AMC-20 Amendment 23 — Change information

The European Union Aviation Safety Agency (EASA) publishes amendments to the General Acceptable Means of Compliance for Airworthiness of Products, Parts and Appliances (AMC-20) as consolidated documents. These documents are used for establishing the certification basis for applications submitted after the date of entry into force of the applicable amendment.

Consequently, except for a note '[Amdt 20/23]' under the amended paragraph, the consolidated text of the AMC does not allow readers to see the detailed amendments that have been introduced compared to the previous amendment.

To allow readers to see these amendments, this document has been created. The same format is used to show the amendments as for the publication of notices of proposed amendments (NPAs):

The text of the amendment is arranged to show deleted, new or amended text as shown below:

— deleted text is ~~struck through~~;

— new or amended text is highlighted in blue;

— an ellipsis '[…]' indicates that the rest of the text is unchanged.

However, due to the fact that extensive, major amendments have been made to EASA AMC 20-136 and AMC 20-158, a completely new text is proposed.

Note to the reader

In amended, and in particular in existing (that is, unchanged) text, 'Agency' *is used interchangeably with* 'EASA'*. The interchangeable use of these two terms is more apparent in the consolidated versions. Therefore, please note that both terms refer to the* 'European Union Aviation Safety Agency (EASA)'.

AMC 20-136A Aircraft Electrical and Electronic System Lightning Protection

1. PURPOSE

a. This AMC describes an acceptable means, but not the only means, for demonstrating compliance with the applicable certification specifications (CSs) related to system lightning protection (CS 23.1306/2515, CS 25.1316, CS 27.1316, and CS 29.1316). Compliance with this AMC is not mandatory, and an applicant may elect to use an alternative means of compliance. However, the alternative means of compliance must meet the relevant requirements, ensure an equivalent level of safety, and be approved by EASA on a product or ETSO article basis.

b. The modal verb 'must' is used to indicate which means are necessary to demonstrate compliance with the applicable CSs by using this AMC. The modal verb 'should' is used when following this AMC to indicate that an action is recommended but is not necessary to demonstrate compliance with the applicable CSs when using this AMC.

c. Appendix 1 addresses definitions and acronyms. Appendix 2 contains examples.

2. SCOPE AND APPLICABILITY

a. This AMC provides possible means to demonstrate compliance with CS 23.1306/2515, 25.1316, 27.1316, and 29.1316 for the effects on electrical and electronic systems due to lightning transients induced or conducted onto equipment and wiring. This AMC may be used by applicants for a new type certificate (TC) or a change to an existing TC when the certification basis requires to address the above-mentioned CSs.

Note: For CS-23 Amendment 5 and higher, there is a new specification, i.e. CS 23.2515, which is similar to CS 23.1306. The associated AMC for CS 23.2515 is published separately in the AMC & GM to CS-23, based on ASTM F3061/F3061M-17. The present AMC 20-136A can still be used as guidance for CS 23.2515, which would be acceptable as equivalent means of compliance as AMC/GM CS-23.

b. Applicants must also comply with CS 23.1306/2515, 25.1316, 27.1316, and 29.1316 for the effects on aircraft electrical and electronic systems when lightning directly attaches to equipment, components, or wiring. This AMC addresses the functional aspects of these effects on aircraft electrical and electronic equipment, components, or wiring. However, this AMC does not address lightning effects such as burning, eroding, and blasting of aircraft equipment, components, or wiring. Compliance for these effects is demonstrated by meeting the applicable CS 23.867/2335, 25.581, 27.610, 27.865, 29.610, and 29.865 and following the associated AMC.

c. For information on fuel ignition hazards due to lightning, see AMC 25.954, *Fuel System Lightning Protection*, FAA ACs 20-53C, *Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Caused By Lightning*, and 25.954-1, *Transport Airplane Fuel System Lightning*

Protection.

d. This AMC does not address lightning zoning methods, lightning environment definition, or lightning test methods. For information on these topics, appropriate EUROCAE/SAE guidance material can be used. For information on fuel structural lightning protection, see EUROCAE policy ER-002 and ER-006.

3. DOCUMENT HISTORY

This AMC supersedes AMC 20-136, *Aircraft Electrical and Electronic System Lightning Protection*, dated 15 July 2015.

4. RELATED MATERIAL

a. European Union Aviation Safety Agency (EASA) (in this document also referred to as 'the Agency')

Certification Specifications:

1. CS 23.867/2335, 23.901/2400, 23.954/2430, 23.1301/2500, 23.1306/2515, 23.1309/2510, 23.1529/2625;
2. CS 25.581, 25.901, 25.954, 25.1301, 25.1309, 25.1316, 25.1529, 25.1705;
3. CS 27.610, 27.901, 27.954, 27.1301, 27.1309, 27.1316, 27.1529; and
4. CS 29.610, 29.901, 29.954, 29.1301, 29.1309, 29.1316, 29.1529.

EASA Certification Specifications (CSs) and Acceptable Means of Compliance (AMC) may be downloaded from the EASA website at www.easa.europa.eu.

b. FAA Advisory Circulars (ACs)

1. AC 20-155, *SAE Documents to Support Aircraft Lightning Protection Certification*
2. AC 21-16, *RTCA Document DO-160 Versions D, E, F, and G, Environmental Conditions and Test Procedures for Airborne Equipment*
3. AC 23-17, *Systems and Equipment Guide for Certification of Part 23 Airplanes and Airships*
4. AC 23.1309-1E, *System Safety Analysis and Assessment for Part 23 Airplanes*
5. AC 27-1B, *Certification of Normal Category Rotorcraft*
6. AC 29-2C, *Certification of Transport Category Rotorcraft*

The applicant can view and download copies from the FAA web-based Regulatory and Guidance Library (RGL) at http://www.airweb.faa.gov. On the RGL website, the applicant should select 'Advisory Circular', then select 'By Number'. ACs are also available on the FAA website at http://www.faa.gov/regulations_policies/advisory_circulars/.

c. European Organisation for Civil Aviation Equipment (EUROCAE)

1. EUROCAE ED-79A, *Guidelines for Development of Civil Aircraft and Systems*
2. EUROCAE ED-14G, *Environmental Conditions and Test Procedures for Airborne Equipment*
3. EUROCAE ED-84A, *Aircraft Lightning Environment and Related Test Waveforms*
4. EUROCAE ED-91A, *Aircraft Lightning Zoning*
5. EUROCAE ED-105A, *Aircraft Lightning Test Methods*
6. EUROCAE ED-113, *Aircraft Lightning Direct Effects Certification*
7. EUROCAE ED-158, *User Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning*
8. EUROCAE ED-234, *User Guide Supplement to ED-14G*

EUROCAE documents may be purchased from:

European Organisation for Civil Aviation Equipment
9-23 rue Paul Lafargue
"Le Triangle" building
93200 Saint-Denis, France
Telephone: +33 1 49 46 19 65

(Email: eurocae@eurocae.net, website: www.eurocae.net)

d. Radio Technical Commission for Aeronautics (RTCA)

1. DO-160, *Environmental Conditions and Test Procedures for Airborne Equipment*. This document is technically equivalent to EUROCAE ED-14. Anywhere there is a reference to RTCA/DO-160, EUROCAE ED-14 may be used.
2. DO-357, *User Guide Supplement to DO-160*. This document is technically equivalent to EUROCAE ED-234. Anywhere there is a reference to RTCA/DO-357, EUROCAE ED-234 may be used.

   RTCA documents may be purchased from:

   RTCA, Inc., 1150 18th Street NW, Suite 910, Washington D.C. 20036, USA

   (Email: info@rtca.org, website: www.rtca.org)

e. Society of Automotive Engineers (SAE International)

1. SAE Aerospace Recommended Practice (ARP) 4754A, *Guidelines for Development of Civil Aircraft and Systems*, December 2010. This document is technically equivalent to EUROCAE ED-79A. Anywhere there is a reference to ARP 4754A, EUROCAE ED-79A may be used.
2. SAE ARP 4761, *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment*, December 1996.

