time for off-loading and reassembly should be specified. Time-trial demonstrations are typically required for qualification. The AC should provide the means for packaging and tying down of any assemblies that must be removed from the air vehicle for transport.

3. *Land Transport*. MIL-STD-209, *Slinging and Tie-Down Provisions for Lifting and Tying Down Military Equipment*, (Ref. 18) and MIL-STD-1366 (Ref. 15) provide relevant information for surface transportation; however, there are not really any defined load requirements for surface transport. Normally, US Army air vehicles are not transported by rail. Also the US Army does not allow highway transport of air vehicles on anything but air-ride trailers; no rough terrain transport is allowed. US Army air vehicles should be capable of being hoisted on and off the trailers. Slings, straps, tie-down fittings, etc., should be provided by the AC. Spreader bars are undesirable; however, if needed, they should be provided by the AC. Time-trial demonstrations for on-loading and off-loading are typically required for qualification. The AC should both define and provide the means by which to package and tie down any assemblies that must be removed from the air vehicle for transport. Highway limitations include the physical, legal, and administrative characteristics of roadways, bridges, and other structures. These limitations vary from state to state in the continental United States

(CONUS) as well as on outside CONUS (OCONUS) highway systems.

4. *Water Transport* MIL-STD-209 (Ref. 18) and MIL-STD-1366 (Ref. 15) provide guidance for water transport also. Other than self-deployment, water transport is the primary means for movement of US Army air vehicles. Roll-on- and roll-off-type ships exist, but there are only a few of them. Air vehicles should be capable of being hoisted into and out of the holds of transport ships and barges. Slings, straps, tie-down fittings, etc., should be provided by the AC. Spreader bars are undesirable and typically are not allowed on some ships. Air vehicles take up space but are relatively lightweight and should be stored below deck, although not necessarily at the lowest level. Above-deck transport is generally not allowed. Contractual requirements for water transport should define the models of ships available, the size and location of areas available (typically belowdecks), transport operational constraints, and length of time onboard.

Considerations for all modes of transport also include the handling equipment, personnel, and time constraints necessary for any disassembly required to load and assembly after unloading the air vehicle.

The PA provides actual vehicles for demonstration when required. Demonstration of those items with critical clearance may be performed on the actual air vehicle or on a mutually agreed upon mock-up or simulation of the air vehicle. All demonstrations should be monitored by a representative of the PA. If a demonstration is unsuccessful, the contractor submits the corrective action. Final disposition and retest requirements are made by the PA.

10-9 MANPRINT

Manpower and Personnel Integration (MANPRINT) refers to the comprehensive management and technical effort necessary to ensure total system effectiveness by continuous integration of manpower, personnel, training, human factors engineering, system safety, soldier survivability, and health hazard considerations. Qualification criteria for these domains are addressed in AR 602-2 (Ref. 12), and the domains are described in the subparagraphs that follow. MIL-H-46855, *Human Engineering Requirements for Military Systems, Equipment, and Facilities*, (Ref. 19) establishes and defines the requirements for applying human engineering to the development of military systems. Information concerning the measurement of operator workload can be found in ADS-30, *Human Engineering Requirements for Measurement of Operator Workload*, (Ref. 20). The MANPRINT goals, constraints, and requirements stated in the materiel requirements documents are evaluated through MANPRINT assessments. These assessments aid in obtaining MANPRINT compliance by providing information upon which to make tradeoffs, such as quality and numbers of people, training, technology conditions, standards, costs, and personnel assignment policy.

10-9.1 MANPOWER

Manpower criteria include the human resource requirements and authorizations (spaces) needed for the operation, maintenance, and support of each system. Considerations necessary to establish these criteria include wartime workload data and the analysis of the tables of organization and equipment (TO&E), combat support (CS), and combat service support (CSS) requirements. Manpower requirements criteria (MARC) planning factors are based on providing minimum essential manpower position requirements.

10-9.2 PERSONNEL

Personnel criteria include the aptitudes, experience, and other human physical and mental characteristics needed by those who operate, maintain, and support each system. The skill levels and grades of the military and civilian persons required to operate and support the system in peacetime and wartime should be considered as part of the personnel MANPRINT criteria.

10-9.3 TRAINING

Training criteria include the instruction, time, and other resources necessary to impart the requisite knowledge, skills, and abilities in order to qualify personnel for operation, maintenance, and support of the system. Formulating the training for a new system requires analyses that address the expected aptitude levels, the nature and complexity of the knowledge and skills to be acquired, and the proficiency levels to be attained and sustained.

10-9.4 HUMAN FACTORS

Human factors engineering (HFE) criteria deal with the design of materiel to ensure that its use conforms to the capabilities and limitations of the fully equipped range of personnel that operate, maintain, supply, and transport the system in the operational environment. Considerations should include human characteristics, anthropometric data, system interface requirements, human performance, biomedical factors, safety factors, and work environments.

10-9.5 SYSTEM SAFETY

System safety criteria are used to determine attainment of the optimum degree of safety consistent with mission requirements (Ref. 2). It involves the identification, elimination, or management control of safety hazards. It also involves the identification, assessment (severity, probability, etc.), and resolution through elimination or reduction of associated risks to an acceptable level. It includes the risk management process throughout the life cycle. Specific safety operational readiness qualification requirements should be included in the Airworthiness Qualification Specification (AQS).

10-9.6 HEALTH HAZARDS

Health hazards criteria are developed by the application of biomedical knowledge and principles to identify, evaluate, and control risks to the health and effectiveness of personnel who test, use, maintain, and support the system. Considerations should include exposure to acoustical energy, biological substances, chemical substances, oxygen deficiency, psychological stresses, radiation energy, shock, temperature and humidity extremes, trauma, and vibration. Exposure criteria should be established in accordance with applicable standards and defined to the contractor by the PA. Health hazards should be identified and assessed as provided for in MIL-STD-882 (Ref. 1). Also see par. 9-17.

10-9.7 SOLDIER SURVIVABILITY

Soldier survivability, as defined by AR 602-2 (Ref. 12), is the characteristic of a system that can reduce fratricide as well as detectability of the soldier, prevent attack if detected, prevent damage if attacked, minimize medical injury if wounded, and reduce physical and mental fatigue. Damage, as used here, means injury or harm that impairs value or usefulness.

10-10 LOGISTICS

The contractor should be required to propose and describe the processes to be used to determine the logistic support required to keep the system usable for its intended purpose and the processes to influence the design so that the system and support can be provided at an affordable cost. The contractor's process should be evaluated and compared on a competitive basis. Typically, a logistic support analysis (LSA) process is used. Information concerning the LSA can be found in MIL-STD-1388/1, *Logistic Support Analysis*, (Ref. 21).

Usually, logistic support requirements are determined by an integrated analysis of all operator and maintenance functions and tasks to ascertain task frequencies, task times, personnel and skill requirements, supply support requirements, etc., including all elements of integrated logistic support (ILS). Optimization is achieved through allocation of functions and tasks to specific maintenance levels, repair versus discard analyses, reliability-centered maintenance (RCM) analysis, and formulating design recommendations to optimize maintenance times and logistic support resource requirements. Data from LSA usually are used as direct input into the development of data products associated with each ILS element, such as provisioning lists, personnel and training requirements, and technical manuals.

Whatever means is proposed by the contractor should be capable of providing data in a format compatible with the computer system used by the Government. The integrated product team has to define the required format. The general breakdown of a logistic support analysis record (LSAR) is as follows:

A. Operation and Maintenance Requirements

B. Item Reliability and Maintainability Characteristics

B1. Failure Modes and Effects Analysis

B2. Criticality and Maintainability Analysis

C. Operation and Maintenance Task Summary

D. Operation and Maintenance Task Analysis

D1. Personnel and Support Requirements

E,E1. Support Equipment and Training Material Description and Justification

E2. Unit Under Test and Justification Description

F. Facility Description and Justification

G. Skill Evaluation and Justification

H,H1. Support Items Identification

J. Transportability Engineering Characteristics.

The purpose of the LSAR is to provide a uniform, organized technical database that consolidates the engineering and logistics data necessary to identify the detailed logistic support requirements of a system. One use of the LSAR database should be to determine how the proposed logistic support system affects system RAM characteristics, including operational readiness.

DA PAM 700-50, *Integrated Logistic Support: Developmental Supportability Test and Evaluation Guide*, (Ref. 22) provides a methodology used to perform the evaluation of supportability issues. A logistics demonstration (LD) is a test or series of tests designed to demonstrate that all logistics and requirements have been satisfied. An LD should be performed to evaluate and validate ground support equipment as well as other supportability requirements. The LD is capable of providing data to evaluate the design of materiel with respect to qualitative maintainability aspects, e.g., accessibility, ease of maintenance, use of modular components, incorporation of test points, human factors, safety, and elimination of unnecessary preventive maintenance checks and services. All tasks should be performed at the operator or crew and organizational levels (unit) maintenance and selected tasks at the direct support and general support levels. The LD investigates personnel skill requirements, adequacy of training programs and materials, and the adequacy of equipment manuals. The LD also investigates the allocation of tasks to the appropriate maintenance levels based on personnel skills, maintenance capability, and maintenance allocation charts (MAC), fault diagnosis procedures, and testability of equipment and software. The results of the LD validate and update LSAR data.

10-11 BATTLE DAMAGE ASSESSMENT AND REPAIR (BDAR)

New tactical air vehicles are normally designed to be ballistically survivable on the modern battlefield by incorporating active and passive signature reduction and ballistic tolerance features. A large percentage of these air vehicles return from combat missions with various levels of combat damage. Maximum air vehicle availability is essential during surge operations; therefore, quick assessment and repair of the damage are necessary. To assess damage and determine reusable parts and components, some additional tools and equipment are required, as well as additional training for aviation unit , direct and general support level maintenance personnel.

The types of threats confronting the US Army rotorcraft in combat include kinetic energy projectiles, explosive projectiles, and air-to-air and surface-to-air missiles with explosive warheads. In addition to the threats the rotorcraft might encounter in flight, they are exposed to damage by bombs and artillery while on the ground. Threat studies and tests have shown that modern rotorcraft are highly survivable against the kinetic energy hits, moderately survivable against one or two small explosive hits, and minimally survivable against a large explosive or single air-to-air or surface-to-air missile hit. Being the most survivable of the threats, kinetic energy hits cause most of the damage that maintenance personnel will encounter. Some of these projectiles are the armor-piercing incendiary (API) type and contain a thermally active nose filler. Upon impact, this filler is activated as the projectile penetrates the exterior of the target. This gives the projectile a fire-starting capability in the presence of flammable materials. Damage mechanisms for the explosive threats include fragments, blast, overpressure, fire, and other secondary damage. A BDAR program should be established to provide an expeditious means of combat damage assessment for deferment or repair. The BDAR program should include special techniques, tools, equipment, and procedures to be used by aviation units under combat conditions. The primary function is to provide quick-fix material and techniques to increase air vehicle availability under an intense combat environment. The program should be composed of required hardware and documentation to provide the capability to inspect, assess, and repair the air vehicle. Support documentation includes inspection procedures, damage assessment criteria, serviceability criteria, expedient repair procedures, cannibalization techniques, and assessment and repair handbooks. Hardware includes damage assessment aids (such as die penetrant kits, micrometers, etc.), repair tools, ground support equipment, and repair material.

The assessment process includes evaluating the extent of damage sustained and determining whether deferment is feasible. Scheduled and unscheduled maintenance and minor battle damage, except for necessary lubrication, servicing, and preoperational checks, may be deferred. Unscheduled maintenance, such as the repair of systems and subsystems that have adequate redundancy or are not critical to mission accomplishment, can be deferred if safety of flight is not significantly degraded. Relaxed inspection criteria for repair and air vehicle performance should also be defined. For example, the number of broken strands in flight control cables, leak rates of hydraulic systems, and oil consumption rates of engines and gearboxes should be redefined.

The BDAR process also includes procedures to perform rapid battle damage repair where necessary within the constraints imposed by time, manpower, material, and operational requirements. The primary purpose of rapid battle damage repair is to restore sufficient strength and serviceability to the air vehicle to permit it to fly additional operational missions or to permit partial mission capability. Demonstrations of typical repairs should be made to determine whether the structural integrity, time constraints, tools, and maintenance personnel meet defined requirements.

The types of structure and the material forms should be considered. Primary structures, such as beams, frames, longerons, and fittings, are essential to airworthiness because airworthiness of the entire airframe depends on the distribution of loads through the individual structural elements. When combat damage reduces the strength, stiffness, or stability of these elements, a decision on repair methods must be made. This critical decision should be based on a judgment of whether redistribution of the load may degrade flight safety or adversely affect flying qualities. Sheet stock and extruded materials that are not preformed are needed for most repairs. Typical materials used in modern air vehicles include aluminum, steel, titanium, magnesium, and composites. These materials may be worked and formed into airframe structures, such as brackets, ribs, bulkheads, extrusions, honeycombs, or sandwiched assemblies.

Consideration should also be given to the use of installed instrumentation and monitoring devices to make reusability decisions in the field after a combat incident or resulting crash. Possible devices include but are not limited to accelerometers; maximum g recorders; debris monitors; engine torque, temperature, and RPM monitors; and heat sensitive paint and paper indicators. Knowledge of these damage or crash parameters helps expedite deferment or repair assessment.

Measures used to quantify BDAR qualification may include time to repair (TTR) at each maintenance level and effectiveness of the repair, which is expressed as the number of life units the repair lasts.

10-12 CORROSION PREVENTION AND CONTROL PROGRAM

Air vehicle system and component reliability might be significantly reduced when introduced to a corrosive environment in any phase of the materiel life cycle. A corrosion prevention and control program should be established for aviation systems and implemented through a contractor-prepared corrosion prevention and control plan, contractor-prepared finish specifications, contractor-prepared, system-peculiar corrosion prevention maintenance procedures, and a Government/contractor corrosion prevention action team (CPAT). The program should be established in accordance with AR 750-59, *Army Corrosion Prevention and Control Program*, (Ref. 23) and MIL-STD-1568, *Materials and Processes for Corrosion Prevention and*

Control in Aerospace Weapons Systems, (Ref. 24) for Air Force applications.

The contractor should prepare a corrosion prevention and control plan, which describes the contractor's approach to corrosion prevention and control measures to be implemented to minimize or eliminate potential corrosion of the air vehicle system being procured. This includes installation of Government-furnished equipment (GFE) and contractor-designed associated ground equipment. The plan should include the establishment of a Government/contractor materials review to optimize material selection for a particular application prior to design configuration and fabrication of any part or component. The plan should also include establishment of a test program to determine qualification and verification of the effectiveness of corrosion protection.

The contractor should prepare a finish specification, which describes the specific corrosion protection finish or techniques to be used on the various substrates of all components and assemblies to protect them against corrosion in the environments to which they will be exposed. Information concerning this specification can be found in MIL-F-7179, *Finishes, Coatings, and Sealants for the Protection of Aerospace Weapons Systems*, (Ref. 25). Surface coating methods include using alloy materials that are chemically resistant to corrosion, covering with an impermeable surface coating so air and water cannot reach the coated surface, and coating with a material that will react with corroding substances more readily than the surface material being coated. Surface coating and corrosion resistance testing for compliance with requirements is usually conducted in conjunction with environmental stress testing and includes exposure to salt spray environments and temperature extreme variations.

The primary consideration in the design and construction of aviation systems is the ability of the design to comply with structural and operational requirements. In addition, aviation components are expected to perform reliably and to require minimum maintenance over a specified lifetime. Therefore, during the selection of suitable materials and appropriate processing methods to satisfy structural requirements, consideration must also be given to those materials, processing methods, and protective treatments that minimize the rate of material deterioration and that reduce service failures due to corrosion of parts and assemblies in service. Deterioration modes that contribute to service failures include but are not limited to pitting corrosion, galvanic corrosion, exfoliation corrosion, stress corrosion, corrosion fatigue, thermal embrittlement, weathering, and fungus growth. Throughout the entire design phase attention should be given to precautionary measurements in order to minimize deterioration of individual parts and assemblies as well as the entire system. Precautionary measures include proper selection of materials, limitations of design operation stresses, relief of residual stress levels, shot peening, heat treatments that reduce corrosion susceptibility, and protective coatings and finishes. Information concerning this topic can be found in ADS-13, *Air Vehicle Materials and Processes*, (Ref. 26).

The design of the system should prevent water leaking into or being driven into any part of the system interior, either on the ground or in flight. The air vehicle should satisfy the watertightness requirements of MIL-W-6729, *Watertightness of Aircraft, Testing, General Specification for*, (Ref. 27). Sealed floors with suitable drainage should be provided for cockpits and cargo compartments. Adequate ventilation should be provided in all areas to prevent moisture retention and buildup. Use of dissimilar metals in contact should be limited to applications in which similar metals cannot be used due to peculiar design requirements. The metals should be protected against galvanic corrosion by interposition of a material that reduces the overall electrochemical potential of the joint or by interposition of an insulating or corrosion-inhibiting material. Information concerning determination of the corrosion prevention requirements can be found in ADS-13 (Ref. 26).

The contractor should ensure that the electronic parts and components in aviation systems are protected from corrosion. Relevant information can be found in MIL-STD-1250, *Corrosion Prevention and Deterioration Control in Electronic Components and Assemblies*, (Ref. 28). Protective measures should be sufficient to maintain performance characteristics within specified limits both during and after exposure to moisture, high and low temperatures, corrosive gases, chemicals, and microbial attack. NAVMAT P 4855-2, *Design Guidelines for Prevention and Control of Avionics Corrosion*, (Ref. 29) describes some of the characteristics of the corrosive environment in which US Navy avionics systems and equipment are maintained and operated. Design methods used to prevent corrosion on electronic equipment include material selection, coatings, and environmental enclosures.

Adequate precautions should be taken during manufacturing operations to maintain the integrity of corrosion prevention measures and to prevent the introduction of corrosion or corrosive elements. Surfaces should be adequately cleaned prior to application of surface treatments and coatings. Information concerning cleaning of surfaces can be found in MIL-S-5002, *Surface Treatments and Inorganic Coatings for Metal Surfaces of Weapons Systems*, (Ref. 30). Damage to any previously applied surface treatment or protective finish should be repaired. All parts and assemblies should be given adequate protection to prevent corrosion and physical damage during temporary or long-term storage and shipment.

The contractor should prepare system-peculiar corrosion control procedures that detail the maintenance procedures to be used by personnel in the unit, direct and general support, and depot repair levels. Maximum use should be made of TM 55-1500-344-23, *Aircraft Weapons Systems Cleaning and Corrosion Control*, (Ref. 31) and TM 55-1500-343-23, *Avionics Cleaning and Corrosion Prevention/Control*, (Ref. 32) The procedures should base corrosion inspections on calendar time rather than on flight hours, identify corrosion-prone areas, and establish corrosion limits that require replacement of parts, components, and assemblies.

A Government/contractor CPAT should be established to ensure that the goals of the corrosion prevention and control program are achieved. Periodic reviews of the facilities in which parts are fabricated, processed, assembled, and readied for shipment should be held. Discrepancies are documented and submitted to the PA for resolution.

10-13 STANDARDIZATION AND INTEROPERABILITY

The Joint Chiefs of Staff of the Department of Defense (DoD) have established five priority areas for standardization and interoperability. Three of these areas are primarily applicable to a particular US Army air vehicle system: cross-servicing of air vehicles; ammunition;

and battlefield surveillance, target designation, and acquisition systems.

10-13.1 STANDARDIZATION

DoD Directive (DoDD) 2010.6, *Standardization and Interoperability of Weapons Systems and Equipment Within the North Atlantic Treaty Organization (NATO),* (Ref. 33) defines standardization as the process by which member nations of NATO achieve the closest practicable cooperation among forces; the most efficient use of research, development, and production resources; and agree to adopt, on the broadest possible basis, the use of common or compatible operational, administrative, logistic, and technical procedures and criteria, tactical doctrine with corresponding organizational capability, and common, compatible, or interchangeable supplies, components, weapons, or equipment.

If required, standardization testing and analyses for cross-servicing of air vehicles; ammunition; and battlefield interoperability, logistics and electronic, are explained in Enclosure 2 of DoDD 2010.6. Although standardization of the three areas of cross-servicing of air vehicle; ammunition; and battlefield surveillance, target designation, and acquisition systems is a desired characteristic, interoperability is typically a required characteristic. Interoperability should be tested and demonstrated to ensure that, with reasonable modification of equipment and/or procedures, POL and ammunition may be exchanged between NATO nations. If required by the PA, other tests and analyses should be conducted to ensure that the forces of one NATO nation can service targets acquired and designated by the forces of another nation and can acquire and designate targets for the other nation, and that each nation can electronically provide and accept battlefield surveillance and surveillance, target designation, and acquisition systems should involve form, fit, and function testing of each system involved in these three areas. If applicable, petroleum, oils, and lubricant (POL) specifications should be compatible, and receptacles for those items should be standardized. Also, if applicable, other items, such as ammunition and battlefield surveillance, target designations, and acquisition systems, should be demonstrated to be interchangeable without modification or loss of effectiveness.

10-13.2 INTEROPERABILITY

DoDD 2010.6 (Ref. 33) defines interoperability as the ability of systems, units, or forces to provide to (or accept from) other systems, units, or forces the services necessary for those elements to operate effectively together. Two types of

intelligence data to or from the forces of other NATO nations.

10-14 SHIP-BASED OPERATION COMPATIBILITY

US Army rotorcraft that are able to launch from, recover to, and operate around US Navy ships provide increased strategic and tactical mobility. The ability to use US Navy ships as intermediate refueling and rest stops allows self-deployment of Army rotorcraft for greater distances and partially eliminates the need for US Air Force transport aircraft. While in an area of operations, operations from Navy ships allow longer time-on-station.

Testing and analysis to demonstrate shipboard compatibility involves surveys of the facilities of the ship, demonstration of ability to operate and maintain rotorcraft on a particular ship, and testing to determine the dynamic interface of rotorcraft with the ship electromagnetic compatibility and vulnerability, water intrusion capability, and corrosion control.

10-14.1 SHIP FACILITIES

NAVAIRENGCEN Report NAEC-ENG-7576, *Shipboard Aviation Facilities Resume*, (Ref. 34) describes the physical characteristics and available logistics support and services available on various classes of US Navy ships. Each group of ships may have one or more subgroups (guided missile frigates (FFG) 456 through 467, for example) according to equipment installed. Landing and vertical replenishment (VERTREP) spot dimensions, clearance, deck structure, safety items, and mooring aids are described. Also included is a matrix of available electrical capabilities, petroleum, oils, and lubricants, pressurized air, freshwater, rotorcraft in-flight refueling capabilities, visual landing and navigation aids, hangars, and other equipment and facilities necessary to support, service, and maintain a rotorcraft or other aircraft logistically. Locations for these available services are depicted in platform and profile views of the landing areas.

Limitations on use of available ship services for each class of ships should be established. If required by the PA, limitations should be evaluated by demonstration to determine the impact of operating US Army air vehicles for extended periods of time using only facilities and supplies normally carried onboard the ship. Necessary support that must be brought onboard by the US Army to support the air vehicle should be identified. Examples are ground handling equipment, POL not common to the US Navy, and rotor blade racks or folding supports.

10-14.2 DYNAMIC INTERFACE

Selected US Navy ships possess air-capable ship certification, which signifys that these ships have been formally inspected and certified to be able to provide proper, adequate, and safe aviation facilities and to meet the applicable requirements of *Air-Capable Ships Aviation Bulletin* Number 1G (Ref. 35). However, without certification for US Army rotorcraft to operate on those ships, NWP 42G, *Shipboard Helicopter Operating Procedures*, (Ref. 36) requires a waiver from the Fleet Commander-in-Chief citing specific levels of operation, classes of services provided, types of rotorcraft, operating procedures, missions, geographic locations, times, etc.

Consequently, formal certification of US Army rotorcraft for operation from air-capable ships should involve testing to establish certain specific parameters of subpar. 10-14.1. Dynamics interface testing, commonly referred to as shipboard compatibility testing, should be conducted to establish compatibility and limitations for shipboard operations. Testing should be conducted to determine operating limitations for wind speed and direction, ship roll and pitch, and support equipment. Rotorcraft control response and path control accuracy during shipboard landings and takeoffs should be determined and used to established operating limits. This testing should establish the ship wake effects on the rotorcraft, which are used to establish launch and recovery limitations and procedures.

Level I operations involve day and night operations in instrument meteorological conditions (IMC), Level II operations involve day and night operations in visual meteorological conditions (VMC), and Level III operations involve day only VMC operations. For each type of Army rotorcraft seeking certification, these limitations should be established and characterized on charts depicting launch and recovery wind limitations (also called approach envelopes). Classes of facilities required to support aviation operations are covered in NWP 42G (Ref. 36).

Other operational procedures that should be demonstrated are limitations for ship roll and pitch during launch and recovery, acceptable relative wind velocity and direction relative to the heading of the ship, and restrictions on operation in the presence of shipborne electronic emitters. If different limitations are imposed due to differing rotorcraft gross weights, these limitations should also be established. These demonstrated values, limitations, and restrictions should be documented on the charts depicting launch and recovery wind limitations. A sample of this chart is shown on Fig. 10-4. Launch and recovery wind limitations charts provide the ship approach envelope and are based on ship wake effects and other limitations determined during dynamic interface testing.

For rotorcraft with rotor brakes, limitations for engagement and disengagement of rotors should be established when these limitations are more stringent than those in the operator's manual for the rotorcraft. For rotorcraft that cannot operate main engines without rotors turning, limitations for engine start and stop should be established when they differ from those in the operator's manual.

If rotor brakes are installed and/or rotor folding is required, the operation of the rotor brake should be demonstrated, and wind-over-the-deck limits for rotor blade folding should be established.

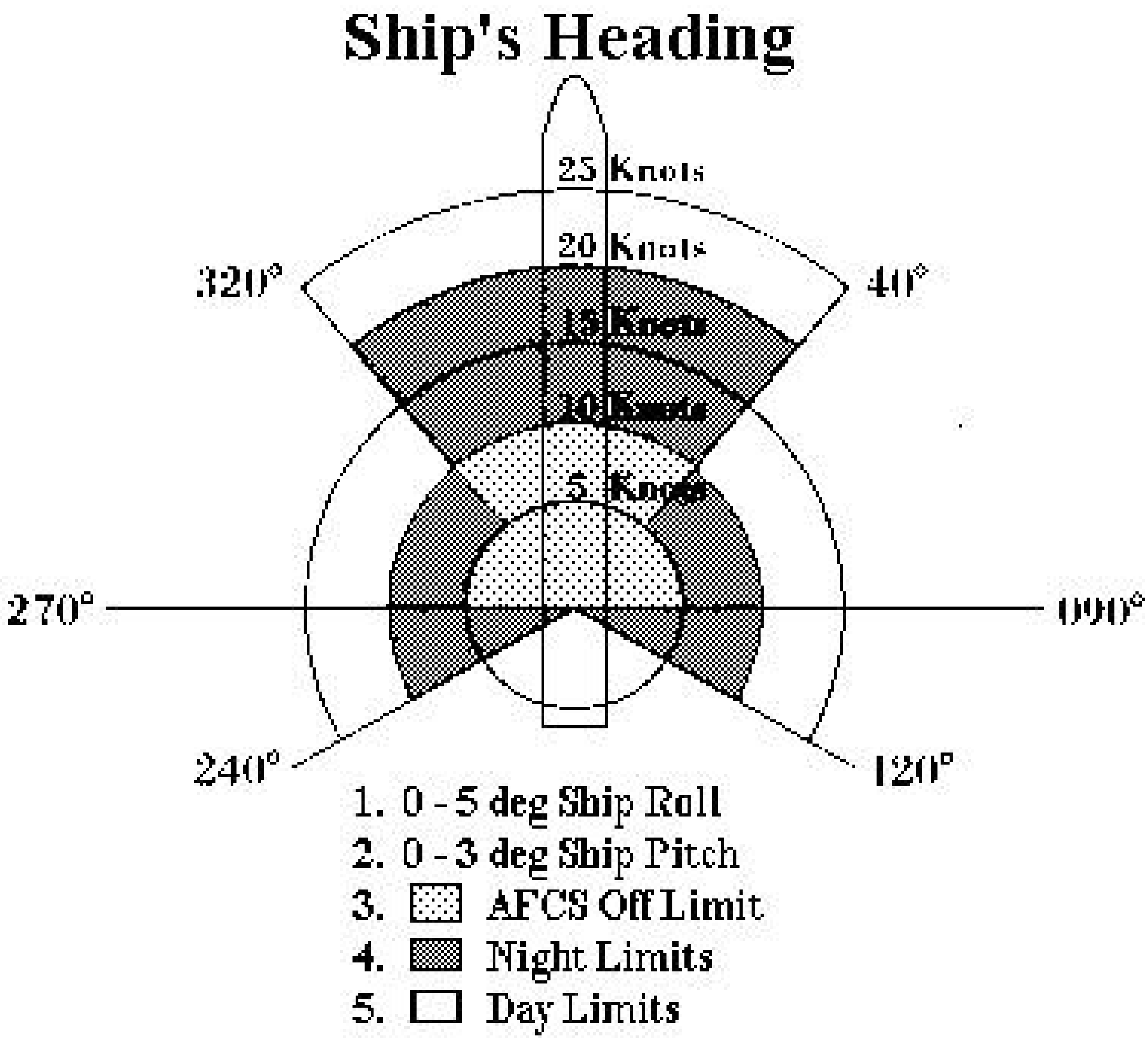
Location of tie-down points on the rotorcraft should be provided as well as the preferred orientation of tie-downs, e.g., 45-deg angles with deck. Rotor engagement/disengagement limitations, blade folding limitations, and tie-down points should be documented in charts separate from the launch and recovery wind limitations charts.

10-15 GROUND SUPPORT EQUIPMENT

Ground support equipment (GSA) includes the equipment that is not part of the air vehicle or system but is required for operation and/or maintenance of the air vehicles. Typical ground support equipment includes but is not limited to ground auxiliary power units (APUs), special tools and test equipment, hydraulic and pneudraulic test stands, boresight equipment, and automatic test equipment (ATE). This equipment also requires preventive and corrective maintenance. Therefore, excessive numbers or quantities of support equipment items increase unit maintenance personnel requirements. The GSE should satisfy MANPRINT and safety requirements. Also health hazards should be identified and eliminated. For additional information and guidance, see MIL-HDBK-470 (Ref. 6). Typical objectives in the GSE area are to

1. Minimize maintenance downtime by designing for rapid and positive identification of parts, test points, and connections.

2. Minimize maintenance downtime by designing for rapid and positive calibration, adjustment, servicing, and testing.



AFCS = Automatic Flight Control System

Degree markings on figure are wind directions relative to aircraft's nose when aligned with ship's lineup line.

