ADS-1B-PRF

AERONAUTICAL DESIGN STANDARD

ROTORCRAFT PROPULSION SYSTEM AIRWORTHINESS QUALIFICATION REQUIREMENTS

GROUND AND FLIGHT TEST SURVEYS AND DEMONSTRATIONS

24 APRIL 1996

UNITED STATES ARMY AVIATION AND TROOP COMMAND

ST.LOUIS, MISSOURI

AVIATION RESEARCH AND DEVELOPMENT CENTER

DIRECTORATE FOR ENGINEERING

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1. REQUIREMENTS.

1.1 PERFORMANCE. The Propulsion systems shall meet their allocated performance and operate in such a manner that the aircraft shall be able to be function safely throughout the operational envelope and meet the performance requirements as defined in the applicable weapon system specification.

1.2 QUALIFICATION. The following qualification requirements for the propulsion systems are required to verify compliance with the performance requirements of paragraph 1.1 above as applicable to the aircraft design configuration.

1.2.1 Analysis and Component Qualification. Design and performance analysis shall be conducted on propulsion system components/assemblies using ADS-9C as a guide. Component qualification shall be conducted in accordance with ADS-50-PRF.

1.2.2 Propulsion Surveys and Demonstrations. Propulsion qualification survey and demonstration requirements for the aircraft shall be as listed below.

a. Engine/Airframe Compatibility
   1. Dynamic Response Characteristics
   2. Starting Performance
   3. Failure Modes Effects
   4. Health Monitoring
   5. Cockpit Indications
b. Propulsion System Vibration
   1. Rotor Induced Effects (Frequency, RPM)
   2. Engine Induced Effects (Frequency, Power)
   3. Other Subsystem Effects
a. Propulsion System Temperature
   3. Power Effects
   4. Flight Condition Effects
a. Engine Air Induction System
   4. Power, Speed, Flow Field Effects
   5. Inlet Pressure Recovery/Losses, Performance Effects
   6. Inlet Pressure/Temperature Distortion
   7. Armament Gas Ingestion
a. Engine Exhaust System
   5. Power, Speed, Flow Field Effects
   6. Losses, Performance Effects
   7. Exhaust Flow Impingement

8. IR Suppressor Performance

a. Drive and Accessory System

b. Lubrication System

1. Usable Oil, Oil Tank Expansion/Pressure
2. Bypass, Vent, Debris Detection Systems
3. Cooling Capacity, Margins

a. Fuel System

8. Fuel Availability/Capacity, Feed System Performance
9. Boost/Transfer Pump, Suction Feed Performance
10. Fuel Management
11. Hot Fuel Performance, Starting
12. Auxiliary Fuel System
13. Pressurization/Explosion Suppression System
14. Refuel/Defuel System Performance
15. Fuel Vent System Performance

i. Fire Detection and Extinguishing System

a. Compartment Drainage

b. Engine Water Wash System

c. Hydraulic System

10. Flight Control System Performance, Temperatures, Pressures
11. Utility System Performance, Temperatures, Pressures
12. Filtration, Contamination, Servicing

a. Pneumatic System

13. High Pressure Systems
14. Low Pressure/Vacuum Systems

a. Environmental Control System

14. Heating/Cooling System Performance
15. Pressurization Performance
16. Nuclear/Biological/Chemical System Performance
17. Defogging, Defrosting, Anti-icing/Deicing Performance
18. Control System Performance

o. Auxiliary Power Unit

2. SCOPE.

2.1 General. This document contains rotorcraft airworthiness qualification requirements for propulsion systems. The issuance of a Contractor Flight Release (CFR) to initiate aircraft ground and flight testing is contingent upon successful completion of the analysis and component qualification requirements as contained in ADS-50-PRF. The issuance of an Airworthiness Release (AWR), from a propulsion point of view, is contingent upon successful completion of the analysis, surveys, and demonstrations listed in paragraph 1.2 above. The remaining paragraphs below, are to be used as guidance in defining the required surveys and demonstrations above. The surveys and demonstrations herein are normally divided into two segments; an initial series of propulsion interface surveys and subsequent propulsion demonstrations. In effect, propulsion surveys are considered a subset of the more formal propulsion demonstrations leading to airworthiness qualification. The original ADS-l addressed only propulsion interface surveys. This revision has been expanded to include all propulsion demonstrations. This ADS has also been updated to reflect current technology and lessons learned from recent flight test programs.

2.2 surveys. Propulsion surveys are conducted early in a flight test program to obtain preliminary engineering performance data pertaining to selected propulsion systems/subsystems. Surveys ara intended to determine the necessary design changes, if any, which must be incorporated in either the engine, airframe, or other propulsion systems, and to incorporate these changes prior to completion of engine qualification and/or subsequent engine/airframe or propulsion system airworthiness qualification. Surveys are performed through portions of an aircraft's operating envelope and over a worst case range of c.g., airspeed, altitude, maneuver load factor, and rotor rpm. Usually, propulsion surveys **are** conducted **prior to completion** of **engine qualification** by the engine manufacturer. A test Preliminary Flight Rating (PFR) engine(s) is installed on the test (prototype) aircraft and limited propulsion interface ground and flight testing is conducted. Propulsion interface surveys normally include: *engine/airframe compatibility* tests to evaluate the torsional stability and control system dynamic response characteristics of the engine/rotor/drive system; *engine vibration,* to measure installed vibration characteristics to determine mode shapes and assess compliance with engine and engine component vibration limits and vibration characteristics of other propulsion components; *propulsion system temperatures,* to measure airflow and temperature within the engine compartment to compare with engine component limits; air *induction system,* to measure inlet distortion characteristics and mass airflow, pressure and temperature distribution, and to map the inlet loss characteristics for use in calculating (installed) engine power and performance; and *exhaust system,* to map temperature, pressure and flow characteristics (exhaust swirl angle) of the exhaust system for use in calculating (installed) engine performance. In those aircraft installations employing IR-Suppression devices, as part of the exhaust system, the increase in part power fuel flow becomes an important consideration. In installations employing (fixed geometry, ejector type) hover suppressors, the increase in aircraft power required (due to high momentum losses in the suppressor), becomes significant in high speed flight. For a new development aircraft program, the above propulsion surveys are considered the minimum tests necessary to clear aircraft limitations in the initial Contractor Flight Release (CFR) and thereby permit subsequent envelope expansion. The propulsion survey test program leads to much more successful and expeditious propulsion qualification testing (demonstrations) at the end of the development program. Propulsion survey results can be used to satisfy the requirements of a propulsion demonstration providing the configuration of the components and systems have not changed appreciably.

2.3 Demonstrations. Propulsion demonstrations are the full complement of ground and flight tests necessary to "qualify" the aircraft propulsion systems throughout the entire aircraft operating envelope. Propulsion demonstrations are intended to verify that the operational and performance characteristics of the propulsion system and associated subsystems meet the performance requirements of the aircraft weapon system specification. Propulsion demonstrations are normally conducted near the end of the development program to insure the tested configuration is representative of production hardware. In addition to validating the survey test results, as described above, propulsion demonstrations also include a functional demonstration of the following: *compartment drainage, engine water wash, lubrication system, drivetrain accessories, anti-ice and de-ice system, condition monitoring/diagnostics, cockpit displays, fuel system (including auxiliary fuel system provisions), auxiliary power unit and accessories, environmental control system, pneumatic system, hydraulic system, and armament gas ingestion.* Any of these demonstrations can be performed early in the program along with the propulsion surveys, particularly if program risk would be reduced by an early investigation, providing the configuration of the components or system does not change prior to production.

2.4 Analysis, Test Plans and **Reports.** The contractor should prepare and submit analysis, using ADS-9C as a guide, and component test reports, in accordance with ADS-SO-PRF, prior to the request for a CFR to initiate aircraft ground and flight testing.. The contractor should then prepare and submit subsequent ground and flight test plans prior to the start of the propulsion system surveys and/or demonstrations. The test plans should discuss all test criteria described herein to show how the ground and flight test requirements are to be verified. The contractor should define the testing to be conducted early in the program as part of the propulsion surveys and the tests that will be deferred to future propulsion demonstrations. The contractor should define all test details for the propulsion surveys and include the instrumentation required to obtain the necessary data to efficiently evaluate the performance of the propulsion systems. Prior to the commencement of the more formal propulsion demonstrations, the contractor 'should submit a demonstration test plan, which revises the original test plan, to include the details of the testing planned due to deferment of testing in the original submittal. The contractor should prepare and submit corresponding test report(s) after the completion of the propulsion surveys and other test report(s) after the completion of the propulsion demonstrations. The test reports should contain the contractor's (and subcontractor's, where applicable) engineering assessment of the test data (including failure investigations, as applicable) along with appropriate recommendations and conclusions. The submittal of the test plans and reports should be in accordance with the applicable Contract Statement of Work and Contract Data Requirements List.

2.5 APPLICABLE DOCUMENTS.

ADS-9c	Propulsion System Technical Data
ADS-SO-PRF	Rotorcraft Propulsion System Performance and Qualification Requirements and Guidelines

3. ENGINE/AIRFRAME COMPATIBILITY TESTS

3.1 General Guidance. Compatibility testing of the engine and airframe should be conducted during steady state and transient operation. Generally, compatibility includes considerations such as steady state and transient response characteristics of the engine and engine control system in combination with the drive system and rotor(s). The aircraft manufacturer should define the requirements to verify compatibility using this ADS as a guide. Details of propulsion system stability test criteria are dependent on the specific operating characteristics of the aircraft. Therefore, detailed test requirements to evaluate torsional stability must be defined by the airframe manufacturer. For instance, the rotor/drive system will be subjected to torsional oscillations due to rotor dynamics and acceptable levels of these oscillations will depend upon the size and design of the particular helicopter. Particular attention must be focused on determining that engine fuel flow is not modulated by unwanted low frequency (aircraft induced rotor passage frequencies) vibrations, that can be fed into the engine control system. Also, on some systems, it may be necessary to devise alternate test methodologies to accomplish the objective of the test; e.g., if the collective cycling and pulse methods do not yield the intended torsional excitation (due to collective stick tsavel limitations, for example), methods using pedal inputs or fuel flow interruption may be necessary.

3.1.1 In military helicopters engine/rotor transient requirements often dictate large power changes over a short time period. Rapid power response to pilot demands may be essential. This combination is more likely to lead to transient torsional oscillations than one with reduced gain or slow response. Therefore, consideration should be given to the response of the engine to input signals at different frequencies. The engine should respond rapidly to very low frequency signals such as pilot demand, and should show little or no response to higher frequency signals, such as excitations at the natural frequency of the helicopter rotor system. For torsional stability purposes, the engine/airframe response at the natural frequency of the helicopter rotor system is of major concern. At this frequency, the absence of fuel flow participation in sustaining torque oscillations coupled with rapid torque attenuation are crucial stability considerations.

3.1.2 The mission of today's military rotary wing aircraft demand improved engine control response to meet the demands for improved handling qualities with improved transient rotor droop characteristics and reduced pilot workload. Pursuant to meeting the increased performance demands is specific testing to define the transient torque response of the engine and the resulting transient rotor droop characteristics of the aircraft. This type of flight testing is broken into engineering and mission maneuver evaluations. Engineering maneuvers define the transient response for single axis (collective or pedal) inputs. Mission maneuvers define the response for multi axis inputs (collective, pedal and cyclic) during typical operational mission maneuvers.

3.1.3 Engine compatibility should be evaluated analytically, using ADS-9C and ADS-50 as a guide, prior to ground and flight testing. These analytical evaluations should include engine control/rotor computer modeling, open and closed loop control bench testing, and full aircraft simulation modeling, where applicable. The ground and flight tests should determine:

a. That engine control and flight control systems communicate and function satisfactorily.

b. That the fuel, air induction, exhaust, and bleed air extraction systems, as well as local ambient temperatures, pressures, or vibratory environment will not adversely affect engine power available or transient response.

c. Satisfactory sensitivity, stability, control response, and torque predictability for the control of rotor speed (rpm) during engine power changes (acceleration and deceleration).

d. Satisfactory operation of "auxiliary" engine control functions (as applicable) such as engine limiting (contingency or emergency power), backup (or reversionary) engine control modes, control anticipation features, and cruise fuel flow optimization.

e. Altitude cold starting and hot restart capability.

3.2 Dynamic Response Ground Tests. The basic purpose of the ground testing is to collect data which will provide evidence to evaluate torsional stability prior to conducting flight testing. Normally, torsional stability testing is first conducted through simulations or on a tied down test article. During aircraft ground tests, the engine and airframe will be subjected to excitations at several different frequencies simultaneously, as opposed to the analysis which can only consider discrete frequencies. Aircraft ground tests focus on the frequencies that the analysis/simulations show are of most concern. In this regard, the adverse effects of secondary excitation modes on the primary excitation mode should be considered when the analysis is being verified. In multiple engine aircraft, each engine should be tested independently. Power/speed perturbations at various average power levels and collective pitch at speed select changes are sources for assessing stability. If the helicopter incorporates power management or power change anticipation devices, which can be operated in an "on" or "off" mode, or if the helicopter is designed to be operable when these devices have failed, stability should be evaluated with the helicopter in each of these modes for the qualification testing. However, for the surveys, the off and failure modes may be evaluated for selected conditions only. The selected conditions will largely be determined by analysis (e.g. failure modes effects and criticality analysis).

3.2.1 Starting and Acceleration to Ground Idle. Tests should be conducted with selected combinations of engine control channels and engines (if multi engine aircraft). In addition, transient response from Ground Idle to Fly should be satisfactorily demonstrated.

3.2.2 Acceleration and Deceleration Tests. Engine gas generator speed (Ng) acceleration and deceleration tests should be accomplished with and without contractor installed air bleed and with automatic and manual engine power control. All power increase and decrease tests should be performed at the maximum acceleration fuel flow or NDOT (rate of change of speed) schedule and at minimum deceleration fuel flow or NDOT schedule. The pilot's methods of increasing or decreasing power should be specified for each teat. Data should be plotted in a time history format to capture the transient response. Specific notations on the time history are required to reveal governor transient response characteristics, torque overshoot or torque undershoot, transient droop or steady state droop, governor stability, and pilot corrective action if required. Engine gas generator acceleration and deceleration tests should include:

a. Increase power from flight idle to the engine Intermediate Rated Power (IRP) while the aircraft is ballasted or tied down.

b. With the aircraft ballasted, decrease power from the maximum attainable power to flight idle.

c. With the aircraft ballasted, increase power from ground idle to maximum attainable power (adjust torque, if required) to maximum transient value without exceeding engine limits.

d. Decrease power from maximum attainable power to ground idle.

e. Return gas generator control to the off position to indicate satisfactory operation of fuel cutoff provisions and accommodation of remaining engine (if multiple engines), and proper cockpit annunciation. Repeat using all methods of cutoff (emergency, PLA OFF, etc.).

3.2.3 Power Control Anticipator and Droop Characteristics. Ground tests should be conducted to record the transient characteristics of the engine. The steady state and transient droop characteristics should be obtained for the range of collective pitch positions from full down to midposition and from midposition to the position that corresponds to the maximum attainable torque value.