3. SAE ARP 5412B, *Aircraft Lightning Environment and Related Test Waveforms*. This document is technically equivalent to EUROCAE ED-84A. Anywhere there is a reference to ARP 5412A, EUROCAE ED-84A may be used.

4. ARP 5414B, *Aircraft Lightning Zoning*. This document is technically equivalent to EUROCAE ED-91A. Anywhere there is a reference to ARP 5414B, EUROCAE ED-91A may be used.

5. ARP 5415B, *User's Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning*. This document is technically equivalent to EUROCAE ED-158.

6. ARP 5416A, *Aircraft Lightning Test Methods*. This document is technically equivalent to EUROCAE ED-105A. Anywhere there is a reference to ARP 5416A, EUROCAE ED-105A may be used.

7. ARP 5577, *Aircraft Lightning Direct Effects Certification*. This document is technically equivalent to EUROCAE ED-113. Anywhere there is a reference to ARP 5577, EUROCAE ED-113 may be used.

SAE International documents may be purchased from:

SAE Customer Service
400 Commonwealth Drive
Warrendale, PA
15096-0001, USA

Website: http://www.sae.org

f. ASTM

F3061/F3061M-17, *Standard Specification for Systems and Equipment in Small Aircraft*

ASTM documents may be purchased from:

ASTM International
100 Barr Harbor Drive
PO Box C700
West Conshohocken, PA
19428-2959, USA

Website: https://www.astm.org

5. BACKGROUND

a. Regulatory applicability. The CSs for aircraft electrical and electronic system lightning protection are based on the aircraft's potential for lightning exposure and the consequences of system failures. The CSs require lightning protection of aircraft electrical and electronic systems with catastrophic, hazardous, or major failure conditions for aircraft certified under CS-25. The specifications also apply to CS-23 (at Amendment 4 or earlier) aeroplanes, and

CS-27 and CS-29 rotorcraft approved for operations under instrument flight rules (IFR). Those CS-23 aeroplanes, and CS-27 and CS-29 rotorcraft approved solely for operations under visual flight rules (VFR), require lightning protection of electrical and/or electronic systems that have catastrophic failure conditions.

For CS-23 Amendment 5, the electrical and electronic systems with catastrophic and hazardous failure conditions must be protected against the effects of lightning where exposure to lightning is likely.

b. **Regulatory requirements.** Protection against the effects of lightning for aircraft electrical and electronic systems, regardless of whether these are 'indirect' or 'direct' effects of lightning, is addressed under CS 23.1306/2515, 25.1316, 27.1316, and 29.1316. The terms 'indirect' and 'direct' are often used to classify the effects of lightning. However, the CSs do not, and are not intended to, differentiate between the effects of lightning. The focus is to protect aircraft electrical and electronic systems from the effects of lightning.

6. APPROACHES TO COMPLIANCE

a. **General.** The following activities describe how compliance with CS 23.1306/2515, 25.1316, 27.1316, and 29.1316 may be demonstrated. Adherence to the sequence shown is not necessary. More detailed information on lightning certification compliance is provided in the User's Manual referred to in SAE ARP 5415B / EUROCAE ED-158.

The applicant should:

1. identify the systems to be assessed (see Section 6(c));
2. determine the lightning strike zones for the aircraft (see Section 6(d));
3. establish the aircraft lightning environment for each zone (see Section 6(e));
4. determine the lightning transient environment associated with the systems (see Section 6(f));
5. establish equipment transient design levels (ETDLs) and aircraft actual transient levels (ATLs) (see Section 6(g));
6. verify compliance with the applicable requirements (see Section 6(h)); and
7. take corrective measures (if needed) (see Section 6(i)).

Sections 7 and 8 give more details on these steps for the compliance of Level A systems as well as of Level B and Level C systems respectively.

b. **Lightning effect considerations.** The steps above should be performed to address lightning transients induced in electrical and electronic system wiring and equipment, and lightning damage to aircraft external equipment and sensors that are connected to electrical and electronic systems, such as radio antennas and air-data probes. Additional guidance on lightning protection against lightning damage for external equipment and sensor installations can be found in EUROCAE ED-113.

Lightning causes voltage and current transients to appear on equipment circuits. Equipment circuit impedances and configurations will determine whether lightning transients are primarily voltage or current. These transient voltages and currents can degrade system performance permanently or temporarily. The two primary types of degradation are component damage and system functional upsets.

1. Component damage

This is a permanent condition in which transients alter the electrical characteristics of a circuit. Examples of devices that may be susceptible to component damage include the following:

(a) active electronic devices, especially high-frequency transistors, integrated circuits, microwave diodes, and power supply components;

(b) passive electrical and electronic components, especially those of very low power or voltage rating;

(c) electro-explosive devices, such as squibs and detonators;

(d) electromechanical devices, such as indicators, actuators, relays, and motors; and

(e) insulating materials (for example, insulating materials in printed circuit boards and connectors) and electrical connections that can burn or melt.

2. System functional upset

(a) Functional upset is mainly a system problem caused by electrical transients. They may permanently or momentarily upset a signal, circuit, or a system component, which can adversely affect system performance enough to compromise flight safety. A functional upset is a change in digital or analogue state that may or may not require a manual reset. In general, functional upset depends on circuit design and operating voltages, signal characteristics and timing, and the system and software configuration.

(b) Systems or devices that may be susceptible to functional upsets include computers and data/signal processing systems, electronic engine and flight controls, and power generating and distribution systems.

c. Identify the systems to be assessed

1. General. The aircraft systems that require a lightning safety assessment should be identified. The applicant should define the elements of the system performing a function, considering similar and/or dissimilar redundant channels that make up the system. The process used for identifying these systems should be similar to the process for demonstrating compliance with CS 23.1309, 25.1309, 27.1309, and 29.1309, as applicable. These points address any system failure that may cause or contribute to an effect on the safety of flight of an aircraft. The effects of a lightning should be assessed to determine the degree to which the safety of the aircraft and its systems may be affected.

The operation of the aircraft systems should be assessed separately and in combination with, or in relation to, other systems. This assessment should cover the following:

(a) all normal aircraft operating modes, phases of flight, and operating conditions;

(b) all lightning-related failure conditions and their subsequent effects on aircraft operations and the flight crew; and

(c) any corrective actions required by the flight crew during or after occurrence of a lightning-related failure.

2. Lightning safety assessment. A safety assessment related to lightning must be performed to establish and classify the equipment or system failure conditions. Table 1 provides the corresponding failure condition classification and system lightning certification level (LCL) for the appropriate lightning regulations. The failure condition classifications and terms used in this AMC are similar to those used in AC 23.1309-1E, AMC 25.1309, AC-27-1B, and AC-29-2C, as applicable. Only those systems identified as performing or contributing to functions whose failure would result in catastrophic, hazardous, or major failure conditions are subject to lightning regulations. Based on the safety classification of the failure condition established by the safety assessment, the systems should be assigned appropriate system LCLs, as shown in Table 1. The lightning safety assessment should consider the common-cause effects of lightning, particularly for highly integrated systems and systems with redundant elements. The lightning safety assessment determines the consequences of failures for the aircraft functions that are performed by the system. The system LCL classification assigned to the systems and functions can be different from the development assurance level (DAL) (ED-79A/ARP 4754A) / design assurance level (DAL) (ED-80/DO-254, ED-12C/DO-178C) assigned for equipment redundancy, software, and airborne electronic hardware (AEH). This is because lightning is an environment that can cause common-cause effects. The term 'design assurance level' or 'development assurance level' (both abbreviated to 'DAL') should not be used to describe the system LCL because of the potential differences in the assigned classifications for software, AEH, and equipment redundancy. The lightning safety assessment must include all electrical and electronic equipment, components and electrical interconnections, assuming that they are potentially affected by lightning. It is not appropriate to use the lightning immunity data for electrical and electronic equipment, components and electrical interconnections as an information input to the lightning safety assessment. This information should only be used in the next phase, to show compliance with the applicable subpart of the lightning regulation, after the required LCL for the system is defined by the lightning safety assessment. The lightning safety assessment results from inputs coordinated between the safety specialist, the system specialist, and the

HIRF/lightning specialist. This process may vary from applicant to applicant. Further details on performing the safety assessment can be found in AC 23.1309-1E, AMC 25.1309, AC-27-1B, AC-29-2C, EUROCAE ED-79A, SAE ARP 4761, and EUROCAE ED-158.