Figure 10-4. Launch and Recovery Wind Limitations (Adopted from Ref. 36)

3. Minimize the complexity of maintenance by designing for minimum maintenance tools, accessories, and equipment.

4. Eliminate the need for special tools to perform unit maintenance.

During maintainability demonstrations, support equipment determined to be inadequate should be reported using the PA-approved data collection, analysis, and corrective action system. For additional information and guidance, see MIL-HDBK-471 (Ref. 5).

10-15.1 SPECIAL TOOLS AND TEST EQUIPMENT

Special tools and test equipment are defined as tools or test equipment that are system or equipment peculiar. As mentioned in par. 10-15, the maintainability design goal is elimination of special tools and test equipment at the unit maintenance level. Testing and measurements for special tools and test equipment should be conducted as part of the logistic demonstration as discussed in par. 10-10. Test equipment and tools required for corrective and preventive maintenance at each maintenance level should be recorded. Use of special tools and test equipment at these levels should be documented and reported using the PA-approved data collection, analysis and corrective action system. The PA should establish specific test requirements, passing criteria, and MTTR penalties for use of special tools or test equipment as required.

10-15.2 BORESIGHT EQUIPMENT

Boresighting is defined as alignment of the sighting subsystems of the weapon with the predicted impact points of the munition within acceptable limits. Normally, this boresight process is accomplished using mechanical fixtures, electronic boresight mechanisms, or a combination of the two.

The boresight equipment for an aviation system should be used with appropriate procedures to demonstrate elapsed time and maintenance man-hours required to boresight all weapons systems. Boresight retention should be periodically rechecked to determine whether significant amounts of preventive maintenance downtime are involved. In addition, boresight retention should be rechecked after weapons firing. Results of these demonstrations should be documented using the PA-approved data collection, analysis, and corrective action system.

Calibration intervals for the boresight equipment should be established by the contractor. Demonstration of calibration procedures, calibration intervals, and resistance to damage should be the subject of calibration validation for boresight equipment requiring calibration.

10-15.3 GROUND POWER UNITS

Equipment in this category includes ground APUs and pneudraulic starters. Environmental conditions that require use of ground power units, e.g., temperatures below a specified value, should be established by the contractor. These ground power units should be subjected to functional tests under the environmental conditions expected for the air vehicle. These functional tests should verify that electrical and pneudraulic power outputs are sufficient to support air vehicle operation and maintenance needs in all of the environmental conditions specified.

Additionally, reliability and maintainability tests should be conducted to ensure that operating and support (O&S) costs and operational availability for the ground power units are within acceptable ranges. Excessive manpower or parts requirements or low availability for ground power units can reduce operational readiness

(OR) rates due to increased the total administrative and logistic delay time (TALDT).

Mobility of ground power units should also be evaluated. Strategic mobility for air vehicles requires that all necessary support equipment be equally deployable. Tactical mobility also requires that support equipment be movable by unit equipment. Strategic or tactical mobility limitations should be identified for ground power units.

10-15.4 AUTOMATIC TEST EQUIPMENT (ATE)

Air vehicle systems supported by ATE are considered units under test (UUT). The purpose of ATE testing is to verify ATE performance and diagnostic fault isolation on each UUT to the levels specified. Systems should be designed to minimize the requirement for use of external ATE. If ATE is required, the designer should make maximum use of existing ATE. Qualification of ATE and associated test program sets (TPS) includes software as well as hardware.

10-16 TIE-DOWNS AND MOORINGS

Discussion of shipboard tie-down qualification is provided in par. 10-14. However, additional qualification requirements exist for the air vehicle. Prior to dynamic component qualification test on a ground test vehicle or tied down rotorcraft, strength of tie-down points and moorings should be demonstrated. Qualification of tie-down points for transportability is discussed in par. 10-8.

Other qualification requirements involve tie-down points for internal cargo. Proper operation of all tie-down fittings and devices should be demonstrated. Using representative demonstration cargoes, the demonstration should be performed in accordance with procedures in the operator's manual. Emphasis should be placed on accessibility and ease of operation of tie-down provisions.

Provisions for tying down main and tail rotor blades should be demonstrated. If a main rotor gust lock is provided, it should be demonstrated under environmental conditions specified by the PA. If tail or main landing gear wheel locks are part of the design, these should also be demonstrated under the same environmental conditions.

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ACRONYMS AND ABBREVIATIONS

AC	=	air vehicle contractor
AFCS	=	automatic flight control system
ALDT	=	administrative and logistic delay time
AMC	=	air mobility command
API	=	armor-piercing incendiary
APU	=	auxiliary power unit
AQS	=	airworthiness qualification specification
ATE	=	automatic test equipment
BDAR	=	battle damage assessment and repairs
BIT	=	built-in test
CA	=	criticality analysis
CMT	=	corrective maintenance time
CONUS	=	continental united states
CPAT	=	corrosion prevention action team
CRAF	=	civil reserve air fleet
CS	=	combat support
CSS	=	combat service support
DoD	=	department of defense
DoDD	-	department of defense directive
DS	=	direct support
DT/OT	=	developmental/operational test
ESS	=	environmental stress screening
f	=	failure rate
g	=	acceleration as a result of gravity
FD/SC	=	failure definition/scoring criteria
FMECA	=	failure mode, effects, and criticality analysis
FRACAS	=	failure reporting analysis and corrective action system
GFE	=	ground support equipment
HFE	=	human factors engineering
HQDA	=	headquarters, department of the army
ILS	=	integrated logistic support
IMC	=	instrument meteorological conditions
IOT&E	=	initial operational test and evaluation
LD	=	logistics demonstration
LSA	=	logistics support analysis
LSAR	=	logistic support analysis record
NATO	=	north atlantic treaty organization
MAC	=	maintenance allocation charts
MANPRINT	=	manpower and personnel integration
MARC	=	manpower requirements criteria
MCTF	=	mean cycles to failure
MOP	=	measure of performance
MRBS	=	mean rounds between stoppage

MTBCF	=	mean time between critical failures
MTBF	=	mean time between failure
MTBUMA	=	mean time between scheduled maintenance actions
MTMC	=	military traffic management command
O&S	=	operating and support
OCONUS	=	outside conus
OMS/MP	=	operational mode summary/mission profile
OR	=	operational readiness
OT	=	operating time
OT&E	=	operational test and evaluation
PA	=	procuring activity
POL	=	petroleum, oils, and lubricant
PRAT	=	production reliability acceptance test
PRST	=	probability ratio sequential test
RAM	=	reliability, availability, and maintainability
RCM	=	reliability centered maintenance
RGT	=	reliability growth test
RIW	=	reliability improvement warranty
RPM	=	revolutions per minute
RQT	=	reliability qualification
RSI	=	rationalization, standardization, and interoperability
SME	=	subject matter experts
ST	=	standby time
TALDT	=	total administrative and logistics delay time
TBO	=	time between overhaul
TCM	=	total corrective maintenance downtime
TMDE	=	test measurement and diagnostic equipment
TO&E	=	tables of organization and equipment
TPM	=	total preventive maintenance downtime
TPS	=	test program sets
TT	=	technical test
TTR	=	time to repair
MA	=	unscheduled maintenance action
UUT	=	units under test
VERTREP	=	landing and vertical replenishment
VMC	=	visual meteorological conditions
VV&A	=	validation, verification, and accreditation

CHAPTER 11
GOVERNMENT TESTING

This chapter describes the objectives of Government testing. Also, the typical scope of contractor preparation and delivery of the test articles to Government test sites are described,.

11.0 LIST OF SYMBOLS

cm		centimeters
D	=	actuator displacement, units
F	=	force applied to the controller by
	=	pilot, units
m	=	
n/rev	=	cycles per revolution
N_1	=	compressor speed, rev/min.
N_2	=	power turbine speed, rev/min.
N_g	=	gas producer speed, rev/min.
N_p	=	power turbine speed, rev/min.
P_c	=	probability of classification
$P_{C/D}$	=	probability of class-ification given detection
P_D	=	probability of detection
P_E	=	probability of engage ment
$p_{E/C}$	=	probability of engagement given classification
$p_{H/E}$	=	probability of hit given engagement
s	=	seconds
t	=	time the force is applied
V_{BG}	=	best glide airspeed, K_t
Vcruise	=	velocity for cruise, K_t
Vcruise climb	=	cruise climb airspeed, K_t
Vmax	=	maximum level flight airspeed, K_t
VmaxROC	=	velocity for maximum rate of climb, K_t
VminROC	=	velocity for minimum rate of descent, K_t
V_{NE}	=	never exceed velocity, K_t
g	=	acceleration of gravity
K_t	=	calibrated airspeed
W/m2	=	watts per meter squared
$\iota\rho\theta$	=	phase delay measured in seconds
$\varpi_{\beta\varpi\phi}$	=	bandwidth measured in radians per second

11-1 INTRODUCTION

Government test and evaluation (T&E) programs should be structured to provide essential information to decision-makers, assess attainment of technical performance parameters, and determine whether systems are operationally effective, suitable, and survivable for intended use. See Department of Defense Regulation, DoD 5000.1, *Defense Acquisition* (Ref. 1). Government developmental testing is conducted to assess specification compliance with critical parameters, identify technological risks, and determine readiness to proceed to the initial operational test (IOT). Appropriate Government operational testing (OT) should be conducted to provide data for operational assessments, with the IOT being conducted to determine operational effectiveness and suitability of the system under realistic conditions. Army Regulation (AR) 73-1, *Test and Evaluation Policy* (Ref. 1) specifies in detail the concepts, objectives, policies, and techniques of Government development and operational testing. In addition to defining the need for development and operational testing, the statement of work should address all requirements for test articles, such as test article preparation, test article configuration, instrumentation, data acquisition and reduction requirements, technical support, maintenance and logistical support, schedule of performance, and contractor support. It is envisioned under current acquisition reforms that OT and Developmental (DT) will be integrated when ever feasible.

11-2 TEST AND EVALUATION MASTER PLAN (TEMP)

The TEMP documents the overall structure and objectives of the T&E program. It provides the framework used to generate detailed T&E plans and documents schedule and resource implications associated with the T&E program. The DoDR 5000.2-R, *Mandatory Procedures for Major Acquisition Programs (MDAPs) and Major Automated Information System (MAIS) Acquisition Programs*, (Ref. 4) addresses the scope and format of the TEMP. The TEMP relates program schedules, test management strategy and structure, and the required resources to address:

1. Critical operational issues and criteria (COIC)
2. Critical technical parameters
3. Minimum acceptable operational performance requirements
4. Evaluation criteria
5. Milestone decision points.

Continuous evaluation (CE) is an overall process which provides a continuous flow of all available T&E information. It should be used to ensure responsible, timely, and effective assessments of the status of a system. CE includes planning, testing, and data collection and analysis, and furnishes evaluations, conclusions, and reports to the decision maker and all members of the acquisition team (AT). Life-cycle CE is discussed in detail in AR 73-1 (Ref. 1).

A Test Integration Working Group (TIWG) is chartered by the program sponsor (the term program sponsor applies to the program manager, project manager, product manager, or equivalent manager) to prepare the TEMP. The TIWG and the types of tests and evaluations applicable to US Army air vehicles are discussed in subparagraphs that follow.

11-2.1 TEST INTEGRATION WORKING GROUP (TIWG)

A TIWG is established to ensure that the various tests are integrated properly. The primary purposes of the TIWG are to optimize the use of appropriate T&E expertise, instrumentation, facilities, simulations, and models to achieve test integration, thereby reducing costs. The TIWG:

1. Integrates test requirements, accelerates the TEMP coordination process by producing a TIWG coordinated TEMP, resolves cost and scheduling problems, and determines test data confirmation.

2. Provides a forum through which T&E coordination among all members of the acquisition team is accomplished.

3. Supports CE by accomplishing early, more detailed, and continuing T&E documentation, planning, integration, and sharing of data. The TEMP is coordinated by the principal TIWG members and staffed by the program sponsor for approval at the decision making level. Also, the TIWG interfaces with other groups that could be chartered to support the program sponsor, such as manprint joint working groups (MJWG), and computer resources working group. The MJWG interfaces the domains of manpower, personnel, training, human factors, system safety, health hazards, and soldier survivability discussed further in Chapter 10. Any modifications affecting the T&E must be coordinated and approved as changes. The TIWG members monitor the T&E specified in the TEMP, participate in the TIWG process on a continuing basis by attending periodic TIWG meetings, and assist in development of the TEMP. The principal TIWG members (and their main responsibilities in addition to assistance with preparation of the TEMP) consist of:

1. Program Sponsor. TIWG Chairman and responsible for TEMP development to include establishing the schedule for development of the TEMP.

2. Combat Developer. Responsible for formulating doctrine, concepts, requirements, and organizations.

3. Developmental Tester. Responsible for the technical detailed test plan and execution of technical testing.

4. Independent Developmental Evaluator. Responsible for technical test integration as a member of the TIWG and development of the independent evaluation plan.

5. Operational Tester. Responsible for the operational detailed test plan and execution of operational testing.

6. Independent Operational Evaluator. Responsible for operational test integration as a member of the TIWG and development of the test and evaluation plan.

7. Logistician. Responsible for independent evaluation of system reliability, availability, and maintainability (RAM).

8. Trainer. Responsible for the training of test and unit personnel.

9. Threat Systems Officer. Responsible for providing the operational threat environment.

10. Survivability/Lethality Analysis Directorate (SLAD) of the US Army Research Laboratory (ARL).

11. Federal Aviation Administration (FAA) Representative if FAA certification will be required.

11-2.2 TECHNOLOGY FLIGHT EVALUATIONS (TFE)

The TFE is a flight evaluation and research effort conducted by the test agency on foreign (non-exploitation testing) and domestic air vehicle to include systems and subsystems. The objective of the TFE is to determine the state of the technology of the air vehicle, systems, and subsystems. A typical TFE test article could be a foreign attack rotorcraft, and the scope of typical TFE testing could include performance, handling qualities, armament, air vehicle survivability equipment (ASE), and mission equipment package (MEP) testing. Test results generated by the TFE are applicable to determining how Army technology compares to foreign technology and evaluation of potential improvements.

11-2.3 FLIGHT SIMULATION EVALUATIONS (FSE)

The FSE is a simulator evaluation conducted by the test agency on motion-based simulators that simulate representative air vehicle stability and control characteristics. The objective of the FSE is to determine if the characteristics of the simulator are representative of the actual flight characteristics of the air vehicle. The scope of FSE testing should include handling qualities and performance tests to determine how well the simulation replicates the air vehicle and the impact of any fidelity limitations. These evaluations may also be conducted on simulators which represent generic air vehicle stability and control characteristics, or are used to evaluate new concepts. A typical simulator is the UH-60 Synthetic Flight Training System (Device 2B38), designed and built by the Link Company, [*] Flight Simulation Division, Binghamton, NY. The simulator is a six degree-of-freedom (DOF) motion and visual system which simulates a natural rotorcraft environment. An FSE was conducted on the simulator by experimental test pilots and included performance and handling qualities' tests. Test results are typically used to upgrade software to allow greater fidelity of rotorcraft and simulator.

[*]The naming of this company in no way implies an endorsement by the US Government.

11-2.4 CONTRACTOR DEVELOPMENT, SPECIFICATION COMPLIANCE, AND QUALIFICATION TESTS

Typically, the contractor accomplishes most development, specification compliance and qualification testing, using the contractor's facilities. Some testing may have to be accomplished at military unique facilities. The PA normally requires submittal and approval of the contractor's test plans and reports as specified in the contract. The development portion of the tests is used to prove out the individual parts, components, subsystems, and total air vehicle system, including separately developed allied equipment and mission equipment package (MEP). Qualification tests are performed to prove that the item under test (component, subsystem, etc.) will perform to specifications for its specified life.

For onboard allied equipment being separately developed, and for which working samples are unavailable, a correctly positioned and secured load of proper weight and volume representative of this equipment should be abroad the air vehicle. Also for air vehicles; the objectives of the contractor's testing should include demonstration of the flight envelope; acceptable limitations, restrictions, and emergency procedures. A contractor flight release is usually required, see Appendix C. Governmental witnessing or monitoring of the tests is conducted at the discretion of the Government. Contractor testing and the purpose of the resulting data should be identified in the TEMP, and included as part of the integrated test program. The TEMP should identify tests that will be conducted by the contractor and witnessed by the Government such that the data can be used to satisfy the Government test requirements.

11-2.5 ARMY EXPERIMENTAL FLIGHT TESTS

Experimental flight testing is that flight testing that has not been previously performed on an air vehicle by the contractor or responsible Government agency. Experimental flight testing includes testing systems, subsystems, components, allied equipment, and MEP. The US Army Aviation and Troop Command ATCOM) should determine the requirements for experimental flight testing on air vehicles that are to be flown by Army experimental test pilots. Army experimental flight testing should be conducted when it is not feasible for a contractor to conduct the test. This may occur when no contract exists and the Government is developing in-house hardware or software requiring flight testing, when a vendor developing a subsystem has no flight test capability, or when the test air vehicle is with an operational unit. Prior to conducting an experimental flight test, the ATCOM agency responsible for issuance of an airworthiness release (AWR) should prepare and approve a flight release for the air vehicle being tested. The AWR should state that the flight testing to be conducted is experimental and approved by ATCOM. Experimental flight testing should be preceded by engineering analyses, ground tests, and simulations, as required. Analyses should be comparable in technical scope to that which would be performed by industry prior to release of the air vehicle for flight testing. Normally, experimental flights should be limited to 80% of the design envelope load factor or to the maneuver conditions for which required control inputs and air vehicle responses can be accurately predicted.

11-2.6 PRELIMINARY AIRWORTHINESS EVALUATION (PAE)

The TEMP should document the requirements for a PAE of an air vehicle system. The PAE could be accomplished during the demonstration and evaluation phase of test or accomplished early in the Engineering and Manufacturing Development Phase. The TEMP should identify critical operational issues and critical technical parameters and should outline the approach that will be used to capture required data. PAE is usually conducted at the contractor's facility on a prototype air vehicle during development, or of a developed air vehicle undergoing major modifications. The overall purpose of the PAE is to conduct early evaluations on the air vehicle system to determine the status of development, specification compliance, and early identification and correction of deficiencies. The PAE can be used to identify design problems, ascertain that solutions are in hand, to support decisions, and provide recommendations as to readiness of the system. A detailed description of the PAE is contained in paragraph 11-3.

11-2.7 ENDURANCE TEST

Endurance tests are conducted at the contractor's facility and/or Government test sites on a prototype or production air vehicle. The test normally is conducted on an accelerated basis encompassing a minimum number of flight hours specified by the procuring activity. The purpose of the test is to determine the endurance and reliability of the basic design and to determine the adequacy of design changes to correct deficiencies revealed during other tests. If the contractor conducts the tests, monitoring or participation by the Government may be required. The endurance test may also be conducted by the Government as lead-the-fleet (LTF) testing on a limited number of air vehicles after fielding of the system. During LTF testing, the LTF air vehicle should be flown using typical mission profiles under an accelerated flying hour program to build up airframe time faster than typical fleet usage. This allows early identification and correction of deficiencies. Sample data collection (SDC) techniques typically used by Army or contractor personnel for RAM requirements are covered in Chapter 10.

11-2.8 AIRWORTHINESS AND FLIGHT CHARACTERISTICS (A&FC) TEST

The TEMP should document the requirements for an A&FC test of an air vehicle system. The PAE typically is accomplished during the Engineering and Manufacturing Development Phase. The role of this test is for Army test pilots to make a final evaluation and document the handling qualities and performance of the air vehicle. The A&FC may be conducted on prototype, preproduction, or production air vehicle, usually at Government facilities. The purposes of the A&FC test are similar to engineering tests. The objectives of the A&FC tests are to obtain the final determination of:

1. Specification compliance in appropriate areas
2. Detailed information on performance, handling qualities, structures, and integrated systems characteristics
3. Feasibility of operational techniques for inclusion in technical manuals and other publications. A more detailed description of the A&FC is contained in paragraph 11-4.

11-2.9 CLIMATIC TESTS

Controlled climatic tests are conducted on development prototype or production air vehicle by the Government or the contractor (under Government supervision) at a Government facility such as the US Air Force (USAF) Climatic Laboratory located at Eglin Air Force Base (AFB), FL. The climatic tests are conducted at extreme environmentally controlled conditions (primarily temperature and humidity), often beyond the normal operating limits. The role of climatic qualification tests is to demonstrate to the Army the adequacy of the total air vehicle system, subsystems, and components to function satisfactorily throughout the full range of the specified operational environment. The climatic test might also establish the limits of safe operation at extreme temperatures. The climatic test is a prerequisite for follow-on developmental testing at the US Army Test and Evaluation Command (TECOM) test centers to include Yuma Proving Ground (desert natural environment), Cold Region Test Center (cold natural environment), and the Tropic Test Center (tropic natural environment).

11-2.10 SURVIVABILITY TESTS

Survivability testing is conducted to determine the capability of a system to avoid or withstand man-made hostile environments without suffering an abortive impairment of its ability to accomplish its designated mission. In general, these threats include ballistics; electronic warfare, nuclear weapons effects; nuclear, biological, and chemical (NBC) contamination; directed energy as well as advanced threats, such as high-power microwave or radio frequency (RF) weapons. Specific weapons should be identified in the SOW. Although the exact procedures and tests to assess the survivability of any system may vary, the general approach is similar. It should address the relationship among avoidance, evasion, and vulnerability capabilities of the system, DA PAM 73-series (Ref. 2). Survivability testing is addressed in the TEMP with the major emphasis on live-fire testing. A more detailed description of survivability tests is contained in paragraph 11-6.

11-2.11 OPERATIONAL TESTS (OT)

OT is a generic term encompassing operational test and experimentation in realistic, operational environments with users who represent those expected to operate and maintain the system when it is fielded or deployed. All OTs that are conducted and the developmental tests that are used as data sources for operational evaluation or assessment should be identified in the TEMP. A more detailed description of OT is contained in paragraph 11-9.

11-2.12 FOLLOW-ON EVALUATIONS (FOE)

The FOE is conducted during follow-on tests (FOT). The FOT is the OT that may be necessary during or after the production phase to refine the estimates made during the IOT, provide data to evaluate changes, verify that deficiencies in materiel, training, or concepts have been corrected, and provide data to ensure that the system continues to meet operational needs and that it retains its effectiveness in a new environment or against a new threat. The TEMP should include planning for FOE.

11-2.13 SOFTWARE TEST AND EVALUATION

Software test and evaluation should be managed and engineered using best processes and practices that are known to reduce cost, schedule, and technical risks

Except when developed by itself, Government participation in software T&E is primarily one of management oversight and procedural test witnessing. The Government's role is to validate that the software being tested meets the established software performance requirements and contributes to airworthiness of the air vehicle. The Government also has a responsibility to provide an independent verification and validation (IV&V) capability for an unbiased assessment of the software and its qualification testing. Planning for software test activities should be documented in the Test and Evaluation Master Plan (TEMP). See paragraph 11-11 of this document.

11-3 PRELIMINARY AIRWORTHINESS EVALUATION (PAE)

The purposes of the PAE are to:

1. Provide quantitative and qualitative engineering flight test data
2. Serve as a basis for an estimate of the degree to which the air vehicle is suitable for its intended mission
3. Assist in determining the flight envelope to be used by Army pilots for future tests and flight operations
4. Detect and allow for early correction of deficiencies
5. Provide a basis for evaluation of changes incorporated to correct deficiencies
6. Provide preliminary air vehicle performance data for operational use.

The evaluations may be conducted in various phases until the procuring activity (PA) determines that the air vehicle is acceptable for starting operational tests. The scope of the PAE depends on the type of system being evaluated, the period of time allocated for the test, and the stage of development of the system. Handling characteristics are usually evaluated;

however, it is not absolutely essential to the PAE . Also, the PAE typically does not result in quantitative performance data unless it is considered a very significant part of the evaluation and approved by the PA. The specifics of the conduct of the PAE are discussed in the following paragraphs.

11-3.1 PAE PREREQUISITE

Prior to the conduct of a PAE by the Army, the contractor should demonstrate to the PA through flight ground, fatigue, and vibration tests and analytical data that, within the allowable flight envelope, the air vehicle is aerodynamically, structurally, and functionally safe for an evaluation by Army test pilots. The contractor should configure the air vehicle as specified by the PA. The contractor should furnish such services, materials, and logistical support necessary to keep the air vehicle in satisfactory operation during the evaluation. Instructions should be provided on the operation of the equipment, operating techniques, handling qualities, emergency procedures, and other information necessary to ensure safe operation. For new air vehicle, sufficient flight instruction should be provided to satisfy test pilot training requirements to prepare them for the PAE.

Prior to start of the PAE, an AWR must be issued by ATCOM to establish the flight envelope and other operating instructions for the test. The flight release should be based upon the determination of contractor compliance with demonstration requirements and any appropriate information derived by the Army during the contractor's program. The test activity should prepare a detailed test plan based on the PAE test objectives and specific objectives defined in the test request prepared by ATCOM and submitted to the test activity.

Prior to the start of the PAE, a pre-test review should be held with representatives from the PA, the test activity, the contractor, and any other organizations concerned with the program. The purposes of the review are to:

1. Review the extent to which reevaluation requirements have been completed.
2. Review the contractor's recommended flight envelope (this may be a subset of the approved envelope in the flight release).
3. Verify the air vehicle configuration.
4. Finalize contract support requirements, coordinate data reduction requirements, define office space requirements, and define other services and supplies to be provided by the contractor.

A complete inspection of the air vehicle should be performed prior to the PAE by qualified maintenance and instrumentation technicians for the test activity. Representatives of the responsible Defense Plant Representative Office (DPRO) charged with plant cognizance at the contractor's facility should participate. The purpose of the inspection is to locate and correct any safety-of-flight discrepancies in the test air vehicle.

11-3.2 FUNCTIONAL TESTS

The objectives of the functional tests are to obtain an early qualitative evaluation of the air vehicle subsystems and equipment for the purpose of determining specification compliance and suitability for military applications. The scope should include, but not be limited to, functional tests of all subsystems and operating equipment in the test air vehicle (engine, flight controls, hydraulic, pneumatics, electrical, avionics, MEP, allied equipment, and any other subsystem required by the PA) should be conducted to determine conformance with the applicable specifications. Each subsystem should be operated in its various modes to verify adequacy of operation and compliance with specifications. Also, night lighting, vibrations, water integrity of airframe, and crew ingress and egress should be evaluated. Typically, enhancing characteristics, shortcomings, deficiencies, and specification compliance issues are identified. Nonconformance and deviation requests should be approved by the PA.

11-3.3 HANDLING QUALITIES

Handling qualities' characteristics of the air vehicle should be determined by flight test conducted in accordance with the provisions of the flight test plan approved by the PA. These tests should be conducted to establish and verify flying stability characteristics. The PA should determine all gross weight, CG, altitude, and rotor and propeller (if any) speeds used in the testing. Although there may or may not be a significant difference in handling properties (depending on hinge offset, etc.) for fully articulated, rigid, and hingeless rotor systems, handling properties testing would not be significantly different. Caution: There could be major differences in aeroelastic properties.

Common testing for rotorcraft and other aircraft involves determination of overall air vehicle static longitudinal, lateral, and directional stability and dynamic stability. Government testing for static longitudinal, lateral, and directional stability and dynamic stability are covered in subpars. 11-4.4 through 11-4.8.

MIL-STD-8785, *Flying Qualities of Piloted Airplanes*(Ref. 9) and Aeronautical Design Standard (ADS) 33, *Handling Qualities Requirements for Military Rotorcraft* (Ref. 10), each include the following common categories:

1. Operational missions
2. Loadings
3. Moments and products of inertia
4. External stores
5. Configurations
6. State of the air vehicle
7. Definitions of service and operational flight envelope (SFE and OFE, respectively).

However, methods used for the two types of air vehicles may differ greatly if an aircraft is qualified using 14CFR Part 23, *Airworthiness Standards: Normal Utility Acrobatic and Commuter Category Airplanes* (Ref. 6); 14CFR Part 29, *Airworthiness Standards: Transport Category Aircraft*(Ref. 7); or 14CFR Part 27, *Airworthiness Standards: Normal Category Rotorcraft*(Ref. 8) as a guide

For aircraft, the PA should identify stability testing conditions to be used in the testing. If 14CFR Part 23 or Part 29 are cited as the source for qualification requirements, the flight test plan should follow the stability of flight guidance in that publication. These conditions include specific airspeeds, flap positions, landing gear status, and power settings for static longitudinal stability testing.

ADS 33D-PRF (Ref. 10) establishes performance requirements for flying and ground handling qualities testing for Army rotorcraft. Use of that publication is meant to ensure that there are no limitations on flight safety or on mission capability due to deficiencies in flying qualities. The Government handling qualities testing should demonstrate or verify flying qualities for rotorcraft in accordance with ADS 33D-PRF (Ref. 10) unless specific deviations are applied.

11-3.4 NOVEL CONTROL SYSTEM EVALUATION

Conventional rotorcraft and other aircraft controls consist of one control for pitch and roll control, one control for collective pitch (or thrust) control, and one set of pedals for directional control per pilot station. These controls have traditionally had a direct mechanical linkage to flight control actuators through control tubes, pulleys, bellcranks, and mixing assemblies. However, with the advent of fly-by-wire and fly-by-light (fiber optic) flight controls, there are no direct mechanical linkages by design, and measurement of control displacements or forces may not be an accurate method of evaluating pilot control inputs. Further complicating this arrangement is the introduction of force-feel controls. With these controls in trimmed flight, a force-feel control can be displaced and released to return to neutral, with the new actuator position being a new control displacement. Generally, the displacement of the actuator will be some function of the force applied and the duration of the application.

An example of a fly-by-light and force-feel control system is the Advanced Digital Optical Control Systems (ADOCS) rotorcraft. For example, in trimmed flight, the longitudinal control could be held forward for one second, driving the actuator to a new position, released and allowed to return to neutral (no force applied), and the airspeed changed to a new value with the same longitudinal stick position. In this way, all graphical plots shown later in this chapter would have the same longitudinal stick position. However, if actuator position is recorded, those positions plotted along the vertical axes would more accurately reflect static and dynamic stability characteristics.

When evaluating novel control systems, elimination of human error in this flight testing may also become a problem. If several controls are integrated into one control stick, pilot attempts to provide input in only one axis must be closely monitored to ensure that no coupled inputs (cross controlling) are inadvertently introduced into flight testing. An example might be a sidearm controller which incorporates longitudinal, lateral, and yaw control for rotorcraft into one stick. In attempting to check inputs in the longitudinal axis, the pilot's arm and wrist may inadvertently induce lateral inputs and a yawing moment to the air vehicle.

Data collection requirements should be very similar to mechanical linkage control systems with the exception of control positions. Actuator positions or some other alternate means of measuring the commanded inputs to the control surfaces, rotors, and propellers should be determined by the test activity based on the testing requirements. In some cases, the effect of a given force application for a given duration may have to be verified. The effect of doubling a force applied to a controller for the same duration may be more than a doubling of the actuator displacement. The system could be designed to substantially increase the rate of actuator displacement for a force greater than a given threshold. In this case, flight test data should include stick force and actuator position verses time.

