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Superseding AIR5060

(R) Electronic Engine Control Design Guide for Electromagnetic Environmental Effects

RATIONALE

This document is being updated to incorporate policy and guidance changes made in the last 5 years in the area of Electromagnetic and Lightning environments.

FOREWORD

This SAE Aerospace Information Report (AIR) provides information and guidance on the nature of, protection against and compliance with requirements relating to the effects of the electromagnetic environment upon electronic aircraft engine control systems. It is intended for use by the engineer who is responsible for specifying or designing equipment to function within the environment, but whose knowledge of the subject may be superficial. It is intended to allow the reader to progress to the technical depth necessary to accomplish the specification or design task, and provides references for those desiring detail beyond that provided herein.

This material is advisory in nature; it is not mandatory. Methods for compliance (FAA or Military) are discussed. However, applications for Government agency approval may elect to demonstrate compliance through alternative methods found acceptable to the appropriate agencies.

Due to continual technological advancements and the evolving nature of Standards and Specifications, it is acknowledged that some material may be outdated at the time of publication.

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1. SCOPE

The purpose of this document is to provide reference material for establishing compatibility of electronic gas turbine engine control systems and associated components with the electromagnetic environment and achieving compliance with associated airworthiness requirements.

1.1 Introduction

The modern gas turbine engine used for aircraft propulsion is equipped with an ever increasing variety of electrical and electronic systems which provide for engine control, instrumentation, and auxiliary functions.

Today's aircraft engines currently in service or in development employ full authority digital engine control (FADEC) systems. The criticality of the electronics employed in these systems, with regard to continued safe operation of the aircraft, has led to a greater emphasis on ensuring that the equipment is immune to both natural and man-made electromagnetic environments.

Some engine control systems employ electronics in a less than full authority role in the form of "supervisory" or "trimming" controls or limiters. Such systems are still required to be compatible with the electromagnetic environment although the allowable effects on the system and the pass/fail criteria for system testing may differ.

In addition to the control system itself, typical aircraft gas turbine equipment includes many other electronic or electrical devices; these include solenoid operated valves to control anti-icing or environmental air supplies, position indicating and pressure operated switches, ignition systems, permanent magnet alternators, etc. Many engines are also equipped with engine monitoring systems or data concentrator units which provide a digital data bus interface to other aircraft electronic systems.

Signal control and power levels range from a small fraction of a milliwatt to several hundred thousand watts during ignition discharges. Acquiring, understanding, and efficiently applying the assortment of specifications, both civil and military, can be a daunting prospect for the engine component supplier or the equipment designer. Arbitrarily applying stringent Electromagnetic Compatibility (EMC) requirements to individual components and subsystems may result in unnecessary size, cost, and weight penalties.

The Project Engineer or Engineering Manager is frequently called upon to make decisions and judgments for which some basic knowledge of electromagnetic environmental effects and associated design, test, and certification compliance is essential.

This document aims to be a central source of information, providing reference and guidance material into each electromagnetic phenomenon. The electromagnetic environment is divided into its main constituents, these being:

a. Electromagnetic Interference (EMI), including High Intensity Radiated Fields (HIRF)

b. Lightning

c. Electromagnetic Pulse (EMP)

Within each chapter, the topic is broken down further into the following main sections:

a. Introduction

b. Description of the Environment

c. Certification/Qualification Requirements

d. Design Considerations

e. Compliance Methods

A bibliography is provided for those seeking a more detailed treatment of any given topic, and references are made to any appropriate industry specification where applicable.

Electromagnetic Compatibility is essentially an air vehicle issue; for a subsystem, such as the engine control, compatibility must be established with other equipment in the aircraft but it is the complete air vehicle which is exposed to, and must be certified/qualified for, the external HIRF or Lightning/EMP threat. A definition of requirements at the subsystem level is required in order to design and test the equipment, prior to the availability of the full-up aircraft, and/or to substitute for full-up aircraft testing. Testing and analysis at the subsystem level is also required in order to achieve engine certification (FAR Part 33) or qualification. However the subsystem levels are dependent upon other equipment electrically connected to the engine, cable routing and shielding, and the effectiveness of the aircraft structure as an electromagnetic shield.

2. REFERENCES

2.1 Referenced Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of the other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

ARP5107 Guidelines for Time-Limited-Dispatch Analysis for Electronic Engine. Control Systems

ARP5412 Aircraft Lightning Environment and Related Test Waveforms

ARP5414 Aircraft Lightning Zoning

ARP5415 User's Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning

ARP5416 Aircraft Lightning Test Methods

ARP5583 Guide to Certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment

2.1.2 EASA Publications

Available from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany, Tel: +49-221-8999-000, www.easa.eu.int.

EASA Interim Policy INT/POL/25/2 and INT/POL/25/4

2.1.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

FAA AC20-136A Protection of Aircraft Electrical/Electronic Systems against the Indirect Effects of Lightning.

FAA AC 20-53A Protection of Airplane Fuel Systems against Fuel Vapor Ignition Due to Lightning, June 5, 2006.

FAA AC 33.28-1 Compliance Criteria for 14 CFR 33.28, Aircraft Engines, Electrical and Electronic Engine Control Systems

FAA AC 33.28-2 Guidance Material for 14 CFR 33.28, Reciprocating Engines, Electrical and Electronic Engine Control Systems", FAA AC 33.28-2, August 13, 2003.

FAA AC 33.4-3 Instructions for Continued Airworthiness, Aircraft Engine High Intensity Radiated Fields (HIRF) and Lightning Protection Features-September 16,2005

FAA AC 20-155 Aircraft Lightning Protection Certification-April 28, 2008.

FAA AC 21-16 RTCA, Inc Document RTCA/DO-160-Environmental Conditions and Test Procedures for Airborne Equipment, December, 20, 2005.

FAA AC 20-158 The Certification of Aircraft Electrical and Electronic System for Operation in the High-Intensity Radiated Field (HIRF) Environment, July 30, 2007.

2.1.4 RTCA Publications

Available from Radio Technical Commission for Aeronautics Inc., 1828 L Street, NW, Suite 805, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA/DO-160E, Section 22 Environmental Conditions and Test Procedures for Airborne Equipment, Lightning Induced Transient Susceptibility

RTCA/DO-160ED14 Environmental Conditions and Test Procedures for Airborne Equipment

2.1.5 U. S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-9495, https://assist.daps.dla.mil/quicksearch/.

MIL-C-38999/27 Connector, Electrical, Circular, Miniature, High Density, Quick Disconnect, "Bayonet, Threaded, and Breech Coupling", Environment, Removable Crimp and Hermetic Solder Contacts, General Specification for

MIL-HBK-217F Military Handbook, Reliability Prediction of Electronic Equip

MIL-HBK-237 Electromagnetic Compatibility Management, Guide for Platforms, Systems and Equipment

MIL-HBK-253 Guidance for the Design and Test of Systems Protected Against the Effects of Electromagnetic Energy

MIL-STD-202 Test Method Standard, Electronic and Electrical Component Parts

MIL-STD-461F Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment

MIL-STD-464A DoD Interface Standard, Electromagnetic Environmental Effects Requirements for Systems

MIL-STD-704E Aircraft Electrical Power Characteristics

MIL-STD-810 Military Standard Environmental Test Methods and Engineering Guidelines

MIL-STD-882 Systems Safety Program for Systems and Associated Subsystems and Equipment, Requirements for

MIL-STD-1310 Shipboard Bonding, Grounding and Other Techniques for Electromagnetic Interference and Safety

MIL-STD-1377 (NAVY); Effectiveness of Cable, Connector and Weapon Enclosure Shielding and Filters in Precluding Hazards of Electromagnetic Radiation to Ordnance, Measurement of

2.1.6 Other Publications

F. A. Fisher, J. A. Plumer, R. A. Perala, "Aircraft Lightning Protection Handbook Report No. DOT/FAA/CT-89/22", FAA Technical Center, Atlantic City International Airport, NJ 08405, September 1989

M. Dargi, E. Rupke, K. Wiles, "Design of Lightning Protection for a Full-authority Digital Engine Control", International Aerospace and Ground Conference on Lightning and Static Electricity, 16-19 April 1991.

M. Dargi,, E. Rupke, K. Wiles, "Certification of Lightning Protection for a Full-authority Digital Engine Control" (ibid).

"Protection of Aircraft Electrical/Electronic Systems against the Indirect Effect of Lightning",- AC 20-136A

Compliance Criteria for 14 CFR 33.28, Aircraft Engines, Electrical/Electronic Engine Control Systems"-, AC 33.28

"Lightning Protection of Aircraft", F. A. Fischer, R. A. Plumer, R. A. Perala, December 2004

The Certification of Aircraft Electrical and Electronic System for Operation in the High-Intensity Radiated Field (HIRF) Environment- AC 20-158

Ghose, Dr Rabindra N., EMP Environment and System Hardness Design, Don White Consultants, Inc.

BDM, "EMP Assessment Handbook", AFWL-TR-78-60.

Aeronautical Design Standard, ADS-37A-PRF, "Electromagnetic Environmental Effects (E^3) Performance and Verification Requirements", U.S. Army, 28 May 1996.

Certification of Aircraft Propulsion Systems Equipment with Electronic Control Systems-AC20-1

RAE, RAE Defense Standard 59-41

National Telecommunications and Information Administration (NTIA) Manual of Regulations and Procedures for Federal Radio Frequency Management, "Radar Spectrum Engineering Criteria (RSEC)

2.2 Bibliography

The following Standards, Handbooks, Guides, etc. may be consulted for further guidance in specifying tests, test levels, and control practices for achieving electromagnetic compatibility.

a. "Electromagnetic Compatibility Principles and Practices", National Aeronautics and Space Administration, Washington, D.C.; N66-16595 (NHB 5320.3).

b. "Design Handbook Series 1-0, AFSC DH 1-4, Electromagnetic Compatibility", Third Edition; 5 January 1975; Department of the Air Force, Headquarters, Aeronautical Systems Division (AFSC), Wright-Patterson Air Force Base, Ohio 45433.

c. "Interference Reduction Guide for Design Engineers", Volume 1; U.S. Army Electronics Laboratories, Fort Monmouth, New Jersey.

d. "Interference Reduction Guide for Design Engineers", Volume 2; U.S. Army Electronics Laboratories, Fort Monmouth, New Jersey.

e. "Prediction of Coupling, Shielding, and Grounds for Low Frequency Fields"; NUSC Report No. 4051; Naval Underwater Systems Center, Newport, Rhode Island 02840.

f. "Electromagnetic Compatibility Design Guide for Avionics and Related Ground Support Equipment"; Navair AD1115.

g. SAE AIR1425, "Methods of Achieving Electromagnetic Compatibility on Gas Turbine Engines for Self-Propelled Land Vehicles".

h. SAE ARP1481A Corrosion Control and Electrical Conductivity in Enclosure Design

j. SAE ARP1870 .Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety.

k. SAE ARP5414 “Aircraft Zoning”

l. SAE ARP5416 “Aircraft Lightning Test Methods

m. SAE ARP5577 “Aircraft Direct Effects Certification”.

n. SAE ARP5583 “Guide to Certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment”.

o. National Institute of Standards and Technology (NIST)

2.3 Abbreviations and Acronyms

AC	Alternating Current or Advisory Circular
A/C	Aircraft
ACARS	Communications Addressing and Reporting System
ACT	Active Control Technology
ADC	Air Data Computer
AF	Audio Frequency
ADF	Automatic Direction Finder
AFCS	Automatic Flight Control System
AMJ	Advisory Material Joint
AMC	Acceptable Means of Compliance
APU	Auxiliary Power Unit
ARINC	Aeronautical Radio Inc.
ASW	Anti-Submarine Warfare
ATL	Actual Transient Level
BB	Broadband
BCI	Bulk Cable Injection
BITE	Built-In Test Equipment
BW	Bandwidth
CDU	Control Display Unit
CE	Conducted Emission
CCF	Carbon Composite Fiber

CLB	Closed Loop Bench
CM	Common Mode
CRT	Cathode Ray Tube
CS	Conducted Susceptibility
DB	Decibels
DC	Direct Current
DFDAU	Digital Flight Data Acquisition Unit
DFDR	Digital Flight Data Recorder
DITS	Digital Information Transfer System
DM	Differential Mode
DME	Distance Measuring Equipment
DMV	Dielectric Withstanding Voltage
DoD	Department of Defense
E3	Electromagnetic Environmental Effects
EADI	Electronic Attitude Director Indicator
EASA	European Aviation Safety Agency
ECS	Environmental Control System
E/E	Electrical/Electronic
EEC	Electronic Engine Control
EED	Electro-Explosive Device
EEHWG	Electromagnetic Effects Harmonization Working Group
E-FIELD	Electric Field
EFIS	Electronic Flight Instrument System
EGT	Exhaust Gas Temperature
EHSI	Electronic Horizontal Situation Indicator
EICAS	Engine Indication and Crew Alerting System
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EME	Electromagnetic Environment

EMI	Electromagnetic Interference
EMIC	Electromagnetic Interference/Compatibility
EMICP	Electromagnetic Interference Control Procedures
EMITP	Electromagnetic Interference Test Procedures
EMITR	Electromagnetic Interference Test Report
EMP	Electromagnetic Pulse
EMV	Electromagnetic Vulnerability
EPR	Engine Pressure Ratio
ESD	Electrostatic Discharge
ESE	Electric (field) Shield Effectiveness
ETDL	Equipment Transient Design Level
EUROCAE	European Organization for Civil Aviation Electronics
EUT	Equipment Under Test
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FAR	Federal Aviation Regulation
FCC	Flight Control Computer
FCC	Federal Communication Commission
FDEP	Flight Data Entry Panel
FMC	Flight Management Computer
Gr/Ep	Graphite/Epoxy
GPS	Global Positioning System
H-Field	Magnetic Field
HIRF	High Intensity Radiated Field
HMC	Hydromechanical
Hz	Hertz (oscillations per second)
IEEE	Institute of Electrical & Electronic Engineers
IEMP	Internal EMP
IF	Intermediate Frequency

JAR	Joint Aviation Regulation
JSC	Joint Spectrum Center
KHz	Kilohertz (10^3 Hz)
LISN	Line Impedance Stabilization Network
LLC	Low Level Coupling
LRU	Line Replaceable Unit
MHz	Megahertz (10^6 Hz)
NIST	National Institute of Standards and Technology
NPA	Notice of Proposed Amendment
NPRM	Notice of Proposed Rulemaking
OATS	Open Area Test Site
PEDS	Portable Electronic Devices
PMA	Permanent Magnetic Alternator
PRF	Pulse Repetition Frequency
RAE	Royal Air Force Establishment
RE	Radiated Emissions
RF	Radio Frequency
RFM	Radio Frequency Modulation
RMS	Root Mean Square
RS	Radiated Susceptibility
RTCA	Radio Technical Commission for Aeronautics
SCD	Source Control Drawing
SGEMP	Space Generated EMP
SIL	Systems Integration Laboratory
STC	Supplemental Type Certificate
TCL	Transient Control Level
TD	Type Design
TLA	Throttle Lever Angle
TLD	Time Limited Dispatch

TRA Throttle Resolver Angle

TSO Technical Standard Order

TVS Transient Voltage Suppressor

TWT Traveling Wave Tube

2.4 Glossary

ABSORPTION LOSS: Attenuation or retention of electromagnetic energy passing through a material, a shield. Absorption loss and reflection loss contribute to total shielding effectiveness (SE).

AC NOISE IMMUNITY: The relative immunity of a device to noise pulses. As pulse width increases, AC noise immunity approaches the DC Noise margin. As the pulse width is reduced toward the propagation delay time, the circuits become less able to respond and a larger noise voltage is required. See Noise-Energy Immunity; DC Noise Margin.

ANODIZE: A preparation by electrolytic process that deposits a protective oxide, insulating film on a metallic surface (aluminum). The oxide defeats electrical bonding. Alodine and iridite finishes on aluminum are conductive.

APERTURE: An opening, such as a nonconductive panel joint, slot or crack, allowing electromagnetic energy to pass through a shield.

ATTENUATION: Attenuation is the general term used to denote a decrease in magnitude in transmission from one point to another. It may be expressed as a ratio or by extension of the term in decibels.

ALS: Advanced Low Power Schottky Logic

AS: Advanced Schottky Logic

AUDIO FREQUENCY (AF): The spectrum (20 to 20,000 Hz) of human hearing, often defined as extending from approximately 20 Hz to 50 KHz and sometimes to 150 KHz. Audio noise is nuisance hum, static, or tones from powerline 400 Hz, switching regulator and digital clock harmonics, or HF, VHF transmitter frequencies.

B-Field: See Magnetic Flux Density

BACKSHELL: Metal shell connecting circuit shields or overbraid to an electrical connector.

BALANCED CIRCUIT: A signal, acting line to line, between two conductors having symmetrical voltages identical and equal in relation to other circuits and to ground, "Differential mode" is line to line; "common mode" is line to ground.

BANDPASS FILTER: A bandpass filter is a wave filter which has a single transmission band, neither of the cutoff frequencies being zero or infinite.

BANDWIDTH (BW): Frequencies bounded by an upper and lower limit in a given band associated with electronic devices, filters, and receivers.

BONDED: Electrically connected by means of welding, brazing, compressing or other mechanical means not likely to be affected by heat or corrosion and which will give a good low-impedance (example <0.1 ohm) electrical path.

BONDING: Electrically connecting two mechanical parts together such that the voltage potential across is very small (millivolts).

BRAID, OVERBRAID: Fine metallic conductors woven to form a flexible conduit or cableway and installed around insulated wires to provide protection against electric fields and radio frequencies. Best when peripherally connected to backshells. A grounding strap/jumper may be made of braid.

BROADBAND EMISSIONS: Term used to describe emissions which have a bandwidth greater than some reference bandwidth. The reference bandwidth may be that of a victim receptor or that of an EMI measurement receiver.

CABLE OR HARNESS: A bundle of separate, insulated, electrical circuits, shielded or unshielded, usually long and flexible and having breakouts, terminations, overbraid, and mounting provisions completely assembled.

CABLEWAY: A solid metallic housing (liner, foil, and coating) surrounding and shielding insulated electrical conductors. Also called conduit, tray, or raceway. Crosswise or transverse openings or breaks in the metallic cableway cause noise voltages to be transferred to internal wire circuits.

CHARACTERISTIC IMPEDANCE: (Assuming Transverse Electromagnetic Wave) The ratio of the root mean square voltage to the current flowing from the source when the conductor they appear on is terminated in the impedance which results in minimum standing wave ratio on the line. Used in transmission line discipline.

CIRCULAR MILS (ABBR. CIR MIL): The diameter of a cylinder squared. 1 mil = .001 in. When multiplied by Pi/4 (or $\pi/4$), equals the area of the circle in square mils.

COMMON IMPEDANCE COUPLING: The means by which two or more circuits sharing common impedance share a common voltage drop across the impedance, thereby coupling it to the secondary source(s). Conducted interference.

COMMON MODE (CM) IMPEDANCE: Impedance or resistance shared by two or more circuits so that noise voltages/currents generated by one are impressed on the others.

COMMON MODE REJECTION: The ability of wiring or an electronic device to reject common mode (line-to-ground) signals and maintain fidelity of differential mode (line-to-line) signals.

COMMON MODE SIGNAL: Identical and equal signals on input conductors or at the terminals of a device relative to ground.

CONDUCTED EMISSION (CE) OR INTERFERENCE: voltage/current noise signals entering or leaving a unit on interface conductors - emission is the general term, interference is undesired noise.