Note: Considering that lightning and HIRF environments may have similar effects on electro-electronic systems (disturbing electrical signals, causing upsets or damage to circuits) and that the applicable regulations are similarly structured, in many cases the system LCL and corresponding HIRF certification level (see AMC 20-158A) should be the same.

Table 1: Indirect effect of lightning most severe failure conditions of the function and system lightning certification levels

LIGHTNING REQUIREMENTS EXCERPTS FROM CS 23.1306/2515, CS 25.1316, CS 27.1316, AND CS 29.1316	MOST SEVERE FAILURE CONDITION OF THE FUNCTION	SYSTEM LIGHTNING CERTIFICATION LEVEL (LCL)
(a) Each electrical and electronic system that performs a function whose failure would prevent the continued safe flight and landing of the aircraft.	Catastrophic	A
(b) Each electrical and electronic system that performs a function, for which failure would reduce the capability of the aircraft or the ability of the flight crew to respond to an adverse operating condition. *Note: Requirement applicable for small aircraft and rotorcraft approved for instrument flight rule (IFR) operations*	Hazardous/ Major	B/C

3. **Level A systems.** The specifications in CS 23.1306/2515(a), 25.1316(a), 27.1316(a), and 29.1316(a) address the adverse effects on the aircraft functions and systems that perform functions whose failure would prevent the continued safe flight and landing of the aircraft. When demonstrating compliance with CS 23.1306(a), 25.1316(a), 27.1316(a), and 29.1316(a), the electrical and electronic system is the one required to perform the function whose failure would prevent continued safe flight and landing. This electrical and electronic system must also automatically recover normal operation of the Level A functions in a timely manner to comply with CS 23.1306(a)(2), 25.1316(a)(2), 27.1316(a)(2), and 29.1316(a)(2). If all equipment and components of the system required for the normal operation of the Level A functions are not susceptible when complying with paragraphs (a)(1) and (a)(2), then it is acceptable that the equipment and components only for non-normal situations do not show compliance with the requirements of paragraph (a). In this case, it is considered acceptable that equipment and components of the system required only for non-normal situations show compliance at least with the requirements of paragraph (b) as a Level B system.

The lightning safety assessment should consider the effects of lightning-related failures or malfunctions on systems with lower failure classifications that may affect the function of Level A systems. The applicant should demonstrate that any system with wiring connections to a Level A system will not adversely affect the functions with catastrophic failure conditions performed by the Level A system when the aircraft is exposed to lightning. Redundancy alone cannot protect against lightning because the lightning-generated electromagnetic fields, conducted currents and induced currents in the aircraft can simultaneously induce transients in all the electrical wiring on an aircraft.

4. **Level B or Level C systems.** Simultaneous and common-cause failures due to lightning exposure generally do not have to be assumed for systems, incorporating redundant, spatially separated installations in the aircraft. If such systems were assigned a Level B or C, the failure of these systems would reduce the capability of the aeroplane or the ability of the flight crew to respond to an adverse operating condition. This is because aircraft transfer function tests and in-service experience have shown that these redundant and spatially separated installations are not simultaneously exposed to the maximum lightning-induced transients. Therefore, the simultaneous loss of all these redundant and spatially separated Level B or Level C systems due to lightning exposure does not need to be considered. However, if multiple systems and their wirings, whose failure would reduce the capability of the aeroplane or the ability of the flight crew to respond to an adverse operating condition, are installed within the same location in the aircraft, or share a common wiring connection, then the combined failure due to lightning exposure should be assessed to determine whether the combined failures are catastrophic. If so, these systems should be designated as Level A systems.

5. **Failure conditions.** The lightning safety assessment should consider all the potential adverse effects due to system failures, malfunctions, or misleading information. The lightning safety assessment may show that some systems have different failure conditions in different phases of flight; therefore, the system LCL corresponds to the most severe failure condition. For example, an automatic flight control system may have a catastrophic failure condition for autoland, while automatic flight control system operations in cruise may have a hazardous failure condition.

d. Determine the lightning strike zones for the aircraft

The purpose of lightning zoning is to determine those areas of the aircraft that are likely to experience lightning channel attachment, and those structures that may conduct lightning current between lightning attachment points. The lightning attachment zones for the aircraft configuration should be determined, since the zones will be dependent upon the aircraft's geometry and materials, and upon operational factors. Lightning attachment zones often vary from one aircraft type to another.

Note: EUROCAE ED-91A provides guidance to determine the lightning attachment zones for aircraft.

e. Establish the aircraft lightning environment for each zone

Zones 1 and 2 identify where lightning is likely to attach and, as a result, the entrance and exit points for current flow through the aircraft. The appropriate voltage waveforms and current components to apply in those zones should be identified. By definition, Zone 3 areas carry lightning current flows between initial (or swept stroke) attachment points, so they may include contributions from all the current components. The Agency accepts analysis to estimate Zone 3 current levels that result from the external environment. The external lightning environment is:

1. caused by the lightning flash interacting with the exterior of the aircraft; and
2. represented by the combined waveforms of the lightning current components at the aircraft surface.

Note: EUROCAE ED-84A provides guidance for selecting the lightning waveforms and their applications.

f. Determine the lightning transient environment associated with the systems

1. The lightning environment, as seen by electrical and electronic systems, consists of voltages and currents produced by lightning currents flowing through the aircraft. The voltages and currents that appear at system wiring interfaces result from aperture coupling, structural voltages, or conducted currents resulting from direct attachments to equipment and sensors.
2. Applicants should determine the lightning voltage and current transient waveforms and amplitudes that can appear at the electrical and electronic equipment interface circuits for each system identified in paragraph 6(c). The lightning transients may be determined in terms of the wire-bundle current, or the open-circuit voltage and the short-circuit current appearing at system wiring and equipment interface circuits. The voltage and current transient waveforms and amplitudes are dependent upon the loop impedances of the system and its interconnecting wiring.

g. Establish equipment transient design levels (ETDLs) and aircraft actual transient levels (ATLs)