3.2.4 Rotorcraft Dynamic System Engine Compatibility. To evaluate engine compatibility under tiedown conditions, two power conditions should be established and test runs at each power condition should be performed. At each test condition, each of the pilot's control inputs should be cycled manually (pilot's induced oscillation (PIO)) and electronically, i.e. frequency oscillator, at the critical oscillation frequencies of the dynamic system(s) and at two frequencies, one on each side of critical. The adjacent frequencies should be in close proximity to the critical frequency to "map" the oscillation characteristics (i.e. amplitude, wave shape). Data should be plotted as a time history.

3.3 Dynamic Response Flight Tests. Flight tests may reveal instability not detected in the ground tests since the engine/airframe system may be subjected to excitations at frequencies not encountered previously. The dynamic response of the aircraft will be dependent on several factors including the configuration, i.e. rotor arrangement, and the operational usage, i.e. combat versus cargo mission. Consequently, the dynamic response testing will be tailored taking these factors into consideration. The tests described below are intended to be a generic standard subject to "tailoring" depending on these factors. Data should be collected and reduced in the same manner as for the ground tests.

3.3.1 Acceleration and Deceleration Tests. The engine gas generator acceleration and deceleration tests which follow should be performed with and without contractor installed air bleed, with automatic and manual engine power control, at least three altitudes from sea level to the service altitude, and at least three (3) airspeeds up to maximum level flight speed. In each of these tests, the pilot's collective should be moved at a rate to provide maximum acceleration fuel flow or NDOT rate schedule and at minimum deceleration fuel flow or NDOT schedule as allowed by the engine. For the altitude gas generator accelerations, the airspeed prior to acceleration should include at least a minimum and maximum rate of descent condition. The flight speed prior to gas generator deceleration should be consistent with minimizing scatter of data which could be attributed to pilot handling techniques. The pilot's method of increasing or decreasing power should be specified. Plotting of data should begin prior to control movement and continue until steady state engine conditions are reached. Acceleration and deceleration time should be plotted over a range of collective position, fuel flow and pressure altitude. The tests should include:

a. Application of power from autorotation (engine flight idle) to maximum rated engine power.

b. Decrease of power from maximum rated engine power to flight idle power.

c. Increase of power from ground idle to maximum rated engine power. If required, increase power to obtain the maximum transient torque limit while remaining within all applicable limits.

3.3.2 Gas Generator Control. At design gross weight and c.g. and at least three altitudes from sea level to the service altitude conditions, steady state engine data should be recorded at minimum and maximum continuous power turbine speeds for each 10 degree increment. Data should be plotted as a function of control position (collective).

3.3.3 Engine/Airframe Transient Response. Testing is required to verify the engine/airframe response characteristics and the transient rotor speed droop characteristics at applicable mission gross weights. A complete set of engineering and mission maneuvers is required to verify compatibility between the propulsion system and airframe relative to mission operability requirements.

3.3.3.1 Engineering Maneuvers. Each of the engineering maneuvers descibed below should be performed to evaluate the response of the engine/aircraft system with single axis input (e.g. Collective, Pedal, and Cyclic).

3.3.3.1.1 Transient Response Maneuvers. Transient rotor speed droop/overspeed and torque overshoot is to be evaluated by performing timed collective pulls from powered descent to quantify rotor speed droop as a function of collective rate application. This maneuver can be summarized as a power on autorotation with the throttle at the FLY position. A typical evaluation of this maneuver would be as follows: the aircraft is stabilized at a steady state airspeed in a descent. At the test altitude, e.g. 5000 ft. density altitude, the collective is raised at a constant rate to a predetermined target value of main rotor torque. A series of test points are performed while increasing the collective rate application from a slow to a fast rate, e.g. 8 seconds down to 2 seconds.

3.3.3.1.2 Hovering Turns. A typical demonstration of this maneuver would be as follows: Directional pedal turns and reversals are initiated from a stabilized hover in winds of 5 knots or less. Pedal is rapidly applied to initiate and stop a 180 degree turn on heading. The maneuver is performed at both HIGE and HOGE. A variant of this maneuver would be to initiate, stop at 180 degrees, then immediately reverse to the starting point.

3.3.3.1.3 Collective Inputs at Hover. A typical demonstration of this maneuver would be as follows: Collective pulls to 100% of the torque limit are initiated starting at a low collective rate and building to the maximum rate obtainable. The maneuver is performed at HOGE while maintaining heading. A variant of this maneuver would be to perform a ‘jump take-off" to a HOGE.

3.3.3.2 Mission Maneuvers. The following Mission Maneuvers should be performed as applicable:

3.3.3.2.1 Quick Stop. Quick Stops can be demonstrated as follows: From a steady state airspeed at a safe altitude, increase pitch attitude and lower collective in a coordinated manner to maintain a constant altitude. Maneuver aggressiveness should be varied by changing the entry speed, maximum pitch attitude, pitch rate and collective rate application. The maneuver is terminated by slowing to a stabilized hover. There are two basic variations to this maneuver, one maintains constant altitude relative to the aircraft c.g. and the other maintains constant altitude over an obstacle (the aircraft is pitched about an axis at the tail instead of at the c.g.).

3.3.3.2.2 Unmask/Remask (Bob-Up and Bob-Down). A typical demonstration of this maneuver is as follows: From a stable hover, increase collective for a quick vertical climb to a predetermined altitude. The aircraft is stabilized for a brief moment (typically 2 seconds) before lowering collective for descent back to the initiation point. The maneuver is repeated building the collective input to obtain 100% torque.

3.3.3.2.3 Acceleration/Deceleration. A typical demonstration of this maneuver is as follows: From a hover, increase power to 100% allowable while performing a level forward acceleration. Upon reaching a steady state airspeed (approx. 50 KTAS), perform an aggressive level deceleration to hover. Peak pitch attitude should be reached just prior to reaching stabilized hover.

3.3.3.2.4 Deceleration to Dash. A typical demonstration of this maneuver is as follows: Initiate the deceleration to dash in level flight by performing a maximum deceleration while maintaining constant altitude. Perform a maximum power available level acceleration.

3.3.3.2.5 Terrain Approach. A typical demonstration of this maneuver is as follows: Initiate terrain flight approach maneuver in unaccelerated level flight by reducing collective and immediately starting a left 180 degree descending and decelerating turn (with and without NR/NP Split = 0/5%). Terminate the approach at a stable hover.

3.3.3.2.6 Ridgeline Crossing. A typical demonstration of this maneuver is as follows: During level unaccelerated flight initiate a 500 ft. climb and immediately descend to initial altitude while holding constant heading and airspeed.

3.3.3.2.7 Rapid Sidestep. A typical demonstration of this maneuver is as follows: Enter the rapid sidestep maneuver from a stabilized hover with the longitudinal axis of the aircraft orientated 90 degrees to the centerline of the runway. A rapid lateral translation is executed with a bank angle of approximately 25 degrees while holding altitude constant with collective. When aircraft lateral velocity reaches a predetermined airspeed, perform a rapid deceleration to hover with an initial bank angle of approximately 30 degrees. Maintain a stabilized hover for 5 seconds, followed by a similar lateral translation in the opposite direction to the initial hover position.

3.3.3.2.8 Roll Reversals. A typical demonstration of this maneuver is as follows: Perform roll reversals from Left to Right, repeat *from* Right *to* Left. Perform maneuver at airspeeds up to maximum cruise speed. The quickness that these maneuvers are performed may result in rotor/engine decoupling.

3.3.3.2.9 Pull-up/Push-over. A typical demonstration of this maneuver is as follows: initiate the pull-up and push-over maneuver in level unaccelerated flight, smoothly pulling aft cyclic, with collective fixed, to reach the minimum normal controllable airspeed. Apply forward cyclic until the maximum normal acceleration limit is reached. Throughout the maneuver, use cyclic and pedals to maintain a steady heading and wings level flight attitude.

3.3.3.2.10 Vertical Remask. A typical demonstration of this maneuver is as follows: initiate the vertical remask at a hover by rapidly descending vertically. The aircraft is then laterally displaced approximately 300 ft. as quickly as possible, ending the maneuver in a stable hover. The maneuver is repeated in the opposite lateral direction.

3.4 Helicopter Dynamic System Engine Compatibility. HOGE at a safe altitude, within the flight limits of the helicopter rotor at design gross weight and center of gravity Testing should be conducted at three power turbine speeds. The pilot's power lever (i.e. collective control, etc.) should be cycled manually at the critical frequencies of the dynamic system(s) and at two frequencies, within 0.1 Hz of critical, on each side of critical. Oscillation within acceptable limits should be determined.

3.5 Engine Starting Tests. This test is to determine the adequacy of the engine starting and shutdown procedures. An engine start should be demonstrated over the operating envelope of the aircraft for the following conditions:

a. Humidity (normal to test site)
b. Battery (fully charged at beginning of test cycle)
c. Reservoirs (hydraulic or pneumatic) at full pressure volumes at beginning of test cycle.

3.5.1 Ground Tests. These tests should determine compliance with both component detail specification and weapon system specification requirements and installation compatibility and operational start procedures. Parameters such as engine start times for normal and emergency starts, both for single and simultaneous starts, where applicable, should be evaluated. Engine automatic functions such as hot start prevention, start temperature limiting, and power turbine overspeed checks should be evaluated. Starts should be accomplished for all applicable operating modes of the aircraft (e.g. with and without the rotor brake or gust lock engaged, cross bleed starts, intake doors open and closed, generator loads on and off, etc. Hot restarts should be accomplished. Degraded mode tests, as applicable, should also be accomplished (e.g. weak battery, depleted hydraulic accumulator, etc.). Buddy starts and ground power cart assisted starts should also be demonstrated as required by the specifications.

3.5.2 Flight Tests. These tests should demonstrate (1) altitude restarting capability to the altitude starting envelope defined in the weapon system specification, and (2) the adequacy of the airborne engine shutdown and altitude restart procedures. Air restarts should be performed at various altitudes. For single engine helicopters, the test should be conducted at the recommended best glide speed. For multi-engine helicopters, additional tests should be conducted using maximum and minimum single engine airspeed or power for level flight.

3.5.3 Instrumentation. Instrumentation to determine at least the following is recommended:

a. Starter temperature
b. Starter rpm
c. Starter current or agent flow, depending on the system
d. Starter terminal voltage or pressure, depending on the system
e. Battery terminal voltage or current, depending on the system
f. Time
g. Voltage and current to engine exciter
h. Torque output of starter (if on a dynamometer)
i. Engine Fuel Flow
j. Engine control system operational modes such as hot start prevention, start temperature limiting, and overspeed test activation.

3.6 Engine Failure *Modes And* **Effects Demonstration.** The contractor should conduct ground and flight tests of the engine control system to demonstrate specific failure modes and their effects on aircraft performance and control response at various combinations of altitude and airspeed.

3.6.1 Purpose. The purpose of these tests is to demonstrate continued safety of flight and proper system degraded operation. Testing should demonstrate engine or flight control system automatic backup modes, or any reversionary or manual control system modes. Demonstration of mixed mode operation should also be accomplished. Ground and flight degraded mode testing should show that the system failures do not cause unexpected engine transients, unacceptable controllability, stability, handling qualities, or require any urgent or excessive pilot action.

3.6.2 Tests. The specific tests should demonstrate the relationship between the engine and flight controlsystem. Selected modes should be verified on the ground prior to demonstration in flight. A range of gross weight, c.g., airspeed, altitude, maneuver load factor, and rotor rpm should be tested. All stability, including torsional, should be demonstrated for degraded engine control modes of operation. The degraded engine control characteristics should be demonstrated by selectively failing signals causing transition in and out of the backup control system modes during ground tests or selecting the mode directly if possible. The system should recognize failed or erroneous data and compensate by either reverting to a backup system, synthesizing a replacement signal, or continuing operation in a degraded mode. Simulated malfunctions and functional backup modes should be displayed to the pilot through normal cockpit warning/caution/advisory displays. Fault diagnostics or recognition resulting from failure modes effects demonstration (FMED) testing should be verified through the health and usage monitioring system.

3.7 Engine Monitoring System. The contractor should demonstrate engine diagnostic and health monitoring functions including an assessment of display information, system accuracy, power assurance functions, and ground support equipment necessary to interrogate and retrieve information from imbedded systems.

3.8 Cockpit Indications. The contractor should functionally verify that cockpit indications demonstrate proper operation, ranges, zones, and accuracy. Testing should include human factors engineering concerns, including display symbology, time delays (failure to annunciate), parameter selection, parameter display clarity and parameter exceedance warnings.

4. ENGINE VIBRATION

4.1 General Guidance. An engine vibration survey is conducted to determine that a satisfactory interface has been achieved between the engine (including subsystems/accessories) and the airframe relative to both high frequency engine excited and low frequency aircraft rotor(s) excited vibrations.

4.1.1 Rotory wing aircraft installations require particular attention be given to the effects of the high *energy* low frequency vibrations generated by main rotor blade passage (fundamental and harmonic) frequencies on the engine and related engine components. Design of the engine mounting system is the key element in obtaining an adequate interface relative to low frequency vibrations. To assess the effects of aircraft induced vibrations on the engine installation, engine mode shapes must be defined (using phased vibration transducers) and strain gauge data taken pursuant to the determination of the structural integrity of the engine case, mounts, exhaust system (including IR-Suppression devices), controls, accessories and attendant drive system components.

4.1.2 Engine induce6 vibrations are generally less problematic than aircraft induced vibrations, however these high frequency vibrations occasionally pose formidable problems; particularly if they are non-synchronous. Non-Synchronous Vibration (NSV) problems are usually associated with installations having engines that incorporate one or more of the following design features: Axial flow combustors, with attendant longer shafts and lower engine case stiffness, squeeze film damped bearings that require incipient levels of whirl to obtain satisfactory bearing life, super critical shafts that require the engine to traverse a critical speed to and from normal operating speed, shaft coupling devices that (inadvertently) allow relative motion between contact surfaces; and working splines that may bind. NSV problems are often insidious and driven by mechanical tolerance stack-up and not easily identified (if at all) during the survey/demonstration test phases of a program.

4.1.3 The goal of the engine vibration survey is to identify early on that no serious engine installation vibration problems exist. The survey's focus is to establish compliance with the installed engine vibration limits (as defined by the engine installation drawings) provided by the engine manufacturer. It is recognized that compliance with engine vibration limits throughout the entire operating envelope of the aircraft is usually not completed in the survey phase; e.g., compliance with engine vibration limits during high load factor maneuvers is typically deferred until (and piggy-backed onto) the structural demonstration testing of the aircraft.

4.1.4 The other propulsion subsystems and accessories may be affected by either the aircraft rotor(s) blade passage frguencies and harmonics or the high frequency modes generated by the engine. The contractor should monitor the vibration levels of pertient components throughout the aircraft rotor and engine speed ranges across the operating envelope of the aircraft during the course of the ground and flight test program. The goal is to insure that vibration levels do not exceed component detail specification requirements that would adversely affect performance or life.

4.2 Engine Vibration Responsibilities. To insure a successful engine installation, the airframe and engine manufacturers should work together to define the requisite vibration limits, instrumentation, conditions to be examined, pertinent data analysis, etc. Typically, the airframe and the engine manufacturer, who normally supplies the engine as Government Furnished Equipment (GFE), will prepare a vibration plan, through an interface agreement, that will define each party's responsibilities. A typical division of the responsibilities is as follows:

4.2.1 Airframe Manufacturer's Responsibility. The airframe manufacturer should prepare an engine installation and propulsion system vibration plan that will include, but not necessarily limited to, the following:

a. A list of primary parameters to be recorded, such as accelerations, velocities, torque, force, stress, and displacement measurements as well as other pertinent parameters including rotor speed, airspeed, altitude, outside air temperature, gross weight, and c.g.

b. Ground and flight test conditions to be examined.

c. Instrumentation requirements.

d. Pertinent data analysis and documentation requirements.

e. Criteria of steady state and transient limits.