CONDUCTED SUSCEPTIBILITY: The response of a system to the presence of noise on the power and signal lines or cables. The noise can be either line-to-line (differential mode) or line-to-ground (common mode).

CROSSTALK: The interference energy transferred from a source to an unintentional load by conductive, inductive or capacitive coupling. Usually of concern when source and susceptor are less than 1/6 wavelength apart. Referred to as Near End or Far End Crosstalk depending on relation of where it is measured, with respect to the source.

CULPRIT: Signal or circuit that is the source of interference.

COUPLING: The transfer of energy between wires or components of a circuit electrostatically, electromagnetically, or directly.

CROSS COUPLING (CROSSTALK): Transfer of signals from one channel, circuit, or conductor to another as an undesired or nuisance signal or the resulting noise.

DAMAGE: The irreversible failure of a component.

DECIBEL (dB): Decibel expresses the ratio between two amounts of power, P1 and P2, at two separate points in a circuit. By definition, the number of dB = 10 log to the base 10 of (P1/P2). For special cases, when a standard power level P2 = 1 mW or 1 W or 1 kW, then the ratio is defined as "dBm," dBw," or "dBkW." Moreover, because $P = V^2/R$ and also $I^{2*}R$, decibels express voltage and current ratios. Ideally, the voltages and currents are measured at two points having identical impedances. By definition, dB = 20 log V1/V2 and dB = log I1/I2. For convenience, V2 or I2 are often chosen as 1 microvolt or 1 microamp and the ratio is defined as dB above a uV or dB above a uA when graphing emission or susceptibility limits.

DC NOISE MARGIN: The difference between the maximum input voltage [VIL (max)] that will still be interpreted as a "0" and the maximum output voltage that can be provided by the source in the "0" state [VOL (max)]. Referred to as the low-level signal line noise margin, VOL (min) = VIL (max) - VOL (max).

DECOUPLING: Filtering, the removing of the coupling effect usually referring to conductive coupling. Decoupling capacitors are used on the power supply to isolate the effects of the load on the distribution system or vice-versa (also Bypass Capacitor).

DIELECTRIC: A material capable of passing electric lines of force but is not conductive.

DIELECTRIC STRENGTH: Voltage withstand capability that an insulating material sustains before destructive arcing and current flow, usually ,in cases such as the PC board conducting layers or conformal coating, it is expressed as volts per mil. For assemblies such as a sensor or actuator it is an overall maximum voltage withstand level. Dielectric withstand voltage is the voltage level at which insulation breakdown occurs.

DIFFERENTIAL MODE (DM) SIGNAL: The signal in a two wire circuit measured from line to line.

DUAL GROUND: Equipment case ground/return through two independent circuit paths to structure implemented in flammable zones and water leakage areas - each path meeting electrical conductivity (resistance) requirements

DUAL IN-LINE PACKAGE (DIP): A pin configuration, common on integrated circuits, where the pins are aligned in two parallel and opposing rows.

EARTH: With respect to charge, the earth is considered an infinite sink, and therefore, the lowest possible zero potential reference.

ELECTRIC FIELD: High-impedance, radiated voltage field, positive or negative, from a voltage source as contrasted to a low-impedance magnetic field from a current source.

ELECTROMAGNETIC COMPATIBILITY (EMC): The capability of electronic equipment to be operated as designed in the intended operational electromagnetic environment.

ELECTROMAGNETIC INTERFERENCE (EMI): Degradation of the electromagnetic environment by an unwanted disturbance.

ELECTROSTATIC DISCHARGE (ESD): Arc discharge across an air gap caused by the electric potential across the gap exceeding the dielectric breakdown voltage of air in the gap.

EMITTER: Source of electromagnetic signal.

FAR FIELD RADIATION: Electromagnetic radiation that occurs at a distance greater than approximately 1/6 wavelength from the source of interference. At these distances the electromagnetic field decreases at a rate inversely proportional to the distance from the source and the ratio of E-Field to H-Field = 377 ohms in free space.

FAULT CURRENT: The maximum current (magnitude and duration) flowing through a fault point - equal to the supply voltage divided by the DC resistance of powerline leads, circuit breakers, and the current return in wire or structure.

FILTERING: Device or unit that passes or rejects a frequency band and designed to block noise from entering or leaving a circuit or unit.

GROUND: (1) Voltage reference which is eventually related back to the potential of the earth. Because of path resistance, usually not at earth potential. Ground is usually of "local" value such that all grounded equipment in immediate area is the "same" potential, irrespective of earth. (2) Low impedance return path for signal or power currents. Deprecated version of "Return". (3) Electron source or sink for the dissipation of electrostatic discharge (ESD) currents.

GROUND PLANE: An equipotential voltage reference to which electronic units are referenced so that the voltage potential between interconnected units is less than or equal to an acceptable noise level.

IMMUNITY: Capability of a circuit or unit to operate within performance specification in a specified electromagnetic interference environment.

INDUCTIVE COUPLING: The detrimental effect which one circuit or subsystem has on another by means of the mutual inductance that exists between them. The amount of coupling is a function of the frequency, the loop area of the systems, and the length and proximity of parallel interacting wiring runs.

ISOLATION: Electrical separation and insulation of circuits from ground and other circuits or arrangement of parts to provide protection and prevention of uncontrolled electrical contact.

JUMPER/STRAP: A short wire, strip, strap, or braid conductor installed to make a safety ground connection, to dissipate electrostatic charge, or establish continuity around a break in a circuit.

LIMITING: VOLTAGE/CURRENT: Semiconductor components, diodes, avalanche devices, or filters designed to clip and shunt to ground an applied transient or steady-state voltage. Used to protect against noise frequencies, faults, lightning, and inductive switching transients.

LOOP: The current caused by a difference in voltage between two points. Occurs only when there are two or more paths between the two points.

LOW FREQUENCY: Those frequencies whose wavelength is 16 times greater than the largest circuit dimension (rule of thumb) .Also 0 to 10 KHz. (Use whichever is smaller.)

MAGNETIC FIELD: A radiated, low-impedance field having lines of "flux" or magnetomotive force associated with an electrical current.

MAGNETIC FLUX DENSITY: The field intensity integrated over the area in question.

MATCHED TRANSMISSION LINE: A transmission line is said to be matched at any transverse section if there is no wave reflection at that section (i.e., the line impedance equals the load impedance).

MULTILAYER: Referring to a printed circuit board which is constructed by laminating two or more layers of etched conductor and substrate together, and connecting layers by plated holes. The conductive layers have dedicated functions such as power, ground, signals laid out in the "X" or "Y" direction, or shield.

MULTISTACKED: Multistacked PCB's are complete double - or single-sided PCB's which are riveted together through holes intended to conduct current. Rivets replace plated through-holes and hold board layers together. These boards may be repaired (where multilayer cannot) by removing the rivets. Not used very often in commercial electronics.

MULTIWIRE (TM): A PCB fabrication technique where power and ground are etched on a single - or double-sided PCB, then coated with adhesive; wire is laid onto the adhesive using a computer numerical controlled wiring machine. The holes are then drilled and plated to make connection to the wires. Multiwire can achieve higher density than multilayer boards and it is simple to make changes. It is relatively expensive and not usually economical for production applications.

NEAR FIELD RADIATION: Electromagnetic radiation that occurs at a distance less than approximately 1/6 wavelength from the source of interference. Electric fields (E-Fields) in the near field attenuate inversely proportional to the cube of the distance for high-impedance sources and $1/r^2$ for low-impedance sources. Near field magnetic (H-Fields) attenuate as the inverse square of the distance from the source for high impedance sources and $1/r^3$ for low-impedance sources.

NOISE: Conducted or radiated emission causing circuit upset, performance disorder, or undesired sound.

NOISE ENERGY IMMUNITY: EN, equals the noise voltage required to cause a circuit to malfunction squared $(Vn)^2$, times the noise pulse-width (PW), divided by the parallel equivalent of the input under evaluation and the impedance of the wiring and circuit connected to it (Ro). $EN = (Vn)^2/Rox(PW)$. Not usually applied to power and ground leads.

NOISE IMMUNITY: See AC Noise Immunity, also Noise-Energy Immunity.

NOISE MARGIN: See DC Noise Margin, also AC Noise Immunity.

PCB: Printed Circuit Board. A substrate with conductors etched out of a conductor bonded to it, used to support and interconnect circuit components. May also refer loosely to multiwire and wire wrap boards.

PICKUP: Interference from a nearby circuit or system. Also crosstalk.

PRECIPITATION STATIC (P-STATIC): Electrostatic discharge, corona, arcing, and streamering, steady state or impulsive, which may cause circuit upset, receiver noise or component damage.

PROPAGATION DELAY: The delay in moving a signal from Point A to Point B through a medium or circuit. The delay is caused by the energy storing characteristics of the medium (such as capacitance or inductance) that need to be satisfied before the next increment of medium in the path can be excited. Each increment requires a finite delay.

RADIATED EMISSION (RE): Electromagnetic energy transmitted and propagated in space usually considered as audio frequency or radio frequency noise.

RADIO FREQUENCY (RF): Frequencies in the electromagnetic spectrum used for radio communications extending from kilohertz to gigahertz.

RADIO FREQUENCY INTERFERENCE (RFI): Electromagnetic interference in the radio frequency range.

RADIATED SUSCEPTIBILITY: The response of a system to the presence of electromagnetic waves.

RECEPTOR: Signal or circuit which responds to electromagnetic noise.

RETURN: The low impedance conductor(s) used to direct current from the load back to the source. Does not have to be ground or earth potential (i.e., balanced line). See Earth, Ground.

SCHOTTKY LOGIC: Logic circuits whose transistors have a metal-semi-conductor diode built in between the collector and base. This diode prevents the transistor from saturating, thereby greatly increasing its switching speed.

SEALANT: An applied substance enclosing and protecting the integrity of a joint, fastener, or electrical bond from moisture, contaminants, oxidation, and acid or alkaline corrosion.

SHIELD: A conductive material, opaque to electromagnetic energy, for confining or repelling electromagnetic fields. A structure, skin panel, case, cover, liner, foil, coating, braid, or cableway that reduces electric and magnetic fields into or out of circuits or prevents accidental contact with hazardous voltage.

SHIELDING: Reducing EMI by interposing a conductive or absorptive and/or reflective medium (shield) between a noise and a receptor.

SHIELD EFFECTIVENESS (SE): The ability of a shield to reject electromagnetic fields. A measure of attenuation in field strength at a point in space caused by the insertion of a shield between the source and the point.

SIGNAL RETURN: A wire conductor between a load and the signal or driving source. Structure can be a signal and power return. Commonly, it is the low voltage side of the closed loop energy transfer circuit.

SINGLE-ENDED CIRCUIT: A circuit with source and load ends grounded to case and structure and using structure as return.

SKIN DEPTH: The distance from a conductor's outside surface to where the current density in the conductor falls to 1/e of its surface value.

STRUCTURE: Basic members, supports, spars, stanchions, housing, skin panels, or coverings that may or may not provide conductive return paths and shields for electrical/electronic circuits.

SUSCEPTIBILITY: Upset behavior or characteristic response of an equipment when subjected to specified electromagnetic energy - identified with the point, threshold, or onset of operation outside of performance limits. Conducted Susceptibility (CS) applies to energy on interface conductors; Radiated Susceptibility (RS) to radiated fields.

SYSTEM: A group of components, circuits, or equipment connected together to provide a complementary function, and thereby having to operate without interference in a mutual electromagnetic environment.

THRESHOLD, NOISE: The lowest electromagnetic interference signal level that produces onset of susceptibility.

TRACE: The conductor bonded to a printed circuit board substrate that conducts current between two or more points.

TRANSMISSION LINE: A combination of conductors arranged in a mutual field, having the characteristics of distributed reactance, and uniform impedance along its length when properly terminated.

UPSET: Temporary interruption of performance that is self-correcting or reversible by manual or automatic process.

UNACCEPTABLE RESPONSE: Upset, malfunction, or degrading of performance beyond the tolerances defined in the certification test plan.

UNDESIRABLE RESPONSE: Change of performance and output, not designated a malfunction or safety hazard, that is evaluated as acceptable as is because of minimum nuisance effects and excessive cost burdens to correct.

VALIDATION: Demonstration and authentication that a final product operates in all modes and performs consistently and successfully under all actual operational and environmental conditions founded upon conformance to the applicable specifications.

VERIFICATION: Demonstration by similarity, previous in service experience, analysis, measurement, or test that the performance, characteristics, or parameters of equipment and parts demonstrate accuracy, show the quality of being repeatable, and meet or are acceptable under applicable specifications.

3. GENERAL TOPICS

This chapter is provided to present general topics which are applicable to any of the Electromagnetic Environmental Effects which are discussed in subsequent chapters.

3.1 Specification Guidelines

As the most general guideline, over-specification should be avoided. This may involve analysis and perhaps preliminary testing at the aircraft and sub-system levels at a stage as early in the development program as possible. This approach should enable threat or emission levels to be tailored to practical, necessary levels at the aircraft engine interface, i.e., avoiding the imposition of "blanket" specification limits which would result in unnecessary cost, weight and reliability penalties resulting from over design. If relaxation can be tolerated it should be included in the procurement document. Obviously insusceptible components should be exempted from any specific requirements.

Requirements which apply only to appropriate interfaces should be specified. For example, conducted emission power circuit requirements on aircraft engine interface leads should be specified only where power is actually supplied by the aircraft source.

3.2 Criticality Assessment

The FAA presently considers all EEC (Electronic Engine Control) systems for primary propulsion to be critical, whether they are supervisory or full authority types, and therefore requires that they be tested as critical systems. However, in the event that anomalies or out of limits are found on specific parameters in the testing, it may be possible to demonstrate that these specific parameters are non-critical and have no adverse effect on the system airworthiness. If this is accepted by the cognizant FAA office, the specifics of the test should be entered in the installation manual to inform the installation engineer.

APU requirements may differ somewhat from those for the primary propulsion control system, in that the equipment may be considered essential or critical. Some greater level of upset than is the case for the propulsion system may be permissible - e.g., switchover to a backup control function or even shutdown.

3.3 General Pass/Fail Criteria

In the certification of civil primary propulsion control systems, the following general Pass / Fail criteria are usually applied in the testing for compliance with Electromagnetic Environmental Effects:

a. No permanent damage results.

b. No false indications which could cause the pilot or crew to take inappropriate and potentially hazardous action.

c. No unacceptable change or effect in thrust or power during the test event, and complete recovery afterwards. (e.g., ±1% for greater than 1 second is often used, however AC33.28 defines “No effect” as “less than +/- 2% of power or thrust change from the normal governing control capability for period of less than one second.” for civil certifications).

d. No lane or channel change or reversion to a back-up system is permissible, unless you can demonstrate both channels are not affected by common mode failures-(i.e. channels with dissimilar architectures)..

e. No anomalous operation of overspeed or reverser circuits.

f. No anomalous operation of propeller control.

Determination of thrust or power variations that may result in an adverse effect is application dependant. In general, thrust variations exceeding 2% of rated power or thrust for a period greater than 1 second for turbofan applications have been considered as adverse. In most cases thrust variations up to 3% have been accepted. In general aviation applications variations of up to 10% have been considered acceptable. Larger, short duration transients during lightning tests may be acceptable while smaller, sustained variations during susceptibility tests may not be consistent with demonstrating “no adverse effect” due to environmental conditions. For additional guidance refer to AC 33.28-(Reference 2.7) and AMC 20-1 (AMC 21-3) (Reference 2-20).

In addition to the above general criteria, there may be other customer specific requirements, or different criteria for military applications.

3.4 System Test Configuration

During the pre-qualification phase of the engine control system development, it will be necessary to compile test plans for each Electromagnetic Environmental Effects test to be performed. Each test plan should declare the intended System Test Configuration, i.e., how the EEC will be interfaced to any supporting equipment, and in which mode(s) it is to be operated during the test. This raises several points regarding the many options which are possible for configuring a certain system test. These are broadly divided into two sub-categories for further discussion:

a. "Full Up" System Test versus "Component" Test.

b. Open Loop versus Closed Loop Configuration.

3.4.1 "Full Up" System Test versus "Component" Test

A "full up" system is defined as one featuring the EEC components connected to a full compliment of production actuators and sensors, production engine cables and airframe cables and interface equipment which may be conformed facsimiles. A "component" test is defined as the simplest configuration which would allow functionality and electromagnetic characteristics of the component to be measured.

Clearly, the closer the test configuration resembles the actual installation (i.e., the full up configuration) the more meaningful the test. Also, test credit may be sought for the other installation components. However, there are usually practical reasons why a complete full up test is not feasible, so the actual test configuration may lie between the two extremes.

a. Wiring Harnesses:

It is generally recognized that the wiring harness plays such an important role in the electromagnetic performance of the EEC system. If only one category of equipment other than the EEC is to be exactly as in the installation, then this should be the wiring harnesses. Engine cables should be conformed production components. In some cases, especially in the case of the airframe cables, these components may be conformed facsimiles in which the relevant construction details (shielding, terminations, bundled, grounding, etc) must be replicated. These production engine cables and facsimiles airframe cables may be "modified" (example removal of an overbraid on double shielded cables to demonstrate margin during a certification test). However modifications must be documented and must be conformed to get regulatory approval prior to test.

b. Engine Sensors and Actuators:

Nothing loads the EEC as representatively as the real system sensors and actuators. However, practical limitations may arise depending upon the intended operating mode during the test. Some sensors are easily adapted for realistic signal simulation (e.g., frequencies can be induced magnetically onto speed pickups). However, certain sensors are not so readily adaptable without invasive methods (thermocouples, pressure sensors, etc.) so a judgment must be made as to whether the ambient conditions experienced by the sensors during the test represent a useable operating condition. This may also be affected by the decision to operate in open loop or closed loop mode.

c. Airframe Interfaces:

Again, a judgment is necessary depending upon the complexity of the interface equipment and the impact of simulating the device. Airframe data busses are more readily simulated by external bus transceivers, and it would usually be infeasible to feature, for example, an Air Data Computer in the EEC test. However, in the case of a device such as a power demand resolver, it may be somewhat straightforward and would make good sense to use the real device.

3.4.2 Open Loop versus Closed Loop Configuration

An open loop test is defined to be an arrangement whereby preset simulated conditions may be set up onto the EEC inputs, but these do not vary in response to the outputs of the EEC. Conversely, a closed loop test is a configuration which features some type of inputs to the EEC are used by the simulation to generate responsive outputs to the actuators, etc. In this manner, the EEC can operate in at least one control mode as it would in the installation. Each type of test has advantages and limitations, and each type has its proponents. Therefore, the type of test method proposed should receive suitable consideration, and be declared for customer and certification authority approval well in advance of the test date. In either case the operating mode should be chosen to be the most sensitive to the applied environment. This may result in different set points for EMI, Lightning and HIRF or differing set points for emissions versus susceptibility tests. A single operating mode can be used to adequately address all applied environmets and operating modes provided sufficient analysis is provided in the test plan for approval. The following is intended to outline some of the advantages and drawbacks associated with each test configuration.

a. Open Loop Testing:

It is to be expected that during open loop testing, the action of the control software within the EEC would be to drive the actuator demand onto a minimum or maximum software limit. It is then argued that any susceptibility on, say, an input, which would tend to drive the output demand in the direction to exceed the software limit would now be masked by the action of the limit. This is cited as unacceptable by those opposed to this method of test. However, the much simpler test arrangement afforded by the open loop test makes a solution to the above problem attractive.