Instrumentation should also be similar to that required for conventional control systems, with the exceptions of requirements to measure actuator displacements and control forces.

11-3.5 TRANSITION FLIGHT

The contractor conducts the initial transitional flight tests. The Government test activity conducts tests and demonstration necessary to validate flying qualities during the transition operation. The transition flight regime is where a propulsive force in the horizontal direction is added to the vertical lift force. For a rotorcraft, this results in a change in fuselage (tail) rotor wake interaction that could have significant controllability effects. For multimode and tilt-rotor air vehicles, transfer of force responsibility is dependent on velocity, angle of attack, thrust vector angle, etc., which therefore defines a characteristic transition corridor. Examples of multimedia aircraft include compound rotorcraft that have both main rotor systems and propellers to provide thrust and main rotor systems and wings to provide lift. Typically, flight test instrumentation is needed to measure pertinent parameters, such as rotor speed, transient rotor droop, collective pitch, pedal position, torque's, pitot and static pressures, vertical acceleration, angle of pitch, roll, and yaw, etc.

The PA should define transition flying qualities to be demonstrated. As a minimum, the testing activity's plan should identify airspeeds, altitudes, propeller/proprotor speeds, thrust vector and wing inclination normal envelopes and angles of attack, emergency envelopes for one-engine inoperative (OEI) operations, and gross weights to be tested. Characteristics to be demonstrated are the same as the qualities demonstrated in par. 9-5. The tests and demonstrations should be documented in accordance with par. 9-6. Future revisions of ADS-33 (Ref. 10) may contain specific handling qualities requirements for this transition mode of flight. Flying qualities of US military piloted vertical and short takeoff and landing (V/STOL) air vehicles are found in MIL-F-83300, *Flying Qualities of Piloted V/STOL Aircraft* (Ref. 11).

11-3.6 PERFORMANCE

The PAE should include testing to determine the air vehicle flight performance capability dependent on requirements for preliminary operational use and initial estimates of specification compliance. The evaluation should be conducted for a limited range of conditions as determined by the PA for the following flight regimes:

1. Hover (rotorcraft)
2. Takeoff
3. Accelerate-stop (aircraft)
4. Landing performance
5. Climb performance
6. Level flight
7. Stall performance (aircraft).

The AMCP 706-204, *Helicopter Performance Testing* (Ref. 12) should be used as a guide for rotorcraft flight performance testing. There is little difference in flight performance testing for a bearingless rotor system; however, there are a number of differences for V/STOL type air vehicles. For instance, there can be different nacelle angles for the same airspeed. MIL-F-83300 (Ref. 11) is useful in developing performance requirements. 14CFR Parts 23 and 29 (Refs. 6 and 7) should be used for other aircraft.

11-3.7 SUBSEQUENT PAE

Subsequent PAEs normally should be considered as necessary to accomplish:

1. Evaluation of mission-essential equipment not previously tested such as weapons, avionics, radars, forward looking infrared (FLIR) sensors, night vision systems, MEP, and ASE
2. Revaluation of characteristics which were not satisfactorily investigated or fully evaluated during earlier PAEs
3. Reevaluation of characteristics affected by changes or modifications installed since the completion of earlier PAEs.

11-3.8 PAE REPORTS

The test reporting requirements should be specified in the test request submitted to the test activity by the PA. The reports are used to provide test data and information for technical manuals and decision making. Distribution and special instructions for test reports are contained in the test request submitted to the test activity. Distribution of test results are generally limited to TECOM, ATCOM, and the PA. Additional distribution may be made with the approval of the PA. The following test reporting procedures apply:

1. Formal Test Reports. Formal test reports are typically required for test programs that either:

a. Have high management visibility

b. Meet test requirements delineated in a TEMP

c. Have test results which are used to assist in making a program decision.

Test results provide engineering flight test data for incorporation into the fielding documentation for the affected aircraft. Advance copies of the formal report are usually submitted to the PA within 75 days after test completion. The report should be reviewed and comments returned to the test activity in 40 days. The test activity incorporates appropriate comments, prints the report, and distributes the report within 68 days. The total processing time for the formal report is usually 183 days.

2. Abbreviated test reports. Abbreviated test reports are used instead of formal reports for those test programs not meeting the criteria of a formal test report. The time to process the abbreviated test report in the same manner as the formal report is 85 days.

3. Memorandum of Effort Reports (MER). The MER stating the test activity effort should be provided for all test requests that do not require a formal or an abbreviated report. The MER is submitted and distributed per the test request within 30 days.

11-4 AIRWORTHINESS AND FLIGHT CHARACTERISTICS (A&FC) TEST

The A&FC tests are conducted at Government facilities with prototype air vehicle, and later with production air vehicle. The objectives of the A&FC tests are to obtain final determination of:

1. Contract compliance in appropriate areas such as performance guarantees

2. Detailed information on performance, handling qualities, structures, and integrated system characteristics

3. Feasibility of operational techniques for inclusion in technical manuals and other publications.

The PA should issue a test request to the test activity at the earliest possible date. The test request should establish the specific test requirements. The specifics of the conduct of the A&FC test are discussed in the following paragraphs.

11-4.1 OBJECTIVE

The final A&FC tests are conducted as directed by the PA to obtain the final determination of:

1. Compliance with contract as appropriate

2. Compliance with military specifications

3. Detailed information on flight performance handling qualities, power plant operation, and integrated systems characteristics

4. Feasibility and development of operational techniques for technical manuals and other publications

5. Adequacy of the air vehicle systems and subsystems, including separately developed allied equipment under extreme temperature conditions

6. Adequacy of the contractor recommended flight envelope for other

ensuing Government development tests and for operational use.

11-4.2 FLIGHT PERFORMANCE

Testing should be conducted with AMCP 706-204 (Ref. 12) as a guide (rotorcraft fight) to determine the rotorcraft performance characteristics throughout the flight envelope. Specific tests should be included to ensure positive determination of compliance with all stated contract performance requirements. Such requirements may vary, depending on the model, design, and series (MDS) of the air vehicle, but the scope might include items such as maximum speed, cruise speed, range, hover ceiling (rotorcraft), service ceiling, and rate of climb. Tests should be conducted at various altitudes and for the full range of gross weights and mission configurations.

Flight performance characteristics should be determined quantitatively to provide a basis for the preparation of Chapter 7, Performance Data, of the appropriate Operator's Manual. Until it is replaced by an acceptable standard; MIL-M-63029, *Manuals, Technical: Requirements for Operator's Manuals and Checklists for Aircraft* (Ref. 13) should be used as guidance for data collection and preparation of flight performance charts; however, a waiver will be needed. The specific flight performance characteristics to be measured include:

1. Crosswind takeoff and landing limitations (aircraft)
2. Engine installation losses
3. Hover power required in and out of ground effect (rotorcraft)
4. Takeoff distance and obstacle clearance
5. Accelerate-stop distances (aircraft)
6. Minimum single engine control (aircraft)
7. Level flight power requirements
8. Climb
9. Landing stop distances (aircraft)
10. Airspeed calibration
11. Low speed critical azimuth (rotorcraft).

The performance instrumentation requirements are dependent on the type of air vehicle and performance measurements to be tested, and are based on the tests to be conducted. A test instrumentation boom system is normally installed on the test air vehicle to obtain angle of attack and sideslip as well as dynamic and static pressure pickups at a location that minimizes position errors for airspeed measurement. Additionally, a flight control rigging check is required prior to performance testing to determine correlation control positions. Engine calibration for the range of power turbine speeds N_p to be used is typically required.

Typical major instrumentation includes pitch, roll, and yaw attitudes; ship and boom airspeeds; outside air temperature; altitude; engine torque; compressor turbine speeds (N_l or N_g); power turbine speeds (N_2 or N_p); turbine gas temperature; vertical speed; elevator, pedal, rudder, aileron, and collective control positions; rotor torque; propeller speed; outside air temperature; fuel temperature; fuel; stall warning; and gear and flap positions. Other data also recorded would include run-stop locator, event, run number, flight number, weight on wheels, and instrumentation controls and indicators. When takeoff and landing tests are conducted, theodolites can be used to determine distances and heights above ground. Video or movie cameras may be required to record cockpit data.

11-4.3 VIBRATION SURVEYS

Rotorcraft vibration testing is conducted to determine its vibration characteristics. Specific tests are included to determine specification compliance. Tests are conducted at various altitudes and gross weights to include the maximum and minimum obtainable. Government vibration testing on aircraft (other than rotorcraft) is not normally conducted.

Rotorcraft vibration testing is conducted primarily to determine the magnitude of rotor induced vibration to evaluate the effect on pilot and passenger comfort, engine/airframe compatibility, structural integrity, etc. The source of low-frequency vibrations in the rotorcraft is the rotor. The forces transmitted to the rotor hub(s) are primarily at frequencies of once per revolution (1/Rev) and which are integral multiples of the number of rotor blades at the rotor hub. Consequently, a three-bladed rotor would transmit vibrations to the controls and fuselage at multiples of three cycles per rotor revolution (3/Rev, 6/Rev, and 9/Rev). Limits for the vibrations at the controls, the pilot's station, passenger stations, weapon platform interface, etc., are delineated in the specification requirements, and are usually expressed as vibration levels or intrusion indices. Measurement of these levels and intrusion indices are covered in ADS 27, *Requirements for Rotorcraft Vibration Specifications. Modeling, and Testing* (Ref. 14).

Contractor vibration testing is addressed in par. 9-7. To verify the results of this vibration testing, ADS-27 (Ref. 8) defines four flight regions to be tested for rotorcraft and tilt rotor air vehicle vibration specification compliance. If required by the PA, the testing activity must verify vibration levels and intrusion indices in these four regions.

Region I consists of all steady flight conditions with load factors between 0.75 and 1.25 g and airspeeds from hover to VCruise and to the maximum rearward and sideward flight speeds while operating within the defined power-on rotor speed limits. Region II applies to all flight conditions outside Region I with duration greater than three seconds, and Region III applies to Region II flight conditions with duration less than three seconds. Region IV applies only to tilt rotor air vehicle. However, for tilt rotor air vehicles operating in a rotorcraft mode or in transition between rotorcraft and other aircraft, Regions I, II, and III requirements may apply, as appropriate.

Crew and personnel station vibration criteria for frequencies up to 60 Hz are identified in ADS-27 (Ref. 14), as are criteria for controls, instrument panels and displays, and weapons sighting devices. Additionally, ADS-27 (Ref. 14) identifies the requirement for new air vehicles or air vehicles undergoing major modification to incorporate onboard rotor vibration diagnostics systems. Demonstration and qualification of this onboard system should be accomplished as part of the flight vibration surveys.

The parameters which must be recorded for vibration tests include oscillatory accelerations, amplitude and frequency, pressure altitude, airspeed, free air temperature, rotor speed gross weight, and mass moments of inertia.

The magnitude of the vibrations is determined primarily by rotor speed and balance, airspeed, load factor, mass distribution, center of gravity (CG), and gross weight. The mass distribution is determined by the configuration, fuel weight and location, and cargo or ballast weight and location. The effects of changing the preceding should be investigated during flight tests. Vibration levels usually increase as airspeed and load factor are increased. The revolutions per minute of the rotor (RPM) affects both the magnitude and frequency of the vibrations. Changing the mass distribution while keeping the gross weight constant can cause significant changes in the vibration levels. Vibration data usually are recorded during stabilized flight conditions throughout the flight envelope. Typically, data would be recorded in level flight at approximately ten (10) knot increments from approximately 40 knots (lowest airspeed at which reliable airspeed can be recorded) to maximum level flight airspeed (VMax), in dives to velocity-never exceed (V_{NE}), in maximum power climbs from maximum rate-of-climb VmaxRoc or cruise climb airspeed VCruise Climb and in minimum power descents from minimum rate of descent VminROD to best glide airspeeds V_{BG} Vibration levels are usually less significant in hover. However, vibration in transition from hover or to a hover often is notable.

Accelerometers are usually used to record vibration data. The accelerometers, should have the appropriate dynamic range and frequency response required to determine by the event(s) being measured. The accelerometers should be appropriately mounted and oriented, so that the measured event(s) are appropriately captured (i.e., vertical vibration measured vertically, etc.). Data can be recorded using constant band width frequency modulation (FM) or high sample rate pulse code modulation (PCM) recorders.

Data should be recorded and reduced as specified by the PA. Generally, fast Fourier transfer techniques are sufficient. The data are usually presented as amplitude versus frequency and peak rotor harmonic amplitude versus airspeed. Amplitude is generally presented in "g", frequency in Hertz, and airspeed in knots, calibrated as shown in Figure 11-1.

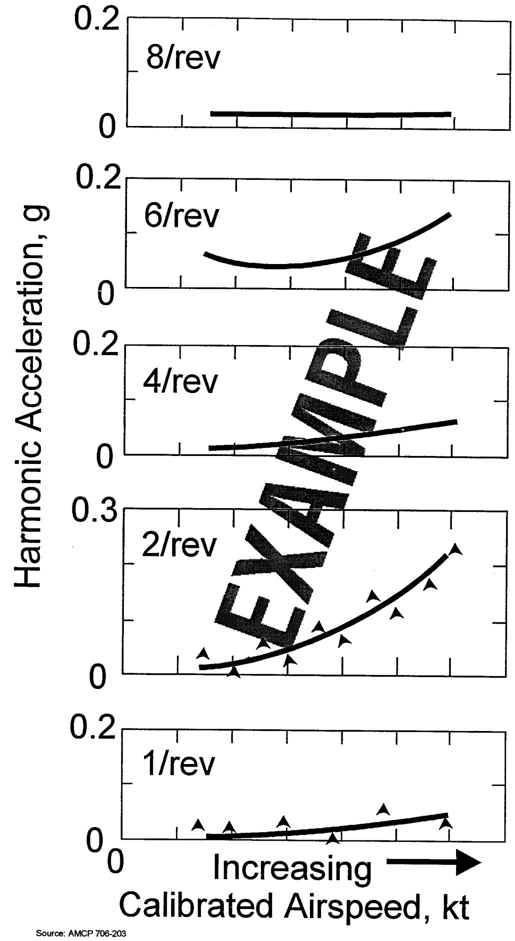


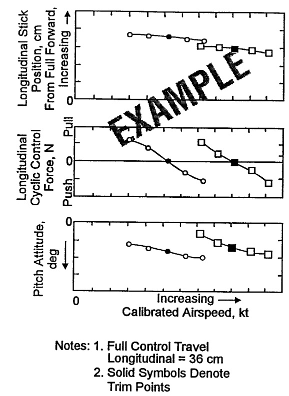
Figure 11-1 Measured Vibration

11-4.4 STATIC LONGITUDINAL STABILITY

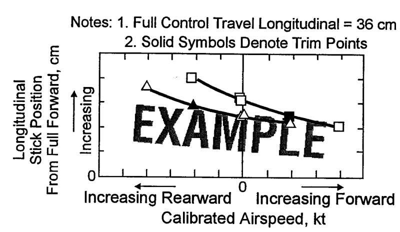
Static longitudinal stability is the measure of the pitching moment about the air vehicle center of gravity caused by forces and moments developed on the various components of the air vehicle in flight. This pitching moment may be stabilizing or destabilizing as a function of airspeed. Static longitudinal characteristics are determined by measuring the control positions necessary to balance the pitching moment about the center of gravity. Since the position of the air vehicle CG and contribution of fuselage moments in various configurations have such a marked effect on static longitudinal stability, Government testing for static longitudinal stability may be conducted at various gross weights, CGs, and configurations defined by the PA. During this testing, collective (thrust) control is normally fixed, and longitudinal control position is varied about trim points for each combination of gross weight, CG, and configuration. Configurations should be varied from minimum fuselage drag ("clean") to high drag configurations, and contributions of the stability augmentation system (SAS) to static longitudinal stability should be considered.

Government static longitudinal stability testing should be primarily concerned with speed stability and angle of attack stability. These tests are conducted to verify that pitching moments about the air vehicle CG are either stabilizing or destabilizing forces as a function of airspeed. Other factors such as wing, tail, and fuselage contributions and power effects for propeller driven air vehicles could also have an effect. However, the test pilot is usually not concerned with the magnitude of pitching moments. The primary operational indications of static longitudinal stability are forward longitudinal, control force required to increase speed and aft longitudinal control force required to decrease speed (positive stability). The control forces required to obtain this response may also be variable, and, at increasing airspeed, a stabilizing moment produced by the rotor with increased speed may be overridden by a destabilizing fuselage pitching moment. If these characteristic are not demonstrated or verified at all test conditions, problems may arise in operational use. Fig. 11-2 illustrates positive static longitudinal stability (negative slope) in both forward flight and at a hover. Unstable longitudinal static stability would be characterized by a positive gradient on these plots which would imply a requirement for more aft control trim position for increased forward airspeed and a more forward trim control position for decreased forward speeds. This type of control response would not be intuitive to most pilots, and would result in increased workload to maintain speed control. In addition, any disturbance from trim which is not compensated for by the pilot results in a divergent response.

Characteristics to be measured may include indicated or calibrated airspeed, longitudinal control position and force,



(A) Static Longitudinal Collective Fixed Stability



Source: AMCP 706-203

(B) Static Hovering Stability

Figure 11-2 Example Parameters Measured to Evaluate Static Longitudinal Stability

outside air temperature (OAT), rotor speed, torque of engine(s), vertical speed, pitch attitude, pressure altitude, fuel quantity, and fuel flow rate. If force controllers are used for longitudinal control, flight control actuator position may need to be recorded versus control position. Instrumentation intervals required resolution and at the specified in a Government approved test plan requirements may include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record the previously named characteristics with the

11-4.5 DYNAMIC LONGITUDINAL STABILITY

Dynamic longitudinal stability is a term that refers to the motion of the air vehicle produced by a disturbing force to the longitudinal axis. Two modes of motion for air vehicle dynamic longitudinal stability must be evaluated for all types of air vehicle. These two modes are the short period and the long period, or phugoid, mode. Short period modes are usually associated with responses to a sharp edge pulse control displacement or to a gust, and the phugoid mode describes the response to an out-of-trim condition or to a near-step input.

An additional mode with an even shorter period might effect the dynamic longitudinal stability for aircraft when tested in a stick-free case. So short is this mode that no speed change occurs. Its' impact is that it might excite a long period mode. Since this testing usually is performed for stick-free flight for Army air vehicles, all three modes should be considered. The objective of the testing is to determine pitch, roll, and yaw attitudes and rates and fuselage angle of attack resulting from longitudinal control inputs.

The short period mode in hovering and forward flight is normally heavily damped and, therefore, nonoscillatory. SAS may be required, however, to dampen out rapid pitch responses to gusts at a hover. Both vertical and horizontal gusts must be considered for forward flight. On the other hand, long period (phugoid) responses may be shown as time histories of parameters denoting the air vehicle attitude. Such responses are shown graphically in Fig. 11-3.

All testing should be conducted beginning from trimmed flight conditions and at gross weights, CG, altitudes, and configurations as directed or approved by the PA. Additionally, iterations may be required with SAS on and off to evaluate the effects of SAS on dynamic longitudinal stability.

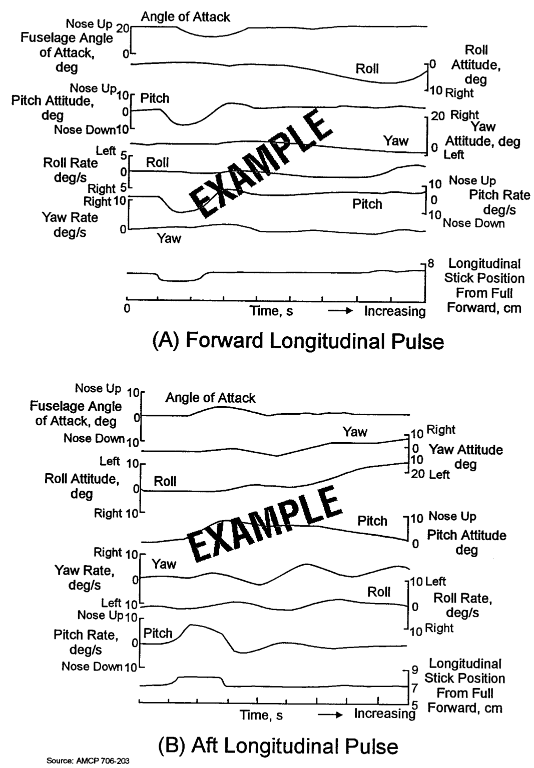


Figure 11-3 Dynamic Longitudinal Stability

For rotorcraft, the short period mode is usually evaluated at a hover starting at a stabilized airspeed of five (5) knots indicated airspeed (KIAS). Longitudinal control position is measured relative to control position in hover. This procedure is repeated in the rearward direction, and readings are taken for both forward and rearward flight. Response to gusts in forward flight is obtained by trimming the rotorcraft at a stabilized test condition. The effect of the long period response is recorded, and gust response in forward flight may be evaluated by introducing a 0.25g normal acceleration with longitudinal control pulse inputs.

Long period (phugoid) modes may be excited by displacing the longitudinal control to decrease the airspeed five (5) KIAS from trimmed airspeed and returning the control to trim. This excitation is repeated for increasing airspeed. Typical results are shown in Fig. 11-3.

Characteristics to be measured include longitudinal and collective (thrust) control positions (or actuator positions in the case of force controllers), normal accelerations in applicable directions, airspeed, pitch, roll, and yaw attitudes, rates, and accelerations, and elapsed time. Instrumentation requirements include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record these characteristics with the required resolution and at the specified intervals. If force-feel controllers are used, actuator positions may have to be measured instead of control positions.

11-4.6 MANEUVERING STABILITY

Stability characteristics of maneuvering Army air vehicles have become particularly important with the introduction of armed rotorcraft and target designating scout rotorcraft. The stability of the platform during maneuvers contributes greatly to weapons accuracy through the target acquisition, designation, and engagement sequence. Flight tests should be conducted by the Government to evaluate the stability of the aircraft during typical high g maneuvers, such as the maneuvers of TABLE 9-1. Pull-ups, recovery from dives, and stabilized turning flight are of primary concern.

The purposes of the tests are to determine the control forces and control or actuator displacements required to develop a steady state acceleration or a pitch and/or roll rate in both level pull-ups and dives and turning flight. Positive maneuvering stability is demonstrated by the requirement for increasing force and aft displacement of the longitudinal control stick for increasing levels of normal acceleration as shown in Fig. 11-4a. Additionally, these tests should identify differences in maneuvering stability when turning left versus right, rotor speed buildup or loss, and transient torque characteristics during maneuvering flight.

For rotorcraft, Section 3.4 of ADS 33D-PRF (Ref. 10) covers mid-term pitch attitude response to a longitudinal controller input, and also covers interaxis coupling. Later paragraphs of that section also cover roll attitude response to lateral controller inputs, as well as roll-sideslip coupling. Appropriate sections of ADS 33D-PRF may be used by the Government in evaluating this characteristic. Criteria for assignment of handling qualities levels are included in that publication, and typical test requirements are shown in Fig. 11-4b.

Characteristics to be measured include indicated airspeed, pressure altitude, OAT, fuel weight, rotor speed, engine torque, longitudinal, lateral, and directional control displacement and force, collective (thrust) displacement, sideslip angle, normal acceleration at pilot's station and CG, rate of climb or descent in turns, pitch and roll rates and attitudes, and yaw rates. Instrumentation requirements may include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record these above characteristics with the required resolution and at the specified intervals in a Government approved test plan.

11-4.7 STATIC LATERAL-DIRECTIONAL STABILITY

For static lateral-directional stability, requirements are that stability be positive for specific ranges of airspeeds for three-control airplanes. For two-control (or simplified control) airplanes, different requirements are cited, including abandonment of controls for two minutes without assumption of dangerous attitudes or speeds.

For rotorcraft, Section 3.4 of ADS 33D-PRF (Ref. 10) covers the requirements for lateral directional stability. The three main characteristics of concern are dihedral effect, directional stability, and sideforce. The objectives of the testing are to determine longitudinal, lateral, and yaw control forces and displacements and fuselage bank angles required to maintain a steady sideslip at various airspeeds. Since sideslip angles are used, reliable airspeed measurements are particularly important for all sideslip angles.

Tilt rotor and tandem rotor rotorcraft may depend on the fuselage for static directional stability, which leads to an unstable air vehicle if the fuselage is unstable. SAS may be required to provide this measure of stability.

Typical test results are shown in Fig. 11-5. Positive lateral directional stability is indicated by a requirement for increasing pedal and lateral control displacement and resulting angle of roll, for increasing sideslip. Characteristics to be measured include indicated airspeed, pressure altitude, OAT, fuel weight, rotor speed, engine torque, longitudinal, lateral, and directional control displacement and force, sideslip angle, pitch, roll, and yaw attitudes, and vertical speed. Instrumentation requirements may include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record the above characteristics with the required resolution and at the specified intervals in a Government approved test plan.

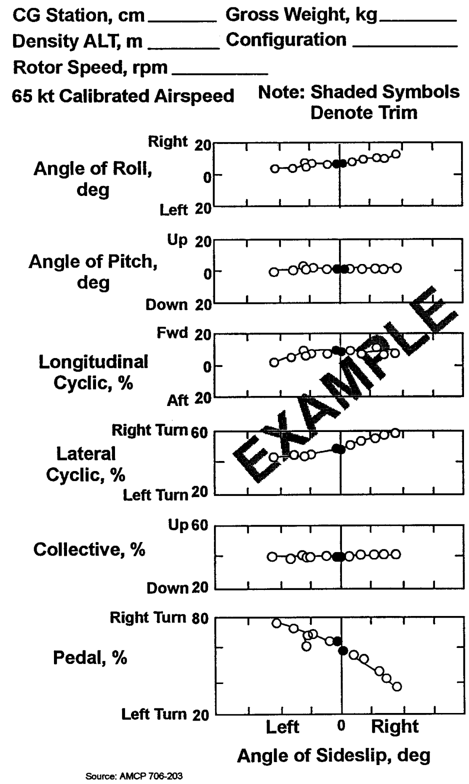


Figure 11-5 Static Lateral-Direction Stability

11-4.8 DYNAMIC LATERAL-DIRECTIONAL STABILITY

Dynamic lateral-directional stability testing is performed to determine air vehicle response to gust disturbances and to evaluate general flying qualities associated with lateral-directional control. Dynamic stability requirements involve testing for short period, roll, and combined lateral-directional ("Dutch Roll") oscillations.

The Dutch roll mode consists of oscillations in roll and yaw, usually at identical frequencies; however, the roll follows the yaw by a finite phase angle. Additionally, the ratio of roll oscillation to yaw oscillation is known as the roll-to-yaw ratio. As a general rule, large roll-to-yaw ratios are undesirable since pilots tend to have more trouble controlling roll than yaw.

A second factor governing the pilot's opinion of the air vehicle may be behavior following a lateral control input. Initial roll acceleration, maximum roll acceleration, final steady-state roll rate, and the time required to achieve a steady-state roll rate all influence the pilot's opinion of the air vehicle. Roll declarations required to stabilize at a bank angle are also an important concern.

After obtaining the desired bank angle through a roll acceleration/deceleration doublet, the pilot's opinion is greatly influenced by the trim holding characteristics of the air vehicle. Three things can occur when trimmed flight is disturbed in a turn. The air vehicle may return to trim, it may stabilize at a new bank angle, or the bank angle may diverge further from the trim angle (an unstable condition).

If any of these oscillations are significant, pilot compensation during tasks such as instrument meteorological condition (IMC) flight may be excessive. ADS 33D-PRF (Ref. 10) contains criteria for evaluation of these handling qualities in normal flight conditions and in terms of degraded visual cue environment.

Characteristics to be measured include indicated airspeed; pressure altitude; OAT; fuel weight; rotor speed; engine torque; collective (thrust) control position; longitudinal, lateral, and directional control displacement and force; sideslip and bank angles; normal acceleration at pilot's station and CG; rate of climb or descent in turns; pitch, roll, and yaw rates and attitudes; and time. Instrumentation requirements may include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record these characteristics with the required resolution and at the specified intervals in a Government approved test plan. Typical graphical outputs for these flight tests are shown in Fig. 11-6.

11-4.9 TRANSITION FLIGHT

For multi-mode air vehicles which can transition from vertical take-off and landing (VTOL) or vertical/short take-off and landing (V/STOL) (primarily rotorcraft) modes to other type aircraft modes, the Government test activity may conduct tests and demonstrations necessary to verify or demonstrate flying qualities during the transition operations. Other multi-mode air vehicles may include compound rotorcraft which have both main rotor systems and propellers to provide thrust and/or main rotor systems and wings to provide lift.

In some cases, two or more possible flight modes may be possible at the same conditions. An example could be flight at 90 knots and maximum gross weight which may be possible with tilt-rotor engine nacelles/thrust vectors in the VTOL mode (zero degrees inclination to the vertical plane), in the fixed wing mode (90 degrees inclination), or any inclination between those values. Another example might be the reduction of lift requirements of the main rotor at high speeds caused by compound rotorcraft variable or fixed wing angles of attack.

The purpose and scope of A&FC flight testing in the transition flight mode is to determine operational and service flight envelopes for each mode. In some cases, airspeed may not be sufficient for continued level flight with a tilt-rotor air vehicle in the fixed wing mode, while in other cases (especially high gross weights), in-ground effect (IGE) or out-of-ground-effect (OGE) hover may not be possible. At lower airspeeds, compound rotorcraft wing surfaces may not be capable of providing sufficient lift for level flight.

The PA should define transition flying qualities to be demonstrated. As a minimum, the testing activity's plan should identify the ranges of airspeeds, altitudes, propeller/proprotor speeds, engine/vector inclination normal envelopes or wing angles of attack, emergency envelopes for one-engine inoperative (OEI) operations, and gross weights to be tested. Characteristics to be demonstrated are the same as the qualities demonstrated in paragraph 9-5, and typical test results are shown in Fig. 11-7.

The tests and demonstrations should be documented in accordance with par. 9-6. Future revisions of ADS 33D-PFR (Ref. 10) might contain specific handling qualities requirements for this mode of flight. These data should primarily be used to provide data for preparation of operator's manual performance information and emergency procedures. Instrumentation requirements could include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record the above characteristics with the required resolution and at the specified intervals in a Government approved test plan.

11-4.10 CONTROLLABILITY

Controllability testing should be conducted by the Government testing activity to determine three characteristics:

1. Sensitivity, defined as the maximum angular acceleration (degrees/second) of the air vehicle per 2.54 cm (one inch) of deflection of a cockpit control, as well as time to reach that maximum acceleration

2. Response, defined as the maximum angular velocity (degrees/second) per 2.54 cm (one inch) of deflection of a cockpit control, as well as time to reach that velocity

3. Control power, defined as the attitude change one (1) second after a 2.54 cm (one inch) control displacement. Using mechanical stops to ensure precise inputs, sudden, near-step inputs are applied to the trimmed controls. This input is maintained until maximum acceleration is attained or recovery is required. These inputs should be applied with a controlled buildup to maximum control deflections if possible. The range of controllability testing should include hover and forward flight testing as specified by the PA.

