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28 MAY 1996

AERONAUTICAL DESIGN STANDARD

ELECTROMAGNETIC ENVIRONMENTAL EFFECTS (E^3) PERFORMANCE AND VERIFICATION REQUIREMENTS

UNITED STATES ARMY AVIATION AND TROOP COMMAND

ST.LOUIS, MISSOURI

AVIATION RESEARCH AND DEVELOPMENT CENTER

DIRECTORATE FOR ENGINEERING

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1.0 **SCOPE**. This document establishes electromagnetic environmental effects (E^3) performance and verification requirements for aircraft systems.

2.0 **REFERENCE DOCUMENTS**. The following documents form a part of this document to the extent specified herein.

STANDARDS

MILITARY

MIL-STD-461D (11 Jan 93)	Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility
MIL-STD-462D(2) (1 Dec 95)	Measurement of Electromagnetic Interference Characteristics
MIL-STD-704E (1 May 91)	Aircraft Electrical Power Characteristics (interface requirements only)
MIL-STD-1385B (1 Aug 86)	Preclusion of Ordnance Hazards in Electromagnetic Fields; General Requirements for (interface requirements only)
MIL-STD-1795A (20 Jun 89)	Lightning Protection of Aerospace Vehicles and Hardware (for guidance only)

FEDERAL AVIATION ADMINISTRATION

Advisory Circular (AC) 20-136	Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning

COMMERCIAL

RADIO TECHNICAL COMMISSION FOR AERONAUTICS (RTCA)

DO-160C, change 1 (27 Sep 90)	Environmental Conditions and Test Procedures for Airborne Equipment

SOCIETY OF AUTOMOTIVE ENGINEERS

SAE AE4L (20 Jun 78)	Lightning Test Waveforms and Techniques for Aerospace Vehicles and Hardware (the "Blue Book")
SAE AE4L-87-3 Rev B (Jan 89)	Recommended Draft Advisory Circular-Protection of Aircraft Electrical/ Electronic Systems Against the Indirect Effects of Lightning (the "Orange Book")

2.1 **DEFINITIONS**

Aircraft Electromagnetic Environment (EME). The Army aircraft world-wide environment is defined in Table I, parts A and B.

Lightning Environment (Direct Effects Testing). For design and verification purposes, the natural lightning environment (which comprises a wide statistical range of current levels, duration, and number of strokes) is represented by current components A through D, and voltage waveforms A, B, and D as defined in paragraph 23.5 of RTCA/DO-160C. Guidance for application of these waveforms is also given in Section 23 of RTCA/DO-16OC.

Lightning Environment (Analysis and Indirect Effects Testing). Appendix III of FAA/AC 20-136 contains idealized mathematical representations of a severe natural lightning environment. Those waveforms A, B, C, and D are derived from cloud-to-ground lightning discharges. Waveform H represents the high rate-of-rise effects including those from intracloud and cloud-to-cloud discharges. These idealized waveforms can be used as the bases for either tests or analyses of the effects of a severe lightning environment on aircraft electrical/electronic systems. Test waveforms, of necessity, will be only approximations of the idealized waveforms. Results from test waveforms that deviate from the idealized waveforms must therefore be analytically relatable to the idealized waveform.

Lightning Attachment Zones. Lightning attachment zones are defined in paragraph 23.2.3 of RTCA/DO-160C. Guidance for locating the zones on particular air vehicles is discussed in the Section 30.1 of MIL-STD-1795.

Lightning Effects (Direct and Indirect). The direct effects of lightning are the burning, eroding, blasting, and structural deformation caused by lightning arc attachment, as well as the high pressure shock waves and magnetic forces produced by the associated high currents. Direct effects includes the direct coupling of lightning currents into electrical wiring associated with external lighting, antennas, and other external equipment. The indirect effects are those resulting from the interaction of the electromagnetic fields accompanying lightning with electrical/electronic equipment inside the vehicle.

Flight Critical Equipment. E^3 generated anomalies involving this equipment would cause immediate or almost immediate loss of aircraft control or unsafe situations with loss of life a likely occurrence.

Flight Essential Equipment. E^3 generated anomalies involving this equipment could cause an emergency landing with possible damage to the aircraft, or would cause the pilot to take other emergency action. Injury or loss of life is possible.

Flight Nonessential Equipment. E^3 generated anomalies involving this equipment would cause reduced safety through lack of redundant systems. Aircraft damage and personnel injury or loss of life unlikely.

Mission Critical Equipment. E^3 generated anomalies involving this equipment would cause immediate or almost immediate mission abort. Injury or loss of life possible though unlikely unless the aircraft is involved in combat, in which case aircraft may not be able to return to base safely.

Mission Essential Equipment. E^3 generated anomalies involving this equipment would cause degraded, or lack of, mission success. During combat, aircraft and crew could be in jeopardy of loss.

Mission Nonessential Equipment. E^3 generated anomalies involving this equipment would create annoyances and minor discomfort with little impact on mission accomplishment.

Safety Critical Equipment. E^3 generated anomalies involving this equipment would cause a safety hazard to personnel or to the aircraft.

Subsystem. A subsystem is a major functional element of a system, usually consisting of several components that are essential to the operational completeness of the subsystem. Subsystem examples include airframe, propulsion, guidance, navigation, and communication with reference to the air vehicle as the overall system. The terms system and subsystem are often used interchangeably in defining a functional element (e.g., flight control system/subsystem, environmental control system/ subsystem, etc.)