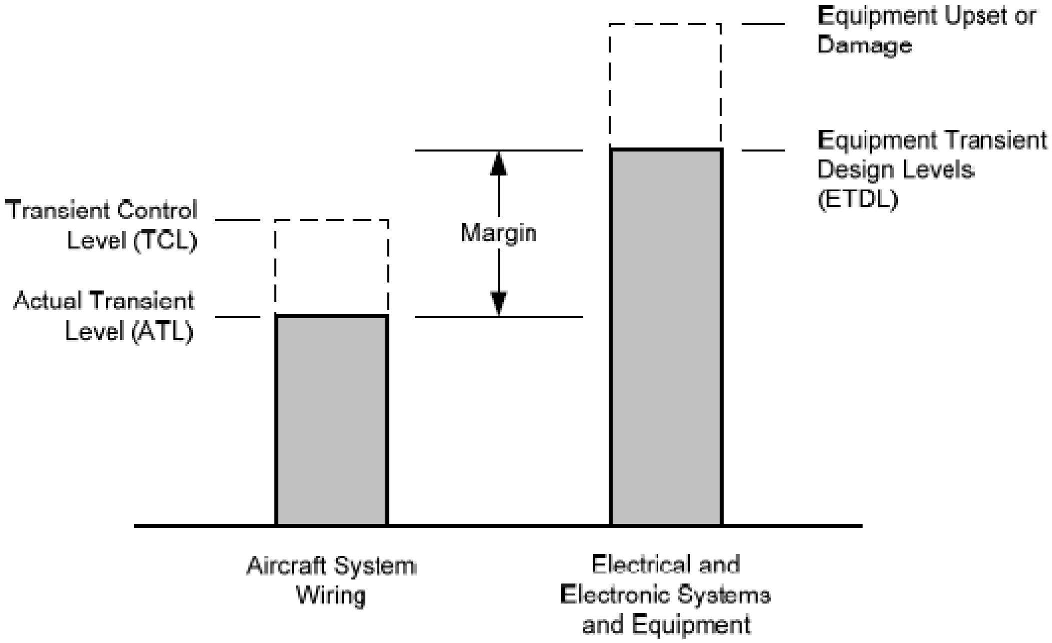
CS 23.1306/2515, 25.1316, 27.1316, and 29.1316 define the specifications in terms of functional effects that are performed by aircraft electrical and electronic systems. From a design point of view, lightning protection for systems is shared between protection incorporated into the aircraft structure and wiring, and protection incorporated into the equipment. Therefore, the requirement allocations for electrical and electronic system lightning protection can be based on the concept of ETDLs and ATLs.

1. The applicant should determine and specify the ETDLs for the electrical and electronic equipment that make up the systems to be assessed. The ETDLs set qualification test levels for the systems and equipment. They define the voltage and current amplitudes and waveforms that the systems and equipment must withstand without any adverse effects. The ETDLs for a specific system depend on the anticipated system and wiring installation locations on the aircraft, the expected shielding performance of the wire bundles and structure, and the system criticality.

2. The ATLs are the voltage and current amplitudes and waveforms actually generated on the aircraft wiring when the aircraft is exposed to lightning, as determined by aircraft test, analysis, or similarity. The difference between an ETDL and an ATL is the margin. Figure 1 shows the relationship between the ATL and the ETDL. The aircraft, interconnecting wiring, and equipment protection should be evaluated to determine the most effective combination of ATLs and ETDLs that will provide acceptable margin. Appropriate margins to account for uncertainties in the verification techniques may be necessary as mentioned in paragraph 7 of this AMC.

3. Typically, the applicant should specify the ETDLs prior to aircraft certification lightning tests or analyses to determine the aircraft ATLs. Therefore, the expected aircraft transients must be based upon results of lightning tests on existing aircraft, engineering analyses, or knowledgeable estimates. These expected aircraft lightning transient levels are termed transient control levels (TCLs). The TCL voltage and current amplitudes and waveforms should be specified based upon the expected lightning transients that would be generated on wiring in specific areas of the aircraft. The ATLs should be no greater than the TCLs. The TCLs for a specific wire bundle depend on the configuration of the aircraft, the wire bundle, and the wire bundle installation. The aircraft lightning protection should be designed to meet the specified TCLs.

Figure 1: Relationships between transient levels



h. Verify compliance with the applicable specifications

1. The applicant should demonstrate that the systems comply with the applicable specifications of CS 23.1306/2515, 25.1316, 27.1316, and 29.1316.

2. The applicant should demonstrate that the ETDLs exceed the ATLs by the margin established in their certification plan.

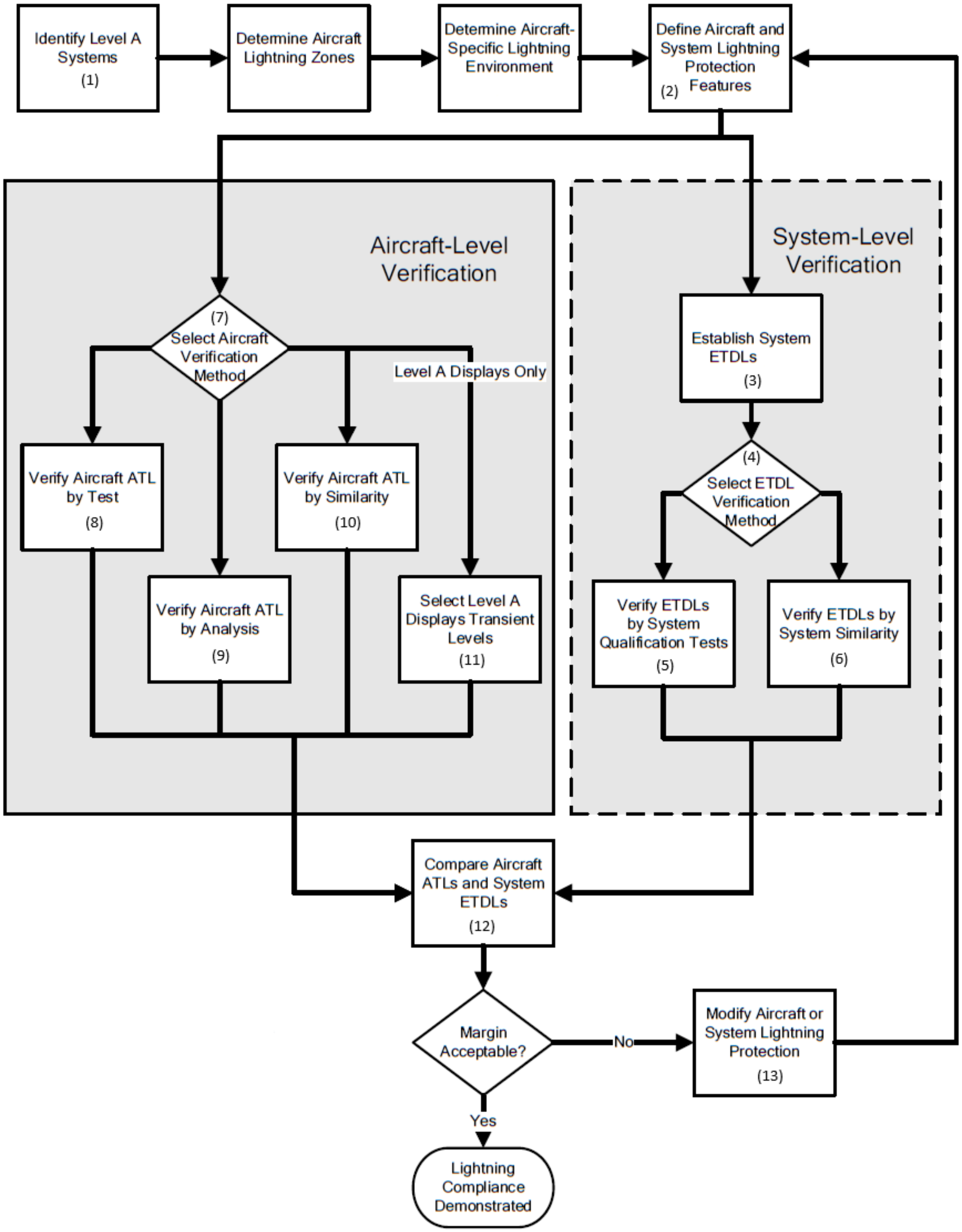
3. Verification may be accomplished by tests, analyses, or by demonstrating similarity to previously certified aircraft and systems. The certification process for Level A systems is contained in Section 7. The certification process for Level B and Level C systems is contained in Section 8.