ADS 33D-PFR (Ref. 10) covers controllability characteristic criteria in Section 3.6, and precision and aggressive maneuvers to be tested are in Sections 4.1 and 4.2 of that same publication. Collection of airframe damping information at various frequencies should normally be included in the testing.

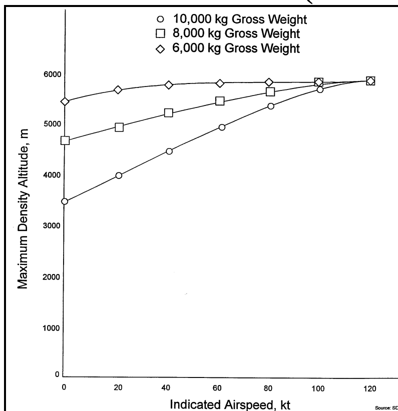


Figure 11-7 Transition Lift and Control
(acceptable at all nacelle angles)

Characteristics to be measured include indicated and boom airspeed; pressure altitude; OAT; fuel weight; rotor speed; longitudinal, lateral, and directional control displacement and force; collective (thrust) displacement; sideslip angle; normal acceleration at pilot's station and CG; rate of climb or descent in turns; and pitch, roll, and yaw rates and attitudes. Instrumentation requirements may include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record the above characteristics with the required resolution and at the specified intervals.

Typical graphical data outputs for lateral inputs, control sensitivity, and damping versus frequency are included in Figures 11-8, 11-9, and 11-10. Acceptable control sensitivity and response is dependent upon air vehicle type and mission requirements and is generally specified by the PA.

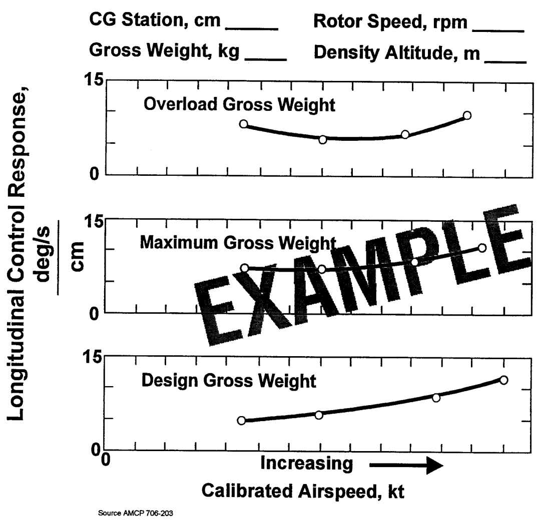


Figure 11-8 Control Response

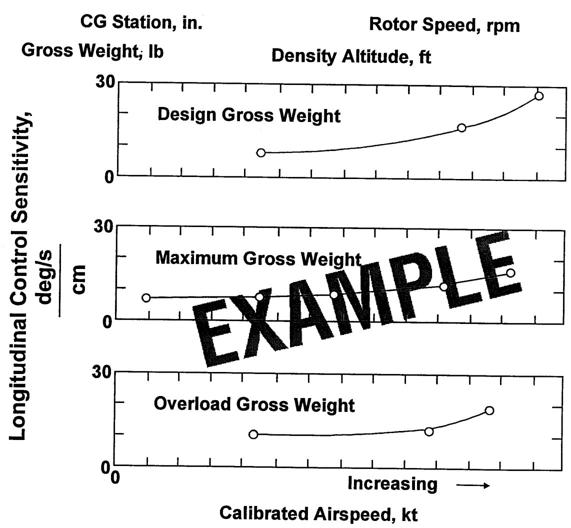


Figure 11-9 Control Sensitivity

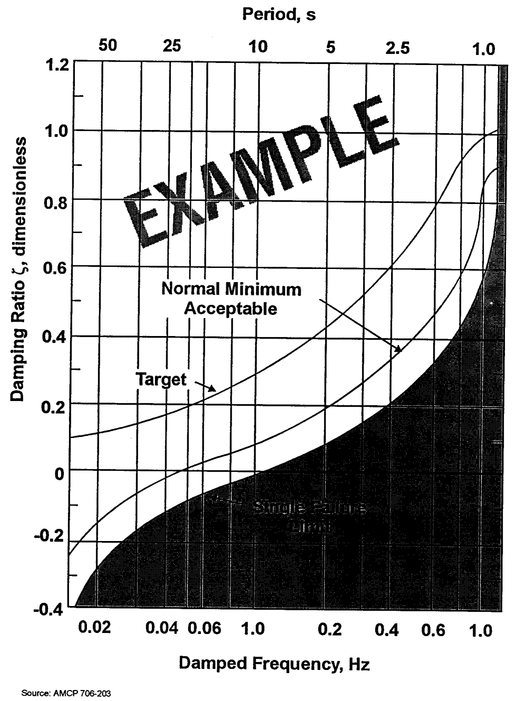


Figure 11-10 Frequency Damping Characteristics

11-4.11 NOVEL CONTROL SYSTEMS

As discussed in par. 11-3.4, the advent of fly-by-wire and fly-by-light (fiber optic) flight controls means that there might be no direct mechanical linkages between the pilot's controls and rotor and control surface actuators, and measurement of control displacements or forces might not be an accurate method of evaluating pilot control inputs. Force-feel controls further complicate this arrangement. With these controls in trimmed flight, a force-feel control can be displaced and released to return to neutral, with the new actuator position being a new control displacement. Generally, the displacement of the actuator should be some function of the force applied and the duration of the application. In trimmed flight, the control could be displaced for some period of time, driving the actuator to a new position, released and allowed to return to neutral (no force applied), and the attitude should change to a new value with the same stick position. In this way, all graphical plots shown in this chapter would have the same stick position. However, if actuator position is recorded, those positions plotted along the vertical axes would more accurately reflect static and dynamic stability characteristics.

When evaluating novel control systems, human error during flight testing has already been mentioned as a potential problem. If several controls are integrated into one control stick, pilot attempts to provide input in only one axis must be closely monitored to ensure that no coupled inputs (cross controlling) are inadvertently introduced into flight testing. An example might be a sidearm controller which incorporates longitudinal, lateral, and yaw control for rotorcraft into one stick. In attempting to check inputs in the longitudinal axis, the pilot's arm and wrist might inadvertently induce lateral inputs and a yawing moment to the air vehicle data collection requirements should be very similar to mechanical linkage control systems with the exception of control positions. Actuator positions or some other alternate means of measuring the commanded inputs to the control surfaces, rotors, and propellers should be determined by the test activity based on the testing requirements. In some cases, the effect of a given force application for a given duration may have to be verified. This is discussed in subpar. 11-3.4.

Instrumentation should also be similar to that required for conventional control systems, with the exceptions of requirements to measure actuator displacements and control forces, and may include oscillograph, magnetic tape, or computerized data acquisition interfaces necessary to record the characteristics with the required resolution and at the specified intervals in a Government approved test plan.

11-4.12 AIRWORTHINESS AND FLIGHT CHARACTERISTICS (A&FC) REPORT

The A&FC report is a formal type of test report, which usually contains a complete evaluation of the handling and performance characteristics of the air vehicle. Refer to para. 11-4 for A&FC test information. The report is used to provide test data and information for the operator’s manual. Also, the report is used to identify and document deficiencies (if any), shortcomings, and non-compliance with specifications. Deficiencies must be corrected before an air vehicle can be fielded. The procedures and reports that apply to the A&FC are the same that apply to the PAE specified in subpar. 11-3.8.

11-5 CLIMATIC TESTS

Adverse climatic conditions, such as those found in arctic, desert, and wet tropical areas should be expected to affect military systems and equipment. Extreme heat and cold, as well as adverse conditions such as sand and salt spray might reduce system and equipment performance capabilities, such as a reduction in response time, etc. Also, extreme climatic conditions might impact the functionally of systems and equipment by causing components to stick, jam, or otherwise fail, or might impact usability because of limitations of the crew caused by required clothing items required to protect individuals from these conditions. MIL-STD-210, *Climatic Information to Determine Design and Test Requirements for military Systems and Equipment* (Ref. 15) or equivalent handbook will provide both climatic data that can be used to derive design and test criteria for military systems and equipment and environmental data for climatic conditions which military equipment can be expected to encounter. AR 70-38, *Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions* (Ref. 16), contains guidance for determining climatic conditions in the research, development, test, and evaluation of materiel (such as air vehicle systems and aviation materiel) used in combat. Air vehicle systems developed by the Army should be designed to operate in specified climatic design types as shown in TABLE 11-1. Climatic tests should be performed under simulated conditions in a laboratory environment (engineering tests) for the required climatic design type and operational conditions specified in AR 70-38 (Ref. 16) for which the materiel was designed. The engineering tests are conducted to identify design and operational deficiencies. Chapter 9 contains information on climatic laboratory tests usually performed by the contractor. Following the engineering tests, and correction of deficiencies, developmental testing by TECOM should be conducted under natural environmental climatic conditions at the

Climatic Design Type	Daily Cycle (QSTAG 360 Equivalents)*	Operational Conditions: Ambient Air Temperature °C (°F)	Operational Conditions: Solar Radiation W/m² (Bph)	Operational Conditions: Ambient Relative Humidity %	Storage and Transit Conditions: Induced Air Temperature °C (°F)	Storage and Transit Conditions: Induced Relative Humidity %
Hot	Hot-Dry (A1)	32 to 49 (90 to 120)	0 to 1120 (0 to 355)	3 to 8	33 to 71 (91 to 160)	1 to 7
	Hot-Humid (B3)	31 to 41 (88 to 105)	0 to 1080 (0 to 343)	59 to 88	33 to 71 (91 to 160)	14 to 80
Basic	Constant High Humidity (B1)	Nearly Constant 24 (75)	Negligible	95 to 100	Nearly Constant 27 (80)	95 to 100
	Variable High Humidity (B2)	26 to 35 (78 to 95)	0 to 970 (0 to 307)	74 to 100	30 to 63 (86 to 145)	19 to 75
	Basic Hot (A2)	30 to 43 (86 to 110)	0 to 1120 (0 to 350)	14 to 44	30 to 63 (86 to 145)	5 to 44
	Basic Cold (C1)	-21 to -32 (-5 to -25)	Negligible	Tending toward saturation	-25 to -33 (-13 to -28)	Tending toward saturation
Cold	Cold (C2)	-37 to -46 (-35 to -50)	Negligible	Tending toward saturation	-37 to -46 (-35 to -50)	Tending toward saturation
Severe Cold	Severe Cold (C3)	-51 (Cold soak) (-60)	Negligible	Tending toward saturation	-51 (-60)	Tending toward saturation

*Designations in parentheses (A1, A2, B1, B2, B3, C1, C2, and C3) refer to corresponding climatic categories in Quadripartite Standardization Agreement 360 Climatic Environmental Conditions Affecting the Design of Military Materiel.

Table 11-1 Summary of Temperature, Solar Radiation, and Relative Humidity Daily Cycles appropriate TECOM developmental test facilities (arctic, tropic, desert, etc.). The developmental tests conducted by TECOM are an extension of the engineering tests and allow for testing of equipment that functions only in the natural environment such as landing skis and Aviation Life Support Equipment (ALSE).

The climatic engineering tests, which are a prerequisite for the natural environmental tests, should be conducted on prototype or production air vehicle. When warranted, the tests may be repeated for production items. Air vehicle system tests should be conducted to evaluate the total effectiveness and operational procedures throughout a predetermined range of conditions. The subsystem effectiveness and operation should be evaluated at the same conditions, and the results used to:

1. Demonstrate adequate safety of operation so that flight releases may be issued for the climatic developmental tests
2. Determine compliance with applicable specifications
3. Formulate necessary recommendations for design changes to maintain acceptable performance standards throughout the operational range.

The most suitable facility for simulating the natural environmental test conditions is the USAF Climatic Laboratory located at Eglin AFB, Florida. Normally, the prime air vehicle contractor has the overall responsibility for the climatic laboratory engineering test. The requirements for the climatic laboratory testing performed by the contractor are contained in subpar. 9-9. The PA should provide the test pilots and the test engineers (usually from TECOM) who should conduct the tests. When required, climatic laboratory reevaluations or retests will normally be performed by the procuring activity without contractor participation.

11-6 SURVIVABILITY TESTS

The objectives of survivability testing should be to identify inherent vulnerabilities and effectiveness of equipment countermeasures. Air vehicle level survivability testing could be accomplished by a contractor or by the Government with contractor support. Depending on the contractor and contract, it often might be more feasible to accomplish this testing at Government test facilities. Elements of system level survivability testing are:

1. Susceptibility Reduction Testing. Inherent signature should be determined by test. Design improvements and aircraft survivability equipment (ASE), if any, should then be tested to demonstrate effectiveness. See subpar. 11-6.3 “Special Electromagnetic Interference (SEMI)” and subpar 11-6.4 “Electronic Warfare" for testing of countermeasures and counter countermeasures.

2. Vulnerability Hardening Testing:

a. Ballistic Hardening. Live fire testing of armor and weapons platform should be accomplished as discussed in ADS 11, *Survivability Program. Rotary Wing* (Ref. 17), and as further discussed in subpar. 11-6.1 “Live Fire."

b. Directed Energy Hardening. Testing should be accomplished to demonstrate hardness against lasers, high power microwave, and radio frequencies, as discussed in ADS 11 (Ref. 17) and DA PAM 73-series (Ref. 2).

3. Nuclear Hardening. Nuclear simulation tests should be conducted. The ground test vehicle, static test article, or other functional mockup should be tested to demonstrate hardening against nuclear electromagnetic pulse, thermal, gamma, and blast as discussed in ADS ll (Ref. 17) and DA PAM 73-series (Ref. 2).

4. Nuclear, Biological, and Chemical (NBC) Hardening. Simulation testing should

be accomplished as discussed in ADS 11 (Ref. 17) and DA PAM 73-series (Ref. 2).

5. Crashworthiness Testing:

a. Crash Avoidance (Aircraft Level Tests). Testing should be conducted to demonstrate the effectiveness of wire cutters and similar devices, as discussed in ADS ll (Ref. 17).

b. Crashworthiness (Aircraft Level Tests). Testing should be conducted to demonstrate overall air vehicle crashworthiness, as discussed in ADS ll (Ref. 17). See discussion and criteria in subpar. 11-6.2 Crashworthiness."

DoDR 5000.2-R (Ref. 4) cites Title 10, United States Code, Section 2366 which requires “...survivability testing and lethality testing on covered major systems and product improvement programs that significantly affect the survivability of a covered weapons system before full-scale production." The term “covered system" means a vehicle, weapon platform, or conventional weapons system that includes features designed to provide some degree of protection to users in combat and is a major system.

Prior to any survivability testing activities, the air vehicle contractor (AC) and PA should agree on the air vehicle damage measures to be applied. Supplemental descriptions and criteria for live fire, crashworthiness special electromagnetic interference (SEMI), and electronic warfare are given in the subparagraphs that follow.

11-6.1 LIVE FIRE

The scope and nature of live fire are described in par. 11-6. Prior to any actual firing tests, analyses should be performed by the AC to identify vulnerable components and subsystems and maximize the efficiency of live fire testing. The System Threat Assessment Report/System Threat Assessment (STAR/STA) is the basic threat document defining the threat environment in which the development system should function. If required by the PA, actual live fire tests (LFTs) should be performed on those components with either actual or simulated surrounding structures and components.

Four elements of ballistic survivability testing might be tested by the Government. These elements are armor, ballistic tolerant structure, and components positioning and separation of subsystems, and fuel ballistic protection. Contractor testing and analyses in these areas is described in par. 9-14.

Threat projectile, impact location, obliquity, tumble, and striking velocity should be specified in Government test plans, and should be recorded and reported for all firing tests. Another element of LFT, lethality, is primarily related to weapons systems effectiveness testing which was also covered in Chapter 9.

Compatibility of armor with typical operators and maintainers should be validated by Government use personnel prior to beginning LFT. Validation is intended to confirm that armor installed in its normal position does not interfere with critical operator and maintainer tasks. If battle damage assessment and repair (BDAR) is a requirement, such repairs should be validated using LFT assemblies and components to demonstrate specification compliance.

Since only vulnerable areas should be tested, measures of the air vehicle airworthiness and mission effectiveness are primarily related to probabilities of suffering a specific type of kill such as attrition, mission abort, or forced landing kills, and may be expressed as the probability of a kill given a hit (PK/H). Instrumentation required to monitor these tests may include video recorders, instruments for monitoring electrical and functional parameters, such as current, torque, and temperatures, and pressure transducers for monitoring transient fluid and blast pressures.

11-6.2 CRASHWORTHINESS

Contractor testing to determine fuel system and crew station crashworthiness and to perform landing gear drop tests is covered in subpars. 8-3.5, 8-11.3, and 8-6.1, respectively. However, total crashworthiness of the system depends upon the likelihood that crew or occupants will either be subjected to acceleration forces in excess of human tolerance or be susceptible to injury by objects invading their stations. Such objects may be either static components displaced by impact or dynamic components which have been broken loose upon impact. If required by the PA, Government testing may involve subjecting a complete air vehicle or representative fuselage to impacts under various conditions. These conditions may include, but not be limited to, various rates of descent, impact angles relative to the fuselage, and percentages of lifting forces applied. Due to the possible danger of such tests, these impacts should not be staged with human subjects. The testing should be accomplished with instrumented, anatomically similar crash "dummies" capable of measuring accelerations, forces at critical parts of the body, and movement of limbs in the simulated crash. Landing gear, critical structural members, and crashworthy seating may also be instrumented to record displacements and stresses during the crash sequence, allowing an estimate of the energy attenuation properties of the landing gear and supports, fuselage, and seating. Video recording of the cockpit and cabin interior during the crash sequence is also desirable.

To conserve test articles, testing should begin conservatively at lower impact angles and velocities and 100 percent lift. In this way, several recordings of increasingly more severe crash data can be made before damage occurs. In this way, an estimate of survivable crash accelerations and velocities can be made, and the data can be incorporated into the operator's manual.

11-6.3 SPECIAL ELECTROMAGNETIC INTERFERENCE (SEMI)

SEMI involves the possible electromagnetic countermeasures that might capitalize on vulnerabilities. While SEMI is not a part of ADS 37A-PRF *Electromagnetic Environmental Effects (E3). Performance and Verification Requirements,* (Ref. 18), it might avail itself of some of the information generated as a result of ADS 37A-PRF testing. As such, SEMI testing might be more appropriately included with electronic warfare (EW) testing.

11-6.4 ELECTRONIC WARFARE

Government testing of EW capabilities for air vehicles may include an evaluation of electronic countermeasures (ECM), and testing of electronic counter-countermeasures (ECCM) capabilities. Typically, it might involve effectiveness testing of the air vehicle and mission equipment for self defense. However, it could also involve effectiveness testing of the air vehicle, target acquisition equipment, and weapons as a total system. These evaluations are similar to the contractor evaluations of par. 9-14. Analyses and testing might be performed to determine:

1. Probability of detection (P_D) by a particular threat at the specified range
2. Probability of classification given detection ($P_{C/D}$) by the threat as correct type of target

3. Probability of engagement given classification ($P_{E/C}$)

4. Probability of hit given engagement ($P_{H/E}$)

5. Probability of kill given a hit ($P_{K/H}$). $P_{K/H}$ is the only one of these parameters not effected by EW characteristics.

As an example of EW testing, the Government might require effectiveness testing of signature control in the acoustic and electromagnetic spectrums as part of the performance measurements of air vehicle survivability. Reduced signatures can mean lower PD, $P_{C/D}$, $P_{E/D}$, and $P_{H/E}$. These signatures may be calculated by computer simulation or analysis, but, if required for specification compliance by the PA, may be subject to verification by flight testing. With the exception of acoustic signatures, all other signatures are dependent on detection of electromagnetic emissions or reflections in some portion of the electromagnetic spectrum.

Testing could involve assessment of probabilities of detection PD, classification Pc, and engagement PE, for specified threats or threat simulators at various ranges. If emission control (EMCON) is a requirement, these tests should be conducted in normal and EMCON mode. Maneuvering flight should be required during the tests if maneuvers can be shown to effect the probabilities of detection, classification, and engagement.

Further Government testing of ECM and ECCM should be conducted to verify ASE effectiveness. ASE is typically categorized as threat sensors and countermeasures. Examples of ASE are infrared (IR) jammers, radar jammers, radar warning receivers, and decoys. Additional survivability features which can aid in defeat of threats using the electromagnetic spectrum include low reflective paint and IR exhaust suppressers. Only the first four examples are described. IR jammers include electrically fired and fuel fired countermeasures sets which are designed to confuse or decoy threat IR guided missile systems. When used in conjunction with low reflective paint and IR exhaust suppressers, these jammers provide jamming of all known threat IR missile systems.

Radar jammers include countermeasures sets designed to detect and protect against both pulse and continuous wave (CW) illuminator radars. Pulse illuminator radar jammers are designed to respond to the most critical threat weapons systems anticipated to be encountered by attack rotorcraft in a hostile environment, while CW radar jammers protect against surface-to-air missiles (SAM) and airborne intercept missiles (AIM).

Radar warning receivers also are designed for pulse and CW illuminator radars. Additionally, there are missile approach detectors which detect the approach of IR guided missiles.

Decoys take the form of flares dispensed to confuse or mislead IR guided missiles, and chaff canisters or cartridges which prevent radar-controlled artillery from detecting, hitting, and destroying the air vehicle dispensing chaff.

The PA should define air vehicle survivability equipment (ASE) effectiveness testing to be conducted by the testing activity. These plans should identify threat systems or simulators to be provided by the PA, and should be subject to approval by the PA. Prior to testing ASE, the PA should provide the AC-established baseline susceptibility or vulnerability of the air vehicle to specified threat weapons systems when not using ASE. This should be done initially by analysis, and verified by flight test using controlled maneuvers, altitudes, and air vehicle configurations. Typical measures would be $P_{C/D}$, $P_{E/C}$, and, possibly, an analytical determination of $P_{H/E}$ without use of ASE. Threat systems or threat simulators may be used to establish the baseline characteristics and to perform effectiveness testing.

Once the baseline characteristics are established, the Government may repeat required flights and testing necessary to determine the reduction in susceptibility or vulnerability (increase in survivability) due to the use of ASE. Any limitations, such as electrical power, maneuvering, or range, brought about by use of ASE should be verified during this testing.

11-7 ELECTROMAGNETIC ENVIRONMENTAL EFFECTS

Other tests that are conducted by the Government at Government test facilities with contractor support are

1. Electromagnetic vulnerability (EMV)
2. Hazards of electromagnetic radiation to ordnance (HERO)
3. Electromagnetic radiation hazard (EMRH)
4. Streamering and included effects lightning
5. Static electricity
6. Emission control (EMCON).

Performance and verification requirements are discussed in ADS 37A-PRF (Ref. 18). Also, the facilities of the US Army Test and Evaluation Command needed for these tests are described in DA PAM 73-series (Ref. 2). The Government has the test facilities and contractors generally do not.

11-8 DEVELOPMENTAL TESTS (DT)

The DT is performed in controlled environments by specially trained individuals to assess the adequacy of the system design, to determine compliance with system specifications and critical technical parameters, determine if the system is ready to enter the next acquisition phase, and to determine how safe the system is for operation by user troops and civilians. Much of the information upon which independent evaluations and assessments are based consists of data generated during testing. The AR 73-1 (Ref. 1) requires implementation of a continuous evaluation process in order to streamline development and to minimize the requirement for duplicate Government tests. Broader objectives of D_T are:

1. Assist the engineering design and development process
2. Verify performance objectives and specifications
3. Demonstrate that design risks have been minimized
4. Estimate the system's military utility when introduced
5. Evaluate the compatibility and interoperability with existing or planned equipment and systems
6. Provide an assurance that the system and equipment are ready for testing in the operational environment.

11-9 OPERATIONAL TESTS (OT)

Operational testing involves estimation of the operational effectiveness and suitability of a new air vehicle for use. Operational testing can be conducted before full scale development (FSD) as an early operational assessment (EOA), during FSD as part of operational test and evaluation (OT&E), or after deployment as a part of follow-on test and evaluation (FOT&E). The following paragraphs describe the two critical areas of operational testing; issues and objectives, and resources and test conduct and reporting requirements.

11-9.1 ISSUES AND OBJECTIVES

The basic objective is to determine if the air vehicle satisfies the performance requirements of the Operational Requirements Document (ORD). The TEMP should describe issues and criteria for operational testing. For additional information see AR 73-1 (Ref. 1) and DA Pamphlet 73-series (Ref. 2). Operational issues should be few in number, encompass the total system, focus on the system mission, be operationally relevant, and be realistic (to system maturity) for the supported decision. The specific objectives of the operational tests should be designed to obtain data to address the operational issues. This includes; but, is not limited to include:

1. Obtaining quantitative information on which to base milestone decisions
2. Estimating the operational effectiveness and suitability of the system
3. Identifying needed modifications and improvements
4. Providing information on tactics, doctrine, organization, and personnel requirements
5. Providing data to determine the adequacy of technical manuals, handbooks, plans, and documentation effectiveness for operation and support of the system.

11-9.2 RESOURCES AND TEST

Operational tests may require a large amount of resources to adequately conduct the test. Typical military operators and maintainers are required for conduct of operational tests. Other service's air vehicles may be required for aerial refueling and transportability testing, and naval ships may be needed for shipboard compatibility and dynamic interface testing. Also, adequate facilities, fuel, and logistic support will be needed. Other air vehicles may be required for a baseline comparison. Threat simulators or actual threat systems may be required for survivability testing.

The EOA should be conducted on a prototype air vehicle, the OT&E should be conducted using an early production air vehicle, and the FOT&E should be conducted using later production air vehicles, possibly with product improvements incorporated to correct deficiencies discovered in earlier operational tests. Operational tests should be conducted in an environment as close to a natural environment as possible to include representative friendly units, support structure and equipment, and enemy threat vehicles. The tests should also be conducted using the anticipated or known tactics and doctrine of friendly and enemy forces. For each operational issue identified in subpar. 11-9.1, the tester should have either qualitative or quantitative measures identified, a means for collecting the required information, a means for analyzing the data (as needed), and a means for drawing conclusions.

11-9.3 REPORTS

Test reports should reference the test plan or request. Significant findings and information concerning the objectives of subpar. 11-9.1 should be submitted at the end of each phase of testing. The general content of a operational test report should include a statement concerning the operational effectiveness and the operational suitability of the tested system. The report should also include supporting data for the conclusions inferred from the test. Classified data must contain the proper security classification on each page of reports, etc. Distribution of the report should be as specified in the test request and should satisfy the requirements of Department of Defense Directives Number 5350.24, *Distribution Statements on Technical Documents* (Ref. 19) and Number 5230.25, *Withholding of Unclassified Technical Data* *from Public Disclosure*(Ref. 20). Normally, these test reports should be submitted at least 45 days prior to milestone decision points.

11-10 FOLLOW-ON EVALUATIONS (FOE)

As mentioned before, FOT&E may be conducted to evaluate modifications or improvements, or may be conducted solely to verify that earlier operational testing accurately evaluated operational effectiveness and suitability. An FOE to evaluate modifications or improvements usually can be conducted using tailoring of requirements, which would result in a significant reduction in resource requirements. An FOE conducted to verify earlier operational test results generally would require the same assets, and be conducted in a similar manner to the original test.

11-10.1 ISSUES AND OBJECTIVES

These issues and criteria revolve around the questions of operational effectiveness and operational suitability. The objectives of the FOE are to:

1. Obtain another estimate of the operational effectiveness and suitability of the system in selected areas
2. Identify additional needed modifications and improvements
3. Provide further information on tactics, doctrine, organization, and personnel requirements.
4. Provide information for reprocurement

11-10.2 RESOURCES AND TEST CONDUCT

Personnel resources for FOE are the same as for EOA and OT&E. Other service air vehicle, naval ships, and/or threat simulators or actual threat systems may be required if deficiencies or improvements involve those areas. As mentioned before, FOE should be conducted using later production air vehicles, possibly with product improvements incorporated to correct deficiencies discovered in earlier operational tests. Test methods for an FOE is similar to methods used for EOA and OT&E, and should include tests conducted using natural environments, threat and friendly forces, and current tactics and doctrine.

11-10.3 REPORTS

Test reports should reference the test plan or request. Test reports detailing significant findings and information concerning the FOE objectives should be submitted at the end of FOE. Test reports should contain conclusions and supporting documentation on the operational effectiveness and suitability of the system. Normally, these test reports should be submitted at least 45 days prior to the final decision to enter low rate initial production (LRIP). Classification and distribution should be as provided for in subparagraph 9-11.3.

11-11 GOVERNMENT SOFTWARE TEST AND EVALUATION (T&E)

Government qualification of software should only be required when the government is the developer of software, for military unique hardware and software, and for modifications to government developed and qualified hardware and software. Government qualification should not be required for commercially developed software and reuse of software.

The contractor should be totally responsible for satisfying both hardware and software performance requirements of the contact; however, to satisfy its' interest in airworthiness and flight safety, the

Government software T&E is concerned with the test activities of all life cycle phases of the software portions of weapon systems computer resources (WSCR). Because each logical element of embedded software cannot be tested at a system, subsystem, hardware configuration item (HWCI) or possibly even computer software configuration item (CSCI) level, testing should occur during every phase of a development to maximize thoroughness and eventual reliability. The Government's level of involvement in each of these various test phases is dependent upon:

1. Criticality (flight safety versus mission essential versus non-essential)
2. Complexity (design and algorithms)
3. Platforms (embedded avionics versus automated test equipment)
4. The nature of the software's use (application and frequency)
5. Available resources (primarily manpower).

11-11.1 INTEGRATED PRODUCT TEAM (IPT) - SOFTWARE

The IPTs are an integral part of the defense acquisition oversight and review process. For additional information see DoDR 5000.2-R, *Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated Information System (MAIS) Acquisition Programs*, (Ref. 4). Software is an important consideration for these teams. The Working Level IPTs (WIPTs) typically will meet as required by the program, project, or product management office (PM) to help the PM plan program structure and documentation and resolve issues. The IPT should provide a forum for review and resolution of issues impacting the acquisition, development, and support of the weapons system. These issues should include; but, not be limited to include, computer hardware and software.