TABLE I - PART A

STANDARD WORLD-WIDE ELECTROMAGNETIC RF ENVIRONMENT (EXTERNAL TO AIRCRAFT) MODULATION PARAMETERS (EXCLUDING PULSE)

FREQUENCY (MHz)	MODULATION TYPE	FIELD STRENGTH (V/m RMS)	SAMPLE FREQUENCIES
.014-1.99	CW, AM	200	Continuous Sweep
2-19.9	CW, AM	200	Continuous Sweep
20-149.9	CW, AM, FM	200	Continuous Sweep
150-249.9	AM, FM	200	Continuous Sweep
250-499.9	AM, FM	200	Continuous Sweep
500-999.9	AM, FM	200	Continuous Sweep
1000-1999.9	AM, FM	200	Continuous Sweep
2000-3999.9	AM, FM	200	Continuous Sweep
4000-7999.9	AM, FM	200	Continuous Sweep
8000-9999.9	AM, FM	200	Continuous Sweep
10,000-40,000	CW, FM	200	Continuous Sweep

NOTES: CW = Continuous Wave

FM = Frequency Modulation. Below 1 MHz use a 20 kHz deviation modulated by 1 kHz tone, above 1 Ghz, use a 1 MHz deviation, modulated by a 10 kHz square wave.

AM = Amplitude Modulation. Modulated by 1000 Hz tone; 50% modulation

TABLE I -PART B

PULSE MODULATION PARAMETERS

FREQUENCY (MHz)	PW (u SEC)	PRF (Hz)	PEAK FIELD (V/m RMS)	AVERAGE FIELD (V/mRMS)	SAMPLE FREQUENCIES
2-24.9	833.3	300	204	102	24
150-249.0	20.0-25.0	200-310	3120	200	4
250- 499.9	25.0-33.0	300	2830	200	6
500-999.9	33.0	100-300	3480	244	3
1000-1999.9	1.0-2.0	670-1000	8420	200	1
2000-3999.9	1.0	250-600	21270	336	3
4000-7999.9	1.0-2.0	250	21270	336	1
8000-9999.9	1.0	150-250	21270	336	2
10,000-40,000	1.0	1000	6892	200	6

NOTES: PRF = Pulse Repetition Frequency
PW = Pulse Width
AVERAGE FIELD = PEAK FIELD * SQRT(PW*PRF)

3.0 E^3 PERFORMANCE REQUIREMENTS.

3.1 **Safety Margins**. E^3 safety margins shall be established for subsystems and equipment assigned to criticality types which would result in a catastrophic failure if susceptible to E^3. Flight subsystems and equipment shall have a safety margin of at least 6 dB. The safety margin for electroexplosive devices (EEDs) shall be 16.5 dB.

3.2 **Electromagnetic Interference (EMI)**. All equipment and subsystems shall meet the requirements of MIL-STD-461 as modified by this document:

3.2.1. CE101, CE102, CS101, CS114, CS115, CS116, RE101, RE102, RS101 and RS103 apply to all equipment and subsystems.

3.2.2. CE106 shall apply to all antenna connected receivers and their associated amplifiers or pre-amplifiers. CE106 shall also apply for all transmitters, with their associated amplifiers or pre-amplifiers, in their standby or non-transmitting mode. Where testing to the CE106 requirement cannot be performed, the requirements of RE102 shall be met with the receiver, transmitter (in the standby or non-transmitting mode) or amplifier and associated antenna tested together.

3.2.3. CE106 shall apply to all antenna connected transmitters and associated amplifiers or preamplifiers in their transmit mode(s). Where testing to the CE106 requirement cannot be performed, the requirements of RE103 shall apply.

3.2.4. RS103 limits shall be changed to the levels and modulations specified in Table I, parts A and B.

3.3 **Electromagnetic Compatibility (EMC)**. EMC is required among all subsystems and equipment internal to a system as well as between the aircraft and supporting subsystems external to the aircraft such as ground support equipment (GSE). All subsystems and equipment shall meet specified performance requirements when operated simultaneously with any single or multiple combination of subsystems and equipment's. This requirement applies for all specified modes of operation for each subsystem and equipment. A minimum 16.5 dB safety margin shall be provided for all EEDs.

3.4 **Electromagnetic Vulnerability (EMV)**. The aircraft shall meet all performance requirements necessary to complete its mission during and after exposure to friendly and hostile electromagnetic emitters as defined by the Army World Wide Environment specified in Table I, parts A and B. This includes satisfactory performance of Built-In-Test (BIT) checks as well as satisfactory performance when electromagnetic energy may be coupled to the aircraft through ground support equipment, aerial refuelers, and any other equipment external to the aircraft.

3.5 **Electromagnetic Pulse (EMP)**. Aircraft subsystems, and equipment shall be protected such that exposure to the EMP threat will not cause permanent damage or hazardous temporary upset to flight critical functions. Mission critical functions shall be similarly protected so as to not lessen the probability of mission completion. The EMP environment shall be as defined in figure 1.