4. The applicant should submit their compliance plan in the early stages of the programme to the Agency for review (see details in paragraph 7(a)). Experience shows that, particularly with aircraft using new technology or those that have complex systems, early agreement on the compliance plan benefits the certification of the product. The plan should define acceptable ways to resolve critical issues during the certification process. Analyses and test results during the certification process may warrant modifications to the design or verification methods. When significant changes are necessary, the certification plan should be updated accordingly.

i. Take corrective measures (if needed)

If tests and analyses show that the system did not meet the pass/fail criteria, review the aircraft, installation or system design and improve protection against lightning.

Figure 2: Routes to lightning compliance — Level A systems



(n) = Step number as described in Section 7 of this AMC

7. STEPS TO 'LEVEL A' SYSTEM LIGHTNING COMPLIANCE

Figure 2 illustrates a process that the applicant can use to demonstrate that their Level A system complies with CS 23.1306(a)/2515(a), 25.1316(a), 27.1316(a), and 29.1316(a).

a. Step 1 — Identify Level A systems

1. Level A systems should be identified as described in paragraph 6(c). The detailed system performance pass/fail criteria should be defined. The applicant should not begin testing or analysing their Level A system before the Agency has concurred on these criteria. Specific equipment, components, sensors, power systems and wiring associated with each Level A system should be identified in order to perform the ETDL verification mentioned in paragraphs 7(g) and 7(h).

2. The system defined for paragraph (a) of CS 23.1306/2515, 25.1316, 27.1316, and 29.1316 is not required to include:

   (a) equipment, components or electrical interconnections required only for non-normal situations; or

   (b) equipment, components or electrical interconnections required only for dispatching under master minimum equipment lists (MMELs) (when operational suitability data (OSD) is applicable).

3. Some systems include mechanical, hydraulic, and/or pneumatic channels as well as electrical and electronic channel(s) to perform functions whose failure would prevent continued safe flight and landing. The lightning safety assessment for CS 23.1306/2515(a), 25.1316(a), 27.1316(a), and 29.1316(a) only applies to functions performed by electrical and electronic systems. The lightning safety assessment should consider electrical or electronic failures that would adversely affect the function of the mechanical, hydraulic, and/or pneumatic channel(s). If electrical or electronic equipment and components, as well as electrical interconnections are used to assist, augment, or monitor for control loop feedback, the mechanical, hydraulic, and/or pneumatic channels in performing the normal operation of functions with potential failures that would prevent continued safe flight and landing, then the electrical and electronic channel(s) must comply with CS 23.1306/2515(a), 25.1316(a), 27.1316(a), and 29.1316(a).

4. CS 23.1306/2515(a), 25.1316(a), 27.1316(a), and 29.1316(a) do not require the applicant to assume pre-existing failure conditions when classifying the functional failure conditions and the scope of Level A systems. The applicant should consider total or partial loss of the systems and malfunctions of the systems, including hazardously misleading information presented to the flight crew during and after the aircraft is exposed to lightning.

5. CS 23.1306(a)(2), 25.1316(a)(2), 27.1316(a)(2), and 29.1316(a)(2) require that Level A systems automatically recover normal operation of the Level A functions in a timely

manner after exposure to lightning. Automatic recovery applies to all redundant active channels of the Level A system required for normal operation unless its recovery conflicts with other operational or functional requirements of the system. The exception for automatic recovery conflicts must be based on aircraft operational or functional requirements independent of lightning exposure.

6. Appendix 2 *Examples of lightning safety assessment considerations — Level A systems* provides examples of systems' scope based on the guidance above.

b. **Step 2 — Define aircraft and system lightning protection.** The applicant should define the lightning protection features to be incorporated into the aircraft and system designs, based on the lightning environments that are applicable to their aircraft and its Level A systems. Equipment, system, and aircraft lightning protection design may occur before aircraft-level tests are performed, and before the actual internal lightning environment is determined. Therefore, the equipment, system and aircraft lightning protection design should be based on an estimate of the expected internal lightning environment.

c. **Step 3 — Establish the system's ETDLs.** The applicant should establish the aircraft system's ETDLs from an evaluation of expected lightning transient amplitudes and waveforms for the system installation, structure and wiring configuration on a specific aircraft. ETDLs that exceed the ATLs by an acceptable margin should be established. In general, the ETDLs for equipment in a complex system will not be the same for all wire bundles connecting them to other equipment in the system. The applicant may use the results of lightning tests on existing similar aircraft, engineering analyses, or knowledgeable estimates to establish the appropriate system's ETDLs. While specific aircraft configurations and system installations may lead to ETDLs that have amplitudes and waveforms different from those defined in EUROCAE ED-14G Section 22, ETDLs are often specified using the information from Section 22. The ETDLs must exceed the ATLs by an acceptable margin.

d. **Step 4 — Select the ETDL verification method.** The applicant should determine whether to perform system qualification tests on the Level A system, or whether to base the system verification on previous system qualification tests performed on a similar system.

e. **Step 5 — Verify the system's ETDLs using system qualification tests**

1. **Equipment test.** Lightning induced transient susceptibility tests (*Tolerance Damage and Functional Upset*) of RTCA / DO-160G / EUROCAE ED-14G (or latest version) Section 22 may be used to build confidence in the equipment's lightning immunity before conducting integrated system qualification tests. Equipment tests may be used to augment the system qualification tests where appropriate. For equipment whose lightning immunity is evaluated as part of the system qualification tests, the individual equipment's lightning testing described in this step is optional.

2. The applicant should identify the equipment, components, sensors, power systems, and wiring associated with the Level A system undergoing ETDL verification tests, specifically considering the system functions whose failures would have catastrophic

consequences. For complex Level A systems, the system configuration may include redundant equipment, multiple power sources, multiple sensors and actuators, and complex wire bundles. The applicant should define the system configuration used for the ETDL verification tests. The applicant should obtain the Agency's acceptance of their system configuration for ETDL verification tests.

3. If the Level A System consists of multiple similar channels, the applicant can propose using one or more channels in the laboratory test set-up for the integrated system, instead of all similar channels. The applicant should demonstrate that the laboratory test set-up adequately performs the functions that must demonstrate compliance with CS 23.1306/2515(a), 25.1316(a), 27.1316(a), and 29.1316(a). The applicant should ensure that the laboratory test set-up represents and monitors any cross-channel interactions, such as cross-channel data links, redundancy management, and system health monitoring.

   Note: Similar channels are composed of equipment that has the same hardware but not necessarily the same part number; if Pin Programming and/or Software are used to identify or configure equipment of similar channels, it must be assessed whether these differences have an impact on the functions performed.

4. The applicant should verify the ETDLs using single-stroke, multiple-stroke, and multiple-burst tests on the system wire bundles. The applicant should use waveform sets and test levels for the defined ETDLs, and demonstrate that the system operates within the defined pass/fail criteria during these tests. No equipment damage that adversely affects the function or system should occur during these system tests or during single-stroke pin injection tests using the defined ETDLs. It could be verified during system test that the equipment ETDL declared by the supplier is not exceeded. EUROCAE ED-14G Section 22 provides acceptable test procedures and waveform set definitions. In addition, EUROCAE ED-105A provides acceptable test methods for complex and integrated systems.

5. The applicant should evaluate any system effects observed during the qualification tests to ensure they do not adversely affect the system's continued performance. The Level A system performance should be evaluated for functions whose failures or malfunctions would prevent the continued safe flight and landing of the aircraft. Other functions performed by the system whose failures or malfunctions would reduce the capability of the aircraft or the ability of the flight crew to respond to an adverse operating condition should be evaluated using the guidance provided in Section 10 of this AMC. The applicant should obtain the Agency's acceptance of their evaluation.

f. Step 6 — Verify the system's ETDLs using existing system data (similarity)

1. The applicant may base their ETDL verification on similarity to previously certified systems without performing more tests. This may be done when:

   (a) there are only minor differences between the previously certified system and installation and the system and installation to be certified;

(b) there are no unresolved in-service system problems related to lightning strikes on the previously certified system; and

(c) the previously certified system ETDLs were verified by qualification tests.