The IPT should include representatives from each of the following: Air vehicle contractor, MATDEV command, combat developer command, each test and evaluation command and the designated life cycle engineering center (LCSEC). The organizations and their IPT software test related roles are described below:

1. The air vehicle contractor as the developer of computer hardware and software is responsible for design, development, test, and evaluation.
2. The materiel developer is the command or program, project, or product management (PM) office which has overall program and management responsibility for the execution of the software development, testing, and fielding. With assistance from associate members, the MATDEV is responsible for ensuring that adequate testing is performed on the software while also striving to reduce T&E costs and shorten test schedules to the maximum extent possible. This should be accomplished by integrating test requirements, eliminating test redundancy, and early identification of potential problem areas in the software during the T&E program. MATDEV command matrix support organizations may provide support to the IPT on behalf of the MATDEV.
3. The combat developer (CBTDEV) represents the user and trainer in the preparation of system level requirements and critical operational issues and criteria (COICs). The principal CBTDEV function relative to testing is to ensure that changes to software requirements due to test phase activities do not adversely impact user doctrine, tactics, or other system level requirements.
4. The testers and evaluators are the representatives from the commands providing the technical testers who review and verify contractor and Government test

plans, technical independent evaluators who prepare independent evaluation plans and reports, operational testers who assist in the identification and elimination of redundant testing and are responsible for the preparation of test evaluation plans and the conduct of operational tests and reporting their results, and operational independent evaluators who assist in problem identification and redundant tests elimination.

5. The designated LCSEC is the software engineering center appointed to be responsible for computer resources development and support of the system to be procured. The principal IPT functions of the LCSEC relative to testing are to ensure that test policies, standards and methodologies are contractually adapted and adhered to in order to ensure procurement of high quality, supportable software products and documentation.

11-11.2 CONTRACTOR SOFTWARE QUALIFICATION TESTS

An open systems approach should be followed for all system elements (mechanical, electrical, and software, etc.) in developing systems. This approach is a business and engineering strategy to choose specifications and standards adopted by industry standards bodies or defacto standards (set up by market place) for selected system interfaces (functional and physical, products, practices and tools; however, contractor qualification of software typically involves a structured series of informal and formal tests conducted throughout the development. The DoD-STD-498 (Ref. 5) contains relevant information; however, this standard may not be specified as a requirement without a waiver.

Informal tests range from individual developer tests through build release tests of CSCIs and can occur on any of the following hosts:

1. Developers desktop or workstation
2. Test benches
3. System integration facilities.

Informal testing comes with a multitude of "built-in" evaluators because integration of software also requires the interaction of software developers. This interaction of software developers during the integration phase provides an early evaluation of system software implementation. Integration forces developers to continually review and evaluate their own products as well as those of others with whom their products must integrate. The degree of evaluation varies from evaluating the lines of code to verifying system performance at the air vehicle level. Rarely is it desirable for the Government to contract for detailed data and reports from these informal test activities and evaluations.

Formal testing is defined as tests which are conducted in accordance with test plans and procedures and witnessed by an authorized PA representative.

A brief synopsis of the various test phases follows.

1. Computer software unit (CSU) tests. CSU tests are informal tests for which the procedures and results are documented in contractor CSU software development folders (SDFs). Resultant changes to the code, documentation and retesting results should be updated in the CSU SDFs. Each decision branch of the software logic should be correctly exercised at least once for each possible outcome.

2. Computer software component (CSC) tests. CSC tests are informal tests of integrated CSUs for which the procedures and results are documented in contractor CSC SDFs. These tests should additionally stress the limits of the code. Resultant

changes to the code, documentation and retesting results should also be updated in the CSC SDFs.

3. CSCI informal tests. CSCI informal tests are tests of integrated CSCs performed prior to formal testing. The test plans, test cases and test results should be documented in contractually required STPs, STDs and STRs. However, prior to formal tests, this information is recorded in the CSCI SDFs. Resultant changes to the code, documentation and retesting results are again updated in the CSCI SDFs.

4. CSCI formal tests. CSCI formal tests are the CSCI tests identified in the STDs that should be witnessed by the Government. The qualification requirements for the CSCIs being tested are those identified in the SRSs. The approved procedures are those in the STPs and STDs. The results are documented in the STRs.

5. System integration tests. The contractor's software organization may utilize system integration facilities for both informal and formal tests.

11-11.3 GOVERNMENT WITNESS OF SOFTWARE VALIDATION

Validation is the evaluation process that determines if the software execution correctly satisfies functional requirements. Typically, it is an end-to-end verification that the code implementation meets the performance requirements. Verification is the term used to state that each incremental phase of a development has successfully and correctly been accomplished to allow transition to the next phase.

Throughout the development activities, the Government should maintain enough insight into the actual software development activities that traceability between requirements and code can easily be verified. The Government should be confident that the path through which the established requirements have been implemented has been satisfactorily verified such that only an end-to-end validation of SRS requirements is needed.

If resources allow Government personnel to work side by side with developers and testers during development and informal testing, then this is a reasonable possibility as well as a valuable source of data. Otherwise, the Government is relegated to simply observing test compliance with STPs and STDs, and reviewing resultant STRs.

11-11.4 GOVERNMENT SOFTWARE QUALIFICATION

Government qualification of software should only be required when the government is the developer of software, for military unique hardware and software, and for modifications to government developed and qualified hardware and software.

The main difference between contractor and government qualification is the more active role that is played by the Government and the added importance of configuration management for the baseline product. The configuration management issue during LCSS should not only address product configuration, but should also be concerned with managing software change requests (SCR), new tests results, and resultant regression testing results.

Equivalent informal test activities should occur in either environment. These are accomplished at various stages throughout the development with testing at the CSU, CSC and CSCI levels. Formal qualification testing is also equivalent among the two environments with the exception of the additional regression testing requirements of the LCSS phase. These will be discussed in subpar.
11-11.5.

11-11.5 LIFE CYCLE SOFTWARE SUPPORT (LCSS) TESTS

In the LCSS role, independent verification and validation (IV&V) tests are conducted to verify new functions and implementation of SCRs. The objective of these tests is to confirm that functions, that were previously performing correctly, continue to perform correctly after a change has been made. The scope of testing required for LCSS tests is dependent on the extent of the change and the potential impact of an undetected error. Regression testing is conducted to verify correction of software trouble reports (STRR) and to ensure integrity of previously established baselines. Following IV&V testing, integration and test (I&T) is conducted using system hardware and software. If subsystems are unavailable at I&T, they are usually simulated. Interface testing should be conducted on failed, new, and modified subsystems. This testing should include checking all interface parameters as described in the interface control document. Rehosted software is software that is modified so that it operates on a different host computer. Testing of rehosted software may require extensive retesting if an undetected error could result in injury or death.

Progress towards satisfactory qualification can be measured by examination of metrics pertaining to the status of "open" SCRs and STRRs, and in the results of STRs. It must be noted that the most detailed DT&E of software occurs at the individual programmer level which is significantly lower than the system evaluator's level. Therefore, the system evaluator does not have as intimate a knowledge of the intricacies of the software; this lack of knowledge can contribute to STRRs being written for errors where none actually exist.

As in all system test situations involving software (and particularly in an LCSS situation), follow-on system level testing may not fulfill expectations. If this occurs, a determination should be made as to whether the cause is requirements, hardware, or software-based. Consequently, an iterative process results with eventual resolution and completion of qualification at all levels.

11-12 SYSTEM CALIBRATIONS

The calibration of instrumented parameters required for performance, handling qualities, and other types of flight testing must be highly accurate. Calibration is the procedure used to check, adjust, or systematically standardize the graduations of a quantitative measuring instrument. Typical measurements required for flight testing are airspeed, altitude, attitudes, rates, accelerations (both air vehicle and pilot seat), stick and pedal positions, total and free air temperature, fuel quantity, engine power parameters, rotor speed and torque, and vibration. Special calibrations are used for boresighting systems such as armament, target acquisition designation (TAD), and forward looking infrared (FLIR). Calibrations of navigational equipment, such as inertial, requires tilt tables and other special equipment. Calibration intervals are established based on parameter history, the importance of the parameter, and on what test is being conducted. Each parameter should have established and agreed to specifications for engineering units, range, accuracy, resolution, sample rate, frequency response, time phase relationships, scaling, and calibration well in advance of testing. Government witnessing of calibrations should be conducted.

A typical instrumentation measurement consists of a transducer, a signal conditioning module, and a record module which may be separate components or combined as one or more units. These components together constitute a system that should be calibrated. The transducer converts the parameter (speed, position, angle, rate, acceleration, temperature, RPM, flow, frequency, etc.) to a recordable signal such as a voltage or digital output. These components should be calibrated as a system on the aircraft, with the signals recorded by the air vehicle recording system, and the recorded data decomutated and scaled by the data processing system that should be used for processing final data. Calibrations are accomplished as required based on the calibration history of each parameter.

Digital recording techniques should be used to prevent measurement accuracy degradation during data recovery. Other FM modes, such as narrow band, constant band, and wide band can be used for cases where time phasing or very high frequencies are important. Multiplex or fiber optic databus data are also used for flight test instrumentation. Early in the development process, flight test instrumentation is used to establish the accuracy of the bus data.

Data sampling is another accuracy consideration. Simultaneous sampling of all parameters is desirable goal but usually does not exist. If a time phase relationship exists between parameters presented in a time history tabulation (or plot) or in a multi-measurement calculation, the accuracy obtained in the individual parameters can be lost.

Records of all component and system calibrations should be maintained in a database and comparisons made to prior calibrations. Calibration at several temperatures or at the expected transducer operating temperature may be required in some cases because temperature is often the major factor in measurement error. When strain gage or bridge type transducers (loads and some pressure transducers and accelerometers) are used, wiring lengths can introduce error. These errors are calculated and corrections applied or they are eliminated by a system calibration.

Pitot static calibration is required to be performed early in the flight test program to determine the position error of the system and to establish the accuracy of airspeed and altitude data for all flight conditions to be tested. Several methods may be used to calibrate the pitot static system, to include ground speed courses, and calibrated "trailing bomb" devices. Trailing bombs are devices which have their own pitot and static ports, and have been calibrated in a wind tunnel. This calibrated device is then connected to the air vehicle using cables and tubing and flown at varying airspeeds. The test air vehicle pitot-static data is then corrected to the results provided by the "trailing bomb." The pitot static system calibration may also be conducted in formation flight using another air vehicle with predetermined and known position error corrections.

The instrumentation calibration data are expressed as slope intercepts, table lookups, or a curve fit and applied to the flight test recorded data.

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None

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LIST OF ABBREVIATIONS AND ACRONYMS

A&FC	=	airworthiness and flight characteristics
ADOCS	=	advanced digital optical control systems
ADS	=	aeronautical design standard
AFB	=	air force base
AIM	=	airborne intercept missile
ALSE	=	aviation life support equipment
AR	=	army regulation
ARL	=	army research laboratory
ASE	=	air vehicle survivability equipment
AT	=	acquisition team
ATCOM	=	aviation and troop command
AWR	=	airworthiness release
BDAR	=	battle damage assessment and repair
Bph	=	british thermal units per hour
CBTDEV	=	combat developer
CE	=	continuous evaluation
CFR	=	contractor flight release
CG	=	center of gravity
COIC	=	critical operational issues and criteria
CSC	=	computer software component
CSCI	=	computer software configuration item
CSU	=	computer software unit
cw	=	continuous wave
D	=	displacement, measured in units of length
DA	=	department of the army
DIDS	=	data item descriptions
DoD	=	department of defense
DOD-STD	=	department of defense standard
DOF	=	degree of freedom
DPRO	=	defense plant representative office
DT	=	developmental test
DT&E	=	developmental test and evaluation
ECCM	=	electronic counter-countermeasures
ECM	=	electronic countermeasures
EMCON	=	emission control
EMP	=	electromagnetic pulse
EMRH	=	electromagnetic radiation hazard
EMV	=	electromagnetic vulnerability
EOA	=	early operational assessment
EW	=	electronic warfare
F	=	force, measured in pounds
^{o}F	=	degrees, measured on Fahrenheit scale
FCA	=	functional configuration audit
FLIR	=	forward-looking infrared

FM	=	frequency modulation
FOE	=	follow-on evaluation
FOT	=	follow-on test
FOT&E	=	follow-on test and evaluation
FSD	=	full scale development
FSE		flight simulator evaluation
g	=	normal acceleration
HERO	=	hazards of electromagnetic radiation to ordnance
HWCI	=	hardware configuration item
I&T	=	integration and test
IGE	=	in-ground effect
IMC	=	instrument meteorological conditions
IOT	=	initial operational test
IPT	=	integrated product team
IR	=	infrared
IV&V	=	independent verification and validation
KIAS	=	knots indicated airspeed
LCSEC	=	life cycle software engineering center
LCSS	=	life cycle software support
LFT	=	live fire test
LRIP	=	low rate initial production
LTF	=	lead-the-fleet
MAA	=	mission area analysis
MATDEV	=	materiel developer
MDS	=	model, design, and series
MEP	=	mission equipment package
MER	=	memorandum of effort report
MET	=	mission task element
MJWG	=	manprint joint working group
MIL-STD	=	military standard
NBC	=	nuclear, biological, and chemical
OAT	=	outside air temperature
OEI	=	one engine inoperative
OFE	=	operational flight envelope
OGE	=	out-of-ground effect
OIPT	=	overarching integrated product team
OT		operational test
OT&E	=	operational test and evaluation
PA	=	procuring activity
PAE	=	preliminary army evaluation
PCM	=	pulse code modulation
PDSS	=	post-deployment software support
RAM	=	reliability, availability, and maintainability
REV	=	revolution
RF	=	radio frequency

RPM	=	revolution per minute
QSTAG	=	quadripartite standardization agreement
SAM	=	surface-to-air missile
SAS	=	stability augmentation system
SCR	=	system software change requests
SDC	=	sample data collection
SDF	=	software development folder
SEMI	=	special electromagnetic interference
SFE	=	service flight envelope
SLAD	=	survivability/lethality analysis directorate
SOW	=	statement of work
SRS	=	software requirements specification
STAR/STA	=	system threat assessment report/system threat assessment
STD	=	software test descriptions
STP	=	software test plan
STR	=	software test report
T&E	=	test and evaluation
TAD	=	target acquisition designation
TECOM	=	test and evaluation command
TEMP	=	test and evaluation master plan
TFE	=	technology flight evaluation
TIWG	=	test integration working group
TREE	=	transient radiation effects on electronics
USAF	=	united states air force
VMC	=	visual meteorological conditions
V/STOL	=	vertical/short takeoff and landing
VTOL	=	vertical take-off and landing
WIPT	=	working level integrated product teams

APPENDIX A
THE ELEMENTS OF AN AIRWORTHINESS QUALIFICATION PLAN (AQP)

A-1 INTRODUCTION

AR 70-62, *Airworthiness Qualification of US Army Aircraft Systems*, (Ref. 1) assigns approval authority for airworthiness of standard and nonstandard Army air vehicles to the Commanding General (CG), US Army Aviation and Troop Command (ATCOM), for all air vehicles and modifications for which ATCOM has engineering cognizance. Air vehicles classified as nonstandard by the Army are normally acquired from other services and federal agencies. Included in this responsibility is the requirement to develop, implement, and maintain a coordinated program for airworthiness qualification of air vehicle systems, subsystems, and allied equipment. Subsystems and allied equipment are defined in AR 70-62 (Ref. 1). AR 70-62 also states that the individual air vehicle or developmental program, project, product manager's office (PMO) is responsible for funding airworthiness qualification efforts and ensuring that the airworthiness of the air vehicle system has been determined. One of the elements of a coordinated airworthiness qualification program is the airworthiness qualification plan (AQP). Either an AQP or fully coordinated statement of work should be required for every acquisition involving qualification. The statement of work should satisfy the same objectives as an AQP. The AQP should convert the general requirements of the operational requirements document (ORD) and acquisition policy into performance and effectiveness criteria. Also, air vehicle design criteria, performance, and limitations to be substantiated for airworthiness qualification should be defined. Objectively, the AQP should not only define means for determining if an air vehicle is airworthy but should also define the means for determining if it will satisfy user required functions and necessary operational capabilities. Survivability and mission performance are major components of the effectiveness of a system. Guidelines for test and evaluation may be found in Department of the Army (DA) Pamphlet (PAM) 73-series, *Test and Evaluation Guidelines*, (Ref. 2). In the larger sense, the AQP should define what is required, when required, where required, who will do it, and how. The need for targets and threat simulators should be defined within this plan. The AQP should be prepared by their respective air vehicle or developmental PMO. Engineering personnel within the PMO should prepare this plan in coordination with functional offices within the ATCOM, US Army Training and Doctrine Command (TRADOC), and other program managers, as applicable. The completed plan can be used in a request for proposal (RFP), request for quotation (RFQ), or included as an addendum to a statement of work (SOW), all for use by the air vehicle contractor (AC) in preparing an airworthiness qualification specification (AQS) and related data as contract deliverables. Depending on the type of program involved (full development or modification of existing air vehicle), the AQP should fulfill its purpose of delineating minimum requirements necessary to verify that the air vehicle and its components are qualified for use during developmental or operational test, or in operational aviation units. Contents of the AQP will be discussed in the following paragraphs.

A-2 AQP CONTENTS

A-2.1 SCOPE[*]

The Scope of the AQP should identify:

1. Required reviews
2. Performance based requirements
3. System safety tasks - information pursuant to this purpose may be found in MIL-STD-882, *System Safety Program Requirements* (Ref. 3)
4. Analysis, modeling, test, survey, and demonstration tasks
5. Mock-up and simulation requirements
6. Procurement, material, and process specification requirements and qualification
8. Functional, structural, environmental, endurance, bench, and survivability tests
9. Provisions for qualification by similarity
10. Software verification and validation (V&V)
11. RAM tests and demonstrations
12. Integrated logistic support (ILS) V&V.
13. Government test. Responsibilities for accomplishment, surveillance or test witnessing, and support for each task should be established in this paragraph.

A-2.2 REFERENCES

For modification programs involving a limited number of components, required specifications, standards, and other references may be cited in this paragraph. For major modification or developmental programs, each paragraph of the AQP should cite applicable specifications, standards, and data submittal requirements, or the requirement for the contractor to develop (and submit for approval) process specifications. Appropriate paragraphs of this handbook should be cited as necessary to further define qualification requirements.

A-2.3 TEST ACCOMPLISHMENT

A-2.3.1 TEST SPECIFICATION

The AQP should specify how the AQP will be used in developing the contractor's airworthiness qualification specification (AQS). Appropriate paragraphs of this handbook should be cited as a guide for preparation of the AQS. Reporting requirements for all applicable tasks of subparagraph A-2.1 should be identified, and Government approval requirements should be specified. This element should refer to the airworthiness qualification specification (AQS) discussed in par. 2-3 and other applicable test specifications. By doing this, traceability of test requirements can be maintained. This traceability will ensure that all required testing is planned, and that any element of the AQS or other test specifications is required by the AQP.

A-2.3.2 TEST ARTICLE AND AVAILABILITY

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[*] The underlined portion of the paragraph number and title identifies the paragraph number and title in the AQP.

The minimum requirements for numbers and types of test articles should be identified. Prequalification and qualification of test articles, (which include but are not limited to components, subsystems, ground test vehicles, and complete air vehicle), should be specified in sufficient detail to allow the AC to use this information to develop an AQS and a master test schedule.

A-2.3.3 <u>TEST FACILITIES</u>

The degree of Government participation in all development test (DT) and operational test (OT) phases should be specified. Guidance should be provided to the AC concerning use of Government test facilities during DT phases. Requirements for contractor furnished equipment (CFE) at Government locations during DT should be identified. Locations and facilities for each phase of OT should be identified. Unless there is a cost or schedule advantage in using contractor facilities, Government OT and DT locations and facilities should be identified and used. Test facilities are identified in DA PAM 73-series (Ref. 2).

A-2.3.4 <u>TEST EQUIPMENT</u>

Guidance should be provided to the contractor concerning support equipment, instrumentation, threat systems and simulators, allied equipment, and test support air vehicle requirements. Government furnished equipment (GFE) should be identified. Commonalty of DT and OT instrumentation and support equipment should be specified by the procuring activity (PA). The Test and Evaluation Master Plan (TEMP) for the system should be referenced and used to further identify sequencing and requirements for threat systems, simulators, allied equipment, and test support air vehicles.

A-2.4 <u>TEST MANAGEMENT</u>

The AQP should specify the required level of Government participation in test conduct and witnessing or surveillance. In order to allow Government personnel to participate in or witness tests, requirements for advance notification of upcoming tests should be specified. A system to be used for managing Government and contractor test coordination should be specified. Test management which may be required by the AQP is discussed in par. 2-5. Requirements for approval of plans and reports submitted by the AC should be specified.

A-2.5 <u>DOCUMENT GENERATION</u>

Within the AQP, submittal of required plans, procedures, reports, analyses, and engineering drawings should be specified, as applicable. The Contract Data Requirements List (CDRL) furnished by the PA typically will specify due dates for initial and subsequent submissions, and Government review cycle times. When Government data will be used by the AC to generate a required report, data reduction responsibilities should also be covered in the AQP.

Bibliography
None

LIST OF ACRONYMS AND ABBREVIATIONS

AC	=	air vehicle contractor
AEFA	=	aviation engineering flight activity
AQP	=	airworthiness qualification plan
AQS	=	airworthiness qualification specification
ATCOM	=	aviation and troop command
CDRL	=	contract data requirements list
CFE	=	contractor furnished equipment
CG	=	commanding general
DA	=	department of the army
DT	=	development test
GFE	=	government furnished equipment
ILS	=	iterated logistic support
ORD	=	operational requirements document
OT	=	operation test
PA	=	procuring activity
PAM	=	pamphlet
PMO	=	program/project/product management
RFP	=	request for proposal
RFQ	=	request for quotation
SOF	=	statement of work
TEMP	=	test and evaluation master plan
TRADOC	=	us army training and doctrine command
V&V	=	verification and validation

REFERENCES

1. AR 70-62, *Airworthiness Qualification of US Army Aircraft Systems*, 25 July 1978.

2. DA PAM 73-1 through -8, *Test and Evaluation Guidelines*, 16 October 1992.

3. MIL-STD-882C, *System safety Program Requirements*, 19 January 1993.

APPENDIX B
THE ELEMENTS OF AN AIRWORTHINESS QUALIFICATION SPECIFICATION (AQS) AND THEIR CONTENTS

B-1 INTRODUCTION

The airworthiness qualification specification (AQS) should be prepared by the air vehicle contractor (AC) in response to the requirements established by the procuring activity (PA) in the airworthiness qualification plan (AQP) and the contracts data requirements list (CDRL). The PA should require that the AC prepare for its approval an airworthiness qualification specification (AQS) for each air vehicle and system that requires qualification or requalification because of major modifications. The AQS should identify the means (reviews, analyses, tests, modeling, and demonstrations), performance, and effectiveness criteria needed to validate compliance with the system specification and airworthiness qualification plan. This should include contractor conducted tests with Government surveillance, and also Government conducted tests with contractor support and surveillance. Facilities, targets, and simulators should be identified in the AQS. Pass-fail criteria should be identified by the AC and approved by the PA. A compliance matrix is typically required as part of the AQS.

The minimum scope of the AQS should satisfy all requirements of the AQP but should not necessarily be limited to requirements in the AQP. ACs may propose additional tests, surveys, reviews, and demonstrations deemed necessary to ensure qualification of the modification or development program.

For modifications involving few components or subsystems, the scope of the airworthiness qualification specification (AQS) should be limited to only those systems modified and those related components and subsystems that are affected by modifications and should be subjected to qualification. Modification programs that involve many components or development programs may require an AQS that essentially involves all areas covered by this handbook.

For such extensive modifications or developments, all major elements of an AQS are described in paragraph B-3. The use of distribution statements as provided for in Department of Defense Directive Number 5230.24, *Distribution Statements on Technical Documents,* (Ref. 1) should be considered for use on sensitive technical information.

B-2 OBJECTIVES OF THE MAJOR ELEMENTS

As cited in Department of Defense Regulation DoDR 5000.2-R, *Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated Information System (MIAs) Acquisition Programs*, (Ref. 2) technical management processes should be applied to reduce technical risk through early test and demonstration of system elements. The major elements of the AQS serve to identify, control, and/or reduce the technical risk associated with modification and development programs from project inception until publication of the Airworthiness Qualification Substantiation Report (AQSR).

Providing aviation systems which are safe for operators is also an objective of the AQS elements. Through the System Safety Program (SSP), establishment of operating limitations, restrictions, and advisory "Notes," "Cautions," and "Warnings" in technical publications, and determination of component fatigue lives, only acceptable risks to operators are present when the airworthiness qualification program is completed.

Various elements of the AQS also aid in conservation of both contractor and Government assets. As part of a coordinated test program, the AQS delineates facilities to be used, minimum testing requirements, test articles to be used, and responsibilities for conduct, reporting, and support. In this way, duplication of effort is eliminated.

Finally, knowledge of mission capability will be enhanced by use of an AQS. Verification of air vehicle ranges, velocities, mission radii, target detection, acquisition, designation, and engagement capabilities, reliability, availability, and maintainability (RAM) characteristics, and other operational capabilities is necessary to verify specification compliance.

B-3 MAJOR AQS ELEMENTS

A tailored set of AQS elements should be identified for the air vehicle development program. These elements will be chosen from the various elements listed below.

B-3.1 SCOPE[*]

This element of the AQS should identify the system being modified or under development, and all variants of that system covered by this AQS. Variants may include models with common dynamic components, but different crew, cargo, and mission equipment package (MEP) configurations, and coproduction versions of the air vehicle .

The purpose of the AQS is to define the approach which will be used by the air vehicle contractor (AC) to satisfy the requirements of the airworthiness qualification plan (AQP), described in Appendix A. The minimum scope of the AQS should satisfy all requirements of the AQP, but should not necessarily be limited to requirements of the AQP. ACs may propose additional tests, surveys, reviews, and demonstrations deemed necessary to ensure qualification of the modification or developmental program.

Essential elements of the AQS include:

1. System Safety
2. Design Review and Release of Drawings
3. Mock-ups
4. Procurement and Process Specifications
5. Component Tests
6. System Surveys
7. Formal Contractor Demonstrations. Together, these elements should form the minimum effort which the AC should expend to ensure that the system developed or modified is qualified for its intended mission, operational, and maintenance environment.

Acquisition cycle phases to which the AQS applies should be identified, as well as the end product of the qualification program (prototype air vehicle or low rate initial production [LRIP] modified air vehicle). If publication of an AQSR for the end product will result from satisfaction of this AQS, that fact should be noted.

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[*]The underlined portion of the paragraph number and title identifies the paragraph number and title in the AQP.

The initial AQS should be prepared by the AC in response to requirements of the request for quotes/request for proposals (RFQ/RFP) developed by the procuring activity (PA). Revision during the development or modification program is often necessary, and the end result will be documentation of the complete qualification effort from RFP/RFQ through fielding of the system. While this effort may be limited for a modification of a previously qualified air vehicle, air vehicles undergoing developmental testing may have more extensive qualification requirements.

This element of the AQS should provide a brief summary of major subsystems undergoing modification, weapons systems which are being developed concurrently and will form a part of the end item (engine development programs, for example, and other information necessary to convey the magnitude of the qualification effort. Responsibilities for accomplishment, surveillance or test witnessing, and support for each AQS element identified in the AQP should be reiterated in this paragraph, and may be identified down to the AQS subelement level, if necessary for clarity.

B-3.1.1 SYSTEM SAFETY

The objective of a system safety program (SSP) is to ensure that, consistent with mission requirements, safety is designed into all materiel, facilities, and support equipment. Relevant information can be found in MIL-STD-882 (Ref. 3). Also, coordination with the environmental hygiene and aeromedical communities of the US Army Health Services Command in support of the requirements of Army Regulation (AR) 40-10, *Health Hazard Assessment,* (Ref. 4) and in support of DoD Acquisition Procedures (Ref. 2), which applies to commercial off-the-shelf (COTS) systems and nondevelopment items (NDI) as well as new developmental systems, is recommended.

To satisfy both qualification and other program requirements, a tailored deliverable stand-alone safety assessment report, including but not limited to results of tailored hazard analyses, and the initiation of hazard tracking, typically should be required. Full development programs may require incorporation of all MIL-STD-882 (Ref. 3) tasks and incorporation of tailored tasks or selected tasks. Only the tasks, rather than the military standard should be specified.

Selected tasks should be identified, and, in the event tasks are tailored, the extent of the tailoring should be specified in the AQS; however, due to the extent of the plan, inclusion by reference may be necessary. In the case of a limited modification program, applicable tasks may be included in the AQS for simplicity. Chapter 3 provides a complete description of the SSP.

B-3.2 APPLICABLE DOCUMENTS

As stated earlier in Chapter 4, applicable documents are documents included by reference in the AQS. All and only those document s referenced elsewhere in the AQS should be listed. If referenced documents are numerous, this listing may occur in an appendix to the AQS.

As system complexity and the number of recognizable subsystems increases, the AC should prepare a specification tree. This tree should contain a listing of all system, subsystem, equipment assembly and component specifications which will be required to support the acquisition, qualification, and spare parts procurement processes. Control of this tree should allow the documents listed in TABLES 4-1 and 4-2 to be related to each system, subsystem, equipment, assembly, and component, and ensure that each specification adequately defines the actual minimum needs of the Government.

References should be listed by document numbers and titles, and may include specific issues or revision numbers where necessary to rigidly control configuration or implementation. Within the text of the AQS, tailoring or modification of requirements of the referenced documents should be identified. The entire referenced document should not be made applicable by reference unless all of its provisions are clearly required.

B-3.3 DEFINITIONS

The inclusion of definitions for terms or phrases can be avoided if requirements are properly stated. If terms must be defined in the AQS, relevant information can be found in MIL-STD-961, *Standard Practice for Defense Specification*, (Ref. 5).
If appropriate, a definition of the system or functional areas, and functional and physical interfaces, include logic, block, and schematic diagrams, and contain pertinent configuration item undergoing airworthiness qualification should be included in this element of the AQS in the form of a brief description. This definition should identify major physical parts, organizational, operational, and logistics considerations and concepts. If multiple common definition terms are used (future attack rotorcraft [FAR] and Federal Acquisition Regulation [FAR], for example, are used, the applicability and use of these terms should be clearly identified, and the terms defined.

B-3.4 GENERAL REQUIREMENTS

Essential performance requirements which apply to design, reliability, personnel, subsystems, etc., of the aviation system, subsystem, or component, should be stated in this section. These performance requirements apply to all facets of the program.

In contrast, detail requirements apply to only certain components or subsystems. These detail requirements should be stated in subpar. B-3.5.

The subpars. that follow provide essential general requirements for airworthiness qualification for modification and developmental aviation programs.

B-3.4.1 TECHNICAL REVIEWS

Chapter 4 (Par. 4-6 1) covers the purposes and types of technical reviews involved in a modification or developmental program. Also, relevant information can be found in MIL-STD-973, *Configuration Management* (Ref. 6) or equivalent interface standard. The PA should determine the type and frequency of required reviews based on the nature of the program. These reviews may be either technical or non-technical (cost and schedule). Reviews should be conducted to ensure completion of scheduled activities, highlight problem areas, and determine appropriate courses of action to resolve problems. These criteria should be applied when establishing the need for program reviews. For example, qualification of a second source for a component which has an approved design may not require all types of reviews.