4.2.2 Engine Manufacturer's Responsibility. The engine manufacturer will establish the location and orientation of vibration sensors and provide their mounting instructions. The sensor locations will be common to both the engine test cell and the helicopter installation test measurements. The engine manufacturer will define acceptable installed engine vibration limits. The limits definition should include: parameters to be measured (e.g. acceleration, velocity, displacement, bending angle); sensor locations; applicable frequency bands; and acceptable vibration magnitude. These vibration limits will reflect considerations of frequency of occurrence of vibration magnitudes which are representative of both steady state and transient flight for the anticipated mission spectrum of the aircraft.

4.3 Test Criteria.

4.3.1 Ground Tests. The ground tests should be conducted at design gross weight and design c.g. unless otherwise specified. Ground tests should be conducted to record data under the following conditions:

a. Engine ground idle power.

b. Slow sweep from ground idle to maximum attainable power.

4.3.2 Flight Tests. Flight tests of the engine and propulsion system installation(s) should cover as much of the flight envelope as possible. Focus is to be placed (but not limited to) those regimes of the envelope that experience has shown produce the highest vibration levels. These tests should be conducted at design gross weight and c.g. for the baseline configuration. The following tests should be performed as a minimum:

a. Approach to hover (flare), 100 percent rotor speed

b. IGE hover, 100 percent rotor speed

c. Normal acceleration, sea level to 6000 ft.

d. Level flight, speed VH, 100 percent rotor rpm

e. Left and Right turns @ 0.5 VH., sea level to 6000 ft.

f. If the aircraft is to be operated at rotor RPM's other that 100 percent, those selected RPM's should be investigated in hover and forward flight.

4.3.2.1 Rotor/Drive Shaft Balance. Prior to acquisition of the engine vibratory data, an assessment of the unbalance of all helicopter rotors and the drive shafting, and of the track of the lifting rotor(s) should be made. Factors to be included in defining acceptable vibration levels are the maximum acceptable unbalance or out of track condition.

4.3.2.2 Special Configurations. The evaluation of special intake or exhaust duct configurations or other kits which significantly change the engine vibratory characteristics should be evaluated in those regimes, which, based upon the baseline data, calculations and estimates, will produce the highest vibrations.

4.4 Instrumentation and Data Analysis.

4.4.1 Instrumentation. Instrumentation for the engine vibratory survey should include:

a. Sensors (acceleration, velocity, or displacement)

b. Signal conditioning equipment
c. Recording equipment
d. Data acquisition system frequency range, dynamic range, overall accuracy, and calibration methods and procedures.

4.4.2 Data Analysis. The airframe manufacturer should specify in the test plan the data analysis procedures which will be used to compare the measured data with the installation vibration limit. The final data presentation specified in the test plan should be in a form which provides direct comparison with the installation vibratory limits. For example, the vibration limits may be specified by the engine manufacturer in terms of:

a. Engine displacements (rigid body motion, and torsional and bending modes).
b. Overall vibration (peak, rms, average, etc).
c. Narrow band and wide band analysis (discrete frequency)
d. Specified combinations of Items a through c.

These procedures should include details such as filter characteristics sweep rates, sampling rates, and the total number of samples per data point, as applicable. The procedure for vibratory evaluation of the engine/airframe which follows is acceptable.

a. The engine manufacturer will determine the effective engine masses, inertia's, and stiffnesses and their required distribution, and will conduct an analysis to obtain the engine's natural frequencies and bending modes of the engine.

b. The engine manufacturer will conduct a free-free vibratory test of the engine to obtain the frequency response characteristics, natural frequencies, and mode shapes. These results will be compared with the analysis in Item a., and a determination will be made of the modifications of parameters required to achieve reasonable agreement between calculated and measured values.

c. The airframe manufacturer should conduct a frequency analysis of the engine installation, taking into account the significant fuselage contributions, to determine the fundamental rigid and flexible-body natural frequencies in the plane(s) of predominant helicopter rotor excitations.

d. The airframe manufacturer should tabulate and identify the inherent airframe excitation sources and their variations with helicopter rotor speed.

e. The engine manufacturer will review the results from Item c and d, and will identify potential problem areas.

f. The airframe manufacturer should draft a test plan to include the engine and other propulsion system components and accessories.

g. The engine manufacturer will review the test plan and either approve the plan or recommend modifications to the procuring activity.

4.5 Engine Vibration and Propulsion System Documentation. Typical documentation of the ground and flight programs should include, but not be limited to, a description of test vehicle and engine installation, test equipment and procedures, flight log, criteria test results, conclusions and recommendations, and a discussion of results. Specifically, the report should define the engine rigid-body and/or flexible modes for the installation and compare these with the helicopter excitation sources. The test results should state and/or show the relationship of the measured data to the applicable criteria, and should describe the predominant frequencies of response and should show engine mode shapes at these predominant frequencies and should present time histories; overall, octave band, or discrete frequency analyses; and mode shape plots for the cruise flight condition and for the condition or conditions producing the highest vibratory levels. The data should be made available to the engine manufacturer. A tabulation of all propulsion components should be presented showing frequencies and maximum acceptable amplitude for each critical component.

5. PROPULSION SYSTEM TEMPERATURE

5.1 General Guidance. A propulsion temperature survey, to include the engine compartment, APU compartment, and adjacent or adjoining structure, should be conducted to determine that the engine/APU installation will provide satisfactory cooling and no problems will occur during the helicopter qualification. Included in the propulsion temperature survey should be the determination of:

a. Engine and transmission oil inlet and outlet temperatures.

b. Temperatures of the engine case surface and all temperature limited engine components whether mounted on the engine or in adjacent areas (e.g. off mounted electronic controls).

c. Temperatures of airframe components such as APU's, generators, starters, hydraulic components, fire detectors, and drive shafting.

d. Critical temperatures of engine compartment structure.

e. Heat exchanger inlet and outlet temperatures for both the hot and cold fluids.

5.2 **Test Criteria.** Testing (ground and flight) should be conducted to indicate that no adverse conditions will occur with regard to the cooling characteristics of the helicopter structure and of the helicopter and engine mounted components during qualification testing. For multi engine aircraft, both single and multi engine testing should be conducted for all aircraft normal and degraded operating modes (i.e. rotor brake/gust lock on/off, generators on/off, etc.). Tests should be conducted at up to the design gross weight and c.g. and at both standard and hot day conditions, unless otherwise specified.

5.2.1 Ground Tests. Ground cooling tests should be conducted with the wind velocity at less than 5 knots and the aircraft in a worst case azimuth position (as determined by initial surveys). Testing should be conducted with ground winds from all four cardinal compass directions relative to the aircraft to insure that cooling is satisfactory with wind from the worst direction. The engine(s) should be run at the listed engine powers until 5 minutes after temperatures stabilize (if possible), and any engine operation limitations should be noted. Temperature stabilization is attained when the temperature increase or decrease is less than 2°C per minute. Data should be recorded at sufficient intervals to determine the temperature profile for all tests and should be recorded for 30 minutes following engine shutdown. The following conditions should be tested:

a. Ground idle power
b. Flight idle power
c. Maximum attainable power
d. Shutdown (soak-back)

5.2.2 Flight Tests. The flight conditions listed should be conducted. Each run should be for the period of time necessary to obtain approximate structural temperature stabilization or for the maximum time within applicable limitations, whichever is shorter. Data should be recorded at 30 second intervals and 5 minutes after temperature stabilization (if possible).

a. Hover out of ground effect (OGE)
b. Hover in ground effect (IGE)
c. Level flight at maximum attainable power
d. Maximum velocity rearward flight
e. Maximum power climb

5.3 **Instrumentation and Data Analysis.** A recommended general list of the temperature data is as follows:

a. Critical engine component temperatures determined by the engine manufacturer
b. Exhaust gas temperature (minimum of four sensors)
c. Ambient temperature
d. Accessory temperatures
e. Generator temperature
f. Critical structural temperatures determined by the contractor and procuring activity
g. Engine compartment air inlet and outlet temperatures.
h. Engine oil inlet and outlet temperatures
i. Engine inlet temperature
j. Measured gas temperature
k. Transmission oil inlet and outlet temperatures
1. Other Propulsion components

5.3.1 Other Parameters. To properly evaluate that adequate cooling is obtained, other parameters require measurement. These include:

a. Pressure altitude
b. Airspeed
c. Time
d. Engine rpm (both gas generator and power turbine) and torque
e. Wind velocity and direction relative to the rotorcraft
f. Engine compartment airflow rate

5.3.2 Temperature Correction. Temperature data should be corrected to hot atmospheric conditions as specified for the aircraft in the respective weapon system specification. Cooling data should be presented for the conditions tested for all individually cooled accessories along with the manufacturer's specified cooling requirements.

6. ENGINE AIR INDUCTION SYSTEM

6.1 General Guidance. The engine air induction survey is conducted to determine the engine airflow conditions and to relate these quantities to freestream conditions. Particular requirements are for detailed measurements of air temperature and total and static pressures at the engine inlet, air induction system interface, from which mean pressures and pressure variations across the engine inlet face can be established. The air pressure and temperature at the engine inlet have a direct bearing on the power output and fuel consumption of the installed engine. Gradients which exceed the allowable limits defined by the engine manufacturer have an adverse effect on operation of the engine and may cause compressor stall.

6.2 Engine Air Induction System. Tests should be conducted at incremental altitudes from sea level to the service ceiling of the aircraft and at least at standard and hot day conditions. Special consideration should be given to evaluating all features associated with the induction system and the possible operating combinations that might occur during normal operation or following the failure of a system. Such systems may include an inlet sand and dust separator with a secondary scavenge system, an inlet screen, a barrier filter with a bypass system, and variable geometry elements. It is important that all normal and failure modes be tested to uncover all potential anomalies and hazards. In a configuration where hot anti-icing air is discharged into the inlet or inlet duct surface heating is employed for anti-icing, additional data should be obtained. This hot air (or hot surface) may have an adverse effect on the engine due to temperature gradients and local separation in the duct (where the hot air is introduced). For helicopters that will be firing armament, an inlet survey should be conducted to determine the adverse effects of armament gas (and debris) ingestion on engine performance (i.e. surge and resulting torque spikes).

6.3 **Test Criteria.**

6.3.1 Ground Tests. Ground and taxi tests, both crosswind and tailwind, should include the following:

a. Ballast helicopter to prevent liftoff.
b. Run a power sweep from ground idle to maximum attainable power.
c. Run up each engine (if applicable) in turn.

6.3.2 Flight Tests. For acceptable results, all flights should be performed in smooth air. In addition to recording inlet pressures and temperatures, it will be necessary to record basic flight-and engine data, including pressure altitude, flight speed, OAT, gas generator speed, fuel flow, measured gas temperature, engine torque, and helicopter rotor speed. Flight tests at design gross weight and c.g. are as follows:

6.3.2.1 Hover (IGE). Establish hover flight in-ground-effect. Establish hover with each engine in turn at maximum power; the remaining engine should provide only the additional power required to maintain the stable condition.

6.3.2.2 Level Flight Speed Sweep. Operate at least two flight speeds between minimum power speed and VH with emphasis on normal operating speeds and speeds critical to the proposed helicopter usage.

6.3.2.3 Severe Aircraft Inlet Flow Fields. Inlet characteristics should be determined for all extreme inlet flow fields, including:

a. Maximum vertical climb
b. Maximum rate of climb
c. Maximum rearward flight
d. Maximum sideward flight
e. Maximum sideslip
f. Maximum decending flight
g. Maximum vertical decent
h. Maximum angle of bank
i. Maximum yaw rate in hover

j. Maximum rotor RPM range of aircraft

6.3.2.4 Armament Gas Ingestion Flight Testing. A series of flights will be required to demonstrate the effects of armament gas ingestion on the engine and drive system, for armed aircraft. Flight conditions will vary depending on the operational scenario pertaining to the individual helicopter. The testing should include firing of all weapons and ordinance (guns, missiles, rockets) that may contribute to gas ingestion. As a minimum, firings should be conducted from both a hover in ground effect and out of ground effect, at forward speed in **50** kt. increment3 up to simulation of a high speed pass. Various firing rates (salvos) of each ordinance should be conducted at each test point. Firing rates will be determined by the individual helicopters weapon system and it's operational scenario. Instrumentation should include, as a minimum, all pertinent engine parameter3 and inlet pressures and temperatures including high speed pressure probes and thermocouples. In addition, in flight infrared photography should be utilized to determine the signature of the ordinance hot **gas** plume. Pressure or temperature sensitive paint should also be used, if available.

6.4 Effect on Engine Performance. Induction system losses should be included when using the engine specification to calculate **power available**. power assurance, and engine fuel flows.

6.4.1 Inlet Pressure Recovery. Determination of inlet pressure loss which is important at the performance guarantee condition or conditions should be provided for the testing.

6.4.2 Inlet Pressure Distortion and Temperature Distortion Effects. Pressure and temperature gradients at the engine inlet will affect governing characteristics of the engine and, therefore; should be measured. Compressor stall may be induced, and the engine may or may not recover from this condition, depending upon its characteristics. In extreme cases of distortion, steady state stall may be induced. Also, **compressor or** turbine blades may be excited by **the** pressure pulses and experience stress levels that are higher than allowable.

6.5 Instrumentation and Data Analysis. The instrumentation required for the inlet survey should include pressure, temperature and airflow rakes in sufficient quantities and locations to adequately-map the inlet characteristics. The engine manufacturer may define special instrumentation requirements for that particular engine installation. In addition, the engine manufacturer may supply special instrumentation peculiar to his design, or provide an instrumented engine inlet section.

6.5.1 Total Pressure. Total pressure probes, i.e., those which measure both static and dynamic pressure, are installed as rakes with several probes on each rake. For convenience, the probes should be located on centers **of equal** annular area in the engine inlet, to **provide** for simple averaging of measured pressures.

6.5.2 Static Pressure. Static pressure in the duct may be measured using a stream static probe on each rake and/or flush wall static's in the same plane as the rakes. When instrumentation locations are defined in the applicable engine model specifications, the same location should apply to the helicopter installation.

6.5.3 Technique. Total and static pressures are recorded on magnetic tape or an oacillograph recorder via a scannivalve. The scannivalve cycles, selects each pressure probe in turn, and applies it to a pressure transducer which is referenced to the ambient pressure (static). The ambient pressure (static) reference should be the same as that used for the altimeter. For moat pressure recordings, it will be advantageous to record the reference pressure at the beginning and the end of each data cycle for ease of identification. Inlet pressure instrumentation should have a flat frequency response from **5** to 100 Hz.