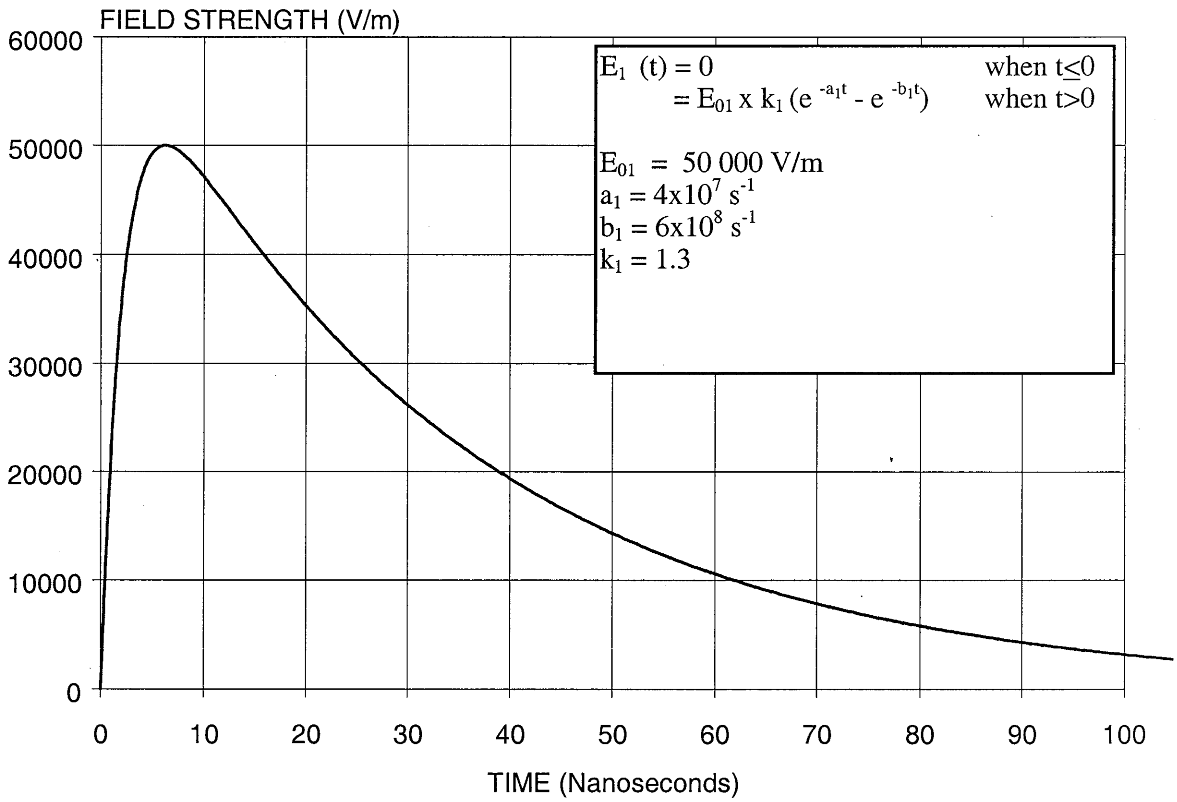

Figure 1. Default free-field EMP environment

3.6 **Radiation Hazards.** Ordnance, fuel, and personnel shall be protected from any form of hazardous electromagnetic energy. Specific requirements are as follows:

3.6.1 **Hazards of Electromagnetic Radiation to Ordnance (HERO)**. The HERO requirements for the aircraft shall be in accordance with the interface requirements specified in MIL-STD-1385 except that the minimum field strength shall be 200 V/m. All modes of operation including packaging, handling, storage, transportation, checkout, loading/unloading, and the in-flight configuration shall meet this requirement. Ordnance subsystems shall not be subject to inadvertent ignition or dudding caused by the external environment. The ordnance shall be considered adequately designed in accordance with these requirements if, in the specified environment, the appropriate stimuli do not exceed the following in any EED in the aircraft:

For Hazards: A 16.5 decibel (dB) margin shall be demonstrated as defined by:

0.15 MNFC <u>or</u> 0.15 MNFV.

$(0.15)^2$ MNFP or $(0.15)^2$ MNFE.

For Performance Degradation: A 6.9 dB margin shall be demonstrated as defined by:

0.45 MNFC <u>or</u> 0.45 MNFV.

$(0.45)^2$ MNFP or $(0.45)^2$ MNFE.

where:

MNFC = Maximum No Fire Current
MNFV = Maximum No Fire Voltage
MNFP = Maximum No Fire Power
MNFE = Maximum No Fire Energy

3.6.2 **Hazards of Electromagnetic Radiation to Fuel (HERF).** Fuels shall not be inadvertently ignited by the radiated electromagnetic environments of Table I, parts A and B.

3.6.3 **Hazards of Electromagnetic Radiation to Personnel (HERP).** Appropriate measures shall be implemented to prevent inadvertent exposure of personnel to electromagnetic levels higher than the maximum permissible exposure (MPE) levels specified in Tables II and III. For pulsed fields, additional requirements for 0.1 to 300,000 MHz are as follows:

a. The peak electric field shall not exceed 100 kV/m for any pulse.

b. For pulse widths less than 100 milliseconds with a pulse repetition period of at least 100 milliseconds, the peak power density for any single pulse shall not exceed the power density in Tables II and III modified as follows: Peak Maximum Permissible Exposure (MPE) = (MPE x Avg time) / (5 x pulse width). Averaging time is from the tables with the same dimension as pulse width. If the pulse width exceeds 100 milliseconds, the pulse repetition period is less than 100 milliseconds, or there are more than 5 pulses during the averaging time, then the total "energy" density (pulse power density integrated over time) during any 100 millisecond period shall not exceed: (MPE x Avg time) / 5.