In a sensibly designed system, the software actuator drive limits do not represent the absolute electrical limits of the actuator drive itself. Therefore, susceptibility of the output circuitry will not be masked in either direction by operating on the software limit. In this case the pass/fail criteria for these outputs must be below the limits of the hardware output capability. Alternatively, special test software could be used which disables the normal control logic connection from input(s) to output(s) and inserts either fixed position commands or constant output commands depending on whether closed loop inner loop actuator control is possible within the test environment. Any position feedback devices should be representative of the actual hardware used in the application and set to a position(s) relevant to the test conditions being evaluated. Test equipment will then be necessary to monitor the control outputs for any test induced disturbances. The problem is then reduced to exposing susceptibility on signal inputs (especially difficult if susceptibility is assessed purely by monitoring the response of the actuator drives). One solution would be, in addition to the electrical monitoring of outputs, to monitor digitized sensor data over a diagnostic data port. Each input parameter could have a predefined pass/fail limit, computed from the overall power/thrust limit, and continuously compared to that limit by a diagnostic computer. Any input excursion could then be logged, and possibly analyzed off line for the expected effect upon the power/thrust limit. Time histories of each input and output should be recorded for use in applying resultant test induced disturbances to the normal operating conditions of the model. Care should be taken to ensure that the update rate of input parameters is adequate to avoid missing short duration susceptibility, although such an upset would have minimal effect on the output. In effect the input update rate should be as fast as that used in the application software.

In considering the effects of input disturbances on power/thrust in establishing limits on each input, the cumulative effect on engine thrust due to disturbances on each input should be considered. As these cumulative effect criteria generally leads to restrictive pass/fail criteria it is common to evaluate power/thrust response by biasing the inputs of an off-line closed-loop engine system model with the recorded digital input disturbances.

b. Closed Loop Testing:

Closed loop testing usually involves a much more complicated and expensive test set up, but as it more accurately represents the installed system, it is usually favored by the certification authorities. There are, however, limitations associated with this method which should be appreciated and accommodated.

The closed loop test is usually arranged so that the most common control loop is utilized. Any susceptibility of those input parameters associated with that control mode would indeed be exposed by an unwanted response of the output parameter. However, there may also be other input parameters which are only used in other control modes and are consequently tolerant of large upsets when operating in the chosen mode. Plans must therefore be made to accommodate this problem; one possible solution would be to monitor digitized input parameters as outlined for the open loop testing. This can also prove useful in providing the capability for evaluating future control software modifications. Another solution would be to arrange to test in every control mode, but this would usually be prohibitively expensive and time consuming.

Another practical drawback to the closed loop test is the potential for test gear/simulation susceptibility, even though the test gear is usually placed in a control room and not directly exposed to the environment, and the problems involved in discerning this from real EEC susceptibility. Resolving this problem usually involves time consuming, detailed investigation at the test site. Similar problems however, occur with data acquisition systems in open loop tests he engine simulation should be valid for small perturbation inputs and validated using actual engine data. The model should have sufficient accuracy, at least to within 10% of the actual engine response, to simulate a 2% power/thrust change. A full non-linear engine simulation is not required if acceptable small signal transient accuracy can be shown with a linearized model. Model validation for small changes should be shown.t is preferable to define test conditions which correspond to a steady state, high power engine operating condition and a lower power engine operating condition where the control loops for fuel flow, stator vane or variable geometry, and surge bleed valve actuators are all modulating. A high power condition where the stator vanes are modulating is preferred over takeoff power, as the stator vane actuator is often at the maximum stop position at takeoff power. A lower power condition where the stability bleed valves are modulating or operating near the switch point – in the case where the bleed valve function is a simple open or closed position command – should also be tested and simulated. The +/- 2% of point power/thrust change is not as important at low power. Unacceptable oscillations of the stability bleed system can be of concern.

3.5 Degraded Mode Operation

Some EEC systems are approved for Time Limited Dispatch (TLD) when the applicant demonstrates compliance with the Guidelines for Time-Limited-Dispatch Analysis for Electronic Engine. Control Systems-provided in ARP5107-(Reference 2-21). TLD procedures permit dispatch of engines with degraded redundancy, provided it can be demonstrated that the system complies with this criteria. One of the TLD criteria is that any dispatchable configuration must continue to meet all of the applicable FARs. Another criterion for TLD is that all dispatchable configurations must continue to meet the certification environment, which includes the electromagnetic environment. In order to demonstrate compliance with this latter criterion, the applicant may be required to repeat the electromagnetic test program with the system in the worst case dispatch configuration. This requires that the applicant determine the worst case dispatch configuration and demonstrate that the system continues to meet the electromagnetic environmental requirements.

4. ELECTROMAGNETIC INTERFERENCE (INCLUDING HIRF)

4.1 Introduction

The interaction between information carrying signals and undesirable electrical energy, commonly referred to as noise, in electrical and electronic system is the basis for electromagnetic interference (EMI). Aircraft electrical and electronic systems offer unique challenges in their need to control a wide array of noise threats. Alternately, EMI pertains to propulsion generated emissions, conducted or radiated, which may result in aircraft system interference. This section provides an overview for the aircraft and its electromagnetic noise environment as it pertains to propulsion electronic control systems.

4.2 Environment

Both the internal and external aircraft environments directly impact the aircraft engine electronic control system relative to EMI. The engine control system must contend with a diverse array of noise emitters while components such as the engine control itself is a noise emitter relative to surrounding electronic equipment in or on the aircraft. Radar and transmitter systems provide a radio frequency (RF) noise environment (HIRF - High Intensity Radiated Fields) of prime concern to an engine control system. The natural lightning environment provides a further noise environment of prime concern. Of military concern is the nuclear Electromagnetic Pulse (EMP) noise environment (lightning and EMP are discussed generally in separate sections of this document). These threats, in addition to noise from other electrical or electronic equipment in or near the aircraft, form the bulk of noise sources that may affect engine controls.

Historically, the requirements placed upon a system regarding the RF electromagnetic environment were prescribed by the civil or military "general" EMI specification. However, in more recent years, due mainly to the changing picture of terrestrial, ship-based and airborne transmitters, a subset of the EMI environment, namely HIRF, has warranted closer attention. The proliferation of high power radar and transmitter systems has necessitated the development of High Intensity Radiated Field (HIRF) requirements. These High Intensity Radiated Fields and the certification requirements are defined in AC20-158 (Reference 2.15) and section 20 of RTCA DO-160 (Reference 2.11). Due to the complexity of the certification requirements and procedures as evidenced by the expansion of RTCA DO-160,Section 20, the Certification or Qualification Requirements for HIRF are discussed separately within section 4.3.3.

4.2.1 Fundamentals of EMI

The EMI community has distinguished between a noise emitting source and a noise susceptible victim by grouping electrical noise measurement into two categories:

a. Emissions (or Interference)

b. Susceptibility

Both categories are further divided into two groups, based on the propagation method:

a1. Radiated

b1. Conducted

This provides a set of four categories into which electrical noise measurement falls today.

1a. Radiated Emissions

1b. Conducted Emissions

2a. Radiated Susceptibility (or Interference)

2b. Conducted Susceptibility (or Interference)

4.2.1.1 Radiated Emissions/Susceptibility

Electrical/Electronic engine control systems are a natural source of emissions which can be radiated from a component enclosure/housing or more predominately from engine and engine to airframe cables. In the former case, metallic housings usually provide more than adequate shield effectiveness (attentuation). However housing discontinuities such as access plate interfaces, drain holes, pressure ports, etc, must be addressed to maintain necessary attenuation. The use of non-metallic, (composite) housings require more in depth consideration to produce adequate shield effectiveness. In the second case, cable/wiring configurations can result in less than desired attenuation and ultimately significant emissions. System to system coupling, inductive or capacitive,can occur with collinear routed cables and increased emissions due to inadequate cable attenuation and can also,adversely effect radiated emissions.

One of the most significant problems, which mandates emissions limits, is radiated coupling to aircraft receivers. Such emissions, if in-band,can disrupt aircraft communications and result in a reduction of reception range. Such emissions can adversely affect GPS, TCAS, Transponder, etc. operation. In low frequency emissions, cables are usually the prodominant source of emissions, in high frquency cases aperture leakage is typically prevalent. Even in these cases, cables are usually the predominant source of emissions. When adequate shields cannot be deployed on cables, filtering may have to be used on input/output interfaces. Radio frequency radiated emissions are normally determined over a broad frequency range. Often the measurements are made so as to distinguish between broadband and narrowband emissions. Radiated emissions can also take the form of pulse or spike emissions in real time and are not necessarily periodic but may be random in characteristic. Typical sources of potential noise in an engine control are switching power supplies, processor clocks, and data busses.

Radiated Susceptibility focusses on the potential of on board transmitters or external sources (radar, other aircraft, etc) immersing the engine control system in the radiated fields. Such radiated fields can couple to the control system, again primarily through the cable coupling media, and result in system susceptibility. It should be noted that apperature coupling is a potential path for radiated field suscetibily and should not be ignored. High Intensity Radiated Fields have been confirmed and defined as an environment and form the basis of the radiated susceptibility requirements. To insure compliance to these requirements, utilize a layered scheme comprised of:

- Designing the electronics for high immunity (levels as high as practically possible)
- Producing enclosures which are effective shields
- Extending this protection to the cables with the use of wiring shields
- Designing the nacelle to produce the first effective attenuation/protection barrier.

4.2.1.2 Conducted Emissions/Susceptibility

Conducted emissions or interference limits apply to power lines from the airframe and input/output cables that interface with the airframe (TLA, ARINC,etc). Of particular concern are the power line emissions which are generally due the switching regulators but may also have clock harmonics. These emissions can contribute to the bus harmonic content and may be directly coupled to equipment using the same bus. In the case of AC power lines, emissions can be a contributor to harmonic distortion. Lastly, as most power lines are not shielded they can be a source of radiated emissions or interference.

For the interconnecting cables the harmonic content can be due to many sources. These can range from the processor clock to data transmissions (ARINC, CAN, 629, etc.). These emissions are controlled and therefore a lesser concern for conductive interference/emissions and are ineffective couplers to remote interfacing engine equipment. Such conducted emisssions may provide evaluation data should radiated emissions exceedances occur. Limits in RTCA DO-160 Section 21 are generally relaxed on interconnecting cables due to the inherent decrease in emissions from the interconnecting cables relative to low impedance power busses. Later revisions of MIL-STD-461 have deleted the limit entirely as there is also a power correlation with radiated emissions. Conducted emissions can be differential or common mode and these must be addressed in filtering schemes to ensure compatibility.

Conducted Interference/emissions limits are typically not applied to engine cables which interface between engine components. In the remote case that an engine cable's conducted emissions were a problem, this intra-engine compatability would be an engine functionality problem and would be addressed in advance of qualification since it resides totally within the domain of the engine manufacturer. On the other hand conducted inteference tests should be measured on the engine to airframe interface cables, as they are the primary interface with the customer/aircraft and may be routed in close proximity to cables servicing numerous aircraft systems. Ultimately the installation has to meet the airframers installations requirements (i.e. not interfere with aircraft antennas, receivers and electronics).

Conducted susceptibility is the reverse problem, in that the system is subject to noise which may be pulses or transients (CS115 or CS116) or may be broad range continuous wave or AM modulated signals induced on power and interconnecting cables. In the later case, it can range from 30HZ to 400 MHZ (Sections 18 and 20 of RTCA DO-160) or CS101 and CS114 of MIL-STD 461. In the lower or audio frequency range it is typical of power lines and the harmonic content of these lines. In the case of R.F. noise, as in CS114, the source can be due to illumination of the system or aircraft by high powered transmissions. Fast transients, however, may be coupled directly from interfacing components or may be coupled by coliniar cable routings.

4.2.2 Aircraft Source/Victim Phenomena

It is convenient to categorize sources of emissions as radiated or conducted. However, many emitters of EMI are sources of both conducted and radiated. As stated above, within the EEC, power supply switching regulators and computer clock frequencies are common sources. At the aircraft level, ignition systems or unsuppressed switched inductive loads are common sources. Onboard communication systems provide a common source of conducted and radiated emissions. Electric motor drivers, especially those which may share the same power bus as the EEC are a common source of conducted and radiated emissions. While the engine has sources which can effect aircraft systems, the aircraft is also a source of emissions (examples transmitters, motor drives, data busses) which can adversely effect engine systems.

4.2.3 Basic Coupling Mechanisms

The coupling method of conducted interference from other equipment into the EEC system or from the EEC system into other equipment is along effected leads which are common to both source and victim. However, the proximity of these leads to other leads within the same harness or shielded bundle may result in magnetic or electrical coupling to these previously uneffected inputs or outputs.

Radiated interference can enter an electronic unit by direct penetration through an aperture or seams of the unit enclosure. Within the unit enclosure, the geometry of the wiring and printed circuit boards will act as antennae to the radiated interference. Additionally, an inadequately shielded wiring harness may act as an antenna to the interference, coupling the unwanted signal into the EEC in the same manner as a conducted emission threat.

4.2.4 Qualification Level Determination

It is recommended that the purchaser specify detailed EMC requirements in procurement/test requirement documents for system or components based upon the best understanding of the environment. The statement "Shall be designed to meet the requirements of MIL-STD-etc." is insufficient to ensure cost effective EMC designs. The component/subsystem designer is not in a position to determine either maximum permissible emission levels or installed environment susceptibility levels.

It is extremely important to give due consideration to EMC during the proposal stage for an aircraft and its propulsion system. Consideration should also be given to applying the least stringent specification limits that will provide adequate compatibility in order to minimize system weight, cost and complexity.

4.2.4.1 CE/CS Methods

Specify conducted emission requirements on aircraft engine interface leads only where power is actually supplied by the aircraft power source.

Specify signal and control requirements with limits tailored to practical, necessary, levels at the aircraft engine interface.

Example A - If it is known that X number of dB relaxation can be tolerated for a given CE method, it should be included in the procurement document.

Example B - If it is known that for Conducted Susceptibility test at a given frequency, the signal level will be high but at all other frequencies, the level will be quite low; these levels should be specified in lieu of blanket CS limits.

Engine driven generators or alternators are not a natural source of noise as they are low frequency AC machines. However, if generator regulators or converters are integrated or mounted on the engine, they may be a source of interference which through crosstalk or conduction to the airframe can contribute or instigate a susceptibility of another system. If such regulators or converters are used they must be designed such that the interference on the power feeders is complaint to the conducted interference/emissions limits in the required EMI standard. The data must be provided to the airframe manufacturer to ensure electromagnetic compatibility.

4.2.4.2 RE/RS Methods

Following implementation of good EMC design practices[1], engineering test data should be taken for use in design guidance. Consider the specific use of the proposed equipment and its exact function. Suggest limits that are practical and necessary.

Example A - If certain of the engines' electrical/electronic components are within a shroud, 10 dB relaxation of standard limits for Radiated Emissions is suggested at frequencies below 150 kHz.

Example B - Exempt obviously unsusceptible components from any or all of the Radiated Susceptibility methods. This will reduce test time and costs.

4.3 Certification or Qualification Requirements

This section defines the certification or qualification requirements for Electronic Engine Controls. 14 CFR Part 33 defines policy used to approve EECs as part of a civil engine certification program. EASA requirements define policy used by European countries in their engine certification programs. Certification data are then validated by USA certification authorities under the bilateral agreements if the engine is to be installed on an aircraft registered or manufactured in the USA. Most U.S. military programs that involve EECs are qualified to MIL-STD-464/461(Reference 2.8, 2.16, and 2.19) for EMI. Foreign military programs that involve EECs are qualified to the applicable specification required by the particular foreign military (Example: RAE Defense Standard 59-41).

4.3.1 FAR Requirements for EMI

FAR Part 33 defines the requirements for civil engine certification. Under Part 33 the engine is required to maintain its safety and airworthiness throughout its operating range and in all operating environments. FAR Part 33.28 (Reference 2.7) defines the certification requirements for the EEC.

For EECs the overall Part 33 policy regarding environmental levels is to allow the engine manufacturer to certify the EEC system to environmental levels that are then entered in the installation manual required under FAR Section 33.5. The certification test levels become installation limitations for the aircraft manufacturer in his installation. This permits the aircraft and engine manufacturers to allocate installation resources optimally between them. However, the FAA does provide guidelines for EECs during the engine certification program to ensure that the environmental levels are sufficient to meet the Part 33 airworthiness objectives. Among these objectives is that an electronic engine control will be tested to realistic environmental levels that give reasonable assurance that the engine will be installable in an aircraft. Also, the FAA policy is to certify an engine for all applications as specified in the installation manual.

[1] The bibliography lists sources of good EMC design practices.

In the case of EMI, the FAA requires that the applicant test the EEC in accordance with DO-160 (latest rev. letter) or equivalent criteria, even though DO-160 is directed toward TSO (Technical Standard Order) box-level tests. Although DO-160 Section 20.0 Radio Frequency Susceptibility (Radiated and Conducted) is directed toward box level tests, applicants have adopted the test to electronic engine control system level tests for HIRF. SAE ARP 5583 provides further guidance for R.F. susceptibility (conducted and radiated) system tests, and should be used as guidance for certification of complex systems such as FADECs. Tailoring may be necessary to adapt RTCA DO-160 procedures and even test levels may be tailored based on specific installation features (Example: nacelle attenuation). All tailoring should be defined in the test plan for the system. This may require the applicant to write the HIRF test plan independently of DO-160 Section 20.0. Section 4.3.3.5.1 of this document discusses HIRF in more detail.

MIL-STD-461 test method CS114 has been accepted as an alternative to DO-160 Bulk Cable Injection (R.F. Conducted Susceptibility).

The FAA requires engine manufacturers to include a brief summary of the EMI test program and test results in the installation manual. Deviations from the DO-160 test limits and the HIRF requirements that are approved by the FAA are entered in the installation manual as installation limits. Usually the EMI test report is referenced for additional detail information. The objective of this entry in the installation manual is to provide the engine installer with sufficient information to design the engine installation to meet aircraft certification requirements.

4.3.1.1 Test Plan

The applicant is required to submit an EMI test plan to the FAA. Concurrence prior to test execution is required. As a minimum the plan should define the test setup, test methods, test equipment, equipment under test, monitoring points and measurement accuracy, modulation, critical operating point, operating frequencies and pass-fail criteria. The EMI test for the EEC is a system test and should be designed to demonstrate that the system complies with the FAR requirements. Type design (TD) components of the EEC system should be used in the test wherever possible. Where components differ from the type design hardware, they must be reconciled. The system should be as representative of the type design configuration as possible. This is beneficial to the applicant because in most cases certification credit is given by the FAA for all system components included in the test.

The applicant is required to operate the system as a minimum at one of the most susceptible engine operating points during the EMI test. An analysis or justification should be provided to support the choice of the selected operating point. In some cases it may be necessary to conduct the test at more than one operating point in order to adequately demonstrate compliance with the FAR. In order to set the system at an engine operating point it usually is required to include an engine simulation to provide the necessary feedback signals to close the loop around the control system under test.

In some cases it may be possible to adequately demonstrate compliance using open loop test setups. However, in the event of an anomaly under test, this approach requires that the applicant be able to adequately represent the effect of the anomaly on an engine simulation to clear the anomaly or provide corrective measures to clear the anomaly. Another difficulty encountered in conducting open loop tests on EEC systems is that without feedback, the loop integrator usually causes the system to be driven to a limit so that detection of upset or anomaly may not be possible. In such cases it may be necessary to modify the trim and or application software to put the outputs in a desired or commanded position. (See 3.4.2 for a general discussion on open loop versus closed loop testing).