6.5.4 Considerations. Installations where hot gas ingestion from the engine or other sources, such as armament, is suspected will dictate the use of additional probes. Probes should be sensitive enough to measure rapid changes in pressure and temperature. The inlet total temperature probes should be balanced against a freestream probe of known recovery factor; in this way, a more direct reading of temperature increase is obtained. Probes exposed to solar heating or other radiation should be shielded. The cockpit outside air temperature (OAT) gage should not be used as the datum for inlet temperature measurement because it will not provide the required accuracy. Pressure recovery is defined as the mean total pressure (absolute) Ptl at the engine inlet face divided by the freestream total pressure (absolute) Pto. The pressure recovery of the air induction system Ptl/Pto may exceed unity at low forward speed due to the influence of the helicopter rotor's downwash component. The method used to show compliance with pressure distortion limits dictated by the engine manufacturer will depend upon the definition provided in the engine specification. It may vary from a simple statement or percentage of pressure variation about the mean pressure, to a complex evaluation of the period and amplitude of the pressure variation around the engine inlet face. Regardless of the definition used, a convenient method of showing pressure distortion is to plot isobars over the engine inlet annulus, mapping lines of constant Ptl/Pto. From these plots, peaks and troughs are easily identified relative to the mean pressure in the duct. Inlet temperature usually is greater than ambient static temperature due to converting kinetic energy to heat and to the heat added by other sources inherent in the design. Although inlet temperature distortion limits usually are not identified in the engine specification, it is recommended that a distortion of 10°C be reported to the engine manufacturer for his assessment. Among sources of additional heat to be considered are ingestion of exhaust gases from main engines, auxiliary power units, and weapons.

6.6 Air Induction System Documentation. Typical documentation should include comparisons with applicable specification values supplied by the engine manufacturer; test instrumentation; summary of test points; curves of inlet recovery versus flight speed and condition; curves of power and fuel flow effects under various conditions; and pressure distortion plot (where distortion is not a problem, only sample extreme conditions need be addressed). Raw test data and data reduction sheets should be included.

7. ENGINE EXHAUST

7.1 General Guidance. An engine exhaust survey should be conducted to determine the acceptability of the engine exhaust system including Infrared Suppression systems (IRS). Focus is placed on the structural adequacy of the design and the exhaust systems effect on the engine/installation (including installed engine performance). The levels of the mechanical and acoustically coupled vibrations generated by the engine/airframe must not degrade structural design life of the exhaust system. The design of the system must insure that adequate cooling of the engine compartment is obtained throughout the operating envelope of the aircraft. Low power ground operation, particularly with locked rotor often represents the worst case condition relative to over temperature of engine nacelles from exhaust back flow or unacceptable levels of exhaust impingement on the airframe. Low Observable performance requirements relative to hot metal and plume signatures for IRS systems are typically included in the exhaust survey.

7.2 Test Criteria. All systems which extract air from the engine, the inlet duct, or the engine compartment should be operated normally.

7.2.1 Ground Tests. The engine should be operated on the ground at the power settings which follow under static and taxi conditions:

a. Ground idle (with and without gust lock or rotor brake engaged)
b. Maximum attainable power

7.2.2 Flight Tests. The engine should be operated over the range from flight idle (autorotation) to maximum power in flight at incremental test 'altitudes from sea level to the service ceiling of the aircraft.

7.3 **Instrumentation and Data Analysis.** Data acquisition and reduction systems, calibration techniques, location and installation of instrumentation, general test procedures and other pertinent information influencing the validity of the test data should be documented. A minimum of four pressure rakes each should be installed for the measurement of the static and total exhaust pressure. The following data should be measured:

a. Pressure altitude
b. Airspeed
c. Time
d. Engine RPM (gas generator and power turbine) and torque
e. OAT
f. Engine inlet temperature
g. Engine inlet pressure
h. Exhaust pressure (static and total)
i. Exhaust gas temperature
j. Bleed airflow, temperature, and pressure
k. Fuselage temperatures affected by exhaust gas heating
l. Turbine outlet pressure
m. Tailpipe surface temperatures
n. Exhaust gas flow
o. Ejector pressure and airflow
p. Measured gas temperature

7.4 Exhaust System Survey Documentation. All operating conditions, on the ground and in flight, should be summarized with the documentation of the test data. Exhaust duct coefficients should be determined and compared with the engine manufacturer's reference ducts. Secondary and tertiary airflow, as applicable, should be determined. Data furnished should show effects of the following:

a. Flight speed
b. Total angie of attack
c. Altitude and ambient pressure
d. Temperature
e. Compressor air bleed and power extraction
f. Power setting
g. Installed power and specific fuel consumption of the rotorcraft.

8. DRIVE AND ACCESSORY SYSTEMS

Guidance. Drive system qualification criteria are in ADS-SO-PRF. Prior to aircraft flight, system level tests are conducted on either a propulsion system test bed or a tied down aircraft. After the basic endurance system level tests are completed, the aircraft is cleared to fly. The contractor should then demonstrate aircraft drive system performance to include functioning of the gust lock, rotor brake, overrunning clutches, and drive system accessories and their capabilities at overspeed and/or critical speed conditions. The contractor should demonstrate the adequacy of torque indicating systems and other diagnostics/condition monitoring systems throughout the operating envelope of the aircraft.

9. LUBRICATION SYSTEM

9.1 General Guidance. The lubrication system demonstration is conducted to assure that the system provides adequate lubrication, maintains adequate oil pressure and oil cooling, and is free from excessive discharge at the breather. Component level qualification criteria are in ADS-SO-PRF. The adequacy of the lubrication subsystem components is also evaluated during the engine and drive system bench tests and propulsion system test bed testing (if applicable).

9.2 Test Plan. The contractor should plan to demonstrate the adequacy of the lubrication system throughout the operating envelope of the aircraft, including all attitudes within the envelope and maximum slope angles for ground and ship deck operations. Both steady state and transient attitudes should be demonstrated. Steady state demonstrations include those attitudes sustainable by the aircraft such as level flight, climb, and hover. Transient lubrication system demonstrations such as quick turns, jump takeoff, high angle of bank turns, accelerating or decelerating flight, should be conducted at all attitudes up to the maneuvering envelope of the aircraft.

9.3 Test Criteria. Ground and flight tests should include: the measurement of quantity of usable oil, measurement of oil tank expansion space, oil tank pressure tests, oil system bypass demonstration, oil vent system test, oil tank quantity calibration, and oil cooling demonstration.

9.3.1 Measurement of Usable Oil. The determination of usable oil is initiated with the lubricant tank filled to spillover. The helicopter is flown in a manner to produce the maximum attitudes for normal maneuvers, and the oil pressure is observed for pressure fluctuations. The oil level is successively lowered by removal of oil until fluctuations are observed. Then, a small quantity of oil is added gradually until the fluctuations cease. During this test the oil temperature should be maintained at the maximum continuous level. The usable oil quantity is equal to the net amount of oil removed.

9.3.2 Measurement of Oil Tank Expansion Space. The expansion space should be measured by filling the tank to spillover and then adding additional oil through the tank vent system. The quantity of oil added is the expansion space. The test oil temperature and specific gravity should be recorded. The expansion space should be either 10% of the tank capacity or 0.5 gal, whichever is greater. Calculations should be submitted to verify adequate expansion space for maximum oil temperature.

9.3.3 Oil Tank Pressure Test. Each conventional metal tank, each nonmetallic tank with walls that are not supported by the helicopter structure, and each integral tank should be subject to a pressure of 5 psig unless the pressure developed during maximum limit acceleration or emergency deceleration with a full tank exceeds this value. However, the pressure need not exceed 5 psig on surfaces not exposed to the acceleration loading.

9.3.4 Oil System Bypass Demonstration. This test should demonstrate the proper operation of the engine and transmission oil cooler bypass system. It also should show that inadvertent bypass operation cannot occur. The test should be conducted with the engine operating at military cruise and maximum power conditions for maximum gross weight. Oil is drained from the oil cooler until the bypass warning light is illuminated to indicate actuation of the bypass system. The quantity of oil remaining in the oil system, and the rate of change of oil temperature following bypass actuation, should be determined. During this test the oil should not exceed the oil temperature limits (whether transient or steady-state) as defined in the engine model specification. The test for inadvertent actuation of the bypass system should be conducted inflight with the helicopter oil level reduced to the minimum. Oil sloshing should not cause inadvertent operation of the bypass system during any normal maneuver or extreme flight attitude peculiar to the maneuver envelope of the particular helicopter design.

9.3.5 Oil Vent System Test. The oil vent system should be tested by providing a means of capturing any oil that flows out of the oil tank breather vent. Flight tests should be performed simultaneously with the oil cooling tests and should consist of the execution of all flight maneuvers and extreme fight attitudes required for the oil cooling and fuel system demonstrations. The oil discharge from the vent should not affect materially the quantity of consumable oil.

9.3.6 Oil Tank Quantity Calibration. The oil tank dipstick should be calibrated between the "add oil" mark and the "full" mark in increments of one quart. The oil level should meet the "add oil" mark when the tank holds three-fourths of the usable oil quantity. The dipstick should indicate "full" when the tank is filled to spillover, as in the expansion space tests.

9.3.7 Oil Cooling. The adequacy of the oil cooling system should be demonstrated for all critical flight modes. These tests may be performed in conjunction with the propulsion system temperature demonstration. All temperatures should be stabilized (i.e., temperature change is less than 2° C/min.) for a minimum of 5 min. All data should be corrected to the maximum ambient air temperature stipulated in the weapon system specification. The temperature measurement equipment should be calibrated in accordance with proper test procedures. The corrected data should not exceed the engine manufacturer's prescribed limitations.

9.3.7.1 Hover Cooling. Oil cooling during hover should be checked, using the power available for the maximum ambient air temperature. Data should be recorded both in and out of ground effect. The wind velocity for these tests should be 8 kt or lower.

9.3.7.2 Climb Cooling. The oil temperatures should be stabilized during hover in-ground effect at maximum gross weight. A climb at maximum power should be initiated at best climb airspeed. If a power time limit exists, the power should be reduced to the intermediate and/or maximum continuous rating at the proper time(s). The power setting should be the power available for the maximum ambient air temperature. The climb should continue to the service ceiling.

9.3.7.3 Cruise Cooling. The helicopter should perform level flight at maximum gross weight and maximum continuous power for the maximum ambient air temperature at sea level, 5000 ft., 10,000 ft., and 15,000 ft. The oil temperatures should be stabilized for 5 min. at each test altitude.

9.3.7.4 Other Flight Conditions. Oil cooling capability should be checked at flight conditions other than hover, climb, and cruise which are expected to be critical for oil cooling. Examples of other flight conditions that may be critical for oil cooling are pull-ups and transition flight.

9.3.7.5 Additional Cooling Tests. If the specific design of the oil cooling system or the operational envelope of the helicopter is such that operating conditions other than those discussed previously may be critical, additional tests should be conducted to investigate these conditions.

9.3.7.6 Determination of Cooling Margins. The maximum stabilized oil temperature for the hover and cruise modes and the peak oil temperature for the climb mode should be corrected to the maximum ambient air temperature for the pertinent test altitude. This correction is equal to the numerical difference between the test ambient air temperature and the maximum ambient air temperature specified for the test altitude. It is added algebraically to the stabilized maximum oil temperature read at that altitude for each flight mode tested.

9.3.8 Chip Detector Demonstration. The chip detector(s) should be removed from its receptacle and the magnetic terminals shorted together. The cockpit indicator light(s) should function properly.

10. FUEL SYSTEM

10.1 General Guidance. Fuel system tests are conducted to demonstrate the operating characteristics of the fuel system both on the ground and throughout the flight envelope. Fuel system components are qualified in accordance with ADS-SO.

10.2 **Tests.** All tests should be conducted using the type and grade of fuel specified in the applicable weapon system specification. All tests should be conducted with the primary fuel. The contractor should propose selected tests to be conducted with the alternate and emergency fuels. Laboratory tests may be used to supplement or replace portions of the aircraft ground or flight fuel tests. The operational characteristics of the fuel system should be verified throughout the fuel temperature range of **-65°F** to **160°F.**

10.3 **Test Criteria.**

10.3.1 Fuel Availability. Fuel availability to the engine(s) should be verified for the **specified conditions** by simulator tests and aircraft ground tests. Simulator and aircraft grouna tests should be conducted to determine the quantity of fuel available to the engine(s) at maximum continuous power fuel flow rate. After the fuel tanks **have been** filled, fuel should be drawn out of the tanks by boost pumps and suction feed until flow interruption. Fuel availability testing should be conducted utilizing both -internal and external tanks by normal feed and alternate methods at the following aircraft attitudes:

a normal ground
b: takeoff
c. normal flight attitude (low gross weight, low **airspeed,** low altitude)
d. landing
e. **10°** greater angle than landing **attitude.**

10.3.2 Boost and Transfer Pump Failure Tests. Tests should be conducted to determine the unavailable fuel quantities resulting from various fuel boost pump and transfer pump **failures. If** internal tank pressurization constitutes the primary supply system, testing to explore the intent of the test conditions described subsequently should be conducted by disabling the pressurization system in conjunction with appropriate combinations of inoperative boost and transfer pumps, as applicable.

10.3.2.1 Ground Tests. The engine(s) should be **operated at** intermediate power at normal helicopter ground attitude to determine the following conditions:

a. **The quantity** of unavailable fuel with the boost pumps which normally supply the engine inoperative

b. The amount of fuel which is unavailable with **each** fuel transfer pump rendered inoperative

c. The amount of unavailable fuel with significant combinations of fuel boost or transfer pumps made inoperative

d. The effects on fuel system operation of fuel filter blockage, as applicable

e. Helicopter landing approach attitude with intermediate power fuel flow rates (by operating engine(s) or by an external pump) and the quantity of unavailable fuel with inoperative boost pumps which normally supply the engine from the sump fuel tank.

10.3.2.2 Flight Tests. The maximum altitude at which intermediate and maximum power operation can be maintained on suction feed should be determined by continuous recording of fuel flow **rates,** temperatures, pressures at engine inlet, fuel specific gravity, altitude, atmospheric pressure, and temperature data. The temperature of the fuel and a fuel sample for Reid vapor pressure determination should be taken before and after the flights. The temperature of the fuel should be as close to 57°C as possible before takeoff. The tests to be conducted are:

a. A normal takeoff and climb to minimum safe altitude. Turn off all booster and transfer pumps. Climb at intermediate power at best climb speed to service ceiling, until 10% power loss occurs, or until objectionable engine surge occurs

b. Repetition of above using maximum power.

10.3.3 Vapor/Liquid Ratio Tests. With a fuel temperature of **57°F** and the boost pumps inoperative, the vapor/liquid ratio forming characteristics of the fuel system should be determined for intermediate and maximum engine power fuel flow. The vapor/liquid ratio should be measured at 2,000 foot increments from sea level to the altitude which results in a vapor/liquid ratio in excess of the capability of the engine fuel pump.

10.3.4 Flow Performance. Fuel flow performance of each engine feed subsystem, including the crossfeed system, should be verified by tests on a simulator and during flight tests. Fuel flow should be demonstrated up to 100% of the maximum fuel consumption of the engine(a) plus any fuel flow required for cooling purposes or motive flow for jet pumps. Both fuel temperature and altitude, as well as rate of change of altitude should be tested. The ground portion of the flow performance tests can be conducted in association with fuel availability tests.