Table II. Maximum permissible exposure for controlled environments

Part A Electromagnetic Fields (f is in MHz)				
Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) E-Field, H-Field (mW/cm^2)	Averaging Time $\lvert E \rvert^2$, $\lvert H \rvert^2$ or S (minutes)
0.003 - 0.1	614	163	(100, 1000000)*	6
0.1 - 3.0	614	16.3/f	($100, 10000/f^2$)*	6
3 - 30	1842/f	16.3/f	($900/f^2, 10000/f^2$)*	6
30 - 100	61.4	16.3/f	($1.0, 10000/f^2$)*	6
100 - 300	61.4	0.163	1.0	6
300 - 3000			f/300	6
3000 - 15000			10	6
15000 - 300000			10	$616000/f^{1.2}$

* These plane-wave equivalent power density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

Part B Induced and Contact Radio Frequency Currents (f is in MHz)			
Frequency Range (MHz)	Maximum Current (mA)		
	Through both feet	Through each foot	Contact
0.003 - 0.1	2000f	1000f	1000f
0.1 - 100	200	100	100

Table III. Maximum permissible exposure for uncontrolled environments

Part A Electromagnetic Fields (f is in MHz)					
Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) E-Field, H-Field (mW/cm^2)	Averaging Time (minutes)	
				$\|E\|^2$, S	$\|H\|^2$
0.003 - 0.1	614	163	(100, 1000000)*	6	6
0.1 - 1.34	614	16.3/f	(100, $10000/f^2$)*	6	6
1.34 - 3.0	823.8/f	16.3/f	($180/f^2$, $10000/f^2$)*	$f^2/0.3$	6
3.0 - 30	823.8/f	16.3/f	($180/f^2$, $10000/f^2$)*	30	6
30 - 100	27.5	$158.3/f^{1.668}$	(0.2, $940000/f^{3.336}$)*	30	$0.0636f^{1.337}$
100 - 300	27.5	0.0729	0.2	30	30
300 - 3000			f/1500	30	
3000 - 15000			f/1500	90000/f	
15000 - 300000			10	$616000/f^{1.2}$	

* These plane-wave equivalent power density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

Part B Induced and Contact Radio Frequency Currents (f is in MHz)			
Frequency Range	Maximum Current (mA)		
(MHz)	Through both feet	Through each foot	Contact
0.003 - 0.1	900f	450f	450f
0.1 - 100	90	45	45

3.7 **Control of Static Electricity**. The aircraft shall control and dissipate the build-up of electrostatic charges caused by precipitation static (P-static) effects, fluid flow and air flow to avoid fuel ignition and ordnance hazards, to protect personnel (ground servicing and flight crew) from shock hazards, and to prevent performance degradation or damage to electronics to include antenna coupled p-static interference. The system shall preclude damage or upset from electrostatic discharge (ESD) due to handling of the equipment by operating or maintenance personnel.

3.7.1 **Aircraft Discharge.** The aircraft shall meet its performance requirements when subjected to a 300 kilovolt discharge. This requirement also applies to equipment installed external to the aircraft, including ordnance and fuel tanks.

3.7.2 **Precipitation Static.** The aircraft shall control p-static interference to receivers and other electronics on board the aircraft such that the aircraft's performance requirements are met.

3.7.3 **Personnel Handling of Ordnance.** Ordnance subsystems shall not be inadvertently initiated or dudded by a 25 kV electrostatic discharge caused by personnel handling.

3.8 **Lightning Protection.** The aircraft shall survive the direct and indirect effects of a 200,000 ampere lightning strike, which either directly attaches to the aircraft or occurs nearby. Specifically, the aircraft and its subsystems shall:

(a) prevent hazardous temporary upset and permanent damage to flight-critical electrical and electronic subsystems;

(b) prevent lightning ignition of fuel and ordnance;

(c) prevent catastrophic structural damage to the aircraft and associated flight-critical equipment, which would preclude safe return and landing; and

(d) prevent upset and permanent damage to mission-critical equipment, which would preclude safe return and landing.

The voltage and current waveforms of the lightning attachment are described in section 2.1 of this document.

3.9 **Electrical Power.** The aircraft shall provide electrical power in accordance with (IAW) the interface requirements of MIL-STD-704. The aircraft shall meet all performance requirements when provided with electrical power IAW the performance requirements of MIL-STD-704. This includes surges, ripples, spikes, transients, and other electrical conditions which can cause EMI.

3.9.1 **Transients (General).** Transients caused by electrical power bus switching, load switching, and fault clearing shall not cause upset or damage to the aircraft subsystems and equipment.

3.9.2 **Spikes.** Transients less than 50 microseconds duration (i.e., spikes) shall not exceed +50 percent nor -150 percent of the nominal d-c line voltage, nor +/-50 percent for a-c power lines. Spikes of duration longer than 50 microseconds shall meet the performance requirements of the overvoltage curves in MIL-STD-704. In addition, the operation of individual subsystems and equipment (from on to off, off to on, or from operational mode to operational mode) shall not cause EMI in the other equipment/subsystems.

3.10 **Electrical Bonding.** All aircraft electrical and electronic bonds shall not exceed 2.5 milliohms between the equipment's external mechanical interface and aircraft ground.

3.11 **Life cycle, E^3 Hardness.** The aircraft operational performance and the E^3 requirements of this document shall be met throughout the rated life cycle of the aircraft and includes, but not limited to, the following: maintenance, repair, surveillance, and corrosion control.

4.0 REQUIREMENT VERIFICATION.

4.1 **Electromagnetic Environmental Effects Integration Analysis (E^3 IA).** An E^3 IA shall be conducted prior to finalization of any major design work or modification to the aircraft. This analysis shall clearly establish the contractor's approach for achieving compliance with the requirements of this document. The E^3 IA shall address, as a minimum, the following issues:

(a) Methods and requirements for ensuring that contractor developed or furnished subsystems and equipment will not be affected by interference from sources within the aircraft as well as external to the aircraft nor be sources of interference which might adversely affect the operation of other subsystems.