2. To use similarity to previously certified systems, the applicant should assess the differences between the previously certified system and installation and the system and installation to be certified that can adversely affect the system's susceptibility. The assessment should cover the following:

(a) system interface circuits;

(b) wire size, routing, arrangement (parallel or twisted wires), connector types, wire shields, and shield terminations;

(c) lightning protection devices, such as transient suppressors and lightning arrestors;

(d) grounding and bonding; and

(e) system software and AEH.

3. If the applicant is unsure how the differences will affect the systems and installations, they should perform more tests and analyses to resolve the open issues.

4. The applicant should assess every system, even if it uses equipment and installation techniques that have a previous certification approval.

5. The use of similarity should not be used for a new aircraft design with new systems.

g. Step 7 — Select the aircraft verification method

1. Level A systems require an aircraft assessment. The aircraft assessment should determine the ATLs where Level A systems are installed in the aircraft. The applicant should choose whether to use aircraft tests or previous data from similar aircraft types (similarity). For level A display systems only, the applicant could select the ETDLs as proposed in Table 3.

2. If analysis is used to determine the ATLs, test data should be provided to support this analysis. Any analysis results should take into account the quality and accuracy of the analysis. Significant testing, including aircraft-level testing, may be required to support the analysis.

h. Step 8 — Determine the ATLs using aircraft tests. See SAE ARP 5415B / EUROCAE ED-158, *User Manual for certification of aircraft Electrical and Electronic systems for the indirect effects of lightning*, and EUROCAE ED-105A *Aircraft Lightning Test Method* for guidance on how to determine the ATLs.

i. Step 9 — Determine the ATLs using analysis. See SAE ARP 5415B / EUROCAE ED-158 for guidance on how to analyse aircraft to determine the ATLs. Acceptance of the analysis method chosen will depend on the accuracy of the method. The applicant should confirm their analysis method accuracy using experimental data, and gain agreement of their analysis approach from the Agency.

j. Step 10 — Determine the ATLs using similarity

1. The use of similarity to determine the ATLs may be used when:

   (a) there are only minor differences between the previously certified aircraft and system installation and the aircraft and system installation to be certified; and

   (b) there is no unresolved in-service history of problems related to lightning strikes to the previously certified aircraft.

2. If significant differences are found that will affect the aircraft ATLs, the applicant should perform more tests and analyses to resolve the open issues.

3. To use similarity, the applicant should assess the aircraft, wiring, and system installation differences that can adversely affect the system's susceptibility. When assessing a new installation, the applicant should consider the differences affecting the internal lightning environment of the aircraft and its effects on the system. The assessment should cover the following:

   (a) the aircraft type, equipment locations, airframe construction, structural materials, and apertures that could affect attenuation of the external lightning environment;

   (b) the system wiring size, length, and routing; wire types (whether parallel or twisted wires), connectors, wire shields, and shield terminations;

   (c) lightning protection devices, such as transient suppressors and lightning arrestors; and

   (d) grounding and bonding.

4. Similarity cannot be used for a new aircraft design with new systems.

k. Step 11 — Determine the transient levels using RTCA / DO-160G / EUROCAE ED-14G, Section 22, Guidance for Level A displays only

1. The applicant may select ETDLs for their Level A display system using the guidance in this section, without specific aircraft test or analysis. Level A displays involve functions for which the pilot will be in the loop through pilot–system information exchanges. Level A display systems typically include the displays, symbol generators, data concentrators, sensors (such as attitude, air data, and heading sensors), interconnecting wiring, and the associated control panels.

2. This approach should not be used for other Level A systems, such as control systems, because failures and malfunctions of those systems can more directly and abruptly

contribute to a catastrophic failure event than display system failures and malfunctions. Therefore, other Level A systems require a more rigorous lightning transient compliance verification programme.

3. The information in Table 3 should be used to evaluate aircraft and system installation features in order to select the appropriate ETDLs for the system. Table 3 defines test levels for ETDLs, based on EUROCAE ED-14G Section 22, Tables 22-2 and 22-3. The applicant should provide the Agency with a description of their aircraft and display system installation features and compare these with the information in Table 3 to substantiate the ETDL selected for their aircraft and Level A display system installation. When selecting the ETDLs using the guidance provided in this step, an acceptable margin between the anticipated ATLs for display system installations is incorporated in the selected ETDLs.

Table 3: Equipment transient design levels — Level A displays

EUROCAE ED-14G Section 22 levels	**Level A display system installation location**
Level 5	The applicant should use this level when the equipment under consideration, its associated wire bundles, or other components connected by wiring to the equipment are in aircraft areas exposed to *very severe* lightning transients. These are: — areas with composite materials whose shielding is not very effective; — areas where there is no guarantee of structural bonding; and — other open areas where there is little shielding. The applicant can also use this level to cover a broad range of installations. The applicant may need higher ETDLs when there are high-current density regions on mixed conductivity structures (such as wing tips, engine nacelle fins, etc.) because the system wiring may divert some of the lightning current. If the applicant is the system designer, measures should be applied to reduce the need for higher ETDLs.
Level 4	The applicant should describe how to verify compliance. Typically, the verification method chosen uses this level when the equipment under consideration, its associated wire bundles, or other components connected by wiring to the equipment are in aircraft areas exposed to *severe* lightning transients. These areas are defined as outside the fuselage (such as wings, fairings, wheel wells, pylons, control surfaces, etc.).
Level 3	The applicant should use this level when the equipment under consideration, its associated wire bundles, and other components connected by wiring to the

	equipment are entirely in aircraft areas with *moderate* lightning transients. These areas are defined as the inside metal aircraft structure or composite aircraft structure whose shielding is as effective as metal aircraft structure, and without additional measures to reduce lightning coupling to wires. Examples of such areas are avionics bays not enclosed by bulkheads, cockpit areas, and locations with large apertures (that is, doors without electromagnetic interference (EMI) gaskets, windows, access panels, etc.). Current-carrying conductors in these areas (such as hydraulic tubing, control cables, wire bundles, metal wire trays, etc.) are not necessarily electrically grounded at bulkheads. When few wires exit the areas, applicants should either use a higher level (that is, Level 4 or 5) for these wires or offer more protection for these wires.
Level 2	The applicant should use this level when the equipment under consideration, its associated wire bundles, and other components connected by wiring to the equipment are entirely in partially protected areas. These areas are defined as the inside of a metallic or composite aircraft structure whose shielding is as effective as metal aircraft structure, if the applicant takes additional measures to reduce the lightning coupling to wires. Wire bundles in these areas pass through bulkheads and have shields that end at the bulkhead connector. When a few wires exit these areas, the applicant should use either a higher level (that is, Level 3 or 4) or provide more protection for these wires. The applicant should install wire bundles close to the ground plane to take advantage of other inherent shielding from metallic structures. Current-carrying conductors (such as hydraulic tubing, control cables, metal wire trays, etc.) are electrically grounded at all bulkheads.
Level 1	The applicant should use this level when the equipment under consideration, its associated wire bundles, and other components connected by wiring to the equipment are entirely in well-protected aircraft areas. These areas are defined as electromagnetically enclosed.