Since EMI tests on engine controls are system tests and test results generally are heavily dependent on software, the FAA has preferred the use of TD software rather than test software because the software is an integral part of the configuration being certified. Software is often used in EEC systems to enhance the system hardness to EMI. In many cases TD software is not available at the time of the EMI testing. The FAA accepts the use of approved versions of earlier than TD software in EMI tests if the approved versions of software are under configuration control per DO-178 or equivalent. However, the FAA requires reconciliation of the software differences between the version tested and the TD version to demonstrate that the software differences do not affect acceptance of the EMI test results.

Test software is proposed in some cases for EMI tests in lieu of the TD software. However, if an applicant wishes to use test software in lieu of TD software, the applicant is required to provide a rather rigorous analysis to demonstrate that the test with test software is equivalent to that with the TD software. As in the case of open loop test setups, anomalies either need to be corrected or they need to be represented on the engine simulation to provide the technical data to support acceptance of the anomaly as not impacting flight safety or airworthiness. Also, test software, if used, should be verified and validated to the satisfaction of the FAA, which may mean to Level B software as defined in DO-178B.

4.3.1.2 RTCA/DO-160 Tests

Subsequent paragraphs define the purpose of the tests that are provided in the sections dedicated to EMI in RTCA/DO-160. Category Z applies to EEC systems, with the exception of Sections 17 and 20. Category A is the most likely for Section 17 and W or Y for Section 20 (with or without additional HIRF levels - see 4.3.5.1).

4.3.1.2.1 Section 15 Magnetic Effect

This test determines the magnetic effect of the equipment to assist the installer in choosing the proper location for the equipment in the aircraft.

4.3.1.2.2 Section 16 Power Input

This section defines test conditions and procedures for airframe electrical power applied to the terminals of the equipment under test. This section defines categories for equipment intended for use in aircraft a.c. or d.c. electrical systems where the primary power is from constant frequency ac power (400Hz), narrow variable frequency (360 to 650 Hz), or wide variable frequency (360 to 800 Hz) ac input power. In addition, a category is assigned for equipment supplied by engine driven power alternators/rectifiers, or dc generators where a battery of significant capacity is floating on the dc bus at all times. A tailored category is, also, allowed.

4.3.1.2.3 Section 17 Voltage Spike

This test determines whether the equipment can withstand the effects of voltage spikes arriving at the equipment on its airframe power leads, either AC or DC. The main adverse effects could be:

a. Permanent damage, component failure, insulation breakdown.

b. Susceptibility or changes in equipment performance.

4.3.1.2.4 Section 18 Audio Frequency Conducted Susceptibility-Power Inputs

This test determines whether the equipment is immune to frequency components of a magnitude normally expected on airframe power busses when the equipment is installed in the aircraft. These frequency components are normally harmonically related to the power source fundamental frequency and has categories tailored for equipment using constant or variable frequency power sources.

4.3.1.2.5 Section 19 Induced Signal Susceptibility

This test determines whether the equipment airframe interconnect circuit configuration is immune to a level of induced voltages caused by the installation environment. This section relates specifically to audio frequency signals and transients that are generated by other on-board equipment.

4.3.1.2.6 Section 20 Radio Frequency Susceptibility (Radiated and Conducted)

These tests determine whether equipment will operate within performance specifications when the equipment and its interconnecting wiring are exposed to a level of RF power using CW (continuous wave - unmodulated), square wave and pulsed modulation (radiated only), either by a radiated RF field or by Bulk Current Injection (BCI) onto the cable bundles. See 4.3.3.2 for a discussion on how the equipment Category selection for Section 20 may be used to demonstrate compliance with the HIRF environment.

Two test procedures are used: (1) From 10 kHz to 400 MHz, the equipment under test (EUT) is subjected to RF signals coupled by means of Bulk Cable Injection-(BCI) into its cable bundles, and (2) for frequencies between 100 MHz and the upper frequency limit, the EUT is subjected to antenna-generated RF fields. There is an overlap of the tests from 100 to 400 MHz

The primary approach is to simultaneously expose the circuits associated with the equipment connector(s). There may be circumstances where it becomes necessary to assess interface circuits on an individual basis. The individual circuits may require other levels (at their corresponding frequencies) when unique installation conditions prevail. Large equipment with multiple connectors may preclude use of the injection probe method and require other test equipment and conditions. Equipment with special signal, frequency, modulation or bandpass characteristics may require test variation as specified by equipment manufacturers.

The result of these tests is to permit a category to be assigned defining the RF test level of the equipment. Alternately, non-standard levels based on actual airframe or engine tests could be used in which case Category Z would be declared to indicate induced levels.

4.3.1.2.7 Section 21 Emission of Radio Frequency Energy

These factors determine that the equipment does not emit undesired RF noise in excess of the specified levels.

The section describes two types of test, Conducted RF Interference and Radiated RF Interference.

The intent of the Conducted RF Interference requirements is to:

a. Limit voltage distortion on power leads to the equipment

b. Limit interference currents on inter-system interconnecting cable bundles (other than primary power lines).

The intent of the Radiated RF Interference requirements is to limit the radiated fields from the equipment and interconnecting cables to prevent interference with sensitive antenna-connected receivers. The requirements, therefore, are derived quite differently from those governing Radiated Susceptibility, which are derived based upon levels emanating from antenna-connected transmitters (and not spurious equipment emissions). EASA Requirements: JAR requirements invoke European Organization for Civil Aviation Electronics (EUROCAE) ED-14 that is essentially identical to RTCA/DO-160. Although the test requirements are essentially identical, there may be some differences in the interpretation of test results, pass-fail criteria and in the degree of enforcement. There is a high degree of cooperation among aircraft EMI protection specialists worldwide and further progress in international standardization and harmonization of EMI protection requirements and standards will continue to occur.

4.3.1.2.8 Section 25 Electrostatic Discharge

The electrostatic discharge test is designed to determine the immunity or ability of equipment to perform its intended function without permanent degradation of performance as a result of an air discharged 15 000 volt electrostatic pulse. This requirement is applicable to all equipment and surfaces which are accessible during normal operations and/or maintenance of the aircraft/engine. With the equipment in its normal/installed mounting, bonding, and grounding configuration the ESD is applied to the enclosure of the equipment. The ESD pulse is applied with the equipment powered and in its normal operating mode.

4.3.2 Military Requirements for EMI

Much of this section is extracted from MIL-STD-461F (Reference 2.16) and, as required, for EECs. For a more complete description of these tests, the reader should examine this specification.

4.3.2.1 Determining Requirements

MIL-STD-461F provides Table V, Requirements Matrix, (included as Figure 2) which summarizes the requirements for equipment and subsystems intended to be installed in, on, or launched from various military platforms or installations. When an equipment or subsystem is to be installed in more than one type of platform or installation, it shall comply with the most stringent of the applicable requirements and limits. An entry in the table means the requirement is applicable. An L entry in the table means the requirement is limited as specified in the appropriate requirement paragraphs of MIL-STD-461F. An S entry means the procuring activity must specify the applicability and limit requirements in the procurement specification. Absence of an entry means the requirement is not applicable. Table V (Figure 2) cross-references to the requirements listed in Table IV (included as Figure 1), Emission and Susceptibility Requirements. It is a list of all the requirements however many such as CE106 are not applicable. For instance CE106, CE103, CS104 and CS105 are applicable to communications (receivers, transmitters and antenna) equipment and not applicable to Engine Control Systems.

Requirements, limits, test methods, and equipment set up constraints are defined in MIL-STD-461. The appendices of MIL-STD-461F documents are an excellent source of more detailed discussions of topics ranging from the background and intent of each requirement to the construction of test fixtures and the accuracy of specific measurement techniques and devices.

For military programs, four documents are typically required:

a. Design procedures and techniques for the control of EMI are described in the EMICP (Electromagnetic Interference Control Procedures).

b. EMI/Lightning Test Plan.

c. The specific test procedures are described in the EMITP (Electromagnetic Interference Test Procedures).

d. The results of tests performed to demonstrate compliance are contained in the EMITR (Electromagnetic Interference Test Report).

4.3.2.2 Applicable Requirements

Since the scope of this document covers EECs primarily for aircraft applications, only those requirements applicable to EECs will be discussed subsequently. For example, requirements CE106, CS103, CS104, CS105 and RE103, which refer to antennas and transmitters, will not be covered.

4.3.2.2.1 CE101 (Conducted emissions, power leads, 30 Hz to 10 kHz)

CE101 is applicable to Navy aircraft having an anti-submarine (ASW) capability and Army aircraft. The requirement is applicable to power leads, including returns, which obtain power from other sources not part of the equipment under test. Conducted emissions on power leads shall not exceed the limits defined in Figures CE101-1 through CE101-4 of MIL-STD-461F as is applicable for the application.

Requirement	Description
CE101	Conducted Emissions, Power Leads, 30 Hz to 10 kHz
CE102	Conducted Emissions, Power Leads, 10 kHz to 10 MHz
CE106	Conducted Emissions, Antenna Terminal, 10 kHz to 40 GHz
CS101	Conducted Susceptibility, Power Leads, 30 Hz to 150 kHz
CS103	Conducted Susceptibility, Antenna Port, Intermodulation, 15 kHz to 10 GHz
CS104	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals, 30 Hz to 20 GHz
CS105	Conducted Susceptibility, Antenna Port, Cross-Modulation, 30 Hz to 20 GHz
CS106	Conducted Susceptibility, Transients, Power Leads
CS109	Conducted Susceptibility, Structure Current, 60 Hz to 100 kHz
CS114	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz
CS115	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation
CS116	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10 kHz to 100 MHz
RE101	Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz
RE102	Radiated Emissions, Electric Field, 10 kHz to 18 GHz
RE103	Radiated Emissions, Antenna Spurious and Harmonic Outputs, 10 kHz to 40 GHz
RS101	Radiated Susceptibility, Magnetic Field, 30 Hz to 100 kHz
RS103	Radiated Susceptibility, Electric Field, 2 MHz to 40 GHz
RS105	Radiated Susceptibility, Transient Electromagnetic Field

FIGURE 1 - MIL-STD-461F EMISSION AND SUSCEPTIBILITY REQUIREMENT

Equipment and Subsystems Installed In, On, or Launched From the Following Platforms or Installations	Requirement Applicability																	
	CE101	CE102	CE106	CS101	CS103	CS104	CS105	CS106	CS109	CS114	CS115	CS116	RE101	RE102	RE103	RS101	RS103	RS105
Surface Ships	A	A	L	A	S	S	S	A	L	A	S	A	A	A	L	A	A	L
Submarines	A	A	L	A	S	S	S	A	L	A	S	L	A	A	L	L	A	L
Aircraft, Army, Including Flight Line	A	A	L	A	S	S	S			A	A	A	A	A	L	A	A	L
Aircraft, Navy	L	A	L	A	S	S	S			A	A	A	L	A	L	L	A	L
Aircraft, Air Force		A	L	A	S	S	S			A	A	A		A	L		A	
Space Systems, Including Launch Vehicles		A	L	A	S	S	S			A	A	A		A	L		A	
Ground, Army		A	L	A	S	S	S			A	A	A		A	L	L	A	
Ground, Navy		A	L	A	S	S	S			A	A	A		A	L	A	A	L
Ground, Air Force		A	L	A	S	S	S			A	A	A		A	L		A	

Legend:

A: Applicable
L: Limited as specified in the individual sections of this standard
S: Procuring activity must specify in procurement documentation

FIGURE 2 - MIL-STD-461F REQUIREMENT MATRIXES

4.3.2.2.2 CE102 (Conducted emissions, power leads, 10 kHz to 10MHz)

CE102 is applicable to all military aircraft. The requirement is applicable to power leads, including returns, which obtain power from other sources not part of the EUT. Conducted emissions on power leads shall not exceed the applicable limits shown on Figure CE102-1 of MIL-STD-461F.

4.3.2.2.3 CS101 (Conducted susceptibility, power leads, 30 Hz to 150 kHz)

CS101 is applicable to equipment and subsystem AC and DC input power leads, not including returns. If the EUT is DC operated, this requirement is applicable over the frequency range of 30 Hz to 150 kHz. If the EUT is AC operated, this requirement is applicable starting from the second harmonic of the EUT power frequency and extending to 150 kHz. The EUT shall not exhibit any malfunction or degradation of performance or deviation from specified indication beyond the tolerances indicated in the individual or subsystem specification, when subjected to a test signal with levels as specified in Figure CS101-1 of MIL-STD-461F. The requirement is also met when the power source is adjusted to dissipate the power level shown in Figure CS101-2 of MIL-STD-461F in a 0.5 ohm load and the EUT is not susceptible.

4.3.2.2.4 CS114 (Conducted susceptibility, bulk cable injection, 10 kHz to 400 MHz)

CS114 is applicable to interconnecting cables, including power cables. The amplitudes for the requirement applicable to equipment and subsystems is based on intended installation as defined in Table VI of MIL-STD-461F. The frequency range of the requirement for all services is 10 KHz to 200 MHz.

The EUT shall not exhibit any malfunction, degradation of performance or deviation from specified indications, beyond the tolerances indicated in the individual or subsystem specification, when subjected to a test signal with calibration levels as shown in Figure CS114-1 of MIL-STD-461F. The appropriate limit curve in Figure CS114-1 shall be selected from Table VI of MIL-STD-461F.

4.3.2.2.5 CS115 (Conducted susceptibility, bulk cable injection, impulse excitation)

CS115 is applicable to all aircraft and space system interconnecting cables, including power cables. The EUT shall not exhibit any malfunction or degradation of performance or deviation from specified indication, beyond the tolerances indicated in the individual or subsystem specification, when subjected to a calibrated test signal as specified in Figure CS115-1 of MIL-STD-461F at a 30 Hz rate for one minute.

4.3.2.2.6 CS116 (Conducted susceptibility, damped sinusoidal transients, cables and power leads, 10 kHz to 100 MHz)

CS116 is applicable to all interconnecting cables, including power cables, and individual power leads. Power returns need not be tested individually. The EUT shall not exhibit any malfunction or degradation of performance or deviation from specified indication, beyond the tolerances indicated in the individual or subsystem specification, when subjected to a signal having the waveform shown in Figure CS116-1 and having a maximum current as specified in Figure CS116-2 of MIL-STD-461F. As a minimum, compliance shall be demonstrated at the following frequencies: 0.01, 0.1, 1, 10, 30, and 100 MHz. These damped sines in the .01 to 100 Mhz frequency range are typical of nuclear induced transients.Other frequencies known to be critical to the equipment installation, such as platform resonances, shall be added to the test. The test signal repetition rate shall be no greater than one pulse per second and no less than one pulse every two seconds. The pulses shall be applied for a period of five minutes.

4.3.2.2.7 RE101 (Radiated emissions, magnetic field, 30 Hz to 100 kHz)

RE101 is applicable for radiated emissions from equipment and subsystem enclosures and all interconnecting cables. This requirement is applicable for equipment in Navy ASW and Army aircraft. Magnetic field emissions shall not be radiated in excess of the levels shown in Figures RE101-1 and RE101-2 of MIL-STD-461F at the specified distances of 7 centimeters and 50 centimeters.

4.3.2.2.8 RE102 (Radiated emissions, electric field, 10 kHz to 18 GHz)

RE102 is applicable for radiated emissions from equipment and subsystem enclosures and all interconnecting cables. The requirement is applicable as to Army aircraft from 10 kHz to 18 GHz and to Air Force and Navy aircraft from 2 MHz to 18 GHz. For Air Force and Navy applications tests are required up to 1 GHz or 10 times the highest intentionally generated frequency within the EUT, whichever is greater. Electric field emissions shall not be radiated in excess of those shown in Figure RE102-3 of MIL-STD-461F. Above 30 MHz, the limits shall be met both for horizontally and vertically polarized fields.

4.3.2.2.9 RS101 (Radiated susceptibility, magnetic field, 30 Hz to 100 kHz)

RS101 is applicable to equipment and subsystem enclosures and all interconnecting cables. This requirement is applicable to equipment used on Navy ASW and Army aircraft. The EUT shall not exhibit any malfunction, degradation of performance or deviation from specified indications, beyond the tolerances indicated in the individual or subsystem specification, when subjected to the magnetic fields shown in Figures RS101-1 and RS101-2 of MIL-STD-461F.

4.3.2.2.10 RS103 (Radiated susceptibility, electric field, 2 MHz to 40 GHz)

RS103 is applicable to equipment and subsystem enclosures and all interconnecting cables The requirement is applicable as follows:

a. 2 MHz to 30 MHz: Army ships; Army aircraft, including flight line; Navy (except aircraft); and optional for all others.

b. 30 MHz to 1 GHz: all.

c. 1 GHz to 18 GHz: all.

d. 18 GHz to 40 GHz: optional for all (based on procurement specification)

The EUT shall not exhibit any malfunction or degradation of performance or deviation from specified indications beyond the tolerances indicated in the individual or subsystem specification, when subjected to the radiated electric fields specified in Table VII of MIL-STD-461F. Above 30 MHz, the requirement shall be met for both horizontally and vertically polarized fields. Circular polarized fields are not acceptable. Either spot illumination or mode tuned field generation techniques may be utilized.

4.3.2.2.11 RS105 (Radiated susceptibility, transient electromagnetic field)

RS105 is applicable to equipment and subsystem enclosures when the equipment or subsystem is to be located external to a hardened (shielded) platform or facility. The requirement is applicable for equipment intended solely for use on non-metallic platforms when specified by the procuring activity. The requirement is applicable to Army aircraft for safety critical equipment and subsystems located in an external installation. The EUT shall not exhibit any malfunction, degradation of performance or deviation from specified indication, beyond the tolerances indicated in the individual or subsystem specification, when subjected to a test signal having the waveform and amplitude shown on Figure RS105-1 of MIL-STD-461F. At least five pulses shall be applied at the rate of not more than one pulse per minute. This transient/pulsed electromagnetic field is typical of nuclear generated EMP.

4.3.2.3 Acceptability of MIL-STD-461 for Civil Certification

MIL-STD 461 qualifications have been accepted by the FAA in some previous engine certifications. The MIL-STD, however, does not define the HIRF, Lightning and ESD environmental requirements in sufficient detail. As such, the applicant must still address these environments using the requirements defined in FAA Advisory Circulars 20-158 and 20-136A and test procedures in RTCA DO-160 20, 22 and 25 respectively. Pass/fail requirements for the susceptible list sequence must be consistent with those defined in AC33.28

It should also be noted that the DOD also may accept civil certifications in lieu of a re-qualification to MIL-STD 461, depending on the airspace that the military intends to operate the aircraft in. With the exception of EMI tests conducted for HIRF, the test limits included in DO-160 or MIL-STD-461 have been accepted by the FAA in previous engine certification programs. (See 3.3 for a general discussion of Pass/Fail Criteria.)

4.3.3 High Intensity Radiated Electromagnetic Fields (HIRF)

Although HIRF is an extension of the EMI category "Radiated and Conducted Susceptibility", the increase in number and power level of worldwide transmitters has warranted special study of the HIRF environment. This HIRF field definition is based on the data aggregated on worldwide transmitters, both commercial and military. Field intensity is a product of specific distances from the source and in some cases reflects keep out areas in force around military transmitters. The rotorcraft environmental requirements define noticeably greater field intensities, and is, therefore, more severe as their flight regime can put the air vehicle in much closer proximity to transmitters It has also resulted in a separate advisory circular and policy guidelines to demonstrate compatibility within the HIRF environment, as discussed in the following paragraphs. FAA AC 20-158 (Reference 2.15) defines the external environment, and provides approaches to compliance, Interim Policy INT/POL/25/2 continues in use by EASA.