10.3.5 Suction Feed. Flight testing should be performed to verify proper engine performance without boost **pump** assistance, up to the service ceiling of the aircraft and at maximum maneuver loads with **fuel** temperatures **up** to **135°F.**

10.3.6 Priming. The capability of the fuel system to prime the engine(s) and APU should be verified by tests on a simulator and aircraft tests. Priming **of** the fuel system, to allow engine/APU starts, with initially empty fuel lines should be demonstrated. Priming should be demonstrated with fuel **temperatures** of **-65°F** to **135°F.** The capability of the engine feed(s) systems to maintain prime after engine shutdown should be verified by tests on a simulator and aircraft tests.

10.3.7 Hot Restart. The capability to restart each engine with a fuel temperature of **160°F** in the applicable engine compartment fuel line, should be verified by tests on a simulator and the aircraft.

10.3.8 Pressure Capability. The proof pressure capability of the engine feed and transfer subsystems should be verified by installed system teats prior to first flight. Negative pressure capability of one atmosphere should be verified by installed system tests prior to first flight.

10.3.9 Surge Pressure- Surge pressure levels in the engine feed and transfer subsystems should be verified by ground tests, **As a minimum,** surge pressures resulting from rapid engine power reduction, high-level shutoff resulting from fuel transfer and closure of shutoff and crossfeed valves should be verified.

10.3.10 Contaminated Fuel. The ability of the fuel system to remove particles larger than 2,000 microns, before delivery to the engine, should be verified by aircraft inspection.

10.3.11 Engine Feed Independence. Engine feed independence should be verified by ground demonstrations.

10.3.12 Engine Cross Feed. The engine feed subsystem, crossfeed capability should be verified by a demonstration on the system simulator for extreme attitudes and on the aircraft during flight tests for normal operations. The critical conditions for the demonstrations should be identified by an analysis of the subsystem and the mission profiles.

10.3.13 Fuel transfer/management. Verification of the automatic feed and transfer features should be accomplished by tests on the aircraft simulator and aircraft ground and flight tests.

10.3.14 Auxiliary Fuel Provisions. Auxiliary fuel provisions should be verified. Proper installation interface with the helicopter fuel system should be established by insuring that the auxiliary tanks fit properly in the installation, that the fuel is delivered from the auxiliary tanks to the main tanks or to the engine, and that the fuel capacity gage accurately indicates fuel level. Tests to be conducted for auxiliary fuel system are:

a. The auxiliary fuel tanks (as installed) should be filled with fuel at the normal helicopter attitude. The amount of fuel added should be measured in addition to the fuel temperature and specific gravity.

b. A ground test should be performed at idle to maximum power to measure he fuel flowing to the engine and from the auxiliary tank to the main tank.

c. The flow test should be conducted until the auxiliary fuel tanks are empty. Installation and operation of the tank empty sensor should be verified by inspection and aircraft ground tests. The fuel depletion schedule should be compared with the design depletion schedule.

d. The external tank feedout rate characteristics should be investigated under level flight conditions at service ceiling and during maximum power climbout after takeoff. These tests should be consistent with the mission of the aircraft and the intended use of the external tanks. Fuel flow rate and fuel pressure (i.e., boost pump exit) data should be recorded at one-minute intervals.

e. Flight testing to jettison the tanks also should be conducted (if applicable). During jettison tests, verification of fuel, air, vent, and electrical disconnect and breakaway capabilities should be accomplished.

f. Verification that the external tank(s) does not preclude the use of weapons on any store station not used by an external tank(s) should be by analysis and aircraft ground and flight tests, to include weapons firing.

g. Verification of ground clearance sufficient to prevent ground contact under any combination of the following static or dynamic ground conditions should be aircraft ground tests:

1. One or more flat tires.
2. One or more shock absorbers flat.
3. Pitching and/or rolling caused by variations in anticipated runway/taxiway/ or ship surface.

h. Stenciling of tank capacity and type of fuel adjacent to each filler opening should be verified by document review and aircraft inspection.

10.3.15 Cockpit Fuel System Controls. Verification of the pilot's control of the engine feed system(s) and auxiliary tanks should be accomplished by inspection, as well as simulator and aircraft ground tests. Verification of internal/external transfer is progress and pilot capability to close each fire shutoff valve should accomplished by simulator and aircraft ground and flight tests.

10.3.16 Fuel Center-of-Gravity. Ground tests to demonstrate fuel system center-of-gravity changes should be conducted under normal flight conditions and power settings to demonstrate the aircraft does not exceed safe operating, center-of-gravity limits. Tests should also be conducted under engine inoperative conditions on multi-engine aircraft. The data should include possible internal and external fuel tanks and useful load configurations and all possible fuel management control situations. The aircraft should be positioned at normal ground attitude, and refueled to normal capacity. Each test should be conducted from full fuel down to reserve level. At least one test in each series should include usage from reserve down to unavailable fuel. These tests should be performed with the aircraft in its normal flying attitude for each condition, and fuel should be removed from the engine feedlines at the proper flow and pressure. The aircraft weight and center-of-gravity data should be recorded in increments of 50 pounds of fuel transfer. Center of gravity (percent mean aerodynamic chord) versus aircraft gross weight plots should be prepared from this data and compared with the previously calculated data.

10.3.17 Fuel Center-of-Gravity Warning. The operation of the fu

el center-of-gravity warning system (when required) should be verified by analyses and ground tests.

10.3.18 Low Fuel Level Warning. The correct activation level of the low fuel warning device(s) should be verified by ground tests. Aircraft attitudes to be-evaluated are normal ground, level flight (landing pattern), and landing attitude (touchdown). The quantity of fuel remaining upon low fuel warning activation, at each attitude, should be sufficient for 20 minutes of flight at maximum range cruise power and altitude, plus a normal descent and landing with one missed approach. This test may be conducted in conjunction with the available fuel tests above.

10.3.19 Fuel Transfer to Main Tank. The rate of fuel transfer from all tanks transferring fuel to the engine feed tank(s) should be verified by simulator tests.

10.3.19.1 Internal Tank Switchover and Fuel Transfer Rates. Internal fuel tank manual switchover provisions should be demonstrated as applicable. Internal fuel tank transfer rate capabilities should be demonstrated under conditions which the contractor considers most critical for the aircraft. Surge pressure resulting from feed and transfer flow fluctuation should be measured and recorded.

10.3.20 Low Fuel Pressure Indication. Activation pressure level for low fuel pressure indication devices (if applicable) should be verified by aircraft ground and flight tests.

10.3.21 Fire Shutoff Capability. Operation of fire shutoff devices should be verified by tests on the aircraft simulator and aircraft ground and flight tests. Fuel lines upstream and downstream of the shutoff device should be instrumented for recording fluid pressure after actuation of the shutoff device.

10.3.22 Negative and Zero "g". Fuel flow during negative or zero "g" conditions should be verified by aircraft flight tests.

10.3.23 Crashworthiness. It is desirable to verify the crashworthiness of an aircraft by actual aircraft crash tests.

10.3.24 Fuel Tanks.

10.3.24.1 Location and Separation. Verification of the location and separation of fuel tanks should be by document review and/or aircraft inspection

10.3.24.2 Tank Capacity. The capacity of each internal and external fuel tank should be determined and compared with the design capacity. The tanks should be filled by gravity and pressure refueling at the normal ground attitude. The amount of fuel added to fill the tanks should be measured during the refueling operation. In addition to the gallon measurement, fuel temperatures and specific gravity should be taken before, during, and after the capacity check. The fuel weight in pounds should then be determined

10.3.24.3 Fuel Expansion Space. Fuel expansion space at normal ground attitudes for each tank or cluster of tanks should be verified by analysis and aircraft ground tests. The aircraft should be fueled to normal capacity by pressure and gravity refueling; then measured fuel should be added until fuel enters the vent system. The quantity of measured fuel added is equal to the expansion space.

10.3.24.4 Fuel Tank Sumps.

10.3.24.4.1 Sump Volume. Each fuel tank sump capacity should be verified by aircraft ground tests. The sump capacity of each internal and external fuel tank, at normal ground attitude, should be obtained by measuring the fuel drained from the sump after all possible fuel has been pumped/transferred from the fuel tank by its normal transfer method.

10.3.24.4.2 Sump Drains. The capability of the sump drain valve(s) to remove sediment and water, as well as completely drain the fuel tank at normal ground attitude should be verified by document review and aircraft ground test. The residual. fuel, i.e., the fuel remaining after the tanks and sumps are drained, should be determined for the internal and external fuel tanks.

10.3.24.4.3 Fuel Sample. The capability to obtain a fuel sample from each sump without lying on the ground should be verified by aircraft ground teat.

10.3.24.5 Tank Pressure Safety Factors. The fuel tank proof pressure should be verified by ground tests on each fuel tank of each aircraft. The burst pressure capability should be verified by a test on at least one tank which is considered to be the most critical on a structural test model. The remaining tanks burst pressure capability should be verified by analysis. Structural failure, permanent set in excess of threat specified on approved drawings, distortion, or fuel leakage should be cause for rejection.

10.3.24.6 Bladder Tank Cavity Sealing. The sealing and draining capabilities of bladder tank cavities should be verified by ground tests on the aircraft.

10.3.24.7 Internal/Main Tank Filler Openings. Stenciling of tank capacity and type of fuel adjacent to filler opening should be verified by document review and aircraft inspection.

10.3.25 Pressurization and Explosion Suppression Subsystem.

10.3.25.1 Pressurization. Verification of proper operation of the pressurization subsystem, including primary and secondary pressure relief and automatic venting during simulated mission profiles should be performed on the aircraft simulator and during aircraft ground tests. If a common line is used in the cockpit air conditioning and pressurization subsystem, the capability of the subsystem to prevent fumes from entering the cockpit should be verified by document review, aircraft simulator tests, and aircraft ground tests.

10.3.25.1.1 Temperature of Pressurization Air. The maximum temperature of pressurization air entering a fuel tank should be verified by selected instrumented flight test(s). Flight test conditions should be determined from analysis and component test results.

10.3.25.2 Explosion Suppression Subsystem.

10.3.25.2.1 Baffle Material. There are no specific installation tests for the baffle material. However, the fuel system should be monitored during all aircraft simulator, ground and flight tests to determine any detrimental effects on the system or aircraft performance caused by the baffle material.

Limited testing with the baffle material removed, should be conducted during all three types of testing to verify the aircraft can operate satisfactorily, throughout the aircraft operating envelope, without removing or adding any other hardware.

10.3.25.2.2 Nitrogen Inerting System. A ground run should be conducted at maximum continuous power for 5 minutes to determine that the functions of each component of the purge system are accomplished satisfactorily. Data should be recorded at 30 second intervals. Flight tests should be conducted to investigate the most critical conditions for which the nitrogen inerting system was designed consistent with the missions of the aircraft. The tests should verify that the quantity of nitrogen is adequate and that the oxygen concentration of the inerted space never exceeds the 9 percent limit. Verification of the automatic operation of the nitrogen inerting system should be verified during aircraft ground and flight tests.

10.3.25.2.3 Pressurization. The capability of the nitrogen inerting system to maintain a safe differential pressure between the tanks and ambient should be verified by ground and flight test. The pressure in each tank should be measured and recorded during maximum rate of climb and descent with the nitrogen inerting system operating.

10.3.25.2.4 Pressures. Verification that the positive and negative pressures in the fuel tanks do not exceed the design pressure limits of the aircraft, regardless of failure of any component should be accomplished by simulator and ground and flight tests.

10.3.26 Ground Refueling and Defueling Subsystem.

10.3.26-l Refueling Time. The time to refuel the aircraft to capacity should be demonstrated by aircraft ground test. The time, with a steady state pressure at the aircraft adapter of 55 psig, should meet the requirements of TABLE I of ADS 50. Verification that all tanks obtain their capacity shut-off point at approximately the same time should be demonstrated during the aircraft ground test.

10.3.26.2 Gravity Refueling. The capability to gravity refuel the aircraft should be verified by aircraft test. Verification that the filler openings are located to permit refueling from outside the aircraft without overfilling into the tank(s) expansion space should be accomplished by aircraft ground test. Verification that special adapters, if installed, are crashworhty and prevent trapping of fuel outside of the fuel tank should aircraft ground demonstration.

10.3.26.3 Refueling Subsystem Pressure Capability. The pressure refueling capability, with steady state pressures at the aircraft adapter of 20, 30, 40, 50 and 55 psig, should be verified by an aircraft refueling demonstration. A proof pressure test of 180 psig should be performed on the entire refueling subsystem of a test aircraft.

10.3.26.4 Maximum Surge Pressure. Surge pressure levels should be verified by refueling tests on an aircraft simulator and during aircraft ground tests. Surge pressures should not exceed 180 psig. The refueling manifold or aircraft-mounted adapter should be instrumented to determine surge pressures encountered during refueling operations. There should be a minimum of one pressure sensor at each fuel level control valve and each refueling connection. As a minimum, the surge pressures should be measured under the following conditions with a refueling nozzle pressure of 55 psig steady state at maximum flow into the aircraft:

a. Maximum flow - all fuel control valves closed simultaneously
b. Maximum flow - fuel control valves closed singly
c. Maximum flow - all fuel control valves closed as a result of filling to capacity.

10.3.26.5 Pressure Refueling System Tests. Helicopter refueling should be conducted for the pressure refueling system to demonstrate conformance to design requirements and satisfactory operation of the system. The tests may be conducted in conjunction with the refueling tests above. The following should be determined and should meet the requirements of the weapon system specification:

a. Fuel flow rates and nozzle inlet pressures at the time of automatic fuel shutoff
b. Pressure differential across helicopter receiver diaphragm
c. Tank pressures in conjunction with refueling and vent testing
d. System operation under shutoff failure (i.e., leakage past float, tank, and vent pressures).

10.3.26.6 Siphoning Tests. After normal fueling, the helicopter should be placed at normal flight attitude, and the quantity of fuel discharged (if any) from the fuel vent opening should be measured. After normal fueling at ground attitude, fuel should be pumped into the fuel system until a steady stream of fuel is discharged from the fuel vent opening. Then, the fuel being pumped into the system should be shut off and the amount discharged from the vent opening, after shutoff, should be recorded.

10.3.26.7 Maximum Capacity Refueling Attitude. Maximum capacity refueling should be verified by tests on the aircraft.

10.3.26.8 Pressure Refueling Adapter.

10.3.26.8.1 Location. The accessibility and capability to simultaneously refuel and rearm the aircraft should be verified by an aircraft ground demonstration. The capability of the refueling adapter to allow safe hot refueling should be verified by aircraft ground demonstration.

10.3.26.8.2 Installation. The compatibility of the refueling adapter with straight and 45° inlet nozzles should be verified by ground demonstration. Verification that ground support devices are not required for connecting the nozzle should be by ground demonstration. Verification that ample clearance for connection and operation of the nozzle is provided when refueling should be by ground demonstration. Verification of the adapter face being installed as nearly as possible in the vertical plane should be by aircraft inspection.

10.3.26.8.3 Trapped Fuel. Verification that no fuel remains trapped in the refueling system, outside of the fuel tank(s) after refueling should be by aircraft simulator and ground demonstration.

10.3.26.8.4 Filler Caps and Filler Cap Access. The capability of removing and replacing fuel filler cap access panels and fuel filler caps without the use of any tools should be verified by an aircraft ground demonstration.

10.3.26.9 Refueling Power Requirement. The capability of gravity and pressure refueling the aircraft (including external tanks) to any intermediate quantity or to full capacity, including automatic shut-off, should be verified by aircraft ground test.