l. Step 12 — Verify compliance with the applicable requirements

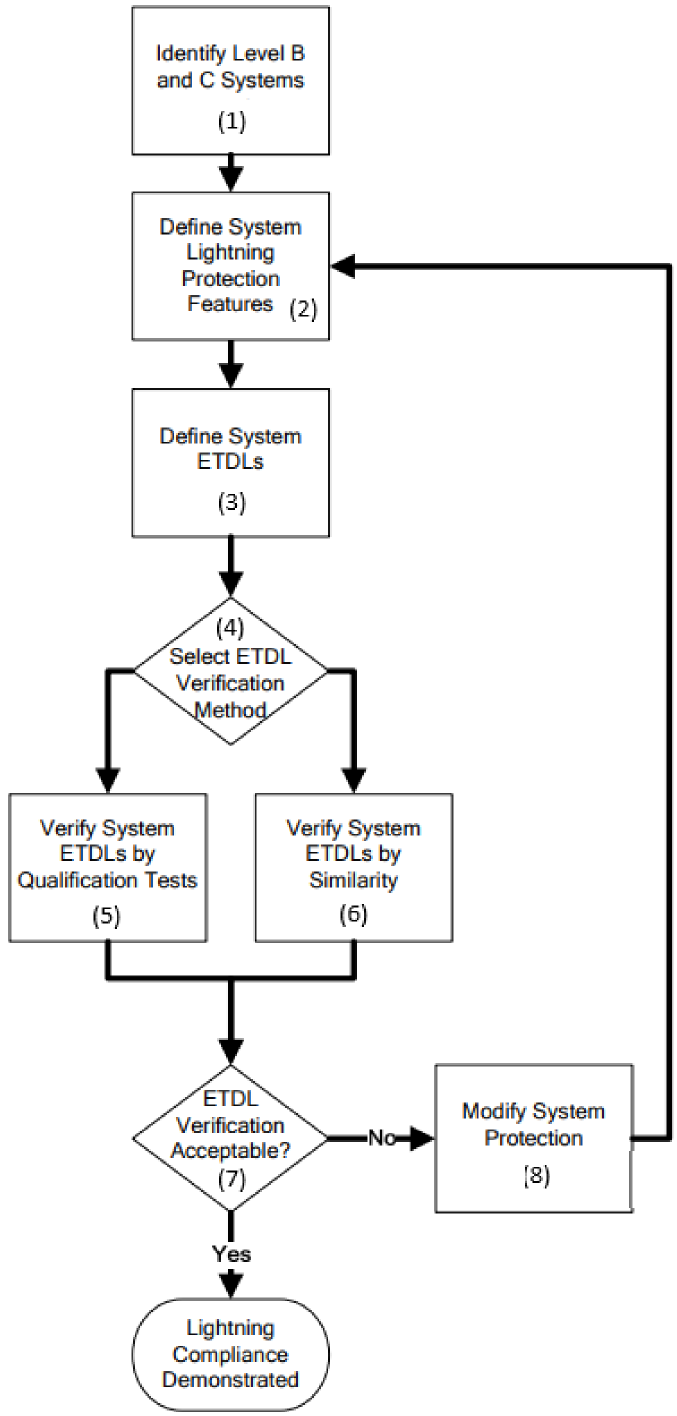
The applicant should compare the verified system ETDLs with the aircraft ATLs and determine whether an acceptable margin exists between the ETDLs and the ATLs. Margins account for uncertainty in the verification method. As confidence in the verification method increases, the margin can decrease. An ETDL exceeding the ATL by a factor of two is an acceptable margin for Level A systems, if this margin is verified by aircraft test or by analysis supported by aircraft-level tests. For Level A display systems where the ETDLs are determined using the guidance provided in Table 3, an acceptable margin is already incorporated in the selected ETDLs. For other verification methods, the margin should be agreed upon with the Agency.

m. Step 13 — Corrective measures

1. When a system fails to meet the certification requirements, corrective actions should be selected. Any changes or modifications made to the aircraft, system installation or the equipment may require more testing and analysis.

2. To meet the certification requirements, the applicant may need to repeat system qualification testing, or aircraft-level testing and analysis (in whole or in part). This may include modification to the system or installation to obtain certification. The applicant should review these changes or modifications with the Agency to determine whether they are significant. If these changes or modifications are significant, the applicant should update their lightning certification plan accordingly. The updated certification plan shall be resubmitted to the Agency in accordance with point 21.A.15(c) for acceptance.

Figure 3: Routes to lightning compliance — Level B and Level C systems



(n) = Step number as described in Section 9 of this AMC

8. STEPS TO 'LEVEL B' AND 'LEVEL C' SYSTEM LIGHTNING COMPLIANCE

Figure 3 illustrates a process that the applicant can use to demonstrate that their Level B and Level C systems comply with CS 23.1306(b)/2515(b), 25.1316(b), 27.1316(b), and 29.1316(b).

a. Step 1 — Identify Level B and Level C systems

1. The applicant should identify their Level B and Level C systems as described in paragraph 6(c).

2. The applicant should define the detailed system performance pass/fail criteria. The applicant should obtain the Agency's concurrence on this criterion before starting tests or analyses of Level B and C systems.

b. Step 2 — Define system lightning protection. The applicant should define the lightning protection features incorporated into the system designs applicable to Level B and Level C systems. The design of equipment and system lightning protection may occur before aircraft-level tests are performed, and before the actual internal lightning environment is determined. Therefore, the equipment system lightning protection design should be based on an estimate of the expected internal lightning environment.

c. Step 3 — Establish the ETDLs

1. The applicant may use the ATLs determined during aircraft-level tests or analyses performed for Level A systems to establish the appropriate ETDLs for Level B and Level C systems.

2. Alternatively, the applicant may use the definitions in EUROCAE ED-14G Section 22 to select the appropriate ETDLs for their Level B and Level C systems. The following should be considered when selecting an appropriate level:

   (a) The applicant can use EUROCAE ED-14G Section 22 Level 3 for most Level B systems.

   (b) For Level B systems and the associated wiring installed in aircraft areas with *more severe* lightning transients, the applicant can use EUROCAE ED-14G Section 22 Level 4 or 5, as appropriate to the environment. Examples of aircraft areas with *more severe* lightning transients are those external to the fuselage, areas with composite structures showing poor shielding effectiveness, and other open areas.

   (c) The applicant should use EUROCAE ED-14G Section 22 Level 2 for most Level C systems.

   (d) For Level C systems installed in aircraft areas with *more severe* lightning transients, the applicant should use EUROCAE ED-14G Section 22 Level 3. Examples of aircraft areas with *more severe* lightning transients are those external to the fuselage, areas with composite structures showing poor shielding effectiveness, and other open areas.

(e) The applicant should provide the Agency with a description of their aircraft and system installation features to substantiate the EUROCAE ED-14G Section 22 levels selected for their system.

d. **Step 4 — Select the ETDL verification method.** The applicant should determine whether they will perform equipment lightning tests on the Level B and Level C systems, or whether they will base the compliance on previous equipment tests performed for a similar system.

e. **Step 5 — Verify the system's ETDL using equipment qualification tests**

1. Equipment qualification tests should be performed using the selected test levels and single-stroke, multiple-stroke, and multiple-burst waveform sets. It should be demonstrated that the equipment operates within the defined pass/fail criteria during these tests. No equipment damage should occur during these equipment qualification tests or during single-stroke pin injection tests using the defined ETDLs. EUROCAE ED-14G Section 22 provides acceptable test procedures and waveform set definitions.

2. Any equipment effects observed during the qualification tests should be evaluated to ensure that they do not adversely affect the system's continued performance. The applicant should obtain the Agency's acceptance of their evaluation.

3. Multiple-stroke and multiple-burst testing is not required if an analysis shows that the equipment is not susceptible to upsets, or that the equipment may be susceptible to upsets but a reset capability exists so that the system recovers in a timely manner.

f. **Step 6 — Verify the system's ETDL using existing equipment data (similarity)**

1. ETDLs may be verified by similarity to previously certified systems without performing more tests. The applicant may do this when:

(a) there are only minor differences between the previously certified system and installation and the system and installation to be certified;

(b) there are no unresolved in-service system problems related to lightning strikes on the previously certified system; and

(c) the previously certified system ETDLs were verified by qualification tests.

2. The assessment should cover the following:

(a) equipment interface circuits;

(b) the wire sizes, routing, arrangement (parallel or twisted wires), connector types, wire shields, and shield terminations;

(c) lightning protection devices, such as transient suppressors and lightning arrestors;

(d) grounding and bonding; and

(e) equipment software, firmware, and hardware.