4.3.3.1 HIRF Requirements

Figure 3, (Table 1 in AC 20-158) defines the HIRF failure condition categories which are applicable to parts 23,25, 27, and 29.

HIRF REQUIREMENTS EXCERPTS FROM §§ 23.1308, 25.1317, 27.1317, AND 29.1317	FAILURE CONDITION	SYSTEM HIRF CERTIFICATION LEVEL
Each electrical and electronic system that performs a function whose failure would prevent the continued safe flight and landing of the rotorcraft/airplane	Catastrophic	A
Each electrical and electronic system that performs a function whose failure would significantly reduce the capability of the rotorcraft/airplane or the ability of the flightcrew to respond to an adverse operating condition	Hazardous	B
Each electrical and electronic system that performs a function whose failure would reduce the capability of the rotorcraft/airplane or the ability of the flightcrew to respond to an adverse operating condition	Major	C

FIGURE 3 - HIRF FAILURE CONDITIONS AND SYSTEM HIRF CERTIFICATION LEVELS

The Certification environment defined in Table 1 for both average and peak fields is applicable to engines utilized in fixed wing and rotorcraft applications for Environments I, II and III . Environments I and II are applicable to fixed wing aircraft. Environments I, II, and III are applicable to rotorcraft. The field strength values for the HIRF environments and test levesl are expressed in root-mean-square (rms) units measured during the peak of the modulation cycle. The AC provides further detail relative to these environments and performance criteria.

Should the selected approach to compliance be by equipment, or in the case of an engine control system by integrated system certification tests, a battery of three tests as defined in AC 20-158 would be necessary. These are R.F. conducted susceptiblity (Bulk Cable Injection), R.F. average field radiated susceptibility, and R.F. pulsed/peak fields radiated susceptibilty tests.

For the radiated susceptiblity fields, tests to 40GHz as defined in Table 1 environments are only required if the equipment under test operates in the 18 – 40GHz range or a system response beyond the defined pass/fail criteria occurs during tests in the 12 – 18 GHz range.

TABLE 1 – HIRF ENVIRONMENTS AS DEFINED IN FAA AC-20-158

	Field Strength-(V/m)		
Frequency	Environment I Peak/Average	Environment II Peak/Average	Environment III Peak/Average
10 kHz- 100 kHz	50/50	20/20	150/150
100 kHz - 500 kHz	50/50	20/20	200/200
500 kHz - 2 MHz	50/50	30/30	200/200
2 MHz - 30 MHz	100/100	100/100	200/200
30 MHz - 70 MHz	50/50	10/10	200/200
70 MHz - 100 MHz	50/50	10/10	200/200
100 MHz - 200 MHz	100/100	30/10	200/200
200 MHz - 400 MHz	100/100	10/10	200/200
400 MHz - 700 MHz	700/50	700/40	730/200
700 MHz - 1 GHz	700/100	700/40	1400/240
1 GHz - 2 GHz	2000/200	1300/160	5000/250
2 GHz - 4 GHz	3000/200	3000/120	6000/490
4 GHz - 6 GHz	3000/200	3000/160	7200/400
6 GHz - 8 GHz	1000/200	400/170	1100/170
8 GHz - 12 GHz	3000/300	1230/230	5000/330
12 GHz - 18 GHz	2000/200	730/190	2000/330
18 GHz - 40 GHz	600/200	600/150	1000/420

When conducting BCI and radiated field tests for certification the following typifies the minimum modulation requirements:

a. 10 KHz - 400 MHz

1. 1 KHz square wave modulation of depth >90%. See RTCA-DO-160 Section 20 figure 20-5 which provides a visual representation of the square wave modulation with a depth of 90% or greater.

2. Continuous wave (CW). The test signal must meet the average requirement.

b. 400 MHz - 40 GHz

1. Pulse modulation with a 0.4% duty cycle and a 1 KHz pulse repetition frequency (prf) is necessary from 400MHz to 4 GHz and a 0.1% duty cycle from 400MHz to 40 GHz. In some applications, there may be a requirement to switch the field on and off at a rate of 1 Hz with a duty cycle of 50% to simulate the effect of rotational radars. The field strength (volt per meter) and test levels are expressed in root-mean-square (rms) units measured during the peak of the modulation cycle, which is how many laboratory instruments indicate amplitudes.

2. In addition, to meet the average field requirements, tests with a 1 KHz square wave modulation with a depth of at least 90% as well as CW are necessary. It may, also, be required that the field be switched on and off at a rate of 1 Hz with a duty cycle of 50% to simulate the effect of rotational radar.

Alternative modulations should be selected on the basis of the most likely characteristics to disrupt the operation of the equipment under test based on its design characteristics.

Regardless of the chosen modulation, test levels when applying modulated signals are in terms of peak as measured by a spectrum analyzer

Specific test procedures are defined in Section 20 of RTCA DO-160 (latest revision) and further guidance, especially for integrated system tests is provided by SAE ARP5583.

4.3.3.2 Routes to Compliance for HIRF

Figures 4 through 6 provide diagrams of the routes to HIRF compliance for Level A (example a full authority digital engine control system) and Level B and C systems (example: prognostics health systems depending on the level of integration)

The figures/diagrams have been taken from AC20-158 (Reference 2.15). This AC , also provides definition of the individual steps (1, 2, 3, etc.) in the routes to compliance and should be used by an applicant.

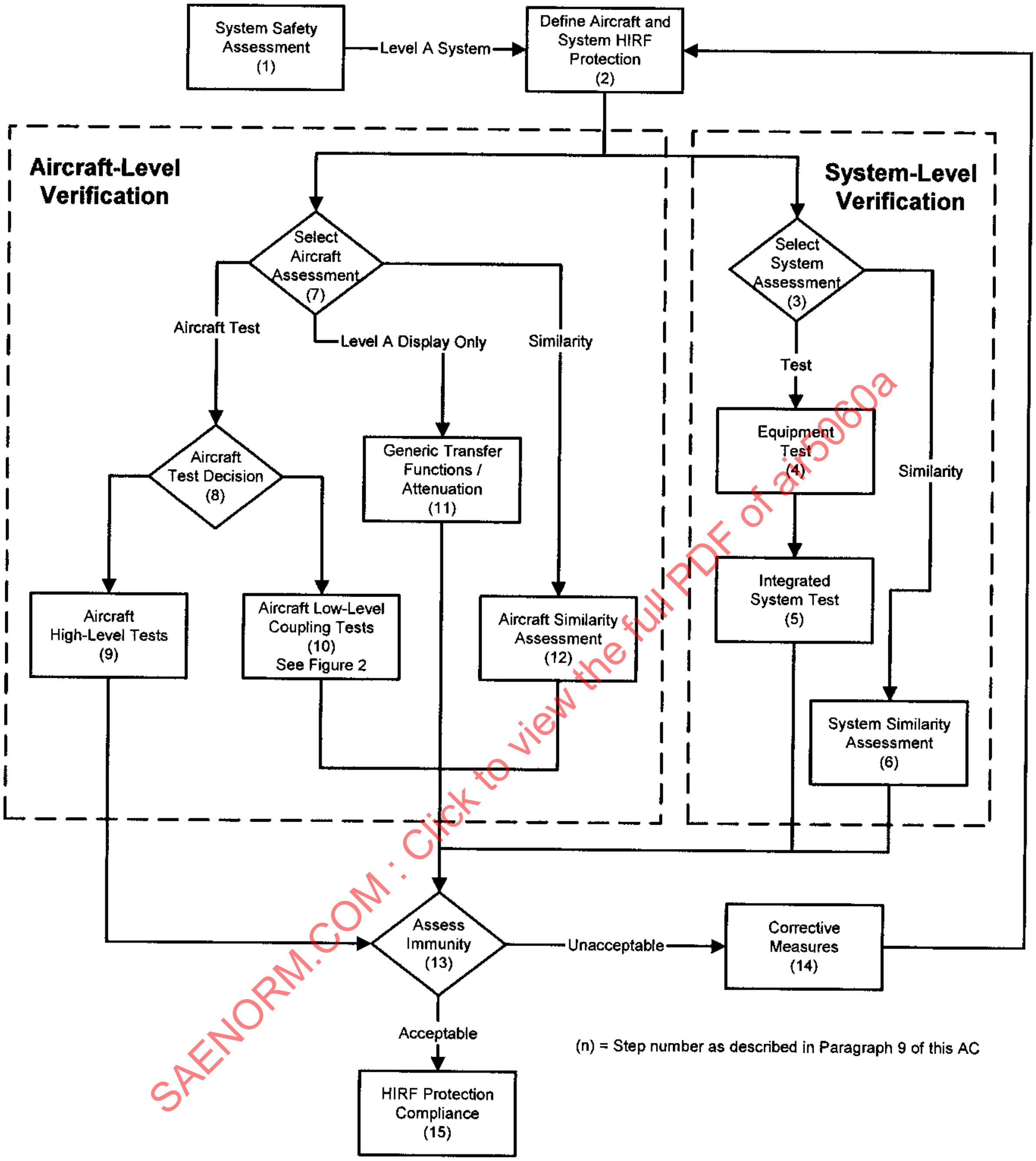

FIGURE 4 - ROUTE TO HIRF COMPLIANCE-LEVEL A SYSTEMS

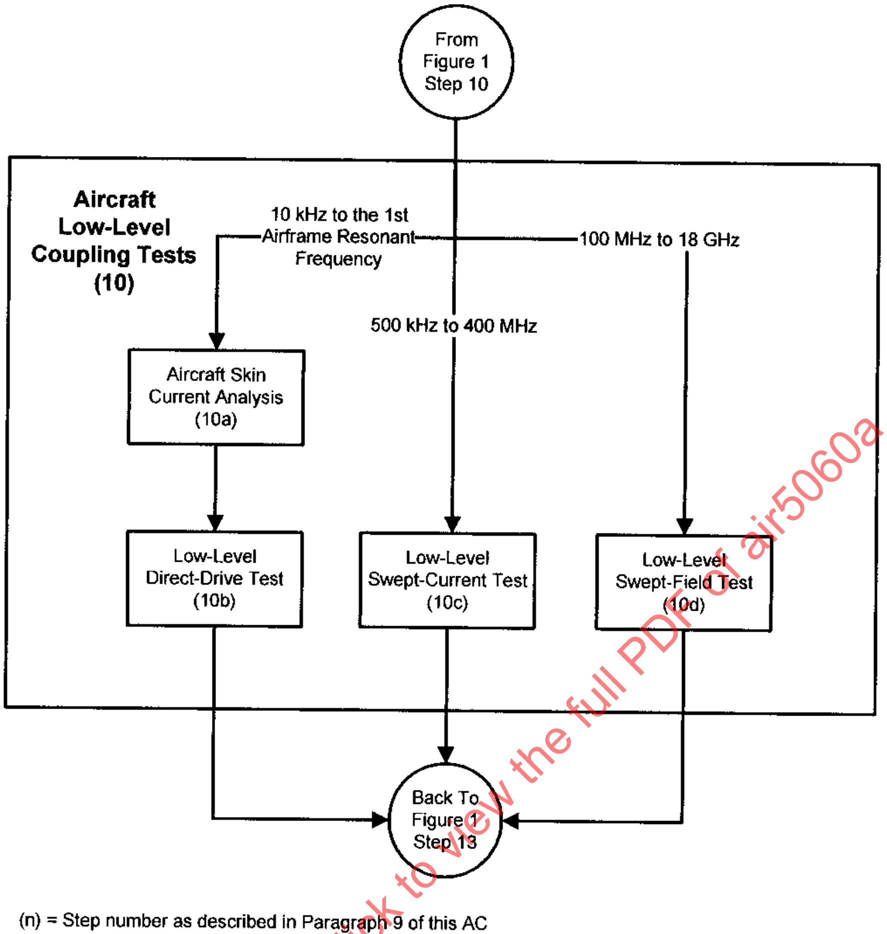

FIGURE 5 - AIRCRAFT LOW-LEVEL COUPLING-TEST LEVEL A SYSTEMS

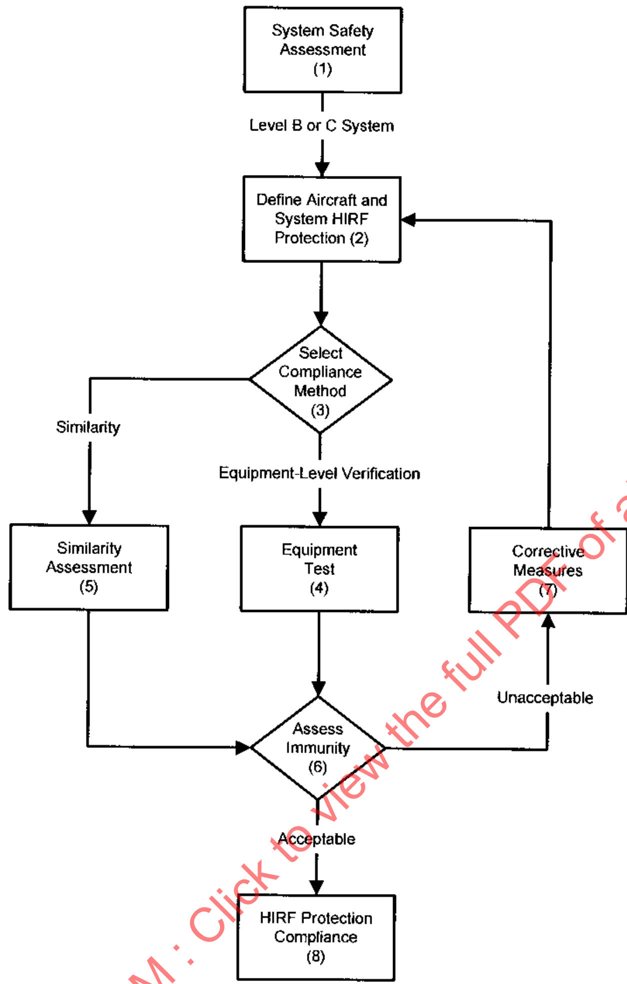

FIGURE 6 - ROUTES TO HIRF COMPLIANCE-LEVEL B AND C SYSTEMS

4.3.3.3 HIRF Certification by Similarity

Similarity is an attractive alternative to system certification by test; however, it can be the most complicated and risky approach to compliance. When this approach is selected the applicant must prepare detailed and factual arguments for all relevant aspects of the engine, its control system, and the installation. The following may comprise a minimum list of details which need to be addressed (for further guidance see HIRF Users Guide, ARP-5583-(Reference 2.14) :

a. What levels was the system certified to for R.F. conducted susceptibility? R.F. average field susceptibility? and R.F. pulsed/peak field susceptibility? Was certification to a category defined in RTCA DO-160 Section 20 or were the test levels tailored (category Z) based on actual airframe/nacelle Low Level Swept, Current and Field tests etc.

b. If attenuation of the airframe and nacelle were used in the prior certification, then similarity of these structures as well as the pylon must be addressed. If the nacelle is provided by the airframe manufacturer, then the airframe manufacturer needs to be consulted and their concurrence with the approach is vital.

   1. Is the nacelle, pylon, and airframe construction the same?

   2. Are any relevant apertures the same?

c. Are the airframe and engine cables similar? Are there differences in:

   1. Lengths?

   2. Routes and bundles?

   3. Intermediate disconnects and connectors?

   4. Cable shielding and grounding/bonding?

   5. Cable plugs and back shells and mating receptacles?

d. Are the electronics (EEC, Ignition Exciter, DCU, sensors, etc.) identical or similar? If not, the differences must be identified and shown to provide the same level of hardness to the stated HIRF environmental requirements. The following should be considered:

   1. Internal filtering

   2. Circuit or component changes

   3. Interconnect changes

   4. P.C. board layout or layer stack changes

   5. Grounding schemes and implementations thereof

   6. Changes to the filtering or sampling aspects of the software

e. Are the electronics and electromechanical housings identical or similar? Are there changes in:

   1. Metal walls (type and thickness)?

   2. Access plate or housing interfaces bolt spacing, flange contact area, etc.)?

   3. Apertures such as drain holes or for indicators or displays?

   4. EMI gaskets?

   5. Electrical connector types?

   6. Housing conductive finishes and type?

   5. Housing electrical bond or mount to structure?

f. Are the locations of electronic and electromechanical line replaceable units (LRUs) the same or similar?

g. Are the electrical bonds of the electronic and electromechanical LRUs the same or similar? Considerations:

   1. Hard mounted

   2. Shock mounted with the same bond strap(s)

   3. Finish for the interface surfaces on both the LRU and structure

h. Are the electronics and electromechanical housings identical or similar? Externals such as the thrust reverser system, whether supplied by the applicant or airframe manufacturer, must be addressed.

i. Is the structure/engine the same? For instance, has a composite section been used to replace a similar metal section?

As can be seen by the prior list of minimum factors to be addressed, similarity arguments must be detailed and depending on the changes may have to be comprehensive and are likely to carry significant risk depending on the type and extent of the changes. In addition, significant coordination with the airframe manufacturer will be necessary.

4.3.3.4 HIRF Compliance by Analysis

Analysis can be a viable alternative for simple or isolated changes requiring recertification, but can be very expensive and impractical for extensive changes. For instance, CAD tools or programs are available to analyze field from conductor wiring even in large complicated cable sets. The applicant, however, needs to weigh the cost benefits versus test as the programs generally focuses on one major difference in the system, are relatively expensive, and require significant engineering support to get the detail necessary for entry in the program. In the end, the models and/or programs must be validated and require the use of additional margin due to uncertainty and as such, the process end can have significant risk.

4.3.3.5 HIRF Certification by Test

4.3.3.5.1 Test Levels

HIRF certification by test may be a two step process. Ultimately, an integrated system test would be necessary for a Level A full authority digital engine control system. As required in the routes to compliance, the test levels whether they are tailored or are specific categories from RTCA DO-160 Section 22, they must be validated, as appropriate for the new installation. There are three predominate approaches:

a. If the airframe manufacturer supplies the nacelle, then overall attenuation of the structure is determined by the airframe manufacturer and becomes a given for the engine and its control systems. In the past, for both wing and aft fuselage mounted engines, RTCA DO-160 Section 20, Category F, has been common for R. F. Radiated Susceptibility and Category W or Y for R.F. Conducted Susceptibility. Also, it has not been unusual to see the R.F. Conducted Susceptibility levels tailored based on low level swept current tests that were run on the nacelle by the airframe manufacturer.

b. The applicant might certify to the “no attenuation” levels, such as Category L in RTCA DO-160 Section 20. In this case the applicant needs to search for a test facility, either semi-anechoic or mode tuned, with the associated capability as it is not universally available. The level is generally more difficult to reach in the semi-anechoic facility and necessitates many antenna positions increases with frequency to satisfy Section 20 test procedures. For the mode tuned room the applicant needs to find a facility that has a calibrated volume sufficient to allow the system set up, including cables.

c. If the nacelle is provided by the engine manufacturer, low level swept current and field tests can be conducted to determine internal levels which would be used for the system bench tests. The engine manufacturer must still coordinate with the airframe manufacturer to get concurrence on the test levels applicable to airframe and pylon mounted components and cables.