(b) Predicted problem areas and proposed methods of approach for solution of problems not resolved by compliance with MIL-STD-461 and MIL-STD-462.

(c) Radiation characteristics from aircraft antennas, including fundamental and spurious energy, and antenna to antenna coupling.

(d) Detailed approach to cable design and installation, including wire categorization criteria, labeling, segregation of potentially interference generating or susceptible wires, shielding and termination techniques, as well as the criteria and methods for determining the amount of shielding required.

(e) Impact of corrosion control requirement on meeting and maintaining E^3 performance requirements and recommendations for resolution of problems areas.

(f) Design criteria and required tests for lightning protection and design impacts in individual subsystems and equipment.

(g) Criticality categorization and degradation criteria for each subsystem and equipment. including safety margins, where required.

(h) Design criteria and required tests for electrostatic buildup, including precipitation static, propulsion and fuel system charging, and electrostatic discharge.

(i) Methods for spike protection and minimization for subsystems and equipment connected to the power bus.

(j) Bonding and grounding criteria and methodology for all subsystems and equipment.

(k) E^3 requirements and hardening allocations for off-the-shelf and government furnished equipment.

(l) Spectrum utilization details.

(m) The specific test and analysis methodology for verification of each of the E^3 requirements.

(n) Details of the life cycle provisions for ensuring that all E^3 requirements are maintained over the life of the aircraft.

(o) Radiation hazards analysis for personnel, fuel and ordnance.

If required by contract, a report detailing this analysis shall be prepared using Appendix A as guidance.

4.2 **Subsystem/Component EMI Tests**. EMI tests shall be conducted on all contractor furnished electrical and electronic subsystems and equipment to verify the requirements of section 3.2 of this document. Testing shall be in accordance with MIL-STD-462 except as modified by this document.

(a) RS103 modulations shall be changed to those specified in Table I, parts A and B. For pulsed modulation testing in frequency ranges where a range of pulse widths (PWs) and pulse repetition frequencies (PRFs) are specified, a single PW and PRF shall be chosen which represents the worst case stimulation of the equipment under test.

(b) RS103 test levels shall be as follows:

(i) For Flight and Safety Critical equipment and subsystems, the full levels in Table 1, parts A and B, shall apply. (Note: When appropriate, and where swept frequency testing cannot be adequately performed due to test facility limitations, discrete frequency testing may be approved by ATCOM engineering, AMSAT-R-ESE. In this event, specific frequencies, PWs, and PRFs will be provided to the contractor. The minimum number of sample frequencies per band shall be as specified in Table I, part B)

(ii) For all other equipment, testing shall be performed at the levels provided in Table I, parts A and B except as provided below. Where limitations in test lab capabilities prevent exposure to the specified levels, testing shall be conducted to the maximum capability of the test lab. Tests with this equipment shall be conducted to a minimum of 200 volts per meter (peak). Where discrete frequency testing can be performed at higher levels than the swept frequency levels, discrete frequency testing shall be performed in addition to swept frequency tests. (Note: In this case the specific frequencies, PWs, PRFs, and levels shall be coordinated with ATCOM Engineering, AMSAT-R-ESE).

(c) Equipment and subsystem criticality shall be as determined by the Electromagnetic Environmental Effects Requirements Board(s) for the aircraft that the equipment will be installed on.

(d) Safety of flight EMI test requirements. As a minimum, the following shall apply:

(i) All equipment and subsystems shall be tested to the requirements of CE101, CE102 and RE102 prior to flight.

(ii) All flight and safety critical equipment and subsystems shall be tested to the requirements of CS101, CS114, CS115, and RS103 prior to flight.

4.3 **Electromagnetic Compatibility (EMC) Verification.**

4.3.1 **Safety of Flight Test (SOFT)**. EMC safety of flight shall be assured for each aircraft. Prior to the first flight, an EMC SOFT shall be conducted on the aircraft. The EMC SOFT is an abbreviated test of the essential flight systems to demonstrate that EMI does not affect these equipment in any manner that would endanger the aircraft, the crew, or prevent accomplishment of flight test activities. This testing shall consist of ground and flight testing.

(a) Transmitters shall be transmitted on each frequency to be used during the test program.

(b) All flight critical and flight essential equipment and subsystems shall be tested as victims versus all equipment that will be operated during the flight test program, including all flight test instrumentation.

(c) Safety margins shall be established for all safety critical ordnance prior to their use.

(d) In-flight evaluation of all anomalies experienced during the ground portion of the testing as well as those equipment and subsystems that can not be fully tested on the ground.

4.3.2 **System Electromagnetic Compatibility**. An evaluation of the operational EMC of the aircraft shall be performed to verify the requirements of section 3.3 of this document. Proper interaction of subsystems will be established to preclude the false identification of multi-subsystem failures (i.e., when only one subsystem is susceptible and other subsystems are responding properly to the invalid command of the susceptible subsystem). Due to various aircraft designs, many or all of these tests may have to be conducted during simulated flight (i.e., ground run). All equipment will be operated as victim equipment in predetermined modes, while all other equipment are operated as sources. Outputs and displays of the victims will be monitored for possible malfunction or indications of degradation while being subjected to all EMI sources. All data will be logged by identification of the source and victim, measured levels of undesirable response, indications or malfunctions an the EMI frequency where applicable. When testing tunable transmitters and receivers, a minimum of twenty freqeuncies shall be used, evenly spaced across each operating band. Frequency hopping radios shall utilize a hopset(s) which covers the entire operating band. The following combinations will determine the EMI effects for the E^3 evaluation:

a. Ambient (background noise) measurement.

b. Cross Talk (circuit isolation).

c. Receiver to receiver.

d. Transmitter to receiver.