When not specifically scheduled by the PA, the AC should schedule required reviews in a manner which will logically support the design and qualification process. The contractor's Systems Engineering Management Plan (SEMP) may be referenced for detailed scheduling and planning of program reviews. Program events, such as milestone decision points, first flight of prototypes, and gunfire testing, should be considered in scheduling these reviews. Agendas, topics for discussion, approval processes, and minutes for each review should be as specified by the PA in the Contract Data Requirements List (CDRL), DD Form 1423, and supported by Data Item Descriptions (DIDs), DD Form 1664.

Chapter 4 contains more detailed information on the types and purposes of reviews.

B-3.4.2 DATA AND DOCUMENTATION

Data and documentation required to support the airworthiness qualification process should be supplied in accordance with Government direction. DIDs used should be cited, including AQS paragraph number(s) and data requirement titles.

Delivery schedules and methods should be specified in a contractor-prepared CDRL based on Government requirements. When tailoring or contractor format is proposed, changes to DIDs should be reflected in the subject CDRL. Within the AQS, components, computer software configuration items (CSCIs), or subsystems requiring data submissions may be cited along with the appropriate DID. For programs which involve few components, CSCIs, or subsystems, these may be identified in the CDRL.

B-3.4.3 QUALIFICATION ASSURANCE

Depending on the nature of the program, the AC should propose selected elements of the program necessary to ensure specification compliance. Hardware, software, instrumentation, Government participation and approval, validation of test facilities and simulations, testing and specification practices, tooling, standardization, and producibility should be considered for inclusion. Application of selected elements should support transition from development to production.

Chapter 5 of this handbook describes the elements and purposes of the elements of a qualification assurance program. These major elements of the qualification assurance program should be selectively applied (tailored) to fit the scope of the developmental or modification effort. While some may not apply, the contractor should ensure that the elements critical to transition from development to prototype construction to full-rate production are specification compliant.

B-3.5 DETAIL REQUIREMENTS

Detail requirements apply to only certain components or subsystems while general requirements apply to all facets of the program. These detail requirements provide essential detailed requirements for airworthiness qualification of components, subsystems, and CSCIs for modification and developmental aviation programs. The typical detailed requirements of an airworthiness qualification program are described in the following paragraphs.

B-3.5.1 MODELING

Based on PA requirements, the AC should define in the AQS models which should be used to verify airworthiness qualification. The contractor should also define his validation processes, method of updating models throughout the development program, and the extent to which models should reflect actual air vehicle or subsystem configuration. The use of models for multiple purposes should also be defined Models may be either physical models (such as aerodynamic models, mock-ups, or ground test vehicles) or simulations. Chapter 6 provides more information about the use of models in the airworthiness qualification process.

B-3.5.2 COMPONENT TESTS

This element of the AQS should provide component qualification procedures which satisfy the requirements set forth in the AQP. The AC should also include identification of components which will undergo the four main types of qualification testing:

1. Functional qualification in accordance with par. 7-5: These tests are usually based on general specifications for that type of component, and should be conducted using a test environment which is similar to the anticipated operational environment. Monitoring of test parameters should be performed.

2. Structural qualification in accordance with par. 7-6: This qualification involves structural design criteria (to include materials and processes), analysis and test of design (fatigue integrity), structural integrity verification, and structural integrity maintenance. Design philosophies should be documented, plans for monitoring of fatigue critical components explained, and structural integrity verification and maintenance plans described.

3. Endurance and screening qualification in accordance with par. 7-8: This testing and screening is intended to identify failures in the laboratory, where the causes of failure are much less expensive to correct than on a fielded system.

4. Environmental testing in accordance with paragraphs 7-9 and 7-10: Environmental qualification should be divided into physical and electromagnetic environment qualification sections, as appropriate. These test conditions should include all expected environmental stresses which the equipment will be subjected to. TABLE B-1 "Component Qualification Matrix" provides a sample component qualification matrix of typical air vehicle components which have airworthiness implications. By completing a similar matrix, the AC should identify the specific components and planned qualification testing for those components. As can be seen from the sample matrix, a minor modification program involving only a few components will permit significant tailoring of the matrix. A full developmental program may well involve many more components than those listed.

If Federal Aviation Administration (FAA) structural qualification is to be used, those procedures should also be identified in this element of the AQS. Other areas to be addressed, as applicable, include the contractor's methods for parts control, survivability, optical and electrooptical, material, process, and spares and repair parts qualification.

Chapter 7 provides more detailed discussions of component test requirements.

B-3.5.3 SUBSYSTEM QUALIFICATION

This element of the AQS should describe qualification of major subsystems and their interface effects with other subsystems and components. For developmental programs, all components effecting airworthiness should be considered, and their qualification procedures identified. For modification programs, only those subsystems added, modified, or affected by addition or modification of other components should be considered.

Chapter 8 covers major subsystem qualification requirements. These major subsystems which may require airworthiness qualification are shown in the second column of TABLE B-2, "Subsystem Interface Qualification Effects." A table similar to TABLE B-2 should be included in the AQS to define subsystem qualification requirements and interface effects. In all modification or developmental programs, the interface effects of subsystems should be defined. For developmental programs, all major components should be listed under their appropriate subsystem.

The example shown in the sample TABLE B-2 is for the addition or modification of an auxiliary power unit (APU). APU addition or modification may have an effect on engine performance (starting, hydraulic, pneumatic, and cabin pressurization subsystems electrical power subsystem analysis, electrical and electronics cooling subsystems), cockpit and instrument lighting subsystems, and environmental control subsystems. For the APU modification or addition, these subsystems must be requalified according to the procedures specified in the corresponding subparagraph of this handbook. These subparagraphs are cited to the right of the APU entry in the table, indicating that qualification activities described in those subparagraphs must be performed in addition to those for the APU because of the interactions between the APU and their systems.

Other effects of addition or modification may have airworthiness impacts which are not covered in Chapter 8. AR 70-62, *Airworthiness Qualification of US Army Aircraft Systems*, (Ref. 7) defines those modifications which require qualification.

B-3.5.4 SYSTEM QUALIFICATION

This element of the AQS should describe how the air vehicle system will be qualified once subsystems have been qualified. Major system will be qualified once subsystems have been qualified. Major system qualification concerns are covered in Chapter 9, and include these major areas:

1. Structural integrity demonstration
2. Propulsion and power demonstration
3. Flight load survey
4. Dynamic Stability
5. Aerodynamic demonstration
6. Vibration testing
7. Acoustic noise testing
8. Climatic laboratory testing
9. Icing flight tests
10. Electromagnetic Environmental Effects (E) tests
11. Weapons systems effectiveness tests
12. External stores separation testing

TABLE B-1
COMPONENT MATRIX

QUALIFICATION TEST TYPE	COMPONENT TYPES									
	STRUCTURAL				ELECTROMECHANICAL			HYDROMECHANICAL		
	Rotor Blades	Drive Shafts	Castings	Crew Seats	Generator/ Alternators	Fuel Boost Pumps	Oil Cooler Fan	Landing Gear Oleo Strut	Flight Control Actuator	Landing Gear Retraction Cylinder
Functional	1	1	1	1	1	1	1			
Structural	1	1	1	1	1	1	1	1	1	1
Endurance & Screening	2	2	2	2	2	2	2	2	2	2
Environmental					2	2	2			

QUALIFICATION TEST TYPE	COMPONENT TYPES							
	MECHANICAL			ELECTRICAL		AVIONICS		
	Rotoro Hub	Transmission	Overriding Clutch	Voltage Regulator	Anti-icing/Deicing Element	Radio	Intercom	Mission Computer
Functional	2	2	2	1	1	2	2	2
Structural	1	1	1					
Endurance & Screening	2	2	2	2	2	2	2	2
Environmental				2		2	2	2

KEY: 1. PRE-INSTALLATION REQUIREMENT
2. PRE-FLIGHT REQUIREMENT

SOURCE: SDI

13. Survivability testing
14. Avionics testing
15. Test-analyze-fix-test.

Details of the required testing are included in chapter 9. For a major modification or developmental program, all areas may need inclusion in the AQS. Unarmed air vehicles obviously would not need weapons systems effectiveness testing, and minor modification may need application of only a few areas. In major modification and development programs, changes in one subsystem will have an effect on other subsystems and total system performance, as shown in TABLE B-2. The synergistic effects of combining subsystems into a total air vehicle system should be considered in this section of the AQS.

B-3.5.5 FLIGHT SAFETY PARTS QUALIFICATION

Flight safety parts (FSP) are covered in paragraph 3-13. Special qualification requirements are required for these parts, and are covered in subpar. 3-13.2. The contractor should identify their proposed procedures for qualifying FSP, how FSP will be identified, how records will be maintained for FSP, how surveillance will be performed on FSP, and how FSP will be disposed.

B-3.5.6 OPERATIONAL READINESS QUALIFICATION

AR 702-3, *Army Materiel Systems Reliability Availability. and Maintainability* (Ref. 8) defines operational availability, or readiness, as the proportion of time that a system is either operating or is capable of operating, when used in a specific manner in a typical maintenance and supply environment. The contractor should specify in element 5.6 the AQS planned testing to support this qualification. Accounting methods used for calendar time in a specific period may need to be identified and considered in calculating this proportion. Elements of this calendar time are defined in the glossary of AR 702-3 (Ref. 8), and include operating time (OT), standby time (ST), total corrective maintenance downtime (TCM), total preventive maintenance downtime (TPM), and total administrative and logistics delay time (TALDT). The contractor should specify all deviations from AR 702-3 (Ref. 8) definitions in his AQS.

Operational readiness qualification is covered in more detail in Chapter 10.

B-3.5.7 PREPARATION FOR GOVERNMENT TEST

The AC should identify prerequisites for Government test. These prerequisites may be in the form of events to be completed or resource requirements. The AC should identify all pretest qualification events, instrumentation requirements, and shipping, training and maintenance support. Particular emphasis should be placed on Government support to developmental test and proposed contractor participation in operational test.

B-3.6 GUIDANCE INFORMATION

This element should contain any guidance received by the contractor in preparation of the AQS. This section and associated subsections are provided for information only.

B-3.6.1 TEST INTEGRATION WORKING GROUP (TIWG)

AR 73-1, *Test and Evaluation Policy*, (Ref. 9) provides for the air vehicle program manager (PM) to form and chair a TIWG for programs involving test and evaluation (T&E) for undemonstrated requirements. For fielded air vehicles subject to minor modifications, the TIWG may not be required.

The TIWG serves to implement T&E coordination and solve routine T&E problems. This element of the AQS should detail contractor participation in, and proposed areas for consideration by, the TIWG. Airworthiness qualification areas which have significant risk should be identified in this element.

B-3.6.2 INTEGRATED PRODUCT TEAM (IPT)

This element of the AQS should document all IPTs participating in the decision process. These IPTs should consider both hardware and software. Proposed plans of action and milestones should be documented.

B-3.6.3 GOVERNMENT TESTING

Requirements for Government test participation, witnessing or surveillance, and logistics and maintenance support for Government test should be described in this element of the AQS. The contractor should identify support he will provide in these areas. Independence of Government testing should be addressed, as well as responsibilities for data collection and management, and test planning and reporting.

B-3.6.4 USE OF GOVERNMENT TEST FACILITIES

Government test facilities required for airworthiness qualification should be identified and described in this element of the AQS. When a unique Government test facility, such as an anechoic chamber or large test range, is needed, justification should be provided for use of this facility. Anticipated dates and duration of usage should be provided. When significant Government testing is proposed, this information may be shown in a table or by a graphic.

APPENDIX B
LIST OF ACRONYMS AND ABBREVIATION

AC	=	air vehicle contractor
APU	=	auxiliary power unit
AQP	=	airworthiness qualification plan
AQS	=	airworthiness qualification specification
AQSR	=	airworthiness qualification substantiation report
AR	=	army regulation
AQS	=	airworthiness specification
CDRL	=	contract data requirements list
COTS	=	commercial off-the-shelf
CSCIs	=	computer software configuration items
DIDs	=	data item descriptions
E^3	=	electromagnetic environmental effects
FAA	=	federal aviation administration
FAR	=	federal acquisition regulation
FSP	=	flight safety parts
LRIP	=	low rate initial production
MEP	=	mission equipment package
NDI	=	nondevelopment items
OT	=	operating time
PA	=	procuring activity
PM	=	program manager
RAM	=	reliability, availability, maintainability
RFQ/RFP	=	request for quote/request for proposal
SEMP	=	systems engineering management plan
SSP	=	system safety program
ST	=	standby time
T&E	=	test and evaluation
TALDT	=	total administrative and logistics delay time
TCM	=	total corrective maintenance downtime
TIWG	=	text integration working group
TPM	=	total preventive maintenance downtown

REFERENCES

1. DoDD 5230.24, *Distribution Statements on Technical Documents,* 18 March 1987

2. DoDR 5000.2-R, *Mandatory Procedures for Major Defense Acquistion Programs (MDAPs) and Major Automated Information System (MAIS) Acquisition Programs,* 15 March 1996.

3. MIL-STD-882. *System Safety Program Requirements,* 30 March 1994.

4. AR 40-10, *Health Hazard Assessment,* 1 October 1991.

5. MIL-STD-961, *Department of Defense Standard Practice for Defense Specification,* 22 March 1995.

6. MIL-STD-973, *Configuration Management*, 17 April 1992

7. AR 70-62, *Airworthiness Qualification of US Army Aircraft Systems*, 15 July 1978.

8. AR 702-3, *Army Materiel Systems Reliability Availability and Maintainability, 25 March 1985.*

9. AR 73-1, *Test and Evaluation Policy*, 27 February 1995.

APPENDIX C
ELEMENTS OF A CONTRACTOR FLIGHT RELEASE (CFR)

C-1 INTRODUCTION

AR 95-20, *Contractor's Flight and Ground Operations*, (Ref. 1) establishes requirements for all ground and flight operations by contractors using Government air vehicles for which the Government has assumed some of the risk. AR 95-20 also identifies approving authorities for contractor operations.

The US Army Aviation and Troop Command (ATCOM) has airworthiness authority for all air vehicles for which it has engineering cognizance. The scope of this authority is provided in Army Regulation (AR) 70-62, *Airworthiness Qualification of US Army Aircraft Systems*, (Ref. 2). ATCOM signifies acceptance of airworthiness responsibility by issuing a contractor flight release (CFR), airworthiness release (AWR), or statement of airworthiness qualification (SAQ). An agency, other than the US Army having engineering cognizance of an air vehicle typically signifies its acceptance of airworthiness responsibility by some other means, such as a type certificate. A CFR might not be required for a leased air vehicle when the contractor assumes all liability.

As provided for in AR 95-20 (Ref. 1), the Government flight representative (GFR) is responsible for surveillance of all contractor flight and ground operations involving the previously described air vehicles. As such, the GFR might want assurance that a Government furnished air vehicle is airworthy.

A contractor might want the Government to assume part (or all) of the liability for flight test operations. Also, ATCOM Engineering might want assurance that a contractor has complied with airworthiness requirements contained within a contract. Hence, the ATCOM contract clauses often include issuance of a CFR as a precondition for flight. Such contract clauses might require a CFR prior to the maiden flight of a prototype or initial flight following major modification, or upon request by the program, project or product manager (PM), weapon systems management officer (WSMO), Government plant representative office, Government flight representative (GFR), or contracting officer (KO).

Format of the CFR should be in accordance with the approving authority's established standing operating procedure (SOP) or outside military command(s) or agency general correspondence format.

The use of distribution statements as provided for in Department of Defense Directive Number 5230.24, *Distribution Statements on Technical Documents*, (Ref. 3) should be considered for use on sensitive technical information.

C-2 CONTENTS

Contents should be as specified in the following paragraphs.

C-2.1 ADMINISTRATIVE INFORMATION

The administrative information that follows should be provided in the letter of transmittal or prior to the main body of the CFR.

C-2.1.1 ADDRESSEE

A letter of transmittal by the point of contact (POC) to transmit the CFR through the GFR and to management of the contractor. Only a POC can transmit an approved CFR to a contractor. The first and second tier technical points of contact should be identified on the cover sheet or within the transmittal letter. Typically, these technical POCs will be the GFR and the air vehicle systems engineer at the procuring activity (PA), respectively.

C-2.1.2 SIGNATURE, REVISIONS, AND DATE

Technical approval is usually indicated by the ATCOM Director of Engineering signing the cover page of the CFR. Typically, all technical content is coordinated and validated by the appropriate technical offices and safety office prior to being signed by the Director. Any identified hazard or risk should have been eliminated or reduced to an acceptable level. Also, security markings and classified information should be coordinated with the security office of the approving authority. A classified CFR should not be sent to a GFR or contractor unless they are authorized to receive the data. The Director approves the basic CFR and all revisions to the CFR. Revision number and effective date should be included on the cover sheet or first sheet of the CFR. Unless there is an SOP-related limitation on the number of revisions prior to the issuance of a new CFR, the CFR with the highest revision number should supersede all previously issued CFRs.

C-2.1.3 SUBJECT/SCOPE

The cover sheet or first page of the CFR should clearly identify that this is a contractor flight release for a specific type (ground or flight) of test, evaluation, or operation of one model, design, and series Army air vehicle with identifying serial number(s). Model, design, and series prefixes and suffixes should be included.

An example follows:

CONTRACTOR'S FLIGHT RELEASE FOR FLIGHT TEST OF YAH-68A HELICOPTERS SERIAL NUMBERS 95-00001, 95-00002, AND 95-00003 or SERIAL NUMBERS 95-00001 THROUGH 95-00003 INCLUSIVE.

C-2.1.4 TERMINATION

Prior to the main body of the CFR, a termination date or clearly defined event for cancellation of the CFR should be identified. This termination date or event is defined as the date or completion of event after which this CFR or revision is no longer valid. For example, the termination provisions should read: "This CFR/revised CFR is terminated upon completion of Stability Augmentation System Testing, defined in Contractor Test Plan Number XXYYZZ, or on date (DAY MONTH YEAR), whichever is sooner."

C-2.2.1 REFERENCES*

References cited in the main body of the release should be listed in the order in which they are referenced, or they may be included in an appendix. If an appendix is used, that appendix should be cited in this paragraph. Operations and maintenance manuals, contract numbers, Government and contractor specifications, test plans, previous Federal Aviation Administration or military (FAA or MIL) type certificate(s), and systems safety assessments should be cited as appropriate. CONTRACT NUMBER CONTRACTOR'S SPECIFICATION NUMBERS ###### (AS NECESSARY TO DEFINE CONFIGURATION) OPERATOR'S _________________MANUALS AND CHECKLISTS TM 55-1520-XYZ-10 AND TM 55-1520-XYZ-lOCL (DRAFT AND/OR FINAL, WITH CHANGES CITED) CONTRACTOR'S APPROVED GROUND AND FLIGHT OPERATIONS PROCEDURES NUMBER ###### CONTRACTOR'S APPROVED TEST PLAN NUMBER AABBCC MAINTENANCE MANUALS TM 55-1520-XYZ-23 (DRAFT AND/OR FINAL, WITH CHANGES CITED) MODIFICATION WORK ORDERS (MWOs) AND TECHNICAL BULLETINS (TBs) INCORPORATED. Fig. C-l. CFR Generic References Example C-2.2.2 REVISIONS

Revisions to the CFR should be documented in tabular format. Minimum contents of this table should include revision number and date, a brief description of changes, and identification of affected pages. An example of revision documentation is shown in TABLE C-l. If there is an SOP-related reissue of the CFR due to the number of changes, the baseline CFR which these revisions have changed should be identified.

TABLE C-1

TYPICAL CFR REVISION TABLE

REVISION ACCOMPLISHMENTS		DESCRIPTION OF CHANGES	PAGES
REVISION NUMBER	DATE AFFECTED		
R-1	DDMMYY	Change Maximum SAS Off Airspeed to 90 KIAS from 100 KIAS to 200 KIAS	4
R-2	DDMMYY	Increase Vne from 193 KIAS to 200 KIAS	5

C-2.2 MAJOR ELEMENTS

C-2.2.3 CONFIGURATION

Configuration of the subject air vehicle should be defined by reference to contractor or Government specifications and drawing numbers, modification work orders (MWOs), technical bulletins (TBs), approved engineering change proposals (ECPs), etc.

*The underlined portion of the paragraph number and title identifies the paragraph number and title in the CFR.

These documents should be referenced in par. 1 of the CFR (explained in subpar. C-2.2.1 of this appendix) or may be included in an appendix to the CFR, and should completely and clearly identify the configuration to be operated, tested, or evaluated. Also, version descriptions for all flight critical software such as that defined software for automatic flight control, control and display, engine, and weapon systems should be described or identified by release number. Changes to the configuration during subsequent revisions should be documented as shown in TABLE C-2.

TABLE C-2

TYPICAL CONFIGURATION DEFINITION TABLE

DESCRIPTION OF CHANGES	REVISION NUMBERS		
	R-1	R-2	R-3
Incorporation Increased Authority Stability Augmentation System (SAS) (Drawing Number XXYYZZ)	X	X	X
Incorporate Programmable Stabilator (Drawing Number AABBCC)		X	X
Incorporate “Stabilator Fail” Warning Indicator (Drawing Number DDEEFF)			

C-2.2.4 <u>OPERATING INSTRUCTIONS, PROCEDURES, LIMITATIONS, AND RESTRICTIONS</u>

This element of the CFR should include, as a minimum, all operating instructions, procedures, restrictions, and limitations not included in referenced operator's manuals. Reference to approved and applicable operator's manuals is acceptable in whole or in part. Only limitations, restrictions, procedures, and instructions applicable to this/these particular air vehicle(s) are required, and special emphasis should be placed on characteristics of this/these particular air vehicle(s). The use of "NOTES," "CAUTIONS," AND "WARNINGS," (see glossary for definitions) , in the text of the CFR, should occur only when not cited in referenced documents or when necessary for added emphasis.

C-2.2.4.1 <u>OPERATING INSTRUCTIONS</u>

This paragraph should identify additional, deleted, and amended operating instructions which modify the content of approved operator's manuals cited by reference. Reference to approved and applicable operator's manuals is acceptable in whole or in part. Addition, deletion, substitution, and/or supplementation of operator's manual procedures should identify applicable page and paragraph numbers. An example, showing both an additional instruction and substitution of instructions, follows: "The AC should operate subject air vehicle using the following additional instruction, added as paragraph 8-20.1, page 8-8 of TM 55-1520-XYZ-10:

8-20.1 TEXT OF ADDITION"

"The AC shall delete existing paragraph 8-25, page 8-12 of

TM 55-1520-XYZ-10, replace with paragraph below, and operate subject aircraft in accordance with paragraph below:

8-25 TEXT OF SUBSTITUTION"
Replacement text inserted here.

C-2.2.4.2 PROCEDURES

Approved contractor's ground and flight operations procedures shall be cited for normal operations of these air vehicles. This element of the CFR should identify the method the Government should use to approve and monitor those procedures. Normally, a GFR will perform those approval and monitoring functions for the contractordeveloped flight procedures.

If not covered in the contractor's procedures, requirements for preflight briefings, postflight debriefs, and chase and rescue air vehicles should be discussed.

A brief example of this element follows: "The contractor should conduct flight and ground operations of subject air vehicle in accordance with AR 95-20 and CONTRACTOR'S APPROVED GROUND AND FLIGHT OPERATIONS PROCEDURES NUMBER ######, dated DDMMYY. Changes to these procedures shall be approved by the GFR prior to operations, and procedures should be subject to monitoring by the GFR.

The contractor should coordinate the chase air vehicle with the Government Test Coordinator/GFR in accordance with AR 705-24, *Management of Test and Test Support Aircraft*, (Ref. 4) prior to each flight."

C-2.2.4.3 LIMITATIONS

Limitations which are different or missing from operator's manual limitations should be cited in this paragraph. Unless required for added emphasis, only those limitations different from the limitations in approved operator's manuals should be cited here. Such limitations may include, but are not limited to, limitations on flight envelopes, operating limitations for fatigue critical components, and mission equipment operating limitations. These limitations may be in the form of numerical values (airspeeds, rotational speeds, voltages, etc.); they may be in the form of procedural limitations (no operation of subsystem x while subsystem y is inoperable for more than two minutes); or they may be a combination of the two forms (no operation above 100 KIAS with subsystem x inoperative). Fatigue critical components are typically listed in a separate element of the CFR. An example follows:

"The contractor shall observe three additional limitations for operation. These limitations are:

1. Maximum airspeed for external cargo jettison when transporting SYSTEM XYZ externally shall be 70 KIAS.

2. Maximum main rotor speed shall be 334 Revolutions Per Minute (RPM).

3. The Radar shall not be operated for more than twenty (20) minutes in the 'active' mode, and each period in the 'active' shall should be followed by a minimum period of five (5) minutes in either the 'standby' mode or with power off."

This element of the CFR should include important operating limits and restrictions that should be observed during ground and flight operations. Typical limitations are most forward and aft center of gravity locations, maximum allowable gross weight, maximum and minimum allowable rotor speeds, maximum allowable torques, maximum allowable oil temperatures, never to exceed velocity, maximum allowable slope landing capability, and maximum allowable towing speeds. Mission equipment limitations, such as maximum allowable rate of fire should also be included.

C-2.2.4.4 RESTRICTIONS

A restriction is like a regulation. Certain actions and areas are to be avoided, etc. Any type of restriction that affects operation, such as environmental, procedural, and electromagnetic vulnerability, should be covered. Environmental restrictions may identify temperature, humidity, precipitation, icing, sand and dust, vibration, and altitude conditions which may have an adverse action on the air vehicle operation, reliability, or flight safety. Procedural restrictions may include bans on flight in instrument meteorological conditions (IMC), prohibition on single pilot flight, or prohibition on flight without a crew chief and flight engineer. Electromagnetic vulnerability restrictions may place restrictions on flight within close proximity to transmitters with specified output power in identified frequency ranges. These restrictions may be more or less restrictive than those in the operator's manual. If necessary, these may be presented in graphical format, and included as an appendix to the CFR. An example follows: "The contractor shall not perform flight into known or forecast moderate or more severe icing conditions."

C-2.2.5 MAINTENANCE PROCEDURES, INSPECTIONS, AND FREQUENCY OF INSPECTION

This element should describe additional maintenance procedures, inspections, and inspection frequencies not cited in referenced maintenance manuals. In all subparagraphs of this element,, reference to approved and applicable maintenance manuals and supplemental procedures is acceptable in whole or in part, and should be used where applicable. The use of "NOTES," "CAUTIONS," AND "WARNINGS," should be the same as defined in paragraph 4 of the CFR (par. C-2.2.4 of this appendix), and should occur only when not cited in referenced documents or when necessary for added emphasis.

C-2.2.5.1 MAINTENANCE PROCEDURES

All special maintenance procedures which are not included in approved maintenance manuals should be identified. Reference may be made to maintenance manuals, contractor's approved procedures, and appropriate safety of flight (SOF) messages. Considerations for safety of flight and safety of maintenance monitoring by the GFR are described in AR 95-20 (Ref. 1). An example of such a cited procedure would be a required inspection which is cited in the maintenance manual using one inspection with a chemical compound, but is changed to use a different chemical.

C-2.2.5.2 INSPECTIONS

This element should include additional or modified inspection requirements for inspections performed during preflight, postflight, and periodic or phase maintenance on the air vehicle systems or mission equipment packages (MEP), and not contained in referenced maintenance manuals. These inspections may be necessitated by additional or modified equipment for modification programs, may be based on experience gained during prototype air vehicle flight and maintenance operations, or may be desirable to address concerns surfaced or to verify analysis performed during the design phase. An example would be the requirement to inspect fire control computer connections for moisture or corrosion after flight in visible moisture.

C-2.2.5.3 FREQUENCY OF INSPECTION

The objective of this element is to define inspection frequencies which have changed from referenced maintenance manual frequencies. Only frequencies which have changed from maintenance manual frequencies should be included in this paragraph. The application of these additional or modified inspection frequencies to modified air vehicles may be simple. However, prototype air vehicles may not have well established maintenance inspection frequencies. This lack of established frequencies may require reference to an attachment for complete definition.

Three types of frequency of inspection changes may be required. Scheduled maintenance inspections which have frequencies changed from maintenance manual frequencies should be cited. Additionally, new scheduled inspection requirements may be generated due to equipment additions in a modification program or based on experience gained during prototype air vehicle flight and maintenance operations. Finally, excessive repetition of scheduled inspections may induce maintenance related failures, and inspection frequencies may be reduced in order to evaluate the effect on safety.

Inspection frequency changes should identify the scheduled inspection and revised frequency (expressed in days, flight hours, cycles, rounds, etc.). An example follows:

INSPECTION REQUIREMENT REVISED FREQUENCY CLEAN &
LUBRICATE ARMAMENT SYSTEM, XM-201 2000 ROUNDS CLEAN &
LUBRICATE ARMAMENT SYSTEM, XM-201 MONTHLY

C-2.2.6 APPENDICES

Appendices may be used to show configuration data, list references, provide operating and maintenance limitations figures, other graphical data, and information which is too voluminous for inclusion in the main body of the CFR. Additionally, when a limited amount of classified information is to be a part of the CFR, a classified appendix may be used to allow the main body of the CFR to remain unclassified. All appendices used should be referenced in the appropriate paragraph of the CFR, and should be packaged in the order in which they are referred to in the CFR.

ATTACHMENT TO APPENDIX C
DEFINITIONS

NOTE - An operating procedure, practice, or condition that must be highlighted. CAUTION - An operating procedure, practice, or condition which**,** if not strictly observed, could result in damage to or destruction of equipment, or minor injury to personnel. WARNING - An operating procedure, practice, or condition which, if not correctly followed, could result in severe injury to personnel or loss of life, or loss of a major system.

APPENDIX C
LIST OF ACRONYMS AND ABBREVIATIONS

AR	=	army regulation
ATCOM	=	aviation and troop command
AWR	=	airworthiness release
CFR	=	contractor flight release
ECPs	=	engineering change proposals
FAA	=	federal aviation administration
GAR	=	government flight representative
IMC	=	instrument meteorological condition
IR	=	infrared
KO.	=	contracting officer
MEP	=	mission equipment package
MIL	=	military
MWOs	=	modification work orders
PA	=	procuring activity
PM	=	program/project/product manager
POC	=	points of contact
RPM	=	revolutions per minute
SAQ	=	statement of airworthiness qualification
SOF	=	safety of flight
SOP	=	standing operating procedure
TB	=	technical bulletin
WSMO	=	weapon systems management officer

APPENDIX C
REFERENCES

1. AR 95-20, *Contractor's Flight and Ground Operations*,
Vol 1, *Contractor's Flight and Ground Operations*, November 1991,
Vol 2, *Government Flight Representative Guidance*, November 1991.