4.3.3.5.2 HIRF System Bench Tests

HIRF laboratory tests are usually conducted on an engine control system using a Closed Loop Bench (CLB) setup (see 3.4 for a general discussion on System Test Configuration). The CLB should include the conformed engine mounted components (electronics, electromechanical components, cables, etc.) as well as aircraft interfacing components (throttle, data transceivers, etc.) as provided by the airframe manufacturer or airframer approved simulation of the same. Component electrical bonding in the integrated test set up must emulate the installation and it should be noted that bond methods and requirements may differ between those for the engine and those for the airframe (pylon, wing and fuselage). Test levels (especially BCI) differ due to differences with nacelle and airframe (pylon, wiring, etc.). The CLB setup is usually provided with hydraulic pressure to move actuators to close the inner actuating loops. In addition, the system set up usually includes a simplified engine simulation to close the outer engine loop. In some cases, open loop bench tests conducted with test software have been accepted by the certifying agency. If the applicant elects to conduct open loop bench tests, the following factors should be considered:

a. The test software should be developed and implemented to guidelines defined for Level B in RTCA/DO-178, respectively. In some cases, the application code is modified to include the required test code features. At the very least, the test code should be under configuration control IAW DO-178B so that the test results can be reconciled with the software version to be used in service.

b. The system test setup should be instrumented to monitor the output drive signals, as well as input signals.

c. Anomalies observed on inputs or outputs should be duplicated on the engine simulation to determine whether the resulting power or thrust perturbations comply complies with the pass/fail criteria.

In either case the closed or open loop set up outlined above constitutes an integrated system set up.

HIRF system tests must be set up with the system controlling to one of the most sensitive operating points as determined by the applicant. The system is then exposed to the HIRF environment (BCI, Average Field and Peak Pulsed Fields) while operating at this setpoint. FAA AC 33.28 provides guidance relative to system operating mode as well as specific pass/fail criteria. The pass/fail criteria for HIRF are usually the same as that for other Electromagnetic environmental tests: that there be “no effect” on the operation or operational characteristic of the system. “No effect” is defined as a power or thrust perturbation of less than ± 2% for a period of less than 1 second (see 3.3 for cases where a larger perturbation may be tolerated). In addition, transfers to backup or reversionary modes, component damage, arming or activation of the overspeed protection system, and erroneous fault codes recorded in the fault memory and/or annunciated are also considered to be test failures.

Also, it should be noted that although a system may be implemented with a hydromechanical (HMC) backup control system, transfer from the primary electronic control mode during the HIRF testing is considered a system failure.

Applicants should, also, be aware that for approval of Time Limited Dispatch, the FAA requires that EEC dispatchable configurations must continue to meet environmental requirements of the certification.

4.4 Design Considerations

The EEC is normally categorized as flight critical. According to application it may be located on the engine, in the nacelle, or it may be airframe mounted. It should be designed such that its susceptibility to EMI and generation of emissions are kept to a practical minimum. The location and installation of the EEC and associated equipment should be configured to support these aims.

4.4.1 Hardware Considerations

In 3.1 the importance of considering overall system design and system testing, rather than concentrating on individual components, was emphasized. Broad tradeoff studies, in which EMI design is considered in the context of its impact on reliability, cost, weight and fault tolerance and continued air worthiness, are essential if a robust and satisfactory protection scheme is to be achieved.

Hardware design is thus an iterative process, with consideration being given to the following principal areas:

a. EMI Environment and Threat Levels

b. Equipment Location

c. Wire Routing

d. Shielding

e. Housing Design

f. Grounding and Bonding

g. Circuit Design

It is good practice, and a requirement for most military programs, to produce and maintain an EMC Control Plan. Such a document acts as a focus for design and test activities, ensuring that EMI protection, test facilities, and verification planning is considered throughout the design and development cycle.

4.4.1.1 Equipment Location

The location of the EEC should, if possible, provide some degree of protection from electromagnetic fields. Thus it should be located away from areas allowing the direct ingress of interference. Examples are:

a. Major Apertures in the Fuselage

b. External Composite Sections

c. Equipment Access Doors

It is also desirable to keep the EEC away from equipment likely to generate high levels of interference. Locating the EEC in a shielded compartment is desirable from an EMC point of view, but may not be a viable option in a system context, and could result in longer engine interface cables and hence increased coupling.

4.4.1.2 Wire Routing

The routing of the interconnecting wiring between the EEC and the engine sensors and actuators, the cockpit and other airframe systems is subject to the same considerations as the location of equipment. Segregation of the wiring for the two channels in a dual redundant control scheme will enhance fault tolerance. Bundling the harness in with wiring from other systems, could to give rise to coupled interference,and should be avoided.

4.4.1.3 Housing Design

The EEC should be housed in a metallic case designed to be an integral shield, to provide protection for the internal circuits, and to control the emission of any internally generated potential interference. Generally a metal enclosure is used as this provides an acceptable level of shielding effectiveness. Composite cases with conductive coatings can be used under favorable circumstances, but they may provide a lower level of EMI attenuation. Use of composite housings may also require certification to additional requirements defined by specific airframe manufacturers. EMI effectiveness is determined both by the nature of the conductive material employed and its thickness.

To ensure that its shielding effect is not compromised, the enclosure should be properly grounded, openings should be avoided wherever possible, and low resistance joints made between the case, access covers and external connectors. Mesh shields may be required over features such as display windows or ventilation holes. Mating surfaces in joints require the use of corrosion resistant conductive finishes, for example chromate conversion, to ensure low resistance in the long term. A sufficient number of fixing bolts should be provided to give good electrical contact over the whole area of each joint. Conductive gaskets between the joining faces may be necessary to give the most consistent low resistance performance.

The housing should also be designed to control the importing and exporting of conducted interference. Figure 7 shows three different ways in which this can be achieved. Unscreened cables can be routed into a dirty area of the housing, which is partitioned off from the clean area containing the circuit components. Feedthrough Axial filters mounted on the partition between the clean and dirty zones may be used to limit the frequency band of imported and exported signals. Alternatively, connectors with integral filters may be used in some cases, allowing signals to be routed directly to and from the clean zone. Finally, where the wiring harness is suitably screened, filters and dirty zones may be dispensed with. However, in this case care must be taken to ensure that a single shielding failure can not affect adversely the control function.

Partitions may be employed within the enclosure or circuits segregated by function to maintain control channel segregation and to isolate individual circuits, which might generate excessive interference, or are particularly susceptible to noise.

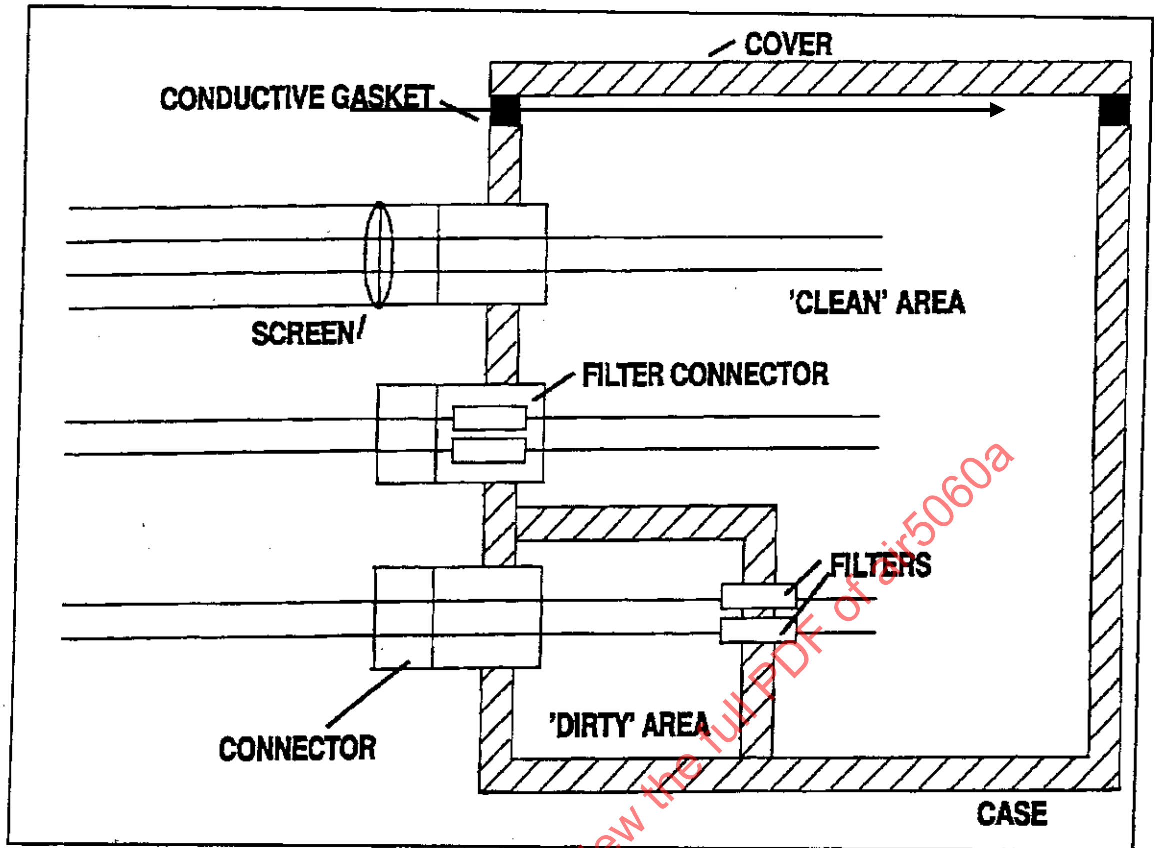

FIGURE 7 - HOUSING DESIGN FOR INTERFERENCE CONTROL

4.4.1.4 Grounding and Bonding

The engine control system requires proper grounding for satisfactory EMI control. Each electronic LRU should provide a single internal ground reference point for its circuits. Each circuit is multipoint grounded to a local reference plane. These reference planes are then terminated to the chassis. Star connection is to be preferred.

Alternately, the EEC may be designed using circuit isolation. The most common is to provide isolation for airframe interfaces from circuit ground to case. Power would be isolated from primary to secondary thereby allowing the circuit ground for engine interfaces and data processing circuits to be referenced to case. Isolation on the primary side produces the ability to stand off higher transient voltages without the use of suppressors; however, power line filtering complexity increases as both common and differential noise must be addressed. Isolated designs require more attention to detail relative to circuit board layout.

The equipment chassis must then be bonded to the aircraft or engine structure. For rack mounted equipment bonding will normally be via the rack and panel connector or electrical bond straps. For other equipment a bonding receptacle, a mounting bolt or direct contact bonding may be employed. An engine mounted EEC will normally be fitted with antivibration mounts. In this case an electrical bonding strap should be used to connect the chassis to the engine structure plane.

4.4.1.5 Shielding

The design of the interconnecting wiring and screening in an engine control system is particularly important in protecting the electronic circuitry from HIRF (BCI and Radiated Susceptibility Fields) and the indirect effects of lightning strike. Shielding can be used to advantage in conjunction with sensor, actuator, instrumentation and databus wiring to control emissions and minimize susceptibility. Wiring will normally be arranged in twisted screened pairs or triplets as appropriate. Power lines are shielded in exposed areas (nacelle, pylon, etc.) of the aircraft but are typically not shielded in the fuselage or a shielded bay. The shielding must be grounded to be effective.

Shielding for low frequency protection is best arranged with only one end grounded. However, this arrangement is not suitable if protection from the indirect effects of lightning, high frequency (RF) noise or fast transients is also required (see 5.4.1.1). These require both ends of the cable screen to be grounded. Where the highest level of combined protection is desired, then an overall screen grounded at both ends may be used in a harness with a number of inner screens, which are grounded at one end only. For best performance the harness connectors should be fitted with RFI backshells. The outer screen should be arranged so as to make a full circumferential connection with the backshell. Inner screens are grounded according to the needs of the individual circuits. If there is no overall outer screen, then individual screens should be grounded peripherally to the backshells at each end of the harness with minimal length pigtails. The harness and box connector shells should be designed to make a low resistance bond when mated.

4.4.1.6 Circuit Design

Circuits used within the engine control system should be selected with a view to minimizing their susceptibility to EMI, and ensuring that they do not generate unacceptable emissions, either internally or externally. Interface circuits in particular must be able to cope with induced RF noise and transients. Differential input stages are useful in helping to control limited bandwidth common mode interference. EMI filters are especially effective in controlling imported and exported radio frequency interference. The filters should be selected so as to provide the required frequency response, without interfering with circuit operation and performance. Circuit board mounted filters may be required to eliminate low frequency common mode interference and aliasing effects.

Within the control enclosure the layout of the circuits should be assessed carefully, keeping sensitive circuits away from potential sources of noise emission, and employing decoupling to limit the transmission of interference. Minimum necessary bandwidth should be used for signal processing and transfer within the unit:

a. Bandwidth Limitation for Analog Circuits

b. Control of Rise Times for Digital Circuits

4.4.2 Software Considerations

Software can provide a means for further enhancement of the system's ability to tolerate EMI. Digital filtering techniques can be applied to continuously varying signals. Multiple sampling of discrete, switched inputs readily overcomes short term transient upsets. Error detection/error correction techniques can be applied to both analog and digital signals. Software also has a significant role to play in detecting faults, which can result from the loss of a particular hardware protection feature.

The importance of software upon EMI immunity raises other considerations namely, the effect of post-qualification software changes. It follows that if certain software features can protect against EMI, then software changes could also modify the system response to EMI and compromise the qualification basis. Changes which modify signal filtering, or use existing signals in different ways or new control schemes could all fall into this category. Consequently, when post-qualification software changes are planned, the approach for re-establishment of the qualification basis must be considered.

The plan for re-qualification could follow one of the three options below:

a. Analysis: A detailed analysis against each EMI requirement showing why each software change would not detrimentally affect the outcome of each test. This should be supported by calculations and simulation results as required.

b. Retest: A complete retest would be the most rigorous confirmation, but is likely to be prohibitively expensive and time consuming, especially when several software updates are likely in a product life cycle.

c. Partial Retest: A combination of the above. The analysis would cover those EMI requirements/tests which are less likely to be affected by the software changes, and a smaller subset of the test plan would be repeated, probably concentrating on susceptibility testing only.

The effectiveness of the selected approach will depend upon the extent and nature of the software modification. The above considerations apply equally to lightning and EMP.

4.5 General EMI Compliance Methods

4.5.1 Compliance by Test

The following sub-paragraph describes typical test facilities. For radiated susceptibility and interference tests of an integrated subsystem, current standards RTCA DO-160 and MIL-STD 461 require that tests be conducted in a semi-anechoic or mode tuned room.

4.5.1.1 Test Facilities

4.5.1.1.1 Shielded Room

A shielded room is a room commonly fabricated from 4 feet by 8 feet plywood or particle board with galvanized sheets of steel on both sides. The sheets are assembled together with metal ribs at the seams so to form a room: walls, floor, and ceiling. The doors are specialized metal doors with metal fingers, such as beryllium copper, and a unique latching mechanism. The purpose of the metal walls and doors is to keep ambient RF signals out of the room and keep EMI signals generated within the room in. Air vents may also be used to allow fresh air into the shielded room. Air vents are normally of the honeycomb type and provide RF attenuation equal to the enclosure itself. Power entering (115 VAC 60Hz,and 400Hz, 28VDC, 230 AC) the room is filtered at entry. There are other types of shielded rooms such as solid modular rooms, continuously welded rooms and room with copper screen verses sheets of metal and plywood. The amount of attenuation "shielding" normally expected is 100 db. A copper screen room will provide about 60 db depending upon the construction methods.

A shielded room is relatively inexpensive to setup. With proper maintenance the room can retain its 100 db shielding. The setup of the equipment inside can be very flexible. The main difficulty with the shielded room is the reflections off the walls from the RF radiators in the room. These reflections if not dealt with technically can contribute 20 db errors in testing.

These rooms can be used for conducted susceptibility, lightning, and ESD tests but cannot be used for R.F. radiated interference/emissions or R.F radiated susceptibility (HIRF)

4.5.1.1.2 Semi-anechoic Chambers

Anechoic chambers are considered the next step up from a simple shielded room because they start with a shielded room then add anechoic material to the walls, floors and ceiling. The anechoic material absorbs the incident RF signals and reflects only a minimum amount of the RF signals back. Standard such as RTCA DO-160 or MIL-STD 461 provide guidance and specific requirements on the use of the absorber and ultimate performance of the material. In Shielded rooms or Semi-anechoic facilities only sections of a set up (based on antenna beam width) might be illuminated. Room resonance produced nulls and hot spots in excess of the required level. Ultimately, multiple antenna positions (increasing with frequency) are necessary to fully test an integrated system. In addition troubleshooting tests could be necessary to determine whether an abnormal system response was a product of a hot spot. Therefore, an integrated system may necessitate the use of a much larger room to match the system square footage and that of the calibrated volume. Lastly, any anomalous system reactions may necessitate additional troubleshooting since the entire system has been illuminated.

An anechoic chamber is expensive. The anechoic material requires air-conditioning to keep its RF absorbing properties. An Anechoic chamber combined with a shielded room can typically have shielding in the range of 130 db (assuming well-designed doors and bulkheads). For those frequencies where the RF absorber material is effective, the anechoic chambers reduce the RF reflection problems seen with radiated emission or radiated susceptibility tests; however, it is not necessary to use anechoic chambers for conducted type (interference or susceptibility) EMI tests.

4.5.1.1.3 Mode Tuned or Stirred Chambers

Mode tuned or stirred chambers are an extension of a shielded room. A good quality shielded room with a highly reflective internal surface, capable of supporting a standing wave pattern, is the basis of a mode stirred chamber. The Q - factor of the room is a measure of its ability to act as a resonant cavity. A room with a high Q - factor will typically support standing waves in the 200 MHz to 18 GHz range (the minimum frequency is determined by the chamber dimensions; the maximum frequency by chamber energy losses). A "paddle wheel tuner" is then added, which serves the purpose of moving the peaks and troughs of the standing wave pattern around the room. When multiple positions of the tuner are used a uniform RF exposure of the articles in the room is achieved. The tuner may be turned by stepping or rotated continuously. The test article is generally in the middle of the room, the tuner is either on the ceiling or on one side of the room, and in some cases there may be multiple tuners. The transmitting and receiving antennas are pointed away from each other so that reflections are created and received. The test article and tuner positions are best selected to avoid symmetry in the chamber (and consequent mode degeneracy).

A shielded room maybe modified to obtain a mode tune or stir facility by adding the paddle wheel tuners/stirrers, motors, electronic controllers, a computer and software to adjust steps, frequencies, dwells, etc. Alternately turnkey facilities with controlling software are available. The technique of using a mode stirred and tuned rooms is well documented by the NIST (see Bibliography reference). The mode stirred or tuned chamber uses relatively low RF power sources (when compared to sources necessary to achieve the same field strength in an anechoic chamber) to conduct Radiated Susceptibility tests. The test may take longer because the tuner must be rotated fully for each test frequency and mode of the system being evaluated and if stepping is used the test is repeated for each step. The mode tuned chamber or test technique is currently acceptable for RTCA D0-160 and MIL-STD 461 for Radiated Susceptibility test. The MIL STD- 461 requires the use of mode tuned techniques. RTCA DO 160 Section 20 allows the use of either mode tuned or mode stirred techniques.

Mode tuned or stirred susceptibility tests have the advantage of illuminating an entire integrated system simultaneously at the relatively uniform field intensity. It should be noted that applicants must be aware that mode tuned stirred rooms have a calibrated volume which is a smaller percentage of the room volume.Therefore the applicant must insure that the calibrated volume is sufficient to take the integrated system otherwise another larger test facility will be necessary.