(1) Fundamental, harmonic, and spurious frequencies.

(2) Receiver spurious response.

(3) Intermodulation.

(4) Cross modulation.

e. Transmitter to active devices.

f. Transmitter to passive device.

g. Receiver to active device.

h. Receiver to passive device.

i. Receiver noise floor testing.

j. Active device to passive device.

k. Active device to receiver.

l. Electrical power system transients.

m. Electrical/electronic subsystems transients.

n. EED safety margin testing.

o. Flight evaluation.

4.4 **Electromagnetic Vulnerability (EMV) Evaluation**. An EMV evaluation shall be performed to determine the overall compatibility of aircraft electrical and electronic equipment and subsystems and associated GSE with the external electromagnetic environment. This evaluation is to verify the requirements of section 3.4 of this document The aircraft shall be exposed to the environment of Table I, parts A and B. (Note: When appropriate, and where swept frequency testing cannot be adequately performed due to test facility limitations, discrete frequency testing may be approved by ATCOM engineering, AMSAT-R-ESE. In this event, specific frequencies, PWs, and PRFs will be provided to the contractor. The minimum number of sample frequencies per band shall be as specified in Table I, part B). Aircraft equipment, including associated GSE, will be exercised solely and jointly as would occur during typical mission conditions. Specific evaluation phases shall include the following:

a. Pre-flight checks on external power.

b. Pre-flight checks on Auxiliary Power Unit (APU)

c. Pre-flight checks with engine operating.

d. Simulated launch, approach, and touch-and-go operations with engine operating.

e. Simulated aircraft mission scenarios.

4.5 **Electromagnetic Pulse (EMP) Tests**. The requirements of section 3.5 of this document shall be verified by test and analysis. Equipment tests will include EMP tests, per MIL-STD-462, to ensure the equipment will withstand EMP transients. These tests, together with safety margin analyses, define the maximum EMP signal permitted in cables in the aircraft, and therefore, evaluates the adequacy of EMP protection. Full aircraft testing shall be performed when adequate safety margins cannot be adequately evaluated or when the amount of coupling cannot be determined to a sufficient enough accuracy.

4.6 **Radiation Hazards.** The requirements of section 3.6 shall be verified by test and analysis.

4.6.1 **HERO Verification.** The HERO requirements of section 3.6.1 shall be verified by test.

4.6.2 **HERF Verification.** The requirements of section 3.6.2 of this document shall be verified by a combination of tests, analysis, and inspection.

4.6.3 **HERP Verification.** The requirements of section 3.6.3 of this document shall be verified by a combination of tests, analysis, and inspection.

4.7 **Static Electricity Verification.** The ability of the aircraft to meet the requirement of section 3.7 of this document shall be verified by test and analysis.

4.7.1 **Static Electricity Analysis.** A static electricity analysis will be conducted to determine maximum airframe charging rates for vertical and horizontal flight as well as hovering near the ground. The analysis will determine the adequacy of proposed design techniques to control P-static noise in avionics and prevent hazards to personnel during sling-load operations, maintenance, rearming, and refueling. The analysis shall specifically address conditions experienced by a hovering helicopter, near the ground level in dry dust, sand and snow conditions. An ESD analysis of all equipment shall verify that the equipment provides sufficient inherent protection so that any ESD sensitive components are not susceptible to damage or upset from ESD due to handling of the equipment by operating or maintenance personnel.

4.7.2 **Static Electricity Tests.** Static electricity tests shall be conducted to demonstrate the protection of personnel, equipment, fuel systems and ordnance from electrostatic build-up and discharge. Aircraft level tests shall be conducted on a fully configured aircraft; which means that all mission equipment, including complete provision items and applicable EEDs, are installed when these tests are performed.

4.7.2.1 **Aircraft Component Static Electricity Tests.** As a minimum, the following full-scale production subsystems and equipment shall be tested using simulated static electricity discharges: fuel subsystem components and weapons subsystem components. The maximum electrostatic discharge (ESD) level associated with a hovering helicopter is 300 kilovolts (kV) which is represented by a 1000 picofarad (pF) capacitance discharging into 1 ohm (maximum) resistance. The maximum ESD level associated with personnel is 25 kV which is represented by a 500 pF capacitance discharging into a 500 ohm resistance. Other subsystems and equipment shall be tested as required based on their criticality and likelihood of experiencing these discharges.

4.7.2.2 **Full-Scale Aircraft Tests.**

4.7.2.2.1 **P-Static Tests.** A P-static test will be performed by electrostatically charging the aircraft until corona develops. Avionics, fuel system, flight control and other equipment will be monitored for unintentional responses linked to P-static build-up and discharge. Charge/discharge currents will be measured. Receiver noise floors shall be monitored for degradation and the amount of degradation shall be quantified.

4.7.2.2.2 **P-Static Control Tests.** Testing shall be conducted to demonstrate the effectiveness of all P-static dissipation devices on the aircraft. Results shall be used to demonstrate that the aircraft does not attain voltage potentials which are hazardous to personnel for the expected charging conditions.

4.8 **Lightning Protection Verification.** The ability of the aircraft to meet the requirements of section 3.8 of this document shall be verified by analysis and test.