2. AR 70-62, *Airworthiness Qualification of US Army Aircraft Systems*, 15 July 1993.

3. DoDD 5230.24, *Distribution Statements on Technical Documents*,
18 March 1987

4. AR 705-24, *Management of Test and Test Support Aircraft*,
15 May 1978.

APPENDIX D
ELEMENTS OF AN AIRWORTHINESS RELEASE (AWR)

D-1 INTRODUCTION

AR 70-62, *Airworthiness Qualification of US Army Aircraft Systems*, (Ref. 1), prohibits Army aviators from operating an air vehicle in the performance of official duties if there is no airworthiness release, interim statement of airworthiness qualification, statement of airworthiness qualification, or airworthiness approval. The US Army Aviation and Troop Command (ATCOM) is the approval authority for airworthiness of standard and nonstandard Army air vehicles for which it has engineering cognizance. As implied, the ATCOM does not have engineering cognizance for all Army air vehicles. Depending on how the air vehicle was acquired, the Federal Aviation Administration (FAA), National Aeronautics and Space Agency (NASA), US Air Force (USAF), and US Navy (USN) might still have engineering cognizance. Occasionally, the ATCOM Directorate of Engineering can accept responsibility for a modification to an air vehicle it did not qualify. However, the original qualification and design requirements must either be known or ATCOM must be able to establish sufficient engineering cognizance to validate the modification.

An airworthiness release (AWR) is the technical document that ATCOM issues to provide interim operating and maintenance information necessary for safe flight operation of an air vehicle system, subsystem, and allied equipment. Other agencies signify airworthiness approval by means other than an AWR, such as a type certificate or supplemental type certificate. An AWR (type certificate, etc.) is required prior to operation of a new air vehicle system or a fielded air vehicle system that has undergone a major modification as defined in AR 705-24, *Management of Test and Support Aircraft*, (Ref. 2). An AWR is also required prior to operation of an air vehicle with FAA, USAF, NASA, or USN airworthiness approval, if operator's manuals are unacceptable.

Format of the AMR should be in accordance with the established standard operating procedure (SOP) of the approving authority.

D-2 CONTENTS

Contents should be as specified in the following paragraphs.

D-2.1 ADMINISTRATIVE INFORMATION

Prior to the main body of the AWR, the following administrative information should be provided.

D-2.1.1 REVISION AND DATE

Changes to AWRs should be made using a specification revision technique with the annotation in the right hand margin utilizing a revision number (R-1, R-2,...) of the portion of the release that has been updated. AWRs should contain a basic date and the date of all revisions on the first page of the release. Unless there is an SOP-related limitation on the number of revisions prior to the issuance of a new AWR, the AWR with the highest revision number should supersede all previously issued AWRs.

The use of distribution statements as provided for in Department of Defense Directive Number 5230.24, *Distribution Statements on Technical Documents*, (Ref. 3) should be considered for use on sensitive technical information.

D-2.1.2 ADDRESSEE

The AWR will be addressed to the owner of the air vehicle and the agency incorporating the change or performing the test (if a standard Government test organization), and the project/product manager if one has cognizance of the change or test. Informational copies should also be sent as a minimum to the major command (MACOM) of the air vehicle, systems, or test activities. If the air vehicle is owned by an operational unit, the organization responsible for maintenance oversight (ATCOM Directorate for Maintenance, for example) should be provided an informational copy. If the air vehicle is undergoing formal materiel release processes, the organization responsible for technical testing (Army Material Systems Analysis Activity [AMSAA], for example) should be provided an informational copy. Both the cognizant procuring activity safety office and the service office responsible for safety oversight (Test and Evaluation Command [TECOM] safety office, for example) should also be provided copies of the AWR.

The user and the approving organization use the AWR to document the configuration authorized for flight and attendant changes to flight and maintenance procedures. If the AWR is not properly addressed and distributed, preliminary airworthiness evaluation (PAE), airworthiness and flight characteristic (A&FC) testing, operational test (OT), follow on evaluation (FOE), concept evaluations, and use of special mission modified air vehicle can be delayed at a significant cost. Crews, support personnel, facilities, and equipment idled by misdirected AWRs can quickly expend valuable program resources.

If technical testers and evaluators or cognizant safety personnel do not receive copies of the AWR in a timely manner, the materiel release and safety release for the air vehicle can be delayed, causing later delays in all program activities.

D-2.1.3 SUBJECT

The subject of the AWR should clearly identify that this is an airworthiness release for a specific ground or flight test, evaluation, or operation of one model, design, and series Army air vehicle with identifying serial number(s). The subject should summarize the special mission or modification addressed in each particular AWR. Model, design, and series' prefixes and suffixes should be included. The general form is: "Airworthiness Release for (ground/flight) (test/evaluation/operation) of the (model identification XX-00Z) (air vehicle type) with (identify special mission/other major modification from the basic model identifier)". An example follows: "Airworthiness Release (AWR) for Test Flights of UH-60L Helicopter, S/N 89-XXXXX with the Portable Engine Analyzer Installed"

D-2.2 MAJOR ELEMENTS

D-2.2.1 REFERENCES

References cited in the main body of the release should be listed in the order in which they are referenced, or they may be included in an appendix. If an appendix is used, that appendix should be cited in this paragraph. Operations and maintenance manuals, contract numbers, Government and contractor specifications, test plans, previous FAA/MIL type certificate(s), and systems safety assessments should be cited, as appropriate. Changes to referenced documents should require changes in references with an accompanying revision of the AWR. When such changes affect air vehicle configuration, procedures, limitations, or restrictions, appropriate changes to the other elements of the AWR should be accomplished. An example of references follows:

a. Technical Manual 55-1520-XYZ-10, 8 January 1988, through Change 15, 29 November 1991, *Operator's Manual, UH-1H Helicopters*.

b. Contractor's System Specification ###### (as necessary to define configuration).

* The underlined portion of the paragraph number and title identifies the paragraph number and title in the AWR.

c. Technical Manual 55-1520-XYZ-23, 8 January 1988, through Change 5, 29 November 1991, *Aviation Unit Maintenance Manual. UH-lH Helicopters.*

d. *System Safety Assessment*, 9 February 1989,
UH-lH Helicopter, US Army Aviation and Troop Command Safety Office.

e. Federal Aviation Administration Type Certification, *Bell Helicopter Model 206*, 3 February 1976.

D-2.2.2 PURPOSE

The purpose of the AWR should be defined by reference to the subject air vehicle model(s), serial number(s), test types, dates and time intervals, and termination criteria. While this purpose may be brief for a modification of a previously qualified air vehicle, an air vehicle undergoing developmental testing may have more extensive testing requirements. A brief description should also be provided to define developmental qualification or required modification testing. An example is as follows: "This memorandum constitutes an Airworthiness Release (AWR) in accordance with AR 70-62, for the purpose of authorization to conduct maintenance test flights on UH-60L Helicopter, serial number 89-XXXXX, with the Portable Engine Analyzer installed. Three tests shall be performed, using personnel trained and certified by the major command. This AWR is terminated upon test completion."

D-2.2.3 CONFIGURATION

Configuration of the subject air vehicle should be defined in this element of the AWR by reference to contractor or Government specifications and drawing numbers, modification work orders (MWOs), technical bulletins (TBs), approved engineering change proposals (ECPs), etc. Software for automatic flight controls, engines, and weapon systems should be described or identified by release number.

These references should be included in paragraph 1 of the AWR (described in paragraph D-2.2.1) or may be included in an appendix to the AWR. The referenced documents should completely and clearly identify the configuration to be operated, tested, or evaluated, including serial numbers for the air vehicle and installed or modified equipment. Other serial numbers of unmodified components are included in the air vehicle historical records, and need not be cited here. An example is as follows:

"The basic UH-60 Rotorcraft is defined in the reference lx manual with exceptions noted in the respective DD Form 250 acceptance document. UH-60L rotorcraft serial number 89-12345 is modified by the temporary installation of the portable engine analyzer per reference lx and drawing number AABBCC for conduct of maintenance test flights only. The Portable Engine Analyzer installed may be any one of serial numbers PEA-001, -003, or -004."
Changes to the configuration during subsequent revisions should be documented accordingly by each revision number.

D-2.2.4 OPERATING INSTRUCTIONS, PROCEDURES, LIMITATIONS, AND RESTRICTIONS

This element of the AWR and the subparagraphs under it should include, as a minimum, all operating instructions, procedures, restrictions, and limitations not included in referenced operator's manuals. Only limitations, restrictions, procedures, and instructions applicable to subject air vehicles are required, and special emphasis should be placed on characteristics of the subject air vehicle. The use of "NOTES," "CAUTIONS," and "WARNINGS," as defined in the Glossary, in the text of the AWR, should occur only when not cited in referenced documents or when necessary for added emphasis.

D-2.2.4.1 OPERATING INSTRUCTIONS

Maximum use should be made of existing operating manuals and pilot's checklists for standard Army air vehicles when such manuals have been approved. This element should identify additional, deleted, and amended operating instructions which modify the content of approved operator's manuals cited by reference. Addition, deletion, substitution, and/or supplementation of operator's manual procedures should identify applicable page and paragraph numbers. Example formats, showing both an additional instruction and substitution of instructions follow: "The subject air vehicle shall be operated using the following additional instruction, added as paragraph
8-20.1, 8-20.1 TEXT OF ADDITION" "Delete existing paragraph 8-25, page 8-12 of TM 55-1520XYZ-10; replace with paragraph below; and operate subject air vehicle in accordance with paragraph below:

8-25 TEXT OF SUBSTITUTION" "Replacement text inserted here."

D-2.2.4.2 PROCEDURES

This element should identify, by reference, the approved ground and flight operations of the air vehicle. Additional requirements for operating, preflight, and post flight procedures should also be discussed. The AWR should be prepared in compliance with the minimum equipment required for flight conditions specified in AR 95-1, *Flight Regulations*, (Ref. 4). An example paragraph follows: "The helicopter shall be operated in accordance with the reference “lx” Operator's Manual and this document. All flights performed with Portable Engine Analyzer equipment installed are to be conducted only with approved maintenance test pilots. If there is a conflict between the reference lx manual and this document, this document shall prevail. Maintenance test flights shall be performed in accordance with the reference “ly” Technical Manual."

D-2.2.4.3 LIMITATIONS

This element should include limitations which are different or missing from referenced operator's manual. Such limitations may include, but are not limited to, flight envelopes, operating limitations for fatigue critical components, and mission equipment operating limitations. An example follows: "Flight with the Portable Engine Analyzer installed shall be limited to the conditions for a maintenance test flight per reference lx and the following:

1. Maximum main rotor speed shall be 334 revolutions per minute (RPM).

2. Takeoff profiles and engine operating limits shall be maintained in accordance with Figures ly - lz of portable engine analyzer svstem specification (reference lx)."

D-2.2.4.4 RESTRICTIONS

Changes to flight envelope, weight and balance, flight and mission equipment operation, and environmental limitations should be cited. These restrictions may be more or less restrictive than those in the referenced operator's manuals. If necessary, these may be presented in graphical format, and included as an appendix to the AWR. An example follows:

1. Flight shall be accomplished only during day visual meteorological conditions (VMC).
2. Flight shall be accomplished only over areas suitable for emergency landing.
3. The portable engine analyzer is to be installed single engine only. Dual engine installation is prohibited."

D-2.2.5 MAINTENANCE PROCEDURES, INSPECTIONS AND FREQUENCY OF INSPECTION

The subparagraphs of this element should describe additional maintenance procedures, inspections, and inspection frequencies not cited in referenced maintenance manuals. In these subparagraphs reference to approved and applicable maintenance manuals and supplemental procedures is acceptable as a whole or in part, and should be used where applicable. The use of "NOTES," "CAUTIONS," and "WARNINGS," as defined in the Glossary, in the text of the AWR, should occur only when not cited in referenced documents or when necessary for added emphasis.

D-2.2.5.1 MAINTENANCE PROCEDURES

The objective of this element is to identify and explain the use of maintenance procedures, special tools, maintenance aids, or maintenance personnel not cited in referenced maintenance manuals. Detailed maintenance procedures should be referenced to applicable technical manuals whenever possible. Special or supplemental maintenance procedures, to include special tools, maintenance aids, or maintenance personnel should be defined. Reference to any applicable maintenance advisory and Safety of flight messages should be included. These types of maintenance procedures may include non-destructive inspection, calibration, pressure test, alignment, boresight, and maintenance test flight and maintenance operational check requirements before, during, and after flight. Special tools identified are those which are not part of the using unit's equipment, and may include test instruments, fixtures, alignment jigs, hand tools, and inspection equipment. The application of these procedures to modified air vehicle may be simple. However, prototype air vehicles may not have well established maintenance procedures, special tools, maintenance aids, or maintenance personnel requirements. This lack of established requirements may require reference to an attachment for complete definition. An example follows:

"The air vehicle should be inspected and maintained in accordance with all applicable maintenance manuals and associated maintenance advisory and safety of flight messages. Any discrepancies should be evaluated/repaired prior to the next flight to ensure continued airworthiness of the air vehicle.

The cables for the portable engine analyzer should be routed and clamped in such a way that assures protection from physical abuse, i.e., being stepped on, door slammed on, or hung from as a handhold. The cables should be adequately protected from vibration, chafing, or stretching. Cables should not be clamped to control tubes or cables, fuel lines, hydraulic lines, etc." Calibration of the portable engine analyzer shall only be performed by manufacturer's representatives authorized in writing by the ATCOM Directorate for Engineering."

D-2.2.5.2 INSPECTIONS

This element should include additional or modified inspection requirements needed during preflight, post flight, and periodic or phase maintenance on air vehicle systems or mission equipment packages (MEP), that are not contained in referenced maintenance manuals. These inspections may be necessitated by additional or modified equipment for modification programs, and may be based on experience gained during prototype air vehicle flight and maintenance operations. Special or supplemental inspection procedures, to include special test equipment, should also be defined. The application of these additional or modified inspections to modified air vehicle may be simple. However, a prototype air vehicle may not have well established maintenance inspection frequencies. This lack of established requirements may require reference to an attachment for complete definition.

All nonstandard installations which attach to primary structure, attach to dynamic components, or which have the potential of initiating a crack will require supplemental inspections. Installations which could disable essential avionics and electrical systems; initiate fire; damage fuel, pneumatic, and hydraulic lines; jam or damage controls; damage hub and rotor blades; or strike an occupant, or cause an occupant to fall from the air vehicle will be inspected for progressive wear and damage.

If avionics or electrical system changes are involved, a qualitative electromagnetic compatibility (EMC) test should be conducted prior to first flight to demonstrate that the newly installed equipment is not a source of, or victim of, electromagnetic interference (EMI). This should be accomplished by monitoring the performance of all new and existing subsystems as the individual subsystems are operated in turn. The operation of this equipment must include a power on/power-off cycle, initializing or warm-up (if applicable), and all modes of operation. All equipment should be in the "inflight" configuration and should be operated using air vehicle generated power. The flight test portion of the EMC test should be conducted under day visual meteorological conditions (VMC).

An example of the inspection element follows: "A pre-flight visual inspection shall be made of the portable engine analyzer to ensure that no progressive structural deterioration is occurring, that there is no loss of security and that no damage to the host air vehicle exists."

D-2.2.5.3 FREQUENCY OF INSPECTION

The objective of this element is to define inspection frequencies which have changed from referenced maintenance manual frequencies. Only frequencies which have changed from referenced maintenance manual frequencies should be included in this element. The application of these additional or modified inspection frequencies to air vehicles be simple. However, a prototype air vehicle may not have well established maintenance inspection frequencies. This lack of established frequencies may require reference to an attachment for complete definition. Three types of frequency of inspection changes may be required. Scheduled maintenance inspections which have frequencies changed from maintenance manual frequencies should be cited. Additionally, new scheduled inspection requirements may be generated due to equipment additions in a modification program or based on experience gained during prototype air vehicle flight and maintenance operations. Finally, excessive repetition of scheduled inspections may induce maintenance related failures, and inspection frequencies may be reduced in order to evaluate the effect on safety.

Inspection frequency changes should identify the scheduled inspection and revised frequency (expressed in days, flight hours, cycles, rounds, etc.). Special inspections may be required when:

1. Checks are required to verify structural integrity
2. Test flights are required
3. The condition of the new or modified equipment, attachments, cables, and connections are unknown (basic aircraft inspection is part of routine inspection)
4. The new or modified equipment could possibly lead to a dangerous condition
5. Maintenance actions are necessary
6. Limitations exist in the AWR after the electromagnetic compatibility (EMC) checks are complete
7. Air vehicle operating instructions, limitations, or restrictions have changed.

Omission of a special inspection could lead to safety of flight or maintenance concerns, loss of the air vehicle for further test or operation, or more extensive inspection requirements at a later date. If this omission has any of these consequences, the impact of such an omission should be specified in the AWR.

D-2.2.5.4 PARTS AVAILABILITY

The objectives of this paragraph are to specify availability and to define conditions when parts may need to be locally procured or manufactured to allow operation of the affected air vehicle. If possible, approved sources for available parts or materials should be provided for ease of procurement, along with interface requirements. Conditions may involve circumstances where acceptable commercial off-the-shelf components are available, can be procured other than on a "sole-source" basis, or have shorter lead time (procurement, manufacturing, and delivery time) than parts in the military supply system.

This element should define procedures for manufacturing or obtaining non-standard air vehicle parts as well as parts used in air vehicle modifications. Reference will be made to equipment specifications and drawing numbers, wherever possible. An example may be as follows: "Parts needed for this modification may not be available in the supply system. Your activity or facility must locally procure/manufacture the modification parts (plus any additional spare parts). This AWR is not authorization to procure any material or sources 'Sole Source'."

D-2.2.5.5 WEIGHING

This element should contain procedures for compliance with air vehicle weight and balance as contained in AR 95-3, *General Provisions, Training. Standardization and Resource Management*, (Ref. 5). The proper forms to be included in the logbook of the subject air vehicle should be identified. The forms defined by MIL-STD-1374, *Weight and Balance Data Reporting Forms for Aircraft (Including Rotorcraft)*,
(Ref. 6) should be used to document modifications to production air vehicles and weight and balance conditions for prototype air vehicles. As a minimum, the DD Form 365F defined by Ref. 8 should be included in the air vehicle logbook. Other forms, such as the DD Form 365A and DD Form 365C, should be included in the air vehicle historical records, and the cognizant engineering activity should require copies of all cited forms. Special instructions should be noted in that the subject air vehicle will not be loaded outside the center of gravity (cg) limits. If any deviation from the approved limits exist and are acceptable for test conditions, reference shall be made in the paragraph of this AWR where operational restrictions are specified (par. 4.4). Examples of the AWR citation follow:

The DD Form 365F for UH-60L rotorcraft serial number 88-12345 is included at attachment A to this AWR.

The DD Forms 365A and 365C for UH-60L rotorcraft serial numbers 89-12345, 89-67890, 90-23456, and 91-34567 are included at attachment A to this AWR. These forms should be used to update individual rotorcraft DD Forms 365F prior to flight under the conditions of this AWR. This AWR is not authorization to operate these rotorcraft outside established weight or center of gravity envelopes.

D-2.2.5.6 DESIGNATION PREFIX ASSIGNMENT

This element will contain the instructions for required assignment of a special prefix to the air vehicle designator. The procedures, criteria, and conditions for assignment of these prefixes are contained in AR 70-50, *Designating and Naming Defense Equipment Military Aerospace Vehicles*, (Ref. 7). The special prefixes are defined as follows:

"J" - Special Test, Temporary - Air vehicles on special test programs by authorized organizations, or on bailment contract (as defined by AR 95-20, Volume 1, *Contractor Flight and Ground Operations* and Volume 2, *Government Flight Representative Guidance*, (Ref. 8), whose installed property has been temporarily removed for the test.
"N" - Special Test, Permanent - Aerospace vehicles on special test programs by authorized activities or on bailment contract, whose configurations are so drastically changed that to return them to their original condition is not practical or economical. "Y" - Prototype - A few aerospace vehicles procured, usually before production decision, to serve as models or patterns.

D-2.2.6 AIRCRAFT LOGBOOK ENTRIES

Each AWR should contain only the applicable logbook entries required by the preparer. Logbook entries should be in accordance with DA PAM 738-751, *Functional Users Manual for the Army Maintenance Management System - Aviation (TAMMS-A*), (Ref. 9)

The explanation and proper use of the various DA 2408 series forms is included in (Ref. 6). Entries should be made on Department of Army (DA) Form 2408-13-1/2408-13-1-E. The appropriate status symbol should be specified in the AWR, with a reference of the AWR release date entered in the Fault Information Block. A red dash should be used in the status block for procedures that are required prior to the next flight, i.e., EMC tests, special inspections, and/or functional checks. For readiness reporting purposes, AWRs which require perpetual circle red "X" write-ups (semi-permanent restrictions) shall not cause the air vehicle to be reported as partially mission capable (PMC). For those purposes, air vehicles which are nonstandard configured and operating under the AWR may be reported as fully mission capable (FMC).

The air vehicle DA Form 2408-15/2408-15-E should be annotated to reflect the successful completion of the EMC test and/or special inspections and to cite the AWR by subject and date. The DA Form 2408-15/-15-E need to be annotated to reflect temporary installations, as well as, permanent changes to configuration.

An exact copy of the AWR describing the operating procedure, limitations, and restrictions should be inserted in the air vehicle logbook and another copy inserted in the Air Vehicle Historical Record File.

D-2.2.7 TERMINATION OF RELEASE

A termination date or clearly defined conditions for cancellation of the AWR should be identified. This termination date or event is defined as the date or completion of event after which this AWR or revision is no longer valid. For example, the termination provisions may read: "Three tests will be performed, using personnel trained and certified by the major command. This AWR is terminated with test completion. This air vehicle should be returned to standard configuration prior to transfer or turn-in to an overhaul facility."

D-2.2.8 SIGNATURE OF ISSUE AUTHORITY

The AWR should be approved and signed in accordance with AR 70-62 (Ref. 1) and the policies of the approving authority's SOP.

All technical content should be coordinated and validated by the appropriate offices within the policies of the approving authority's SOP. All classified information should be coordinated with the approving authority's Security Office prior to submittal for approval. All AWRs should also be coordinated with the approving authority's safety office prior to submittal for approval. Any identified hazard or risk should have been eliminated or reduced to an acceptable level. Acceptable risk may be shown by compliance with applicable standards or specifications that support an engineering judgment or formal resolution through the hazard risk management process in accordance with AR

385-16, *System Safety Engineering and Management*, (Ref. 10), or in accordance with the managing activities system safety management plan.

D-2.2.9 APPENDICES

Appendices may be used to show configuration data, list references, provide operating and maintenance limitations, figures, other graphical data, and information which is too voluminous for inclusion in the main body of the AWR. Additionally, when a limited amount of classified information is to be a part of the AWR, a classified appendix may be used to allow the main body of the AWR to remain unclassified. All appendices used should be referenced in the appropriate paragraph of the AWR, and should be packaged in the order in which they are referred to in the AWR.

APPENDIX D
LIST OF ACRONYMS AND ABBREVIATIONS

A&FC	=	airworthiness and flight characteristic
AMSAA	=	army material systems analysis activity
AWR	=	airworthiness release
cg	=	center of gravity
ECP	=	engineering change proposal
EMC	=	electromagnetic compatibility
EMI	=	electromagnetic interference
FAA	=	federal aviation administration
FMC	=	fully mission capable
FOE	=	follow on evaluation
MACOM	=	major command
MEP	=	mission equipment package
MWO	=	modification work orders
NASA	=	national aeronautics and space administration
PAE	=	preliminary airworthiness evaluation
PMC	=	partially mission capable
RPM	=	revolutions per minute
SAQ	=	statement of airworthiness qualification
SOP	=	standing operating procedure
TB	=	technical bulletins
TECOM	=	test and evaluation command
USAF	=	us air force
USN	=	us navy
UT	=	user test
VMC	=	visual meteorological conditions

APPENDIX D
REFERENCES

1. AR 70-62, *Airworthiness Qualification of US Army Aircraft Systems*, 15 July 1978. 1988.

2. AR 705-24, *Management of Test and Test Support Aircraft*, 15 May

3. DoDD 5230.24, *Distribution Statement of Technical Documents*, 18 March 1987.

4. AR 95-1, *Flight Regulations*, 30 May 1990.

5. AR 95-3, *General Provisions. Training, Standardization, and Resource Management*, 27 September 1990.

6. MIL-STD-1374, *Weight and Balance Data Reporting Forms for Aircraft (Including Rotorcraft)*, 13 September 1977.

7. AR 70-50, *Designating and Naming Defense Equipment Military Aerospace Vehicles*, 18 May 1990

8. AR 95-20, Volume 1, *Contractor Flight and Ground Operations*, and Volume 2, *Government Flight Representative Guidance*, November 1991.

9. DA PAM 738-751, *Functional Users Manual for the Army Maintenance Management System- Aviation (TAMMS-A*, 15 June 1992.

10. AR 385-16, *System Safety Engineering and Management*, 3 September 1985.

APPENDIX E

ELEMENTS OF A STATEMENT OF AIRWORTHINESS QUALIFICATION (SAQ)

E-l INTRODUCTION

AR 70-62, *Airworthiness Qualification of US Army Aircraft Systems*, (Ref. 1) establishes the requirement for preparation of a statement of airworthiness qualification (SAQ). Format of the SAQ is essentially the same as an airworthiness release (AWR) and should be prepared in accordance with (IAW) established standing operating procedure (SOP) or outside military command or agency general correspondence format. The SAQ is normally prepared by the Air Vehicle Systems Engineer or designated preparer from the organization having engineering cognizance over the system.

E-2 CONTENTS

E-2.1 ADMINISTRATIVE INFORMATION

Prior to the main body of the SAQ, the following administrative information should be provided.

E-2.1.1 EFFECTIVE DATE

An effective date for the SAQ should be identified. This effective date is defined as the date after which this SAQ or revision becomes effective. For example, the effective date provisions should read:

"This SAQ/revised SAQ is effective as of date (DAY MONTH YEAR)."

E-2.1.2 ADDRESSEE

Once approved, the SAQ becomes part of the Airworthiness Qualification Substantiation Report (AQSR), and will usually be routed, using a distribution list, through the program, product. project manager (PM) to all authorized users of the subject system. These users may be operators in table of organization and equipment (TO&E) units, training and testing activities, and other authorized operators. The first and second tier technical points of contact (POCs) should be identified on the cover sheet or within a transmittal letter prepared by the approving authority. Typically, these technical POCs will be the PM Systems Engineer and the Air Vehicle Systems Engineer at the procuring activity (PA), respectively.

E-2.1.3 SUBJECT

The cover sheet or first page of the SAQ should clearly identify that this is an Interim/Final Statement of Airworthiness Qualification for a specific type (ground or flight) of test, evaluation, or operation of one model, design, and series Army air vehicle with identifying serial number(s). Applicable operating units may be identified. Model, design, and series prefixes and suffixes should be included.

An example follows:

INTERIM STATEMENT OF AIRWORTHINESS QUALIFICATION FOR OPERATIONAL FLIGHT TEST OF YAH-68A HELICOPTERS SERIAL NUMBERS 95-00001, 95-00002, 95-00003, 95-00004, AND 95-00005 <u>or</u> SERIAL NUMBERS 95-00001 THROUGH 95-00005

INCLUSIVE WITH MODIFIED XM-201 WEAPONS SYSTEM INSTALLED AT US ARMY AVIATION TECHNICAL TEST CENTER. The use of distribution statements as provided for in Department of Defense Directive Number 5230.24, *Distribution Statement on Technical Documents*, 18 March 1987
(Ref. 2) should be considered for use on sensitive technical information.

E-2.2 MAJOR ELEMENTS

E-2.2.1 REFERENCES*

References cited in the main body of the SAQ should be listed in the order in which they are referenced, or may be included in an appendix. If an appendix is used, that appendix should be cited in this paragraph. Operations and maintenance manuals, contract numbers, Government and contractor specifications, AQSRs, previous Federal Aviation Administration (FAA) or military certificate(s), and systems safety assessments should be cited as appropriate. An example follows:
CONTRACT NUMBER
CONTRACTOR'S SPECIFICATION NUMBERS ###### (AS NECESSARY TO DEFINE CONFIGURATION)
AIRWORTHINESS QUALIFICATION SUBSTANTIATION REPORT NUMBER ##### FOR THE YAH-68A ROTORCRAFT OPERATOR'S MANUALS AND CHECKLISTS TM 55-1520-XYZ-10 AND TM 55-1520-XYZ-lOCL (DRAFT AND/OR FINAL, WITH CHANGES CITED) MAINTENANCE MANUALS TM 55-1520-XYZ-23 (DRAFT AND/OR FINAL, WITH CHANGES CITED) TO&E NUMBERS. Changes to referenced
documents should not require changes in the SAQ. When there are changes to rotorcraft configuration,procedures, limitations, or restrictions, changes to the other elements of the SAQ will not normally be required. These changes normally require issuance of a separate airworthiness release (AWR) reflecting those changes. AWRs are covered in Appendix D of this handbook.

E-2.2.2 PURPOSE

The SAQ constitutes the final Airworthiness Release (AWR) issued in conjunction with the Airworthiness Qualification Substantiation Report (AQSR). An AQSR is described in Appendix F of this handbook. While this purpose may be brief for a modification of a previously qualified air vehicle, an air vehicle undergoing developmental testing may have more extensive testing requirements. Because of the extensiveness of the testing requirements, the purpose of the SAQ may be quite involved for these developmental air vehicles.. Issuance of the SAQ normally completes the airworthiness qualification process.

E-2.2.3 CONFIGURATION Configuration of the subject air vehicle should be defined by reference to contractor or Government specifications and drawing numbers, modification work orders (MWOs), technical bulletins (TBs), approved engineering change proposals (ECPs), software version descriptions, etc. These references should be included in paragraph 1 of the SAQ (explained in paragraph E-2.2.1 of this appendix) or may be included in an appendix to the

*The underlined portion of the paragraph number and title identifies the paragraph number and title in the SAQ.

SAQ, and should completely and clearly identify the configuration of each air vehicle to be operated, tested, or evaluated. When individual air vehicles are configured differently, citation of a reference unique to one or more air vehicles should identify, by serial number, applicable air vehicle.

E-2.2.4 AIRWORTHY OPERATION

This element should include, as a minimum, all operating instructions, procedures, restrictions, and limitations not included in referenced operator's manuals. Reference to approved and applicable operator's manuals is acceptable in whole or in part. Only limitations, restrictions, procedures, and instructions applicable to this/these particular air vehicle(s) are required, and special emphasis should be placed on characteristics of this/these particular air vehicle(s). The use of "NOTES," "CAUTIONS," AND "WARNINGS," as defined in the Glossary., in the text of the SAQ, should occur only when not cited in referenced documents, or when necessary for added emphasis.