RTCA- DO-160 recently allowed the used of mode tuned or stirred techniques for R.F. Radiated Interference tests.

4.5.1.1.4 Open Area Test Sites

The Open Area Test Site (OATS) was devised for the FCC to test computer type devices for radiated emissions. The test site as the name implies is usually outdoors or in a RF transparent (i.e., plastic/fiberglass) house. The article under test is put on a rotating pedestal while being measured at various heights for radiated emissions. Local ambient emissions are noted and recorded for omission from the test data. It is highly desirable that the test site have a low local ambient RF environment with minimal local emitters. OATS are generally not used for Radiated Susceptibility Test, however, where frequency allocation permits radiation of high power RF signals (like at the Navy's facilities in Patuxent River, MD) test are conducted on aircraft and large test articles or integrated systems outdoors.

OATS may also be used to run vehicle or engine low level swept CW tests as defined in SAE ARP 5583. They would however, not be acceptable for RTCA DO-160 or MIL-STD 461 test sequences which require the use of semi-anechoic or mode tuned shielded rooms.

4.5.1.1.5 System Integration Laboratory

A Systems Integration Laboratory (SIL) is some combination of the test article with other related systems in a physical situation allowing the development, engineering, testing and validation of the interrelationship of the equipment involved. The lab may be representative of the entire aircraft avionics suit or just the engine control system and its related aircraft systems. The wiring and cabling of the laboratory may not be totally representative of the aircraft wiring. Cable lengths may be different; wire termination may be different; grounding and bonding may be to an equipment rack via the airframe. Aircraft overbraided cables may not be used in the lab. EMI backshells may have been eliminated to simplify the lab build up. Furthermore, the equipment may not be representative of the flight or production engine control system. All these type factors play into the first aspect of a SIL's ability to represent the test article and its interfaces, and must be considered in detail as part of the plan or test. Once determined that the SIL is representative, then the SIL may be used for all EMI type tests. The problems occur in scheduling the SIL for EMI tests, and setup and operating EMI equipment in the limited space of the SIL. In the case of radiated emission tests the ambient environment needs to be clean of emissions from nearby systems and test equipment not associated with the article under test.

The SIL does however, have significant value as it can be used to evaluate the system response to steady state or transient EMI.

4.5.1.1.6 EMI Test Bench

The EMI Test Bench is unique to DO-160 or MIL-STD-461. The bench is generally a large table with a copper ground plane on the top positioned in a shielded room. The copper or brass ground plane should have a minimum thickness of .25 mm for copper or .63 for brass and is 2.25 square meters or larger in area. The ground plane is bonded to the shield room such that the DC bonding resistance is 2.5 milliohms or less. Bond straps should be placed every 90 cm apart along the wall common with the bench. Equipment stands should be bonded to the ground plane. All cables placed on top of the ground plane should be 5 cm above the surface (this is usually done by using 2 inch x 4 inch blocks for stand-offs). Each external interface to the engine controls system is brought out through EMI filters to outside the shielded room and then to the test equipment, simulated loads, or associated system.

4.5.1.2 Personnel

EMI tests should be conducted by personnel (technicians and/or engineers) trained in the area of EMI, EMC or E^3. When test are outsourced experience should be evaluated and in some cases, contracted facilities have undergone certification which should be evaluated for releverance and confidence.

4.5.1.3 Engine Control System Configuration

4.5.1.3.1 Open Loop

An open loop test of an engine control system involves simulated inputs and monitoring of the outputs of a control system while conducting the EMI/EMC test.

See section 3.4.2 for more information on Open Loop testing.

4.5.1.3.2 Closed Loop

A dry closed loop test of an engine control system usually involves the use of simulated engine inputs and outputs. The outputs from the EEC are inputted to an engine model, which in turn generates signals to the EEC in response to those inputs. The engine model is usually a computer simulation, but analog electronic models have also been used.

See section 3.4.2 for more information on Closed Loop Testing.

4.5.1.3.3 ATE versus Manual

Whether the test is open or closed loop the monitoring and exercising of the control system can be performed by a computer or by manual operator. Automated Test Equipment (ATE) using a computer allows the continuous monitoring and checking of the data inputted and outputted by the control system. ATE allows the tracking of data trends. Tests that are repetitive are particularly suitable for ATE. Manual tests use operator judgment to observe and record data and execute the test procedures. Test procedures for susceptibility tests are usually looking at static modes of the control system, i.e., ground idle, cruise, and occasionally spool up or spool down transitions. Test procedures for emissions tests can be dynamic, i.e., spool up spool down transitions, and start up. Static modes could be monitored manually, while dynamic test could be thoroughly monitored by ATE.

During the plan for test, ATE which are typically not hardened and are typically vulnerable to EMI and lighting transients must be considered and properly set up to avoid false indications or damage. ATE are typically sources of emissions which could compromise test results without proper consideration and suppression.

4.5.1.4 Test Techniques

4.5.1.4.1 Radiated Test Techniques – Emission

The radiated emission test looks for signals radiated from the control system that exceeds a specified level. The level of the signal was set on the assumption that signals may couple to other systems, such as sensitive receivers, and degrade operations. The emission signals take two forms, broad band or narrow band. The narrow band signal is an emission at a fixed frequency where, no matter how narrow the resolution bandwidth of the receiver, the signal is the same level. A broad band signal has many frequency components and as the resolution bandwidth of the EMI receiver is changed the signal level will change (usually 10 db per a factor of 10 in bandwidth change for equipment where power is usually measured, such as a spectrum analyzer, or 20 db for signal level measurement, such as a receiver).

The test setup for the radiated test uses a series of broad band antennas placed at a meter from the control system. The control system is usually placed in a dynamic mode. The EMI receiver is scanned across the frequency range. The scan speed (time) or dwell time at any one frequency is based on the clock rates, data rates and signal characteristics of the control system or how long it takes to execute the dynamic mode procedure for the control system.

4.5.1.4.2 Radiated Test Techniques - Susceptibility

The susceptibility test setup is the situation where the control system is being radiated by a high gain antenna connected to a high power source. The antenna is usually one meter away from the control system. The control system is put in a static mode. The signal is radiated at the control system and the control system is monitored for upset. When susceptibility is encountered the RF level should be reduced to determine at what level the control system will function properly. The RF signals used should be two types: CW and modulated. The CW signal test determines if the system can dissipate the RF energy and if the CW signal results in detection and upset. The modulated signals have a suggested default type of a 1 kHz square wave at greater than 90% depth. In some cases, it is required to further superimpose a 1 to 3 Hz square wave (more commonly when using DO160). The level of one pulse would equal the peak RMS value. The frequency would be scanned at a rate slow enough for the monitoring of the static test of the control system.

A unique test to the military engine control systems is the radiated EMP test. The EMP test is a single event signal. Typically several static modes are evaluated and currents induced on wires and or cable bundles are measured and recorded. The induced cable current can be used for comparison with conducted susceptibility test.

4.5.1.4.3 Conducted Test Techniques – Emission

The conducted test setup is done using current probes on the control system cables. Again the control system is operated in some dynamic mode and current emissions are measured using an EMI receiver. The scan time is determined by the dynamic mode test procedures. The types of emission are like radiated emission categorized as broad band and narrow band. The narrow band signal is an emission at a fixed frequency where no matter how narrow the resolution bandwidth of the receiver is used the signal is the same level. A broad band signal has many frequency components and as the resolution bandwidth of the EMI receiver is changed the signal level will change (usually 10 db per a factor of 10 in bandwidth change for equipment where power is usually measured, such as a spectrum analyzer, or 20 db for signal level measurement, such as a receiver).

4.5.1.4.4 Conducted Test Techniques – Susceptibility

A conducted susceptibility test injects current on to the control system wires and cable bundles using either a current probe or a Line Impedance Stabilization (LISN) Network. The LISN is used on power lines to minimize the effects of the power source impedance on the injection of current to the control system. In other words the LISN is used to minimize the source of power supply source impedance variation which could occur with the use of different laboratory power supplies and can result in inconsistant or false test results. The signals injected on to the wires or cable bundles may be CW RF, modulated RF, EMP Transients or simulated power spikes. The modulated signals have a suggested default type of a 1 kHz square wave at greater than 90% depth. In some cases, it is required to further superimpose a 1 to 3 Hz square wave. The level of one pulse would equal the peak RFM value. The RF frequency would be scanned at a rate slow enough for the monitoring of the static test of the control system.

4.5.1.4.5 Engine Control System Test Techniques - Emission

The emission test of the control system usually uses a dynamic mode of the system. The dynamic mode should exercise the system in such a manner that it will create switching transients, changes in power consumption, varying data rates, high duty cycle communication, high current operation, and other EMI noise creating operation.

4.5.1.4.6 Engine Control System Test Techniques – Susceptibility

The susceptibility test of the control system usually uses a static mode of the system, unless a transition from mode to mode of the control system is important to engine operation. The control system that uses various gain schedules and leveling loops should be tested in each control loop at a near maximum gain point in the gain schedules. In this situation if EMI was picked up by the control system then the interference would be amplified to the maximum level of interference and the control of the engine for each control process (i.e. fan speed, or jet pipe temperature) would be evaluated.

4.5.1.5 Test Data

4.5.1.5.1 Test Plan

The test plan should be the document to detail the approach to conducting the test and identify any unique methods to be used during the test. Testing of an engine system is clearly different from testing avionic systems that documents like DO-160 or MIL-STD-461 are intended for. Therefore, the test plan will tailor the standard test technique to the engine control system. The test plan should, however, address the customer's requirements and data item requirements.

4.5.1.5.2 Test Procedures

The test procedure should be the document that describes the test environment requirements modes of operations and pass/fail criteria. The test house usually will be responsible for providing the step by step instructions for performing the test and the generation of the test report

4.5.1.5.3 Test Report

The test report is the place to historically record the actual events that occurred during the test. The report details the final test method, test data and conclusion regarding the compliance of the engine control system to the EMI requirements. The test report must provide objective evidence of compliance for each test and should address customer data item requirements.

5. LIGHTNING

5.1 Introduction

This section describes considerations in protecting EECs against the effects of lightning strikes in aircraft. It is assumed that the EECs and associated cabling are protected from direct lightning effects by their installation in the airframe structure. Thus, the discussion concentrates on indirect effects, although the lightning environment and its coupling with the airframe are also described. Much of the information presented here is extracted from the FAA Aircraft Lightning Protection Handbook (Reference 2.1). The following is not a conclusive description of these references but is provided to briefly highlight the comprehensive topics and usefulness relative to the phenomena and power plant design for compliance in this external environment.

5.1.1 AC20-136A-Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning

This advisory circular recommends how an aircraft electrical or electronic system can be protected from lightning effects. It, also describes a typical compliance process for Level A systems (Figure 4 of the AC20-136) and a second (Figure 6 of AC20-136) for a Level B and C systems. Each step in the process is defined in the AC. The relationships between transient waveforms are, also established and are basic to the Indirect Effects of Lightning and control systems compliance. Additionally, the AC defines Instructions for Continued Airworthiness and the need to develop Maintenance and Surveillance plans for specific protection features

5.1.2 AC 20-155- Aircraft Lightning Protection Certification

This advisory circular provides formal recognition of two key SAE Aerospace Recommended Practice (ARP) documents, SAE ARP 5412A Aircraft Lightning Environment and Related Test Waveforms (Reference 2.9) and 5414A Aircraft Lightning Zoning (Reference 2.6) which are recommend for use to develop lightning protection for the system.

5.1.3 SAE ARP5412A Aircraft Lightning Environment and Related Test Waveforms

This aerospace recommended practice provides a description of and data on natural lightning, and its interaction with aircraft.. It also defines engineering waveforms pertinent to the Direct Effects of Lightning and Indirect Effects of Lightning. Multiple Stroke and Multiple Burst waveform sets are also defined. These waveforms, both idealized external current components and induced transient waveforms, are defined graphically as well as mathematically. Although the equations defining the waveforms do not have the trailing edge crossing zero, in reality they can and do. These waveforms are the basis for the Direct Effects requirements in Section 23 of RTCA DO-160 and the induced lightning transients defined in Section 22. Lastly, Tables 5,6,and 7 of the ARP provide test levels for individual conductor transients due to Component A currents (Pin Injection), cable bundle transients due to Component A (applicable to Single and Multiple Stroke tests)and cable bundle tests levels due to Component H (applicable to Multiple Burst). Design and test levels, however, should be taken from Section 22 of RTCA DO-160 which has additional information as to applicability. Installation (engine) test data and subsequent waveforms and amplitudes should be used in lieu of Section 22 alternatives as they are more representative and proven as a necessary for Level A systems.

5.1.4 SAE ARP5414 Aircraft Lightning Zoning

This aerospace recommended practice provides the relationship between the aircraft lightning environment, Zoning and Direct Lightning Effects as well as lightning induced transients applicable to Indirect Effects. The document provides text on lightning interaction with aircraft and the process of locating zones and provides typical zoning relevant to FAR 23, 25, 27 and 29 aircraft. It also provides typical zoning of power plants.

5.1.5 SAE ARP5415 User's Manual for the Indirect Effects of Lightning

The User's Manual outlines analytical methods to determine transient control and equipment transients design levels, defines an approach to compliance for electrical/electronic equipment, discusses lightning coupling and provides insight on maintenance surveillance, repair and modifications. It also has appendices that define the FARS and JARS related to lighting protection, discusses lightning coupling and provides lightning transient protection design considerations.

5.1.6 SAE ARP5416 Aircraft Lightning Test Methods

This advisory circular provides more in depth information on Direct Effects test methods, aircraft or engine test to develop equipment transient design levels for Indirect Effects and provides more insight into integrated system test methods

5.1.7 DOT/FAA/CT-89/22 Aircraft Lightning Protection Handbook

The FAA Lightning Protection Handbook and the updated version, Lightning Protection of Aircraft published by Lightning Technologies Inc. provides a comprehensive source of technical information and data on the subject. These documents (References 2.1 and 2.12) provide in-depth discussions on numerous topics ranging from the lightning environment to the attachment phenomena, to direct and indirect effects, to the design of direct and indirect effects protection, cable response and design, and the certification process. For instance the section titled Lightning Environment includes data on the distribution of peak currents for the first and subsequent strokes and an isokeraunic map of the world. The section titled Aircraft Lightning Attachment Phenomena discusses attachment points, provides data on aircraft lightning strike incidents vs. altitude and flight regime when struck, lightning strike mechanisms, and even a paragraph on the effects of engine exhaust on lightning attachment. "The Lightning Effects of Lightning on Aircraft" includes a paragraph focusing on the "Direct Effects on Propulsion Systems which includes turbine stalls. There is even a section on "The Physics of Indirect Effects" which provides an analytical development that may be useful for predictions or assessments. Sections on "The Response of Aircraft Wiring" and "Shielding", also, develop analytical tools which are particularly useful prediction or assessment of power-plant indirect effects transients and are, therefore, valuable tools to insure electrical and electronic design adequacy. These references close with sections devoted to circuit design techniques for protection against indirect effects, and general test techniques for Indirect Effects on electrical/electronic components and systems. RTCA DO-160

FAA AC21-16, which indicates that RTCA DO-160 is to be used for equipment certification, has two sections dedicated to lightning test. Section 23 is used for Direct Effects with test techniques expanded in SAE ARPs 5416 and 5577. Section 22 provides test methods, standard test waveforms, waveform sets, and amplitude selection levels for Indirect Effects, which are Pin Injection, Single and Multiple Stroke, and Multiple Burst. While RTCA DO-160 was developed for TSO equipment, test methods can be tailored for integrated system (system rig) tests. SAE ARP5415 (Reference 2.6) provides guidance on integrated system (system rig) tests. Waveforms and amplitudes can also be modified based on actual installation (power plant) tests. A User's Guide is anticipated for future editions of RTCA DO-160.

5.2 An Approach to Compliance

The following steps are necessary elements to achieving integrated system compliance with the Indirect Effects of Lightning.

5.2.1 Zones and Direct Effects

The first step to protecting the control system is the need to insure that there is no direct attachment and Direct Effects protection is designed and in place for any components. The nacelle provides this protective medium. It must be designed to provide the necessary protection, i.e. no punctures, etc. In addition it must be certified by test, usually coupons, or by analysis/similarity. If the nacelle is provided with the power plant, this task/step is the responsibility of the engine manufacturer.

The process, however, begins with zoning. When an aircraft or engine gets struck the lightning flash attaches to, or enters at one point and exits from one or more other points. Usually, these are the extremities such as the engine tailpipe or the aircraft tail, vertical stabilizer, or rotor blade tips on rotary wing aircraft. Once the zoning is completed the nacelle manufacturer will know what Lightning Components are applicable and the necessary protection level based on waveform and amplitude. It should be noted that this process is, also, fundamental to determining the appropriate Indirect Effects waveforms and amplitudes. Current on the nacelle will instigate magnetic coupling to interior wiring and this results in induced voltages and currents in the cables and at the pins of electrical connectors for electronics such as FADECS, and electrical components such as actuators and sensors. So, for the aft fuselage engine, the preponderate Zone is 2A. So, Component A current for one, would apply at amplitude of 100KA. For the wing mounted engine, however, there are several zones but Zone 1A typically exists back through the fan cowl door. Component A in this case would be 200KA. This higher amplitude nacelle current could therefore instigate larger cable induced voltages and currents on the interior cable and connector pins. It is, therefore, the preeminent zone on this engine for the engine mounted (usually fan case) control system. Note to, that nose, tail, wing attachments can also result in control induced voltages and currents, but relative to engines the nacelles inlet and exhaust are typically worst case.

Since most aircraft fly more than their own length within the lifetime of most flashes, the attachments can change as the flash reattaches to other spots aft of the initial entry point. The exit point may do the same if the initial exit point is at a forward portion of the aircraft.

There are some regions on the aircraft where lightning is unlikely to attach and others which will be exposed to attachment for only a small portion of the flash duration. For purpose of protection design, the Aircraft Lightning Zones used by regulatory agencies have been defined in SAE ARP5414A/ED84 (Reference-2.2) as follows:

Zone 1A: First return stroke – All areas of the aircraft surfaces where a first return stroke is likely during a lightning channel attachment with a low expectation of flash hang on.

Zone 1B: First return stroke with long hang on – All areas of the aircraft surfaces where a first return stroke is likely during lightning channel attachment with a high expectation of flash hang on.

Zone 1C All areas of the aircraft surfaces where a first return stroke of reduced amplitude is likely during lightning channel attachment with a low expectation of flash hang on.

Zone 2A: All areas of the aircraft surfaces where subsequent return stroke is likely to be swept with a low expectation of flash hang on.

Zone 2B: All areas of the aircraft surfaces into which a lightning channel carrying a subsequent return stroke is likely to be swept with a high expectation of flash hang on.

Zone 3: Those surfaces not in Zones 1A, 1B, 2A, and 2B, where any attachment of the lightning channel is unlikely, and those portions of the aircraft that lies within or beneath or between the other zones, which may carry substantial amounts of electrical current between direct or swept stroke attachment points.

Figures 8 and 9 depict typical zones for wing mounted engines and aft fuselage mounted engine. These are typical and must be adjusted (especially Zone 1A) for aircraft speed and may be further refined based on actual airframe or power plant experience.