4.8.1 **Lightning Protection Analysis.** A Lightning Protection Analysis (LPA) of the air vehicle, its subsystems and equipment shall be made to determine potential lightning damage susceptibility. This analysis shall be performed early in the program to identify the potential lightning effects to the vehicle and to categorize them based upon the criticality of the lightning hazard and the zone or zones within which the subsystem is located. The potential effects of lightning (direct effects and indirect effects) shall be a part of the analysis. The analysis shall specify the portions of the air vehicle, its subsystems and equipment requiring protection consideration. In addition, this analysis shall address the following:

(a) The LPA shall partition aircraft surfaces for the purposes of lightning zone identification IAW with the zone definitions of section 2.1 of this document.

(b) The LPA shall identify the lightning environment for the above zones as well as for each aircraft subsystem and equipment for design and test. Section 2.1 of this document defines the lightning environment as well as guidance for application of the same to the respective zones, subsystems and equipment.

(c) The LPA shall identify flight/mission-critical/essential systems, subsystems, and equipment under the appropriate categories defined in section 2 of this aeronautical design standard.

(d) The LPA shall define prediction and analysis/test techniques to be used for assessing the safety and susceptibility of the aircraft and the associated subsystems, including as a minimum the structure, mechanical subsystems, fuel/hydraulic subsystems, electrical/electronic subsystems, personnel, and external stores/ordnance to the lightning environment.

(e) The LPA shall define the approach for direct-effects protection of the air vehicle. The materials, fabrication, and assembly techniques to be employed for protection shall be discussed. Protection verification methods to be used during the development and qualification phases shall be delineated such as risk reduction testing conducted on representative panels or coupons of the aircraft skin, joints, and structural members. Potential problem areas shall be addressed along with plans for their resolution.

(f) The LPA shall define the approach for protection of electrical and electronic subsystems against indirect effects of lightning. The LPA shall address the methods to be employed in integrating the lightning requirements with other E3 and air vehicle performance requirements as applicable; i.e., whether lightning protection provisions will adversely affect static discharge control, antenna patterns, aerodynamics, and/or other factors related to aircraft performance. Protection of newly designed and existing equipment shall be addressed along with the protection verification methods to be used during the development and qualification phases. Potential problem areas shall be discussed along with the plans for their resolution.

(g) The LPA shall address the cumulative effects of recurring strikes, potential problem areas, and plans for their resolution. The number of strikes to be tolerated beyond that required for flight safety depends upon life cycle considerations; e.g., subsystems and equipment which are likely to receive many lightning strikes during their lifetime should be designed to tolerate these effects.

(h) The LPA shall identify how the lightning-related electrical bonding requirements are to be met without unacceptably degrading the corrosion control measures. The plan shall especially address how these measures are to be integrated with the E3, personnel protection, electrical bonding, and corrosion control measures which apply to other than lightning-protection related designs.

(i) The LPA shall identify a comprehensive approach for analysis and testing to be performed during developmental phases. Test articles (e.g., breadboards, skin and joint coupons, prototype systems), facilities, instrumentation, and voltage and current waveforms to be used shall be described.

(j) The LPA shall identify all verification criteria that will be used to demonstrate that the air vehicle, subsystem, or component has satisfied lightning protection requirements. Criteria shall include discussions of design margins and pass/fail rationale.

(k) The LPA shall discuss life cycle aspects of the lightning protection design integrity such as repair, maintenance, integrity verification and inspection requirements. The following are some examples of life-cycle considerations:

(i) Whether the protection designs are accessible and maintainable or whether they are designed to survive the design lifetime of the air vehicle without mandatory maintenance or inspection. Identify bonding, shielding, or other protection devices which can be disconnected, unplugged, or otherwise deactivated during maintenance.

(ii) Whether protection design measures are repairable or replaceable without degradation of the initial level of protection.

(l) The LPA shall discuss manufacturing implementation of critical lightning protection designs, and control of changes. Change documentation shall be identified and its traceability discussed.

(m) The LPA shall discuss lightning protection measures implemented for redundant subsystems (e.g., flight and engine controls), especially in regard to flight safety.

(n) The LPA shall develop design margins for indirect effects IAW FAA/AC 20-136, especially for flight-critical electrical/electronic subsystems and equipment. A design margin is the difference between the voltage and/or current level at which a component begins to degrade in performance and the voltage and/or current level that is produced (induced/coupled) at the input of the component as a result of a 200,000 lightning strike to the air vehicle.

4.8.2 **Lightning Protection Tests.** Lightning protection verification tests shall be conducted. The simulated lightning voltage and current waveforms to be used are defined in section 2.1 of this document.

4.8.2.1 **Aircraft Component Tests.** As a minimum, the following full-scale production subsystems and equipment shall be tested using simulated lightning discharges: rotor blades, fuel subsystem components, and weapons subsystem components. Injection tests for cables and/or pins shall be included for mission- and flight-critical subsystems and equipment to address susceptibility due to lightning-induced pulse interference. This test is normally a part of MIL-STD-462 testing. Systems shall be operating during the event.

4.8.2.2 **Full-Scale Aircraft Tests.** The following tests demonstrate, at the aircraft level, that the aircraft will survive the direct and indirect effects of a severe lightning strike and that arcing and sparking occurring during these events will be at acceptable levels for flightcrew, fuel system, ordnance, other external stores, and mission- and flight-critical equipment (Note: These tests are generally conducted by the Government at a Government test facility. The contractor provides assistance to the Government in the form of test planning, procedure, and reports. The contractor provides appropriate engineering consultation to the Government to resolve anomalies observed during the testing). These tests are performed on a completely provisioned aircraft.

4.8.2.2.1 **Streamering Test.** Exterior of the aircraft shall be subjected to an electric field. Arcing and sparking across skin panel joints and other discontinuities in the airframe are systematically observed to ensure that the resultant phenomena are compatible with the safety of the aircraft in general, and in particular pose no hazard to the crew, fuel system, ordnance, and flight critical equipment.