E-2.2.4.1 OPERATING INSTRUCTIONS AND PROCEDURES

This element should identify additional, deleted, and amended operating instructions which modify the content of approved operator's manuals cited by reference. Reference to approved and applicable operator's manuals is acceptable in whole or in part. Addition, deletion, substitution, and/or supplementation of operator's manual procedures should identify applicable page and paragraph numbers. An example, showing both an additional instruction and substitution of instructions, follows:

"Air vehicle (Serial Number Identification[s]) should be operated using the following additional instruction, added as paragraph 8-20.1, page 8-8 of TM 55-1520-XYZ-10:

8-20.1 TEXT OF ADDITION"

"The air vehicle contractor (AC) should delete existing paragraph 8-25, page 8-12 of TM 55-1520-XYZ-10, replace with paragraph below, and subject air vehicle should be operated in accordance with paragraph below:

8-25 TEXT OF SUBSTITUTION".

(Revised text would be placed here.)

Revisions to the approved operating instructions, procedures, limitations, or restrictions may be documented in tabular format in the SAQ. Minimum contents of this table should include revision number and date, a brief description of changes, and identification of affected pages. An example follows:

REVISIONS TO (DOCUMENT IDENTIFICATION)

REV #, DATE		DESCRIPTION OF CHANGE	AFFECTED PAGES
R-1	DDMMYY	CHANGE MAXIMUM SAS OFF AIRSPEED TO 90 KIAS FROM 100 KIAS	5-21

R-2, DDMMYY INCREASE Vne FROM 193 KIAS 5-23
TO 200 KIAS

If not covered in other references, requirements for preflight briefings, postflight debriefs, and chase and rescue air vehicles should be discussed.

E-2.2.4.2 LIMITATIONS AND RESTRICTIONS

Limitations which are different or missing from operator's manual limitations should be cited in this paragraph. Such limitations may include, but are not limited to, limitations on flight envelopes, operating limitations for fatigue critical components, and mission equipment operating limitations. An example follows:

"Operators of the air vehicle should observe three additional limitations for operation. These limitations are:

1. Maximum airspeed for external cargo jettison when transporting SYSTEM XYZ externally should be 70 KIAS.

2. Maximum main rotor speed should be 334 revolutions per minute (RPM).

3. The Radar should not be operated for more than twenty (20) minutes in the 'active' mode, and each period in the 'active' mode should be followed by a minimum period of five (5) minutes in either the 'standby' mode or with power off."

Changes to flight envelope, weight and balance, flight and mission equipment operation, and environmental limitations should be cited in this paragraph. These restrictions may be more or less restrictive than those in the operator's manual. If necessary, these may be presented in graphical format, and included as an appendix to the SAQ. An example follows:

"The air vehicle should not be intentionally flown into known or forecast moderate or more severe icing conditions. Maximum gross weight should be increased from 24500 pounds to 25000 pounds, and center of gravity limitations should be in accordance with the 'Center of Gravity Limits' shown in Appendix B."

E-2.2.5 SUSTAINING AIRWORTHINESS

This element should describe additional inspections, inspection frequencies, treatment of limited life and flight safety parts, and maintenance procedures not cited in referenced maintenance manuals. In all subparagraphs of this element, reference to approved and applicable maintenance manuals and supplemental procedures is acceptable in whole or in part, and should be used where applicable. The use of "NOTES," "CAUTIONS," AND "WARNINGS," should be the same as defined in paragraph 4 of the SAQ (paragraph E-2.2.4 of this appendix), and should occur only when not cited in referenced documents or when necessary for added emphasis.

E-2.2.5.1 INSPECTIONS AND FREQUENCY OF INSPECTION

This element should include additional or modified inspection requirements during preflight, postflight, and periodic or phase maintenance on air vehicle systems or mission equipment packages (MEP), and not contained in referenced maintenance manuals. These inspections may be necessitated by additional or modified equipment for modification programs, and may be based on experience gained during prototype air vehicle flight and maintenance operations. Special equipment required for inspection or testing should also be identified.

An example would be the requirement to inspect fire control computer connections for moisture or corrosion after flight in visible moisture.

Only frequencies which have changed from those specified in the maintenance manual should be included in this paragraph. Three types of frequency of inspection changes may be required. Scheduled maintenance inspections which have frequencies changed from maintenance manual frequencies should be cited. Additionally, new scheduled inspection requirements may be generated due to equipment additions in a modification program or based on experience gained during prototype air vehicle flight and maintenance operations. Finally, excessive repetition of scheduled inspections may induce maintenance related failures, and inspection frequencies may be reduced in order to evaluate the effect on safety.

Inspection frequency changes should identify the scheduled inspection and revised frequency (expressed in days, flight hours, cycles, rounds, etc.). An example follows:

INSPECTION REQUIREMENT	REV. FREQUENCY
CLEAN & LUBRICATE ARMAMENT SYS, XM-201	2000 ROUNDS
CLEAN & LUBRICATE ARMAMENT SYS, XM-201	MONTHLY

The consequences of failure to perform a required inspection should be clearly specified. In the previous example above, failure to lubricate the armament system in accordance with revised frequencies could require a restriction from use of the armament system until the inspection is complete. Appropriate logbook entries caused by uncompleted inspections should be explained in this section of the SAQ.

E-2.2.5.2 LIMITED LIFE AND FLIGHT SAFETY PARTS If retirement lives (point at which overhaul or repair is either unauthorized or not economical) are different from those lives in approved, referenced maintenance manuals, the retirement lives of these fatigue critical parts should be included in the SAQ. The part should be clearly identified along with the retirement criteria, expressed in flight hours, calendar time, exposure, etc. When flight safety parts (FSP) are involved, the procedures for identification, monitoring, surveillance, and disposition should be identified if different from procedures in approved maintenance manuals. If procedures are not established, par. 3-13 of this handbook provides procedures for handling of FSP.

E-2.2.5.3 MAINTENANCE PROCEDURES

All special maintenance procedures which are not included in approved maintenance manuals should be identified. Reference may be made to maintenance manuals, contractor's approved procedures, and appropriate Safety of Flight (SOF) messages. At this point in the developmental or modification program effort, most required maintenance procedures should be included in approved technical manuals. However, due to publication update cycles, some maintenance procedures may not have been incorporated into those manuals. An example of such a cited procedure would be a required inspection which is cited in the maintenance manual using one chemical compound, but is changed to use a different chemical. Most required special tools and ground support equipment should be included in approved maintenance manuals. Depending on the scope of the program (limited number of air vehicles, minor modification, funding for publication updates, etc.), these special tools and ground support equipment may not be included in technical manuals. Additionally, some of the equipment may be obtained by local manufacture. Such local manufacture typically includes tow plates, tow bridles, tow bar adapters, etc. If not included in approved technical manuals, these special tools should be completely described in the SAQ.

E-2.2.6 AIR VEHICLE LOGBOOK ENTRIES

The SAQ should contain only the applicable logbook entries required under the discretion of the preparer. Logbook entries should be in accordance with DA PAM 738-751, *Functional Users Manual for the Army Maintenance Management System - Aviation (TAMMS-A)* (Ref. 3).

The explanation and proper use of the various DA 2408 series forms are included in DA PAM 738-751 (Ref. 3). Entries should be made on Department of Army (DA) Form 2408-13-1/2408-13-1-E. The appropriate status symbol will be specified in the SAQ, with a reference of the SAQ effective date entered in the Fault Information Block. A red dash should be used in the status block for electromagnetic compatibility (EMC) tests, special inspections, and/or functional checks, required prior to the next flight. For readiness reporting purposes, AWRs which require perpetual circle red "X" write-ups (semi-permanent restrictions) should not cause the air vehicle to be reported as partially mission capable (PMC). For those purposes, air vehicles which are nonstandard configured and operating under the AWR may be reported as fully mission capable (FMC).

The air vehicle DA Form 2408-15/2408-15-E should be annotated to reflect the successful completion of the EMC test and/or special inspections and to cite the SAQ by effective date. The DA Forms 2408-15/15-E need to be annotated to reflect temporary installations, as well as, permanent changes to configuration.

An exact copy of the applicable SAQ sections describing the operating procedure, limitations, and restrictions should be inserted in the air vehicle logbook and another copy inserted in the Air Vehicle Historical Record File.

E-2.2.7 SIGNATURE OF ISSUE AUTHORITY

The Commander, US Army Aviation and Troop Command (ATCOM) has delegated airworthiness authority to the Director of Engineering, ATCOM. Typically, all technical content is coordinated and validated by the appropriate technical offices according to the policies in the SOP of the approving authority. Essential classified information should be placed in a classified addendum. The document should be properly marked and coordinated with the security office of the approving authority prior to submittal for approval by the Director of Engineering. Also, prior to submittal of an airworthiness release for signature, any identified hazard or risk should have been eliminated or reduced to an acceptable level in accordance with AR 385-16, *System Safety Engineering and Management*, (Ref. 4) or in accordance with the managing activity's system safety management plan.

E-2.2.8 APPENDICES

Appendices may be used to show configuration data, list references, provide operating and maintenance limitations figures, other graphical data, and information which is too voluminous for inclusion in the main body of the SAQ. Additionally, when a limited amount of classified information is to be a part of the SAQ, a classified appendix may be used to allow the main body of the SAQ to remain unclassified. All appendices used should be referenced in the appropriate paragraph of the SAQ, and should be packaged in the order in which they are referred to in the SAO.

APPENDIX E
GLOSSARY

NOTE - An operating procedure, practice, or condition that must be highlighted. CAUTION - An operating procedure, practice, or condition which, if not strictly observed, could result in damage to or destruction of equipment, or minor injury to personnel. WARNING - An operating procedure, practice, or condition which, if not correctly followed, could result in severe injury to personnel or loss of life, or loss of a major system.

APPENDIX E

LIST OF ACRONYMS AND ABBREVIATIONS

AQSR	=	airworthiness qualification substation report
ATCOM	=	aviation and troop command
AWR	=	airworthiness release
DA	=	department of army
ECPs	=	engineering change proposals
EMC	=	electromagnetic compatibility
FAA	=	federal aviation administration
FMC	=	fully mission capable
FSP	=	flight safety parts
IR	=	infrared
MEP	=	mission equipment package
MWOs	=	modification work orders
PA	=	procuring activity
PM	=	program, product, project manager
PMC	=	partially mission capable
POC	=	points of contact
SAQ	=	statement of airworthiness qualification
SOF	=	safety of flight
SOP	=	standing operating procedure
TB	=	technical bulletin

APPENDIX E
REFERENCES

1. AR 70-62, *Airworthiness Qualification of US Army Aircraft Systems*, 15 July 1978.

2. DoDD 5350.24, *Distribution Statement of Technical Documents*, March 1987.

3. DA PAM 738-751, *Functional Users Manual for the Army Maintenance Management System - Aviation (TAMMS - A)*, 15 June 1992.

4. AR 385-16, *System Safety Engineering and Management*, 3 September 1985.

APPENDIX F
ELEMENTS OF AN AIRWORTHINESS QUALIFICATION SUBSTANTIATION REPORT (AQSR)

F-l INTRODUCTION

AR 70-62, *Airworthiness Qualification of US Army Aircraft Systems* (Ref. 1) requires that an Airworthiness Qualification Substantiation Report (AQSR) be published after successful completion of an airworthiness qualification program. The AQSR will be prepared by the Government organization which has engineering cognizance over the subject air vehicle. Format should be in accordance with (IAW) the appropriate organization's Standing Operating Procedure (SOP), and should contain, as a minimum, the following elements in subpars. F-2.1 and F-2.2.

Distribution statements as provided for in Department of Defense Directive Number 5230.24, *Distribution Statements on Technical Documents* (Ref. 2) should be considered for use on sensitive technical information.

F-2 CONTENTS

F-2.1 ELEMENTS OF: VOLUME I - AIRWORTHINESS QUALIFICATION FINAL REPORT

F-2.1.1 INTRODUCTION*

F-2.1.1.1 PURPOSE

This element should define the primary and secondary purpose of this AQSR. Normally, the primary purpose of an AQSR is to document the results of the airworthiness qualification program(s) for an identified air vehicle and to provide the basis for the issuance of a Statement of Airworthiness Qualification (SAQ) in accordance with AR 70-62 (Ref. 1). The secondary purpose of the AQSR is to provide data and applicable references which can be used to evaluate subsequent changes to the identified air vehicle. For a modification program, this AQSR should provide the data for previously qualified, unmodified components or subsystems which need not be requalified.

F-2.1.1.2 APPLICABLE CONTRACTS

Current contract numbers and identifying data should be cited. In addition, when previous development contracts or modification programs have resulted in data significant to this AQSR, these contracts should also be cited. For example, development program fatigue test results for unmodified main rotor blades used in a later development program would be included in the AQSR. Test results from the original development program should be included in the AQSR, requiring citation of that development contract. results from the original development program should be included in the AQSR, requiring citation of that development contract.

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*The underlined portion of the paragraph number and title identifies the paragraph number and title in the AQSR.

F-2.1.1.3 EXECUTIVE SUMMARY

The executive summary should be in accordance with Government engineering organization SOP, but should contain, as a minimum, an overview of the system/subsystems/components qualified, general types of testing accomplished, and the total ground and flight test hours completed. This element should provide a clear, concise statement of airworthiness qualification accomplishments upon which Department of Defense (DoD) executives outside the developing agency can base program decisions.

Significant program events which affected qualification should be cited or summarized, as should exceptions to full compliance with specifications and requirements. For example, a crash of a prototype or redesign of a major component or subsystem redesign which caused a program qualification delay should be identified. Additionally, failure to achieve specification objective, such as Vertical Rate-of-Climb (VROC), reliability, or stability requirements, should be cited, with appropriate waiver, deviation, or requirements/specification resolution information. The types of major controversy resolution which should be addressed include PM and test or evaluation agency disagreement on specification compliance, PM and contractor disagreement on responsibility for deficiency correction, prioritization of resources for deficiency correction, and logistics and maintenance difficulty resolution efforts caused by lack of qualified vendors.

Finally, areas in which the qualified systems far exceed requirements should be summarized.

The concluding paragraphs of the executive summary should provide a summary of the degree to which the aircraft or subsystems comply with specifications and requirements and recommendations concerning future program development, qualification, production, and/or operating and support efforts.

F-2.1.1.4 STATEMENT OF AIRWORTHINESS QUALIFICATION

The statement of airworthiness qualification (SAQ) should be included as an appendix to the AQSR. The SAQ, described in Appendix E to this handbook, should be referenced in this paragraph, and should cover the basic air vehicle or subsystem as defined in applicable specifications. The SAQ constitutes the final airworthiness release (AWR) issued in conjunction with the airworthiness qualification substantiation report (AQSR). Issuance of the SAQ normally completes the airworthiness qualification process. The SAQ should include an effective date which is defined as the date after which this SAQ or revision becomes effective. Configuration of the subject air vehicle should be defined by reference to contractor or Government specifications and drawing numbers, MWOs, TBs, approved Engineering Change Proposals (ECPs), etc. When individual air vehicles are configured differently, citation of a reference unique to one or more air vehicles shall identify, by serial number, applicable air vehicle. Other elements include airworthy operation, operating instructions and procedures, limitations and restrictions, sustaining airworthiness, inspections and frequency of inspection, limited life and flight safety parts, maintenance procedures, air vehicle logbook entries, and appendices, and are described in detail in Appendix E.

The SAQ constitutes the final airworthiness release (AWR) issued in conjunction with the AQSR. Subsequent changes to the air vehicle or subsystem should be covered individually, and should require issuance of a separate AWR. AWR contents are described in Appendix D of this handbook.

F-2.1.2 DEFINITIONS

This element should contain, as a minimum, terms and definitions which are peculiar to this document. Definitions of terms defined in referenced publications need not be repeated here.

F-2.1.3 AIRCRAFT DESCRIPTION

This element of the AQSR should contain a general description of the air vehicle and its major subsystems or the subsystem being modified and its major components. For modification programs, only major subsystems or components changed from the baseline air vehicle require description. For developmental programs, plan view and profile drawings (with appropriate narrative) may be used to describe the air vehicle. When extensive information is required to describe the air vehicle, such information may be included in an appendix to the AQSR, with only summary information and reference to that appendix included in this paragraph.

F-2.1.4 AIRWORTHINESS QUALIFICATION PROGRAM

This element should contain two major subelements, Program Schedule and Test Program Summary. These subelements are described in the subparagraphs that follow.

F-2.1.4.1 PROGRAM SCHEDULE

This element should describe the overall test program schedule. The schedule may be depicted by a figure or table. As a minimum, the schedule can be an overall program schedule showing only major events and milestones that have occurred during the qualification program. Detailed schedules, including depiction of significant program events which have affected the schedule, may be used as appropriate. In most cases, the use of figures, such as Gant or PERT charts, make the interrelationship of tasks and events easier to understand. Whenever possible, the depiction of these events or tasks should have a key which allows consultation of detailed narrative for more information. Schedules should identify whether Government fiscal year or calendar year is used.

F-2.1.4.2 TEST PROGRAM SUMMARY

This element should contain a summary of ground and flight testing including the number of hours of ground and flight tests. The summary should cover the integration of static, fatigue, dynamic, ground, and flight tests to the maximum extent possible.

An example of units is a description of the integration of static, fatigue, and dynamic testing on flight critical components for a developmental program until all such components are qualified. Further description might include component integration into subsystems and ground test vehicles (GTVs) and further subsystem testing. Finally, flight testing of prototypes and appropriate production air vehicles to substantiate airworthiness qualification would be described. This description should include the deficiencies identified, corrections implemented and retested as necessary, and full documentation of all testing.

When new technologies are being developed, qualification of those new technologies may not have established procedures. Summaries of specification requirements, a description of the methods for developing test and evaluation strategies, and description of new qualification methods employed should be included.

An example of such a new technology might be an artificial intelligence subsystem designed to reduce operator and or maintainer workload. Quantification of workload should be described, along with the evaluation criteria, criticality of functions performed, and allowance for error (including false alarm and failure to detect or act rates) for the subsystem. When tasks performed by the subsystem are critical to flight safety, results of safety assessments for the subsystem should be included.

F-2.1.5 STRUCTURAL DEMONSTRATION SUMMARY

The purpose of this element of the AQSR is to define the design flight, ground, and crash conditions used in structural demonstrations testing, and to summarize the results of that testing. The scope of this summary should include all flight and ground maneuvers, conditions during those maneuvers, conditions during the crash testing, and summaries of the data obtained using those maneuvers and conditions during the testing. Those element should contain a summary of the design conditions (with margins of safety [MOS] to indicate adequate strength for the applicable critical condition. Each development or modification program typically will dictate the contents of this summary. This element should be further divided into the following four subelements: design flight, groan, and crash conditions, and strength summary. Each subelement is described in the subparagraph that follow.

F-2.1.5.1 DESIGN FLIGHT CONDITIONS

The origin of the system's operational flight requirements should be described (required operational capability [ROC], operational requirements document[ORD], etc.). The process for converting this system's operational flight requirements to technical requirements may be described briefly. Derivation of requirements and test request, including margins of safety, should be summarized for flight maneuvers derived from operational requirements. Such flight maneuvers may include, but are not limited to:

1. Symmetrical dive and pullout
2. Vertical takeoff
3. Recovery from rolling pullout
4. Yawing, both steady sideslip and dynamic yawing
5. Positive gust, negative gust or maneuver
6. Autorotative pullout
7. Turn reversals.

Typical contents to be included with each condition include gross weight, lateral, longitudinal, and vertical center of gravity location, meteorological conditions, airspeed and normal accelerations (if so instrumented), dive and climb angles, angular rates and accelerations (if instrumented), initial conditions, and maneuver termination conditions.

F-2.1.5.2 DESIGN GROUND CONDITIONS

The origin (ROC, ORD, etc.) of the system's operational ground requirements should be described. The process for converting this system's operational ground requirements to technical requirements may be described briefly. Derivation of requirements and test results, including margins of safety, should be summarized for ground maneuvers used to verify that operational requirements are satisfied. Such ground maneuvers may include, but are not limited to:

1. Level landing
2. Nose down landing
3. Tail down landing
4. Main gear obstruction loads
5. Taxing and ground handling.

Typical contents to be included with each condition include gross weight, lateral, longitudinal, and vertical center of gravity location, meteorological conditions, ground speed, oleo and tire inflation pressures (if so equipped), angular rates and accelerations (if instrumented), initial conditions, termination conditions, loads on tow rings or plates, and ground slopes.

F-2.1.5.3 DESIGN CRASH CONDITIONS

The origin (ROC, ORD, system safety assessment, etc.) of the system's crashworthiness requirements should be described. (The process for converting these crashworthiness requirements to technical requirements may be described briefly. Typical contents to be included with each condition include gross weight, lateral, longitudinal, and vertical center of gravity location, meteorological conditions, airspeed and normal accelerations (if so instrumented), dive and climb angles, angular rates and accelerations (if instrumented), initial conditions, termination conditions, angles of impact, groundspeed at touchdown, oleo and tire inflation pressures (if so equipped), and ground slopes.

F-2.1.5.4 STRENGTH SUMMARY

Each of the major subsystems of the subject air vehicle should be listed, and will be further subdivided to list all critical components of that subsystem. Each critical component should be identified by part number (PN), nomenclature, margin of safety (MOS), flight, ground, or crash condition used to calculate that MOS, document which contains the MOS calculation, and page number of that document.

When extensive amounts of data are included, this summary may be provided as an appendix, with a summary of all components' MOSs provided in this paragraph. An example of this summary follows in TABLE F-1.

F-2.1.6 COMPONENT LIVES

As a minimum, this element should list component lives for critical components, and life units, such as flight hours (FH), months, cycles, etc. Data to support these calculations may come from structural analyses and flight loads surveys, and will typically be based on predicted or actual mission profiles using actual gross weights and center of gravity locations. Reports which contain these data should be referenced, and each component

TABLE F-1					
STRENGTH SUMMARY FOR CRITICAL COMPONENTS					
SOURCE: DERIVED FROM NARRATIVE DESCRIPTIONS IN ATCOM SOP 5-ED-1 DATED 11/17/92					
PART NUMBER (P/N)	NOMENCLA-TURE	MOS (%)	CONDITION USED	DOCUMENT SHOWING MOS CALC	PAGE #
	ROTOR SYSTEM				
	Rotor System	12	Autorotative Pullout	S12345	12
12346789-1	Pitch Horn	15	Symmetrical Dive and Pullout	S12345	22
	LANDING GEAR				
124567890-11	Left Main Wheel Spindle	13	Limit Sink Speed, 10 Deg Left	S12456	77
	FUSELAGE				
125678901-13	Left Front Main Transmission Mount	10	Limit Sink Speed, 10 Deg Left	S12567	95

identified should identify the report and specific paragraph or page containing component life calculation. When extensive amounts of data are to be provided, these data may be contained in a table in the text or an appendix to the AQSR. An example of a summary is shown in TABLE F-2.

TABLE F-2
COMPONENT LIFE SUMMARY FOR CRITICAL COMPONENTS

PART NUMBER (PN)	NOMENCLATURE	COMPONENT LIFE (UNITS)	DOCUMENT SHOWING LIFE CALC	PAGE#
	ROTOR SYSTEM			
12345678-9	MAIN ROTOR BLADE	3432FH	S12345	23
12346789-1	PITCH HORN	6523FH	S12345	35
	LANDING GEAR			
124567890-11	LEFT MAIN WHEEL SPINDLE	24 MONTHS	S12456	99
	FUSELAGE			
125678901-13	LEFT FRONT MAIN TRANSMISSION MOUNT	5437FH	S12567	36

SOURCE: DERIVED FROM NARRATIVE DESCRIPTIONS IN ATCOM SOP 5-ED-1

F-2.1.7 OPERATING RESTRICTIONS This element should list or depict op erating limits and restrictions which appear in the operator's manual, and provide justification for those limits and restrictions. When extensive amounts of data will be provided, graphical presentation of limits should be considered. Where applicable, the reason for this specific limit, such as a test or analysis reference, should be cited. When multiple limitations conflict, an application criteria should be described.

Due to varying temperatures, pressure altitudes, gross weight s, and airspeeds, many of the limits are more clearly presented by use of a family of curves. For example, at a given temperature and pressure altitude, airspeed limitations at various gross weights may be depicted using a set of curves. Each curve represents predicted power required at various airspeeds. On the same curve, an engine or transmission limit may depict both maximum torque-limited airspeed and maximum airspeed due to power available. This curve is repeated at other combinations of temperature and pressure altitude, thus forming a family of curves.

Other limitations may be generally applied, with discrete sublimits under certain circumstances. An example may be maximum wind speed for engine starting. The general limit may be 30 knots, with lower limits when the wind is from the two aft quadrants relative to the aircraft nose. These sublimits may need to be graphically depicted in a chart.

As applicable, this paragraph should cover, but not be limited to, the following list of restrictions:

1. Minimum crew requirements should be addressed to define the Additionally, non-pilot crew members, such as crew chiefs, flight engineers, gunners, hoist operators, etc. required for ground or flight operation, should be identified.

2. Plots of permissible propeller, rotor, or prop rotor operating revolutions per minute (RPM) versus gross weight at various altitudes and airspeeds should be provided. Any other peculiar airspeed limitations, such as maximum airspeed allowable when opening cargo doors or with cargo doors open, should be specified.

3. Wind velocity limitations for starting and rotor engagement and sideward and rearward flight should be identified. Sideward and rearward flight limitations should be depicted graphically, showing, when available, data points used to establish limitations. Limitations on flight in specified turbulence conditions should be cited.

4. Continuous and maximum torque limits for engines and drive systems components should be defined. When one condition, such as transmission, exhaust gas temperature, etc., limits system torque, this condition should be identified, along with reference to substantiating data. Curves may be used to depict these limits.

5. Bank angle limits for normal operation and operation following selected subsystem's failures should be identified. An example would be a limitation on bank angle when one hydraulic system is inoperative.

6. Minimum and maximum rotor speed limits for normal operation, ground or flight idle, and autorotation should be identified. When applicable, maximum engine speed for rotor engagement and rotor brake application should be identified.

7. Left and right sideslip limits at various airspeeds should be identified.

8. When limited by sink rates, maximum rates of descent for vertical, autorotative, and roll-on landings should be identified.

9. Flight maneuver load factor limitations (Vn diagram) should be provided.

10. Gross weight versus center of gravity (CG) limitations should be identified. When the permissible CG range changes with increasing gross weights, these limitations may be shown in a figure.

11. When applicable, cargo limitations should be identified. Cargo floor loading limitations (pounds per square inch [PSI], total load in cargo compartment, etc.) and maximum tiedown limitations should be listed. When tiedown limitations have different lateral, forward, or rearward values, this fact should be emphasized.

12. External cargo hook and rescue hoist limitations should be identified when applicable. These limitations should consist of maximum loads, hoist speeds, and number of cycles as appropriate.

13. Environmental restrictions, such as flight in icing conditions, should be identified.

14. Auxiliary power unit (APU) operating limitations should be identified. Examples of such restrictions are limitations on usage time, starting main engines, etc.

F-2.1.8 QUALIFICATION DATA SUMMARY AND INDEX

A qualification data summary and index should be included which lists all Government and contractor technical reports and data generated and used during this airworthiness qualification program. All qualification data, including development program contract deliverables, which provide substantiating data should be cited. Consequently, it is important to begin to build this database early in the development program, and continuously update the database throughout the qualification effort.

As a minimum, this summary should contain the document identification number and title.

F-2.1.8.1 CONTRACTOR DATA

Entries in this element should include all airworthiness related data submitted in accordance with development and production program contract data requirements lists (CDRL). These entries are not limited to test reports, and will include all data significant to airworthiness qualification.

F-2.1.8.2 GOVERNMENT DATA

This list should contain all qualification significant data not just test reports. Test request, test plans, the safety assessment report, etc., should be included. This element should cite document identification number, title, and the agency preparing the report.

F-2.2 ELEMENTS OF: VOLUME II - SPECIFICATION COMPLIANCE BY PARAGRAPH

F-2.2.1 INTRODUCTION

Volume II should contain a paragraph-by-paragraph review of the system control document(s) (detail specification, AQS, etc.) All items covered in the specification-test matrix of Chapter 2 of this handbook which affect airworthiness should be listed here.

F-2.2.2 PARAGRAPH COMPLIANCE LIST

Following applicable specification paragraph listing, a brief description of the requirement cited in that paragraph should also be included, along with a statement of compliance or noncompliance and reference documentation. Additional comments may be included to provide more information on the paragraph or some aspect of compliance.

When extensive amounts of data are to be provided, a summary of compliance or noncompliance may be provided here, with reference to an appendix listing all compliance elements. A sample compliance list is provided at TABLE F-3.

TABLE F-3
PARAGRAPH COMPLIANCE LIST
SOURCE: DERIVED FROM NARRATIVE DESCRIPTION LIST

PARAGRAPH	REQUIREMENT	DEGREE OF COMPLIANCE
6.3.1.4.1 (a)	Completion of Fatigue Test on One Specimen for Each Critical Design Component	Partial IAW SAQ Para A.B.C.D(1)
6.3.1.4.1 (b)	Static Test to Limit Load for Critical Airframe Components	Full IAW SAQ Para A.B.C.D(2)
6.3.1.4.1 (c)	Flight Control Software Documonstration	Full IAW SAQ Para A.B.C.D(2)a
6.3.6.6.1.2	Bench Overstress Test of Main Transmission	Full IAW SAQ Para A.B.D.C(3)b
6.3.6.6.1.2	Bench Overstress Test of Canted Tail Rotor Gearbox	Full IAW Para A.B.D.C(3)b
6.3.7.1	Flight Loads Survey	Full IAW SAQ Para A.B.D.E(4)a

GLOSSARY

When a definition is not included in the text, a glossary of terms used in this appendix will be included. A list of acronyms used and their meanings should also be provided.

INDEX

An index should be provided which will allow location of major subjects within the AQSR. As a minimum, the index should list subjects and page numbers or appendices for all numbered elements of the AQSR.

APPENDIX F

LIST OF ACRONYMS AND ABBREVIATIONS

APU	=	auxiliary power unit
AQSR	=	airworthiness qualification substantiation report
AWR	=	airworthiness release
CDRL	=	contract data requirements list
CG	=	center of gravity
DoD	=	department of defense
ECP	=	engineering change proposal
FH	=	flight hours
GTVs	=	ground test vehicles
MOS	=	margin of safety
ORD	=	operational requirements document
PN	=	part number
PSI	=	pounds per square inch
ROC	=	required operational capability
SAQ	=	statement of airworthiness qualification
SOP	=	standing operating procedure
VROC	=	vertical rate-of climb

APPENDIX F
REFERENCES

1. AR 70-62, *Airworthiness Qualification of US Army Aircraft Systems*, 15 July 1978.

2. DoDD 5230.24, *Distribution Statements on Technical Documents*, 18 March 1987.