10.3.26.10 Refueling Controls Location. Location of refueling controls and fuel quantity gages should be verified by document review and aircraft inspection.

10.3.26.11 Required Refueling Personnel. Refueling personnel requirements should be verified by aircraft ground demonstration.

10.3.26.12 Hot Refueling. The capability of the aircraft to be safely refueled with all engines operating and the auxiliary power unit operating should be verified by aircraft ground demonstration.

10.3.26.13 Tank Selection. The capability of the refueling system controls to selectively fill individual tanks should be verified by simulator and aircraft ground tests.

10.3.26.14 Fuel Level Control Valve Precheck. Verification of precheck capability for each fuel level control valve should be verified by document review and aircraft inspection. The capability of the precheck system to isolate a failed level control valve should be verified by aircraft simulator and ground tests.

10.3.26.15 Defueling Methods. Suction defueling of the aircraft, through the pressure refueling adapter and the gravity fill port(s), should be verified by aircraft ground demonstration. Electrical power should not be required for defueling, unless the aircraft pumps are required for defueling. The time required to defuel the internal fuel tanks should be determined for the maximum discharge flow rate. The maximum fuel flow and fuel remaining in the aircraft after defueling should be recorded.

10.3.26.16 Defueling with Failures. The capability to defuel each tank with any single failure in the system should be verified by analysis.

10.3.26.17 Defueling Crashed Aircraft. The capability to defuel each tank under damaged refueling adapter conditions should be verified by analysis.

10.3.26.18 Static Discharge in Fuel Tanks. The freedom of sparks within fuel tanks during refueling should be verified by analysis. Fuel velocities through lines and at the tank entry should be verified by analysis and aircraft simulator or ground test. The bond resistance of all components installed inside fuel tanks should be measured (verified) during installation.

10.3.26.19 Refueling Nozzle Bonding. Verification of the refueling nozzle bonding receptacle location should be verified by aircraft inspection.

10.3.26.20 Refueling Adapter Isolation. The isolation of the refueling adapter from pressures imposed during refueling should be verified by document review and aircraft inspection.

10.3.26.21 Engine and Engine Feed Isolation. The isolation of the engine and engine feedlines from pressures imposed during refueling should be verified by document review and aircraft inspection.

10.3.27 Aerial Refueling Subsystem. Verify all safety features (i.e. breakaway or isolation valves) and capability to refuel (internal and external, if applicable) using standard Tri-Service refueling procedures, equipment, and techniques.

10.3.28 Fuel Vent Subsystem.e)

10.3.28-l Vent Pressure. The ability of the vent subsystem to limit tank pressure, from exceeding the proof pressure of the tank, including single fuel system component failure, should be verified by analysis, aircraft simulator, ground, and flight tests. Ground and flight testing should consist of the following conditions and maneuvers:

a. Maximum refueling flow rate into each tank
b. Simulated level control failure during ground and aerial refueling
c. Maximum defueling flow rate
d. Maximum rate of climb to service ceiling followed by maximum practical rate of descent dive to minimum safe altitude

e. Sideward flight, left and right
f. Hover
g. Rearward flight
h. Autorotation
i. Level flight at V_H
j. Ground taxi, takeoff, and landing with tanks full
k. Inverted and negative "g" flights, if applicable.

During simulator, ground, and flight testing, the vent system should contain a pressure measuring device at each vent outlet, in each tank, and between each bladder tank and tank cavity. The pressure data and other data such as rate of climb, rate of dive, altitude, and quantity of fuel should be recorded in sufficient quantity to demonstrate satisfactory operation of the vent system. Dyed fluid should be used during the indicated tests and maneuver conditions to mark any fuel impingement on the aircraft.

10.3.28.2 Overboard Spillage Through Vents. The freedom of fuel spillage through the vents should be verified by aircraft simulator, ground, and flight tests. The vent subsystem should be evaluated for spillage during all simulator, ground, and flight tests (especially during the tests in 10.3.28.1 above). Any spillage should be investigated with any necessary design changes being made. The capability of the vent subsystem to prevent fuel spillage during or after a rollover or survivable crash should be verified by analysis.

10.3.28.3 Vent System Failure Tests. Failure of components of the fuel system should be simulated to cause fuel to flow from the vent outlets. Freedom from fuel impingement during fuel venting should be verified by flight test.

10.3.28.4 Vent Outlet Location. Verification that the vent subsystem will not collect water and prevent water from entering the fuel system, should be by document review/aircraft inspection. The vent outlets should be observed following aircraft icing tests to determine the extent of ice accumulation.

10.3.28.5 Vent Line Size; Verification of line size should be by analysis.

10.3.28.6 Interconnected Vents. Verification that fuel is not transferred through tanks vents should be by document review and aircraft inspection. Termination of fuel tank outlets should be verified by document review and aircraft inspection.

10.3.29 Fuel Dump Subsystem. TBD

10.3.30 General Requirements.

10.3.30.1 Protective Treatment. The capability of protective treatments to prevent deterioration of materials should be verified by aircraft simulator, ground, and flight tests.

10.3.30.2 Primary Fuel Designation. Fuel system required performance should be demonstrated through aircraft simulator, ground, and flight tests with JP-8 fuel.

10.3.30.3 Icing. Operation of the fuel system with the specified fuel conditions should be verified by aircraft simulator tests. During the tests the accumulation of ice should not obstruct moving parts, plug orifices or bleed holes, or block screens or filters.

10.3.30.4 Hose and Tubing. Freedom from tube rubbing or chafing should be verified by inspection of tubing during flight testing of the aircraft. Freedom from stretching or twisting of flexible hose during installation should verified by aircraft inspection. Freedom from forcing, bending, or stretching of metal tubing to accomplish installation should be verified by inspection during installation. Verification of proper location of self-sealing breakaway valves should be by analysis and document review.

10.3.30.5 Fuel Drains. The presence and suitability of drain provisions, for bladder tank cavities, dry bays, and sheet metal pockets and traps, should be verified by a ground demonstration by pouring water or other suitable liquid into selected compartments and observing any accumulation of fluid.

10.3.30.6 Electrical Bonding. Each component bond resistance should be measured after installation of the component into the fuel system. Bonding of the fuel system should be verified by inspection of installation records for each component.

10.3.30.7 Electrical Leads. Freedom from wire splices for fuel system components should be verified by document review.

10.3.30.8 Thermal relief. The incorporation of adequate thermal relief provisions should be verified by document review and aircraft inspection.

10.3.30.9 External Fuel Leakage. Freedom from external leakage should be verified by inspection during ground and flight tests.

10.3.31 Components.

10.3.31.1 Component Features.

10.3.31.1.1 Electrical Equipment Isolation. Isolation of electrical equipment from fuel should be verified by aircraft inspection.

10.3.31.1.2 Electromagnetic Interference. Component electromagnetic interference compatibility should be verified by aircraft system level tests.

10.3.31.2 Fuel Level Control Valve.

10.3.31.2.1 Surge Pressure/Valve Closure Rate. The ability of the valve to limit surge pressures below the system proof pressure should be demonstrated on the aircraft simulator and during aircraft ground test.

10.3.31.3 Shutoff Valves. Verification that the engine shutoff valve(s) is operated by a switch(es) on the throttle quadrant should be by aircraft inspection.

10.3.32 Environmental.

10.3.32.1 Temperature. The capability of the fuel system to operate under the fuel and ambient temperature extremes should be verified by aircraft simulator and aircraft ground and flight tests. Climatic hangar testing may be required by contract.

10.3.33 Interface.

10.3.33.1 Pneumatic Subsystems. The capability of pneumatic subsystems, which are used in, or interface with the fuel system, to eliminate the collection and freezing of water should be verified by aircraft simulator tests.

10.3.33.2 Instrumentation.

10.3.33.2.1 Low Fuel Pressure. Verification of the installation of a low fuel pressure indicator for each pilot should be by aircraft inspection. Verification of proper operation of the low fuel pressure indicator should be by aircraft simulator, ground, and flight tests.

10.3.33.2.2 Engine Shutoff Valve. Verification of the installation and proper operation of engine shutoff valve cockpit indicating lights should be by aircraft inspection and aircraft simulator and ground and flight tests.

10.3.33.2.3 Fuel Quantity Gaging. Verification of cockpit fuel quantity gaging instrumentation, indicating the weight of fuel in internal and external tanks should be by aircraft inspection. Verification of a continuous readout of total fuel and the quantity of fuel remaining in each main tank should be by aircraft inspection. Verification of the accuracy of the indicator(s), IAW guidance in ADS-SO-PRF, should be by aircraft ground calibration and demonstration. The aircraft simulator should also be used for verification if the simulator replicates the actual aircraft fuel tank(s) geometry.

10.3.33.2.4 Fuel Filter. Verification of a fuel filter impending bypass indicator for each engine filter should be by aircraft inspection. Verification of provisions for engine filter impending bypass should be by document review and aircraft inspection.

10.3.34 Hazards and Failure Concept.

10.3.34.1 Failure analysis. The effects of failures on the fuel system should be verified by the fuel system failure analysis and tests. A failure effect demonstration test program should be conducted based upon the result of an analysis. Only those failures where a reduced level of performance may occur or where special crew attention or control techniques are required, need to be demonstrated. When the failure effect has been demonstrated during subsystem tests, the tests need not be repeated on the aircraft. The failure demonstration should be documented.

10.3.34.2 Fire Hazard Reduction. Verification that a single failure in a fuel line or in another subsystem will not cause a fire should be verified by aircraft inspection. Verification that sources of fuel leakage are not located in the vicinity of ignition sources, should be verified by aircraft inspection. Verification that the only fuel line routed through a nacelle or powerplant compartment is the one feeding the engine/APU in that compartment, should be by document review and aircraft inspection. Verification that fuel lines are not routed through personnel or cargo compartments, except when an occupied portion of the aircraft is the only space available, should be by document review and aircraft inspection. In the event a line(s) is routed through an occupied area; verification that joints are shrouded, held to a minimum, and their compartments drained should be by document review and aircraft inspection.

10.3.34.3 Lightning Hazard. The capability of the fuel system to avoid fire and explosion hazards caused by direct lightning strikes, crossfield streamering, or static electricity within the fuel, should be verified by analysis and subassembly tests.

10.3.34.4 Component Temperature. Verification that the maximum temperature of components and tank walls does not exceed 435°F, should be by analysis and selected instrumentation during flight tests.

10.3.35 Reliability. Reliability should be verified by analysis of flight test data and operational data.

10.3.36 Maintainability. Maintainability calculations should be verified by analysis of historical data. The ability to establish proper operation fuel system components whose operability cannot be determined under normal operation and service, should be verified by a ground demonstration. Accessibility of fuel system components for inspection, cleaning, and adjustment or replacement while installed on the aircraft, with tools found in a mechanic's tool kit and without removal of the engine, fuel tanks, or important parts of the aircraft structure should be verified by aircraft inspection. Interchangeability of components without precise adjustment or calibration should be verified by flight tests. The ability to remove any filter or strainer element without draining the fuel tanks should be verified by an aircraft ground demonstration. Tank access should be verified by an aircraft demonstration. The freedom from possible improper installation of components should be verified by inspection of aircraft installation.

10.3.37 International Standards. Incorporation of the required international standards should be verified by aircraft inspection.

11. FIRE DETECTION AND EXTINGUISHING SYSTEM

11.1 General Guidance. The effectiveness of the fire detection and extinguishing system operation should be demonstrated to determine that the warning system and agent discharge mechanism and quantity performs adequately and meets the weapon system specification requirements.

11.2 **Fire Detection and Extinguishing Documentation.** Typical documentation should included the method for simulating the fire source and the instrumentation required to determine the distribution and concentration of agent distributed within the engine compartment. A means to measure oxygen concentration at the fire source should also be provided. In addition, a schematic diagram of the system showing container sizes, valve sizes, tubing sizes, wall thickness, and discharge outlet sizes should be included. Calculations showing derivations to determine the amounts of agent require from the parameters such as air flow, volume figures, engine surface temperatures, etc., for all zones protected, and information as to the direction and location of air flow in **each zone.** Calculations showing derivations of tubing sizes and discharge outlet sizes. Preliminary installation dsawing showing location of agent containers, tubing, distribution pattern, and materials with respect to the area to be protected. Information as to the effectiveness of the method of sealing compartments to be protected from the surrounding compartments. A layout of the control panel in the cockpit.

11.3 **Ground Test.** A pressure test of the system with dry air or nitrogen at 1000 psig to check the integrity of the tubing **and** fittings from the agent container to the firewall, or as near to the discharge outlet system as possible should be conducted. The simulated fire source must approximate the same radiant energy or temperature (depending on the detection system) as a real fuel fire and be situated to represent the **most** likely fire source within the compartment. The radiant energy level or temperature reached when the detector signals a warning in the cockpit should be recorded. For the primary test of the extinguishing system, the engine should be operating at the maximum power attainable to achieve **a** "light on wheels" condition at maximum takeoff gross weight. The test should be conducted by the pilot in command who should respond in the manner prescribed by the operator's manual. Discharge of the primary fire extinguishing agent should immediately follow the "arming" action. This will test the capability of the system to extinguish a fire while there is significant airflow through the engine compartment. When the simulated fire has been extinguished, the simulated fire source should be re-energized to simulate a re-ignition for the purpose of testing the secondary or backup system. The test of the secondary **or** backup system may be conducted with the engine off. The test of the fire extinguishing system need only be performed in one engine compartment of a multi-engine aircraft. However, the correlation between the pilot selected compartment and the actual discharge must be demonstrated for all compartments, including the APU and weapons bay's (if applicable).

11.4 **Post Test Analysis.** The effectiveness of the system will be determined by analyzing the distribution and concentration of the agent within the compartment as a function of time. This will be compared to the design predictions. The oxygen concentration at the fire source will also be plotted versus time to determine whether the agent purged or limited the oxygen to a level low enough to extinguish a fire.

12. COMPARTMENT DRAINAGE

12.1 <u>General Guidance</u>. Current Environmental Protection Agency (EPA) regulations dictate that certain fluids, particularly flammable ones, be collected so as to not drain on the ground. Similarly, for shipboard operation, flammable fluids must be collected so as to not drain on ship decks. Consequently, the compartment drainage demonstration should include the adequacy of the collection system, both in terms of storage capacity and the ability to dispense with the fluids into approved long term storage facilities. In addition, the contractor should measure compartment drainage pressure differentials to determine discharge characteristics during ground and flight tests. If a fluid collection system is not a contractual weapon system specification requirement, the drain impingement on aircraft surfaces should be evaluated. Drainage in this event should not impinge on aircraft surfaces that are likely to be heated by engine exhaust such that the drainage may ignite, burn, or smoke. Similarly, drainage should not impinge on aircraft surfaces in such a way as to adversely impact the performance of other systems (e.g. landing gear seals/switches or electronic antennae).

13. ENGINE WATER WASH

13.1 <u>General Guidance</u>. The contractor should demonstrate ‘accessibility to, and usage of, engine water wash equipment. The contractor should conduct actual main engine water wash functional checks, including verification of proper safety and clearance from rotating parts and adequate drainage of detergent. Testing should demonstrate dry engine motoring capabilities and starter duty cycles.