4.8.2.2.2 **Induced Effects Test.** Aircraft shall be subjected to a transient test through the application of high-level artificial lightning currents to selected attachment points on the exterior of the aircraft while resulting responses are monitored on interior wiring. These points shall have been previously identified during the analysis. The effects of the artificial lightning strikes are generally observed through instrumentation. (Note: To minimize risk of damage to aircraft or test personnel, the test should be conducted in incremental steps, starting with a minimum discernible current level until the maximum applied threat level is attained). Paragraph 4.2.3 of Report of SAE Committee AE4L, Lightning Test Waveform and Techniques for Aerospace Vehicles and Hardware, 20 Jun 78, and SAE Report No. AE4L-87-3 shall be used as guides.

4.9 **Electrical Power Verification.** The electrical power requirements of section 3.9 of this document shall be verified by test and analysis. This shall include tests of the generating system to verify that it is producing the required power, tests of all utilizing subsystems and equipment to verify that they meet their performance requirements when subjected to all allowed ranges of power, and aircraft level tests to verify the complete integration meets all performance requirements with all normal and emergency modes of power.

4.10 **Bonding.** Bonding measurements shall be performed in order to verify the requirements of section 3.10 of this document. The following areas will be measured:

(a) Avionics bay shelves to airframe (or ground plane).

(1) Shelf to rack.

(2) Rack to equipment.

(b) Racks/consoles to airframe (or ground plane).

Console to control box/instrument, etc.

(c) Instrument panel to airframe (or ground plane).

(d) Antenna mount to airframe (or ground plane).

APPENDIX A - Electromagnetic Environmental Effects Integration and Analysis Report (E3IAR)

A1.0 **Content.** The E3IAR Describes the contractor/developing activity's understanding of the E3 requirements for the aircraft and the engineering translation of these requirements into the aircraft hardware and software. The report describes the contractor's overall E3 interface and performance requirements as they apply to the aircraft systems and subsystems being developed and integrated. The report requires two levels of detail. The first is a top-level or summary overview of the aircraft's E3 requirements and the technical approach being taken. The specific information required is described in section 2.1, below. The second level is the detailed design, analysis, trade studies and other pertinent information for the individual requirements. The specific information required is described in section 2.2 below.

A2.0. **General Instructions.** The E3IAR format is contractor selected. The information provided below is to allow a logical description of the information required and is not to restrict the contractor format.

A2.1. **Summary Overview.** This portion of the report shall be provided prior to a contractual milestone such as the preliminary design review. It provides a general understanding of the contractor's E3 program and how it relates to the overall performance requirements of the aircraft. The following information shall be included:

A2.1.1 **Introduction and Background.**

(a) Provide a summary of personnel and lines of authority of those involved in the E3 program including the extent of their participation in critical design processes.

(b) Discuss any limitations, assumptions or other non-E3 related information that impacts the E3 program.

(c) Provide overall program scheduling.

A2.1.2 **Summary of E3 Requirements.**

(a) Provide an overview of the contractor's understanding of all of the E3 requirements and how they relate to the overall aircraft performance requirements.

(b) Provide an overview of the contractor's overall design approach to meeting these requirements. Including any tradeoffs that are expected to be made.

(c) Provide an overview of the means for verifying these requirements are met.

(d) Provide a summary of all analysis, predictions, studies, investigative tests, and evaluations that have been or will be accomplished.

A2.1.3 **Results, Conclusions and Recommendations.**

(a) Provide a summary of the impacts of results from the above efforts as they pertain to the ability of the aircraft to meet its E3 and overall performance requirements.

(b) Provide a summary of any conclusions that are relevant to the ability of the aircraft and its E3 and overall performance requirements.

(c) State any important aircraft level recommendations which have an impact on the overall integration of the E3 interface and performance requirements with the overall performance requirements of the aircraft.

A2.2 **Detailed Review.** This portion of the report should typically be provided prior to a contractual milestone such as the critical design review. It provides a detailed understanding of the contractor's E3 program and how it relates to the overall performance requirements of the aircraft. This portion of the report should be updated periodically as new information is available and tests are completed. The report should typically be updated at least once per year. The following information should be included.

A2.2.1 **Introduction and Background.**

(a) Provide a summary of personnel and lines of authority of those involved in the E3 program.

(b) Discuss any limitations, assumptions or other non-E3 related information that impacts the E3 program.

(c) Provide program scheduling to show all major testing and other significant milestones of the contractor's E3 program and where they fit with the overall aircraft schedule.

A2.2.2 **Detailed Information.** The contractor shall provide detailed information pertaining to each E3 requirement including all relevant design, analysis, investigation, trade study, testing and evaluations. Specifically, the results of the analysis required in paragraph 4.1 of this document and the following shall be addressed:

(a) Methods of implementation of design changes required to meet E3 requirements.

(b) Methods for monitoring non-E3 design changes to ensure there are no E3 impacts.

(c) Facilities that will be required and made available for the E3 program.

(d) Methods for accomplishing design review and coordination with subcontractors and venders.

A2.2.3 **Results, Conclusions and Recommendations.**

(a) Provide a summary of all tests results to date.

(b) Provide a summary of the impacts of results from the above efforts as they pertain to the ability of the aircraft to meet its E3 and overall performance requirements.

(c) Provide a summary of any conclusions that are relevant to the ability of the aircraft and its E3 and overall performance requirements.

(d) State any important aircraft level recommendations which have an impact on the overall integration of the E3 interface and performance requirements with the overall performance requirements of the aircraft.