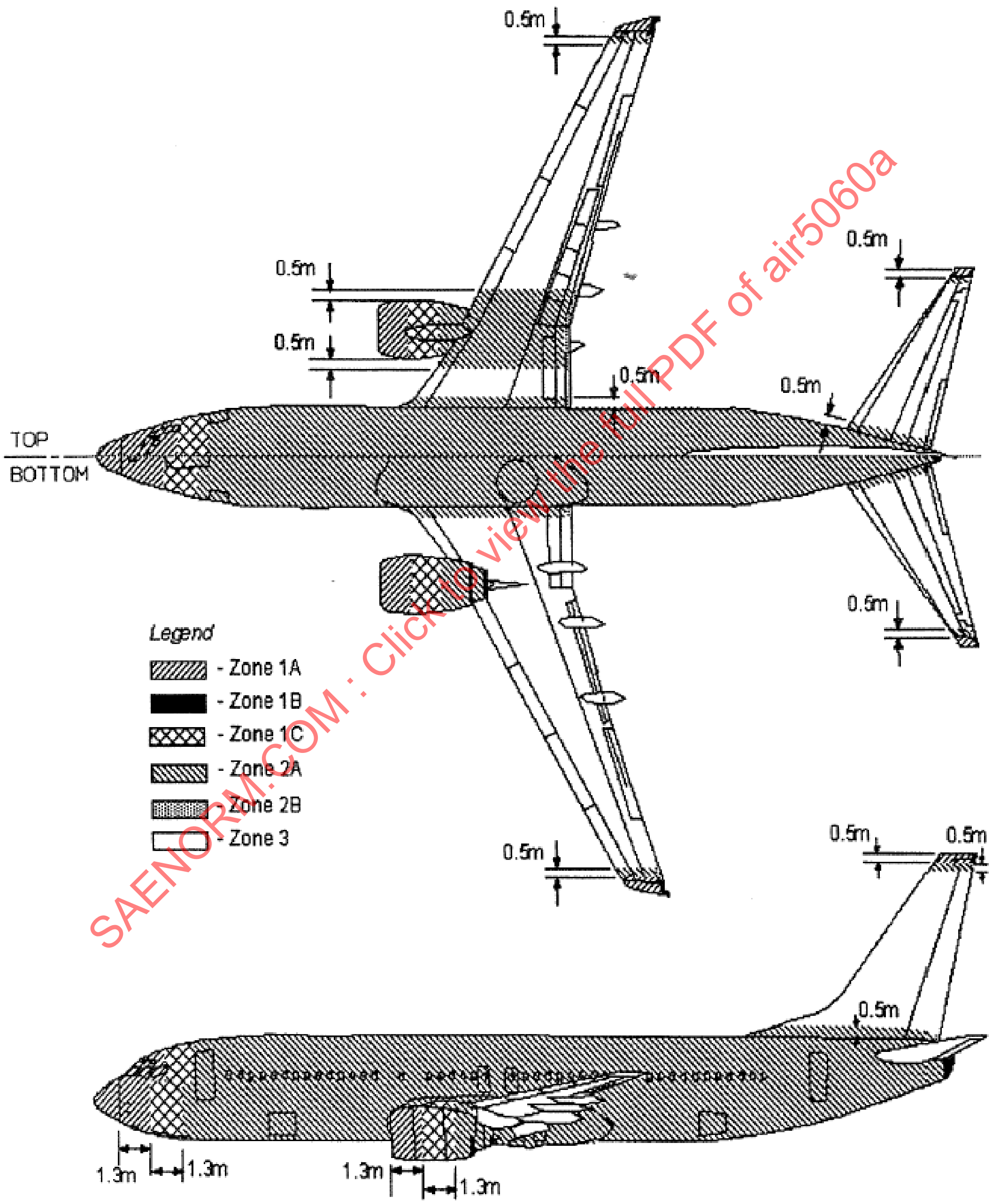

FIGURE 8 - EXAMPLES OF LIGHTNING STRIKE ZONE DETAILS FOR TRANSPORT AIRCRAFT

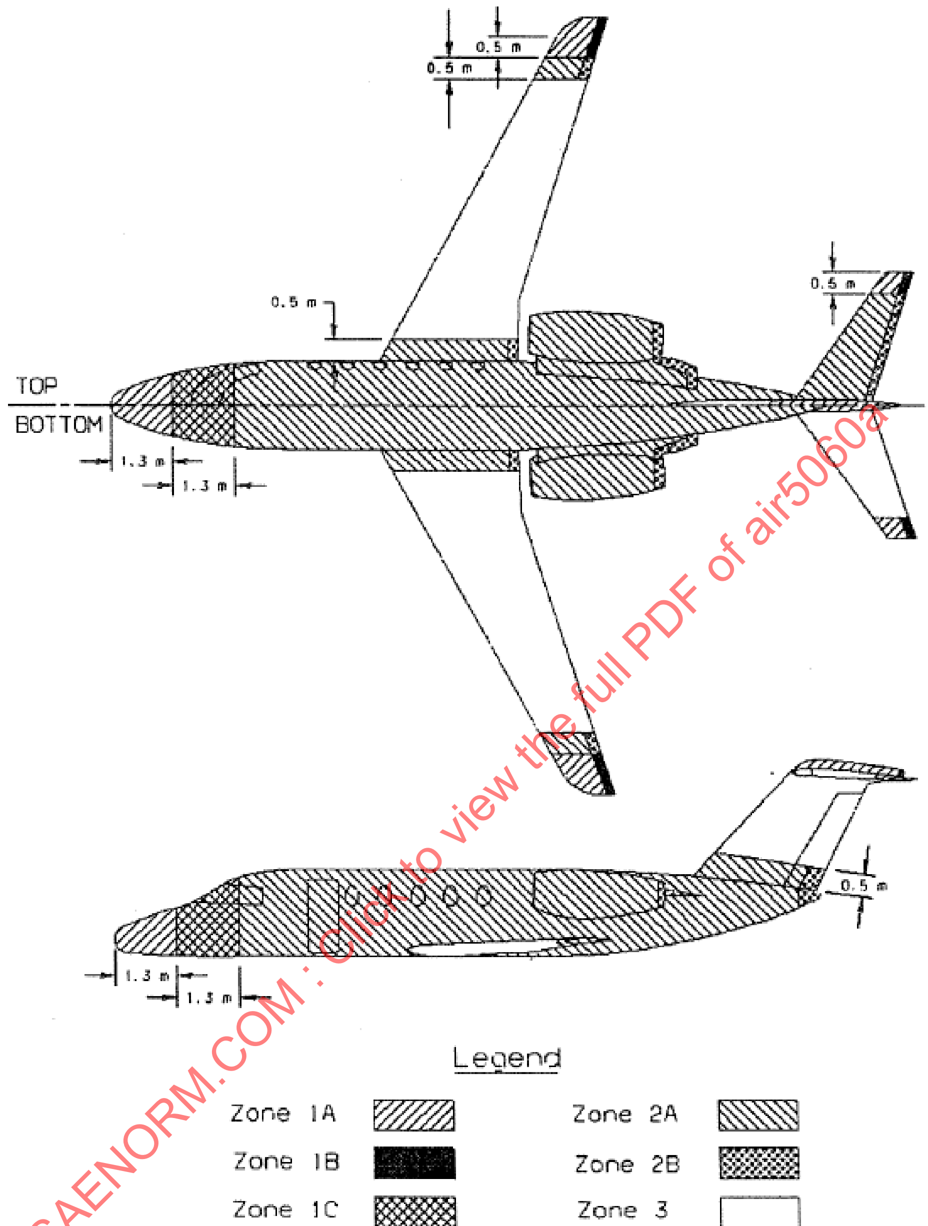

FIGURE 9 - EXAMPLES OF LIGHTNING STRIKE ZONE DETAILS FOR SWEPT WING BUSINESS JET

5.2.2 Indirect Effects Determination

5.2.2.1 Airframe Interfaces

The waveforms and amplitudes for airframe interfaces such as 28VDC power, ARINC, or TRA/TLA are provided by the airframe manufacturer in the SCD or engine specification as they are determined mostly by the cables routed in the wing and the fuselage. In some cases, the cables between the FADEC, for example, and the pylon disconnects could contribute significant amplitudes which may, also, need to be considered.

5.2.2.2 Engine Interfaces

Engine interfaces constitute those power and signal pairs and triplets that are connected between the FADEC and its engine mounted sensors and actuators. Some typical interfaces are PMA, EGT, LVDTs, discretes, torque motors, and solenoids. If the nacelle and nacelle systems, such as the thrust reverser, are provided by the engine manufacturer, then, these also would be “engine” signals. Of course, airframe manufacturer defined waveforms and amplitudes would to those that interface with the airframe.

Engine interface waveforms and amplitudes must, therefore, be determined by test, similarity, or analysis. The waveforms and amplitudes could, also, be taken from the categories and tables in RTCA DO-160, section 22 (Reference 2.10). In, this case, however, since the engine electrical/electronic control system is a Level A system from the functional hazards analysis, these default waveforms and amplitudes must be validated. Typically, the waveforms and amplitudes are determined and validated by test (engine test) or by similarity and analysis based on a prior engine test. Analysis alone is an option and computer programs are evolving with much greater sophistication, but these methods usually require significant levels of detail which compromise time and any computer modeling tools will, ultimately, require validation to insure accuracy.

5.2.2.3 Engine Tests

The engine should be mounted to replicate its interface to the pylon. Engine electrical and electronic components including cables must be mounted and electrically bonded on the engine as they would be on the production engine. All electrical and electronic components would, also, be conformed as ultimately the data will form part of the certification basis. The engine would be set up with a return conductor array for the lightning transient generator return to insure that the measured amplitudes reflect true levels and not those which have been reduced by coupling from the generator return path. SAE ARP5416 (Reference 2.13) Figure 17 depicts such an array for a small aircraft. The test might use more than one transient injection point. For instance, for a wing mounted engine (under the wing pylon mount), the lower lip of the inlet and the exhaust or tail. In some cases the mast may, also, be tested as an injection point. All are driven by field data on engines that have experienced lightning attachments. It should, also, be noted that the engine and the engine electrical and electronic systems would not be functional. It is an inert test bed used to replicate the coupling to the cables in an actual lightning attachment. Two waveforms and hence two transient generators would be necessary for this test. One is Component A (Waveform 1) and one is Component H (Waveform 6h). Waveforms 1 and 6h follow Component s A and H, respectively. Waveform 1 is shown in Figure 10 and Waveform 6h is shown in Figure 11. In Waveform 1 tests cable currents are measured and scaled up. So if an engine to be wing mounted was tested using a 1000 amp Waveform 1 transient, all results must be scaled up by 200 to 1 to reflect the fact that the certification level is 200 000 amps. The scaled up levels becomes the ATLs, Actual Transient Levels, for the Single and Multiple Stroke environments. In this test, conductor voltages and short circuit currents are also measured and scaled up. These are the ATLs for the Pin Injection requirement. In the Waveform 6h tests, cable currents are measured. These must also be scaled up to reflect the proper certification level 10 000 amps. So if the test transient was 500 amps, all measurements would be scaled up by 20 to 1. Then the final amplitudes become the ATLs for the Multiple Burst environment.

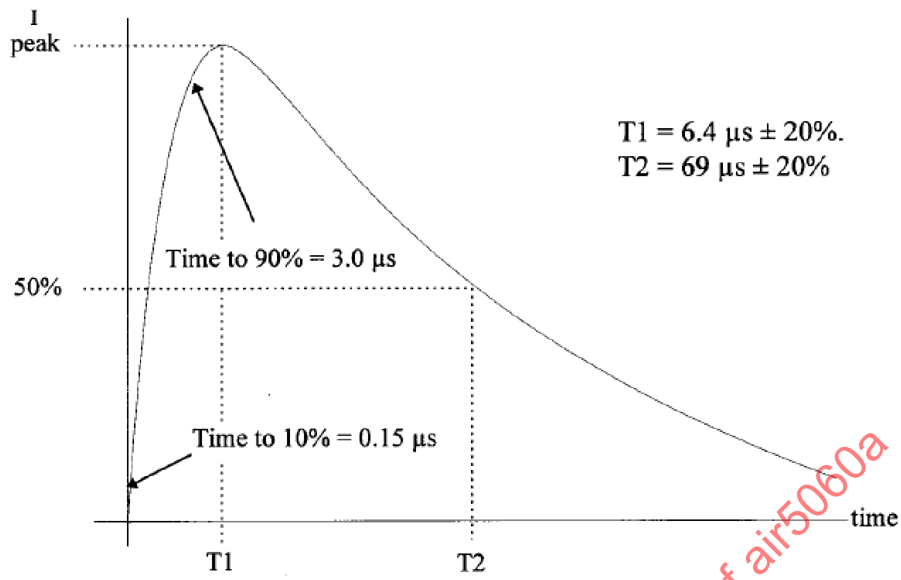

FIGURE 10 - DOUBLE EXPONENTIAL CURRENT WAVEFORM 1

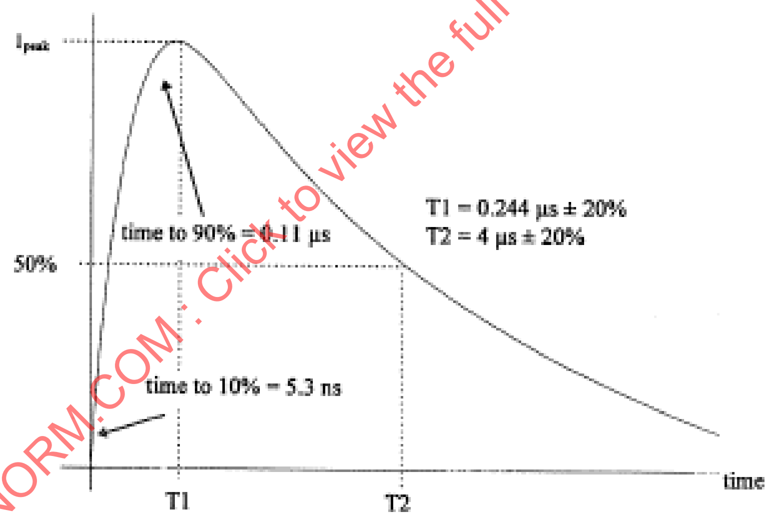

FIGURE 11 - DOUBLE EXPONENTIAL CURRENT WAVEFORM 6H

5.2.2.4 Indirect Effects Design and Test Requirements

The Equipment Transient Design Level (ETDL) is ultimately the Indirect Effects Design and Test requirement as shown in Figure 12 and Figure 1 in AC20-136 (Reference 2.5). Once the Actual Transient Levels (ATL) has been measured the Transient Control Level (TCL) needs to be established. So, for example after reviewing the connector pin voltages that were measured, one might select the largest amplitude as the Transient Control Level. Once selected a margin must be added in. Usually for ATLs established by actual test, which is the most reliable method to obtain the TCL, the margin is 2X that is, it's doubled. The final amplitude is then, the Equipment Transient Design Level or ETDL. This process would continue until the Pin Injection, Single and Multiple Stroke, and Multiple Burst levels have been established. As was previously indicated, Waveform 1 (same waveshape as Component A) is used in the engine tests to establish the Pin Injection and Single and Multiple stroke transients' requirements. The wave shape of the measured transient seldom follows the injected waveform. In most cases, an engineering waveform in RTCA DO-160 Section 22 (Reference 2.10) or SAE ARP5412 (Reference 2.9) can be used for the ETDL as it is a close approximation or a worst case. In some cases, the waveform may be a significant departure from the established engineering waveforms and warrant the use of a tailored waveform on a subset of connector pins or cables.

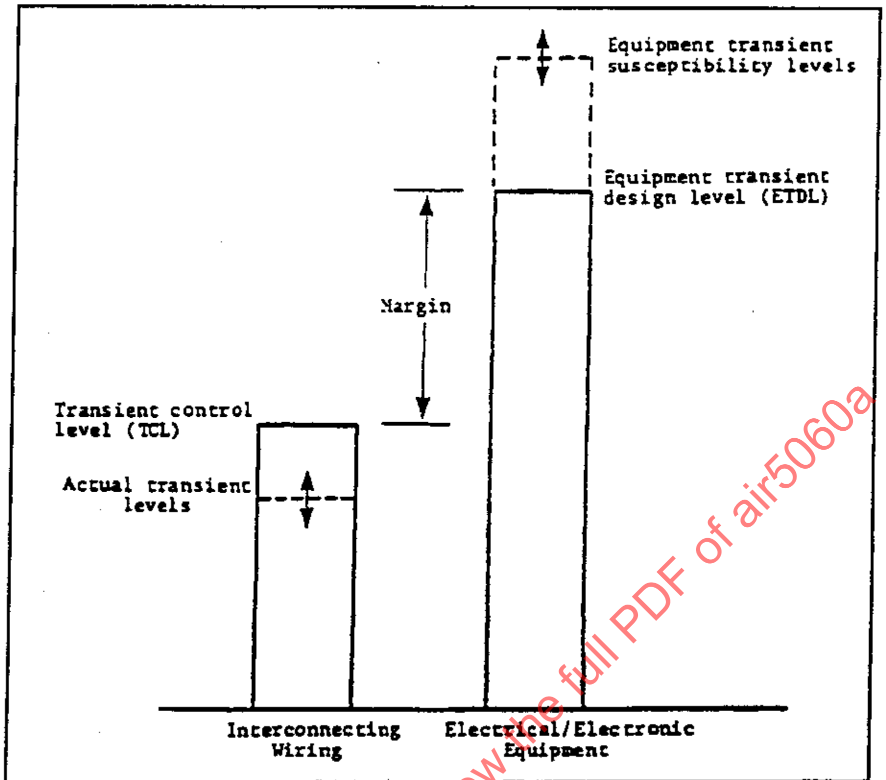

FIGURE 12 - RELATIONSHIPS BETWEEN TRANSIENT LEVELS

5.3 System Design for Compliance

While the heart of the control system is the Electronic Engine Control, and in many cases, a Full Authority Digital Engine Control, all electrical and electronic components must be addressed in the design phase. One must design to manage or minimize the threat, to provide inherent hardness, where possible, and to produce hardware that has the necessary protection over the life of the system. The following indicates the multifaceted task and key elements necessary to produce a compliant system.

5.3.1 Wiring

All engine and nacelle wiring must be shielded. All wire bundles must be routed and held close to the engine to reduce loop area. See Figure 13 (Figure 15.1 of the FAA Lightning Protection Handbook) depicts the placement of conductors which could be cables and the effect on flux coupling. The greater the flux, the greater the induced current on the cable. Each shield must be grounded at both ends of the cable and intermediate breaks to its connector back-shells. This is a critical step as it affects the induced voltage on the interior conductors. The induced voltage must be managed or minimized by reducing the flux coupled directly due to the current on the cable. See Figure 14 (Figure 15.26, of the FAA Handbook.). This figure emphasizes the need to use minimal length pigtails by grounding to the connector back-shell. In addition, the shields must be terminated uniformly and peripherally around the back-shell to get flux cancellation. A good termination aids in keeping the shielded twisted pair or triplet etc. transfer impedance low. Both the termination and shield itself are major factors determining the shield transfer impedance. Typical shielded twisted pairs, etc. have a shield transfer impedance of approximately 32 milliohms per meter. This is significant to the determination of the internal conductor induced voltage and ultimately to the protection necessary in FADECs and engine electrical components. The following simple example will exemplify its role. If engine measurements determine that a particular 3 meter shielded twisted pair had a 100 ampere peak lightning transient and the transient is one of the long double exponentials Waveforms 1 or 5A for example, then we can get the induced voltage as follows:

100 Amps X .032 ohm per meter X 3 Meters = 96 volts