14. HYDRAULIC SYSTEM

14.1 General Guidance. Hydraulic system testing consists of both around and flight tests. For a new development program, ground testing can include testing on a hydromechanical or structural mock-up which can be a dedicated hydraulic system test rig or a full scale propulsion system test bed. The test data can then be reduced and any design changes made prior to installation on the aircraft. The validity of the changes can then be confirmed by conducting aircraft ground tests prior to initiation of flight tests. Ground testing permits considerably more monitoring of system parameters as well as ease of making changes and/or modifications. Flight testing allows determination of system performance under actual conditions and environments. Although many simulated conditions and modes of operation can be provided during ground testing, there are interactions in the system which can be proven only in an actual flight. For specific component design guidelines and qualification performance criteria refer to ADS-50-PRF. System performance should be demonstrated throughout the entire temperature range specified in the weapon system specification.

14.2 **Ground Tests.**

14.2.1 Mockups. Testing on **a** functional **mockup is normally** considered to be a cost efficient and expeditious means of verifying hydraulic system performance early enough in the development program to make adjustments/revisions to the design prior to hardware commitments on the aircraft. The mockup should simulate the actual aircraft installation as closely as possible and should, in fact, utilize aircraft hardware wherever possible. Flight instrumentation, tubing, and fittings should be identical those installed in the first flight aircraft. The intent is to simulate actuator load and no-load operations, to measure system performance parameters, assess maintenance and servicing requirements, **and** uncover design deficiencies and failure modes. One test on the simulator should simulate a mission profile so as to duplicate **an actual aircraft condition.** Items should operate **in sequence** for a check on unusual back pressure, surges, temperature, pump pulsation, etc. All emergency modes and system failure conditions should be demonstrated.

14.2.2 Aircraft. If mockups are not available or programmed, aircraft ground testing should be conducted to evaluate the hydraulic system performance prior to flight. System performance should be evaluated and compared to design predictions. Control system rate under maximum, no-load and intermediate loads should be determined. Normal utility functions should be cycled at no-load and maximum loads to determine parameters such as operating times. Emergency operation modes also should be evaluated in a similar manner. Critical points such as low temperature operation should be included in the test evaluation program. Three cycles of operation for each design evaluation point should be recorded and analyzed. Failures should be simulated and their effects evaluated. Single-system **operation** in a dual system, and failure of one or more hydraulic pumps in a multipump system, should be evaluated.

14.2.2.1 Temperature. Normally, system temperatures are determined and converted to standard day conditions. The stabilized temperatures should be determined for steady-state null flight control and utility system conditions. The system cooling should duplicate that of the helicopter configuration as nearly as possible. The flight control system characteristics can be defined further by cycling continuously at **1/4, 1/2,** and maximum rate until system temperatures stabilize. Utility functions identical to flight control systems may be evaluated in a similar manner. Temperature monitoring should be incorporated **at the following locations:**

a. Pump outlet
b. Pump case drain outlet
c. Pump suction
d. Reservoir return
e. Actuator supply
f. Actuator return.

14.2.2.2 Pressure. Similarly, pressure transducers should be provided at appropriate circuit locations to measure peak pressures generated by water hammer effects due to fast closing valves, assisting external loads, actuators with a relatively high unbalance ratio, and inadequate pump response to "stop flow" signals. Also, "standing waves" should be considered, and additional transducers considered necessary, should be installed to locate the peak points. The reservoir should be positioned at its minimum acceptable takeoff attitude and pressurization. Selected critical test points should then be recorded and analyzed. This effort may include service ceiling ambient pressures and operation at specified minimum fluid temperatures. As a minimum, the measurements should include:

a. Reservoir bootstrap pressure
b. Reservoir return
c. Pump suction
d. Pump outlet
e. Branch circuit supply at using component
f. Branch circuit return at using component
g. Accumulator charge.

14.2.2.3 Filtration and Contamination Evaluation of the system filtration and measurement of contamination generated should be part of the ground testing. Where auxiliary hydraulic pumps are a part of the system, their function should be evaluated, and selected critical design points recorded and analyzed. Similarly, all auxiliary or utility hydraulic system functions, such as wheel brakes, rotor brakes, door actuation, and backup flight control functions, should be evaluated.

14.2.2.4 Servicing. The hydraulic system servicing should be in accordance with the appropriate manuals for the helicopter being tested. In addition to flight test instrumentation, items such as subsystem rigging and travel must be checked and modified, if necessary. The system fluid level and air content should be checked, additional bleed and filling accomplished, and the accumulator precharge checked and serviced, as necessary. Areas such as rod-end bearings should be inspected and lubricated as necessary. The system should be pressurized, by using a ground cart, and checked for external leaks. Any leaks should be corrected. Operation of subsystems should be accomplished in an orderly sequence and pertinent data recorded. The travel, time of operation, function of normal system instrumentation (lights, gages), and any other pertinent information required should be observed and recorded. Items such as flight test instrumentation and recording equipment and pilotoperated switches also should be checked for proper operation. The flight test instrumentation should be calibrated and adjusted as necessary, and the resistance calibration and any other pertinent information observed and recorded.

14.2.2.5 Instrumentation. The ground test instrumentation should be in exactly the same location and of the same type as that used in the flight test survey. This is required for adequate correlation between ground and flight test results. Additional instrumentation may be required to evaluate the vibration characteristics of the system and the associated or adjacent structure. This is likely to be the first time that the system support structure is similar to the helicopter. Vibration pickups are required at the components and the adjacent mounting structure. In addition, the fluid transmission lines and the structure adjoining the support points, particularly any suspected critical areas, should be adequately instrumented where required. The number of points at which instrumentation is desired, including all parameters, may be beyond the capability of airborne simultaneous recording. Therefore, recording in a series (on different flights) may be necessary. The response characteristics of the instrumentation are very important, particularly where system and performance dynamics are involved. All channels requiring significantly high response such as pressure, vibration, and position information should have no significant attenuation out to at least 1000 Hz. Temperature pickups usually need not be as responsive because the rate of change of temperature is quite slow. This may apply to other system performance characteristics as well. For these parameters the recording of the outputs in sequence at discrete time intervals, in seconds or minutes, will be adequate. Adequate system information for analysis and comparison includes the parameters or system characteristics which follow:

a. Power measurement (in current and voltage) may be required for electrically operated or controlled components, and is particularly important for electric motor-operated components and those items associated with primary flight control functions.

b. System temperature pickups, which are required at the following points:

1. Reservoir
2. Heat exchanger (inlet and outlet, if applicable)
3. Pump (outlet, inlet, case drain outlet)
4. Adjacent structure for points considered critical (primary consideration here is possible heat sources)
5. Components (inlet and outlet). In special cases component wall temperatures also may be desirable.
6. Ambient air in closed compartments or near the heat sources

c. System pressure instrumentation required at:

1. Pump outlet section
2. Pump case drain
3. Inlet/outlet ports of each flight control cylinder
4. Inlet/outlet parts of utility system cylinders or actuators.

The reservoir also should be instrumented; if it is a bootstrap-type, it should be instrumented at the pressurization port in addition to the low pressure side. If a heat exchanger is used, it should be instrumented to ascertain if return transients are excessive or higher than the design requirement. If standing waves have been discovered as a result of ground tests, the specific points defined should be instrumented for flight test evaluation. Control surface or subsystem output should have adequate instrumentation evaluation of system rate and response capability. Flight safety is a primary consideration in the instrumentation of flight control systems. Installation of pressure transducers in particular probably will involve system modification by installation of special fittings or the use of additional bosses on components. Extra seals and their possible adverse effects on fatigue life and structural integrity are of primary concern. If both portions of a dual system are instrumented identically, a weak point in both systems possibly could fail in flight and result in the loss of the helicopter. The preceding discussion emphasizes the need for a thorough consideration of dual instrumentation. The minimum approach is to keep the instrumentation installation dissimilar. The recommended approach is the "series" installation and flight test of the system; i.e., the instrumentation, and flight test should be accomplished on one flight control system and the instrumentation removed prior to the evaluation of a companion system.

14.2.2.6 Preflight Tests. Prior to flight, a performance check of the helicopter systems and subsystems is required. In general, the systems will be checked using a ground cart. In the case of a starting system, at least three starts should be made to record instrumentation output. If accumulators are used, the precharge may be set to simulate the minimum expected in service due to temperature, and at least one start demonstrated under this condition. Obviously, checkout of the flight controls must precede flight. At this point, the instrumentation circuits and output should be checked to ascertain that the vehicle operational and vibration environments do not adversely affect their capability.

14.2.2.7 Taxi and Hover Tests. These tests should be secondary to those covering control system dynamics and stability, and hover handling quality tests. The pressure, temperature, vibration, and position transducer outputs should be recorded during the hover testing. The vibration data may be significant and, therefore, should be analyzed closely to ascertain that there are no obvious problems. Since the maximum rate capability of the system will not be checked at this time, the pressure data probably will not indicate any problems. The severity of the ground test makes unanticipated problems highly, unlikely. However, temperature data could be significant since the actual vehicle can have a much different thermal environment than the operation of the ground test setup.

14.3 Flight Test. The primary objective of the flight test program is to confirm the theoretical analysis and ground test results and demonstrate weapon system specification compliance. For the flight control systems this is performed in conjunction with the propulsion surveys or evaluation of the handling qualities of the helicopter. Although the ground tests may have included load simulation, evaluation under actual operational conditions is still a potentially critical final step prior to general service usage. The load effects, system operating characteristics, ambient and fluid thermal characteristics, pilot-system interactions, and performance in the total flight or mission envelope should be evaluated. Pressure transients are important and the load effects can be evaluated in a final manner. Performance parameters such as adequacy of control rates should be checked, including the operation at minimum pump rpm's. The time of operation or rate of utility functions under normal and emergency conditions should be evaluated. The emergency modes include loss of pumps in a multipump system. Altitude effects should be evaluated with emphasis on the pump suction pressure-flow characteristics. The impact on flight safety should be emphasized; the added instrumentation, particularly pressure transducers, must be completely assessed. For full-power (no manual reversion), redundant flight control systems, safety considerations may demand that at least one system at a time is not instrumented. As mentioned previously for the flight control functions associated with dual systems, each system should be evaluated in a "series" during the flight test program. Initial flight tests after the hover program should be conducted at altitudes which provide a safe margin for recovering from inadvertent maneuvers.

14.3.1 Flight Control System Flight Test. A significant part of the hydraulic flight control system evaluation should be a part of the stability and control flight program; including the collective, cyclic, and directional control functions. The pressure, temperature, position, and vibration transducer readouts should be recorded and analyzed. The evaluation should be conducted in accordance with a detailed flight test procedure developed prior to initiation of the flight test program. In this procedure the critical points of the flight envelope should be defined, and various stick rap techniques and maximum rate cycling outlined. The following points should be evaluated: maximum actuator rate (no-load or near no-load), maximum load, and at least two intermediate loads. In addition, performance at altitude should include service ceiling, cruise altitude, at 2000 ft, and at any other critical points. The system performance should be evaluated at maximum, normal, and minimum speeds of the hydraulic pump. Simulated failure effects of one system in a dual system and/or one or more pumps in a multipump system should be evaluated at all test conditions. For each test point developed, at least three test cycles should be recorded for evaluation and analysis. In addition to the basic performance evaluation, the system test results should be evaluated for conformance with applicable specifications, including ADS-50.

14.3.2 Utility Subsystem Flight Test. The utility subsystem flight tests should be similar to the flight control system flight test program. All utility functions used in flight should be evaluated during this phase including landing gear, door, winch, armament, wheel brake systems, etc. In addition, any emergency backup functions-manual release and pneumatic, pyrotechnic, and hydraulic operations should be evaluated relative to the specified performance requirements. The pressure, temperature, position, and vibration transducer readouts should be recorded and analyzed. The flight test program should be conducted in accordance with a detailed flight test procedure to be developed prior to flight testing. In this procedure the critical points of the flight envelope should be defined. The various helicopter altitudes, and forward, vertical, and side velocities at the start of each cycle should be specified. Special techniques should be outlined and submitted to the procuring activity for review/approval. The following points should be evaluated:

a. Performance of the maximum, intermediate, and no-load or near no-load, points at the critical altitudes specified, including service ceiling, cruise altitude, and at 2000 ft. unless otherwise specified

b. Performance at maximum, normal, and minimum at hydraulic pump power (speed) points (if the speed is variable)

c. Simulated failure effects of one or more pumps at critical points

d. Emergency modes of operation for critical attitudes and altitudes.

15. PNEUMATIC SYSTEM

15.1 **General.** Guidance. Pneumatic system component design and qualification criteria should be in accordance with ADS-SO. Pneumatic subsystem installations normally are verified by ground tests with subsequent demonstrations used to verify operation of the subsystem. Pneumatic subsystems operating as emergency backups for other subsystems also may require flight testing. Generally, all of these tests are to determine that the installation functions properly under adverse conditions and does not exceed the specified maximum leakage rate, peak pressure, and temperature. The system temperature should be determined during ground tests.

15.2 **Ground Test.** For normal system testing, nominal system pressure should be applied to the whole installation, and each selector valve and control valve should be operated for at least two complete cycles. During this operation, inspection should be made to determine whether:

a. The various functions are accomplished satisfactorily

b. The movement of all components is smooth and positive.

c. Relief valves, automatic devices for terminating an operation, pressure controls, switches and signals, audible or 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.

d. All indicating devices function and synchronize with the movement of the respective component as specified.

e. The specified functioning pressures are controlled and not exceeded. This may need to be determined at only one or at numerous locations in the system, but should not receive major consideration at any point where unrealistic pressures are obtained on ground test as compared with entirely different pressures in flight, unless the unrealistic pressures will adversely affect the systems during operational use. Pressures may be obtained by normal system pressure gages, or electronic equipment as applicable.

f. All tubing and fitting joints and component external seals are free from leaks.

g. All lines, fittings, and components are free from excessive movement and chafing.

h. There is full engagement of mechanical locks and catches.

i. 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 insure that pinching or stretching does not occur.

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

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

1. Ambient temperatures are within permissible limits.

All emergency operations should be tested on all subsystems normally operated by the pneumatic system or operated by the system during the emergency. Each subsystem should be inspected for smooth, continuous operation during the changeover from normal to emergency operation.

15.2.1 High-pressure Pneumatic Subsystems. High-pressure pneumatic subsystems requiring ground 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, in which case verification is accomplished through qualification and acceptance testing on a component basis. Another high-pressure pneumatic is a sealed gas storage bottle which can be used as an emergency backup system; but this is also a "one-shot" operation. This type of sealed gas storage bottle is verified to contain its correct pressure by periodic weighing, as loss of pressure would be indicated by a decrease in weight.

15.2.1.1 Flushing. Ground testing of the integrity of an airborne compressor-charged system requires a preliminary flushing of the system with clean dry air. Manual shutoff valves may be installed in each subsystem pressure line. With a high-pressure pneumatic external source connected to the ground charging valve, each shutoff valve is left open until there is evidence that no foreign matter is exhausting from the subsystem. Components such as subsystem pressure regulators and actuators must be bypassed or disconnected during the flushing operation. If an excessive amount of oil is exhausting from a shutoff valve, all lines and components in the circuit should be removed, inspected. and cleaned or replaced. Air storage bottle drain valves should be opened until all foreign material and moisture have been discharged, then closed. During the flushing period, the system also may be checked for leaks. With the bleed lines closed, relief cracking and reset pressures may be verified by raising the source pressure. After the flushing procedure is completed, components that were removed or bypassed should be properly reinstalled in the system.

15.2.1.2 Dry Air. With the helicopter positioned for testing, an external source of clean, dry air should be connected to the ground charge valve. A manual bleed valve and an accurately calibrated pressure gage should be installed near the ground charge valve. With the air source pressure regulator set to deliver the nominal system operating pressure, each subsystem should be operated to verify operation. A leak check should be made. During charging of the pneumatic system, the pressure gage on the instrument panel should be compared with the external calibrated pressure gage. The system pressure located near the ground charge valve should be verified for accuracy. A detailed ground procedure should be established for each subsystem with maximum regard for safety to test and maintenance personnel.

15.2.1.3 Procedure. For tests using the helicopter airborne air compressor, all external pneumatic power should be removed. The system may be charged to a pressure slightly below the compressor "cut-in" pressure before removal of the external pressure source. Electrical and hydraulic power (if the compressor is hydraulic motor-driven) should be connected to the external power connectors. The pressure at which the compressor "cuts out" should be recorded. The pressure should be bled down slowly through the bleed valve and the "cut-in" pressure of the compressor recorded. This test should be repeated for five cycles with the accuracy of the cockpit gage also checked. When the compressor shuts down, there should be condensate drainage from the moisture separator. Lack of drainage indicates a malfunction. External power sources should be disconnected. To pressure leak test the system, ground charge it to pressure and disconnect the ground charge supply. The permissible leakage rate should not exceed that specified, which usually is measured over a one hour period. During the teat, the ambient air temperature should be kept constant. The temperature of the air inside the system usually is higher than the ambient air temperature due to the reverse Joule-Thompson effect (i.e., the air heats up when charged through a valve). The cooling of this air may result in a pressure decline, and therefore give a false leak indication. Consequently, a temperature pickup should be attached to the akin of the air bottles or the system. Ground charged air bottle subsystems are tested in the same manner as the airborne compressor-charged subsystem.

15.2.2 Low-pressure Pneumatic and Vacuum Subsystems. Low-pressure pneumatic and vacuum subsystems commonly are supplied by bleed air from the engine compressor. The bleed air is normally at a very high pressure when exiting the compressor and, by necessity, the **ducting** is insulated. Extreme caution should be exercised by personnel in handling these subsystems. Safety precautions should be outlined by the contractor. A typical low pressure system consists of supplying pressure for an air-conditioning system, pressurizing a hydraulic reservoir or any desired low pressure pneumatic system. The bleed air pressure of the helicopter engine is regulated to the desired operating pressure with a pressure regulator. Ground testing normally requires disconnecting the helicopter electrical power from the pressure regulator. External electrical power and hydraulic power (for hydraulic related systems) are required. An external pneumatic source should be connected to the bleed air connector of the inlet. The outlet pressure of the source should be regulated to the maximum **desired** bleed air pressure into the subsystem pressure regulator. The test shutoff valve normally is closed. By opening the shutoff valve, pressure is allowed to enter the subsystem, and a check for leakage and pressure drop can be made. To verify relief valve operation, the subsystem pressure regulator must be bypassed to allow the higher pressure to the downstream subsystem. Specified relief valve cracking pressure and reset pressure should be verified. Leakage is verified by pressuring the subsystem to the maximum operating pressure and disconnecting the pneumatic supply. Acceptable pressure drops should be specified in the test procedures. With the ground pneumatic source **connected** to the bleed air **connector,** the inlet pressure should be regulated at its minimum and then its maximum pressure. A calibrated gage-should be placed in the vacuum subsystem line to verify the pressure.

15.3 Flight Test. The satisfactory completion of ground testing should be followed by flight testing. The helicopter should be instrumented **to** measure and record (manually or automatically, as applicable) all necessary pressures, ambient air and system temperatures, component time of operation, and other data required on any individual system. The system(s) should be properly serviced for adjustments. **All** necessary special components should be installed and checked for proper and safe function. With the engine running, all pneumatic subsystems operating from engine bleed air or the airborne air compressor system should be **operated** to insure proper operation. In flight, each pneumatic normal operating subsystem should be operated three times at required altitudes with the helicopter flying at the maximum speed for the subsystem. **For** these conditions, the helicopter should be flown until system temperatures have stabilized prior to testing. All necessary operating pressures, such as the airborne pneumatic **compressor** inlet, outlet, and regulating pressures, should be verified. The temperature of the compressor outlet should be instrumented along with inlet temperatures of the air bottles. **All** instrumentation should be calibrated according to the test procedures. It should be demonstrated that the temperatures do not exceed those to which the components are designed, with consideration given to the percentage of operating time to be encountered at various temperatures and conditions. All pneumatically operated services should be checked to ascertain the number of consecutive full cycles of operation possible before the air bottle(s) are discharged to a pressure below which operation is impossible. For airborne compressor-charged air bottles, the time required to recharge the air bottle(s) to cutout pressure should be verified. The operation of all pneumatic control valves should be checked for possible malfunctions. Any possible inadvertent operation should be checked to determine any malfunctioning which could be encountered. There should be at least one operation of each pneumatic emergency system. These operations should be made at applicable altitudes and speeds. Necessary pressure and elapsed time of operation should be determined. Al.1 auxiliary systems should be suitably tested.

16. ENVIRONMENTAL CONTROL SYSTEM

16.1 **Heating, Ventilating, Pressurization, Air-conditioning, and NBC Systems Guidance.** These systems should meet the allocated performance requirements of the weapon system specification. Ground and flight demonstrations should be conducted. Suitable instrumentation should be installed to measure the system performance and to allow a computer model of the ECS performance to be validated. Meaauranda include, but are not necessarily limited to coolant flowrate, temperature, pressure, humidity, contaminants or contaminant aimulanta, and pressure differential across each major component of the system,, airflow (pounds per minute), the temperature differential, and the pressure drop across each major component of the system, including the electronic equipment and equipment bays. System performance teats should be conducted with a minimum of 75% of the passenger and crew accommodations occupied during cooling teats, and a maximum of 10% of the passenger accommodations occupied during heating teats. Instrumentation should be provided to determine the temperature distribution within the occupied spaces of the aircraft, all electronic equipment bays, and compartments. Instrumentation should be provided to determine the velocities of flow in all occupied compartments under all flight conditions. If the aircraft cockpit or equipment bays are pressurized, instrumentation should be installed to verify that the pressure levels or pressure schedules as required are being achieved under all flight conditions where pressurization is intended.

16.1.1 Air Samples. An investigation of the cleanliness of air supplied to the cabin should be made by collecting air samples in an evacuated container and by analyzing the contents in a laboratory. Samples should be screened for contamination of smoke, oils, water content, Biological and/or Chemical agent aimulanta, end particulatea which may be introduced from the outside air via the bleed air source (if used) and by aircraft specific components such as filters. Samples should be taken in such a manner that the origin of the contamination (i.e. outside air infiltration versus contamination from ECS supply air) can be determined. Sufficient samples should be obtained to cover all flight conditions under which contamination may exist. The moisture content of the air in both crew end passenger compartments also should be determined. After ground teats, flight teats should be conducted to demonstrate safe and satisfactory performance of the system and component equipment under the following conditions:

a. Climb
b. Descent
c. Level flight
d. Maneuvering flight
e. Hover (IGE and OGE).

16.1.2 Smoke and Gas. Smoke or gas removal procedures should be demonstrated to prove conclusively that proposed methods to clear all areas occupied by passengers and crew of hazardous concentrations of smoke or gas within a safe period of time meet the design criteria of ADS-50. The removal of odors from sanitation areas should be demonstrated during use of these facilities.

16.1.3 Solar Radiation. Teats on ventilating and cooling systems should be conducted during the daytime to determine the capability of the system with the full effect of solar radiation and with the maximum daylight electrical load in use within the helicopter crew compartment.

16.1.4 Absence of Solar Radiation. Night time teats of heating systems should be conducted to demonstrate the adequacy of the system In the absence of solar radiation and electrical loads applied within the helicopter cabin. Electrical loads necessary to conduct safe flight teats may be used, but other electrical and avionic loads may not be used unless it can be demonstrated that these loads provide continuous heat output for the duration of each mission and for all variations of avionic complements of the aircraft.

16.1.5 Extrapolation. If the flights cannot be made under the most critical design atmospheric temperatures, sufficient test data should be obtained and an accurate extrapolation with a validated computer model should be made to the design condition(s). Critical design atmospheric temperatures, pressures, and humidity should be as stated in ADS-SO-PRF for the ECS. These criteria and the cooling, heating, pressurization, ventilation, and NBC performance criteria may be superseded by the weapon system specification.

16.1.6 Temperatures. All true air temperatures should be measured by the use of thermocouples. Cabin temperatures should be determined by using both shielded and unshielded thermocouples in order to exclude and include, respectively, the effect of solar radiation. Duct and surface temperatures should be determined with shielded thermocouples to minimize the effect of radiation. All temperatures should be recorded at regular intervals, and thermocouples should be located so as to determine all temperatures necessary for evaluation of the system operation.

16.1.7 Pressure. For pressure measurements, all pressure taps should be located so as to minimize the effect of turbulence caused by valves, elbows, or orifices in the system, and to determine all pressures required for a complete evaluation of system operation. Humidity measurements should be taken within the cabin at regular intervals, using a reliable type of psychrometer.

16.1.8 Air Velocities. Air velocities should be determined by using a suitable velometer in passenger and crew compartments. Air velocities across the cabin thermostat-sensing element and temperature-indicating instrument (if the latter is installed) also should be determined.

16.1.9 Time Histories. Time histories of temperature, pressure, flowrate, humidity, and contaminants or contaminated simulants should be recorded so that the rates of these variables and time intervals required to obtain stabilized conditions can be noted. All test results, measurements, and instrumentation descriptions should be submitted for approval to the procuring activity.

16.1.10 Humidity. Humidity should be measured for the bleed air source, ram air source, all distribution supply air, for the inlet of the ECS Air Cycle Machine turbine inlet if used, for the crewstation(s), and for other humidity critical equipment as required.

16.2 Defogging, Defrosting, and Anti-icing/Deicing Systems. The defogging and anti-icing systems should be inspected and tested to determine compliance with the allocated performance requirements specified in the weapon system specification, including a visual inspection of the general construction and serviceability of the system. Test instrumentation should be adequate to determine heat flows through the area, to determine the dew point at each transparent area and to insure that any area will not be overheated. The windshield anti-icing tests should consist of laboratory and flight tests which demonstrate compliance with the heating requirements in the weapon system specification. The quantity of heat applied to the windshield should be checked in flight to insure that the quantity required (determined during laboratory tests) actually is available. An accepted method of determining heat flow is to measure the inside and outside surface temperature of the transparent area and measure the effect of the OAT. If the thermal properties of the transparent area are known, the heat flow then can be determined. Accuracy of this method will depend upon the available temperature differential, the external heat transfer coefficient, and the ice accumulation rate, and if steady-state conditions have been attained. When ducting is used in any part of the system, it should be tested for flow rates, temperature drops, pressure drops, and duct leakage; and the methods and instrumentation used by the contractor should be outlined. A report required for final approval of the installation system(s) should consist of a compilation of the flight test and laboratory test data, and a comparison of these data with the theoretical information compiled.

16.2.1 Ground and Flight tests. Ground and flight tests should be conducted to demonstrate proper operation of the temperature sensors, overheat warning and control, distribution of available airflow and coolant, and to demonstrate general security and safety of the system for flight testing. As a minimum, flight conditions should include normal takeoff and climb to operating altitude, normal descent and landing, level flight, and hover.

16.2.2 Instrumentation. Instrumentation should be installed to determine the quantity and temperature of air from each heat source and the temperature and quantity of airflow in all main distribution ducts. Appropriate surfaces should be instrumented to provide a chordwise profile of exterior and interior skin temperatures as well as temperature drop and airflow through the double skin passages. The surface to be instrumented should be subject to approval of the procuring activity. Critical structure should be instrumented with sufficient thermocouples to insure that overheating does not occur. Shielded thermocouples should be used to measure air temperatures at locations where there is a substantial difference between air temperature and the surrounding metal. If there are discontinuities in the heated areas, sufficient temperature measurements to determine the effect of tne heat flow from the heated to the unheated areas should be made.

16.3 Control System. Each function of the ECS which is controllable from the crew station's displays or control panel(s) should be demonstrated. These include but are not necessarily limited to the following:

a. bleed air control (on/off) for each engine providing bleed air,
b. ECS off and on,
c. ram air selection (or other appropriate backup cooling scheme),
d. cockpit temperature control,
e. cockpit pressure dump as required,
f. air flowrate as required,
g. individual zone temperature control as required,
h. NBC system on/off as required,
i. defog selection as required,
j. windshield anti-ice as required,
k. safety critical functions as required,
l. mission critical functions as required,
m. all warnings, cautions, and advisories relevant to the ECS/NBC system (These may be simulated under controlled ground test conditions or inflight whichever is more safe or convenient).

17. AUXILIARY POWERUNIT

17.1 General Guidance. The contractor should conduct a functional demonstration of the auxiliary power unit during ground and flight testing. All functional modes provided by the APU should be demonstrated to include electrical generating capability, hydraulic capability, and pneumatic capability. Each functional capability should be demonstrated individually and in combination to demonstrate design goals and weapon system specification compliance. APU qualification should be in accordance with ADS-SO. If the APU installed in the aircraft is to be operated in flight, it should be qualified as an engine.

17.2 Electrical Interface Test. The electrical generating capability testing should demonstrate adequate power generation for ground electronic initialization and system checkout. Testing should demonstrate any backup electrical power capability provided to the aircraft. Worst case electrical load conditions should be validated, including simulated failure of transmission driven electrical generators. A demonstration of the transient electrical capability should be demonstrated by conducting various combinations of electrical load switching, including worst case conditions. If the APU is started electrically, the aircraft start system should demonstrate adequate and repeatable starts.

17.3 Hydraulic Interface Test. The hydraulic capability testing should demonstrate adequate and repeatable APU starts, if applicable, except that the start envelop; for the APU may be less than the main engines. Testing should demonstrate adequate hydraulic supply to all functions, as applicable, such as, landing gear, weapons bay or cargo doors, cargo winches, etc. The demonstration should include worst case hydraulic loads at worst case environmental conditions, per the applicable weapon system specification. If APU hydraulic power is provided as a backup for transmission driven hydraulic power, the APU backup functions should be demonstrated by simulating failed main hydraulic capability at worst case environmental and load conditions.

17.4 Pneumatic Interface Test. If the APU provides pneumatic capability (e.g. for main engine starting or providing bleed air for environmental control), testing should demonstrate adequate air supply under worst case environmental and load conditions. For multi engine applications, testing should demonstrate multi engine simultaneous start capability the weapon system specification requirements.

Certification Board Record

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Rationale for certification:

Requirements section meets the criteria defining a performance specification, and the guidance sections are identified for guidance only.

Decision:

General Type	Decision (check)	Certification
Specification	XX	Performance
		Detail
Standard		Interface Standard
		Standard Practice
		Design Standard
		Test Method Standard
		Process Standard
Handbook		Handbook (non-mandatory use)
Alternative Action		

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