3. If significant differences are found that will affect the systems and installations, the applicant should perform more tests and analyses to resolve the open issues.

g. Step 7 — Verify compliance with the applicable requirements

The applicant should demonstrate that the Level B and Level C systems meet their defined acceptance criteria during the qualification tests at the selected system ETDLs.

h. Step 8 — Corrective measures

When a system fails to meet the certification requirements, the applicant should decide on corrective actions. If the system or installation is changed or modified, the equipment qualification testing may need to be repeated. The applicant should review these changes or modifications with the Agency to determine whether they are significant. If these changes or modifications are significant, the applicant should update their lightning certification plan accordingly. The updated certification plan shall be resubmitted in accordance with point 21.A.15(c) to the Agency for acceptance.

9. LIGHTNING COMPLIANCE DEMONSTRATION

a. Lightning compliance plan. An overall lightning compliance plan should be established to clearly identify and define lightning certification specifications, lightning protection development, and the design, test, and analysis activities intended to be part of the compliance effort. This plan should provide definitions of the aircraft systems, installations, and protective features against which lightning compliance will be assessed. The lightning compliance plan should be discussed with, and submitted to, the Agency for acceptance before initiating lightning compliance activities. If the aircraft, system, or installation design changes after approval, a revised lightning compliance plan should be submitted to the Agency for acceptance. The lightning compliance plan should include the following:

1. a lightning compliance plan summary;

2. identification of the aircraft systems, with their classifications based on the safety assessment as it relates to lightning (see paragraph 6(c)(2));

3. the planned or expected lightning environment for installed systems; and

4. the verification methods, such as test, analysis, or similarity.

b. Methods of compliance verification

1. Various methods are available to aid in demonstrating lightning compliance. Methods acceptable to the Agency are described in Sections 7 and 8 of this AMC. Figure 2 above outlines the steps to lightning compliance for systems requiring Level A lightning certification. Figure 3 above outlines the steps to lightning compliance for systems requiring Level B or Level C lightning certification. The steps in these figures are not necessarily accomplished sequentially. Wherever a decision point is indicated on these figures, the applicant should complete the steps in that path as described in Sections 7 and 8 of this AMC.

2. Other lightning compliance techniques may be used to demonstrate system performance in the lightning environment; however, those techniques should be accepted by the Agency before using them.

c. **Lightning verification test, analysis, or similarity plan.** Test, analysis and similarity are all acceptable methods. The applicant must choose the method or the combination of methods most appropriate for their project. See Sections 7 and 8 of this AMC, and SAE ARP 5415B / EUROCAE ED-158 for additional guidance for selecting the appropriate method. Specific lightning test, analysis, or similarity plans could be prepared to describe specific verification activities. A single verification plan combining various methods for all the selected systems or dedicated verification plans may be necessary. For example, there may be several systems or equipment laboratory test plans, an aircraft test plan, or a similarity plan for selected systems on an aircraft.

1. Test plan

(a) A lightning compliance test plan may include the equipment, system, and aircraft test objectives for the acquisition of data to support lightning compliance verification. The plan should provide an overview of the factors to be addressed for each system test specification. The test plan should include the following:

(1) the purpose of the test;

(2) a description of the aircraft and/or the system to be tested;

(3) system configuration drawings;

(4) the proposed test set-up and methods;

(5) the intended test levels;

(6) pass/fail criteria; and

(7) the test schedule and test location.

(b) The test plan should cover Level A, B, and C systems and equipment, as appropriate. Level A systems may require both systems qualification laboratory tests and aircraft tests. Level B and Level C systems and equipment require only equipment qualification laboratory testing.

(c) The test plan should describe the appropriate aspects of the systems to be tested and their installation. Additionally, the test plan should reflect the results of any analysis performed in the overall process of the lightning compliance evaluation.

2. Analysis plan. A lightning compliance analysis plan should include the objectives, at both system and equipment level, for generating data to support lightning compliance verification. Comprehensive modelling and analysis for voltage and current transients to aircraft systems and structures is an emerging technology; therefore, the analysis plan should be coordinated with the Agency to determine an acceptable scope for the analysis. The analysis plan should include the following:

(a) the purpose and scope of the analysis;

(b) a description of the aircraft and/or the system addressed by the analysis;

(c) system configuration descriptions;

(d) the proposed analysis methods;

(e) the approach for validating the analysis results; and

(f) pass/fail criteria, including margins to account for analysis uncertainty.

3. **Similarity plan.** A similarity plan should describe the approach undertaken to use the certification data from previously certified systems, equipment, and aircraft in the proposed lightning compliance programme. The similarity plan should include the following:

(a) the purpose and scope of the similarity assessment;

(b) the specific systems addressed by the similarity assessment;

(c) the data used from previously certified systems, equipment, and aircraft;

(d) details on significant differences between the aircraft and the system to be certified and the similar aircraft and the system from which the data will be used; and

(e) when data has limited substantiation, a description and justification for margins to account for similarity uncertainty.

d. **Compliance reports.** One or more compliance reports may be necessary to document the results of the test, analysis, or similarity assessments. For new or significantly modified aircraft, lightning compliance reports may include many system and equipment test reports, aircraft test reports, and lightning vulnerability analysis reports. For these types of lightning certification programmes, a compliance summary report may be useful to summarise the results of tests and analyses. For lightning certification programmes of relatively simple systems, a single compliance report is adequate.

1. **Test reports.** Comprehensive test reports should be produced at the conclusion of lightning compliance testing. The test reports should include descriptions of the salient aspects of equipment or system performance during the test, details of any area of non-compliance with lightning requirements, actions taken to correct the non-compliance, and any similarity declarations. The applicant should also provide the supporting rationale behind any deviations from the system performance observed during testing.

2. **Analysis reports.** Analysis reports should describe the details of the analytical model, the methods used to perform the analysis, and the results of the analysis. The reports should identify any modelling uncertainty and justify the margins established in the analysis plan.

3. **Similarity reports.** Similarity reports should document the significant aircraft, system, equipment, and installation features that are common between the aircraft or system that is the subject of the similarity analysis and the aircraft or system that was previously certified for lightning. The applicant should identify all the significant differences encountered, along with the assessment of the impact of these differences on lightning compliance. These reports should also justify the margins established in the similarity plan.

10. MAINTENANCE, PROTECTION ASSURANCE, AND MODIFICATIONS

a. The minimum maintenance required to support lightning certification should be identified in the instructions for continued airworthiness (ICAs) as specified in CS 23.1529/2625, 25.1529, 25.1729, 27.1529, and 29.1529, as appropriate. Dedicated devices or specific features may be required to provide lightning protection for the installation of a system or equipment. Appropriate maintenance procedures should be defined for these devices and features to ensure in-service protection integrity. A lightning protection assurance programme should be proposed in the certification plan to identify all actions necessary to justify or to verify that the maintenance procedures are adequate. This assurance programme may propose a surveillance programme based on a sampling of the fleet for monitoring the effectiveness of the protection features and/or maintenance procedures. See SAE ARP 5415B / EUROCAE ED-158 for more information on these topics.

b. The maintenance procedures should consider the effects of corrosion, fretting, flexing cycles, or other causes that could degrade these lightning protection devices. Whenever applicable, specific replacement times of these devices and features should be identified.

c. Aircraft or system modifications should be assessed for the impact that any changes will have on the lightning protection. This assessment should be based on analysis and/or measurement.

Appendix 1 to AMC 20-136A — Definitions and acronyms

a. Definitions

Adverse effect: a response of a system that results in an unexpected and unacceptable operation of an aircraft system, or unexpected and unacceptable operation of the function performed by the system.

Actual transient level (ATL): the level of transient voltage or transient current that appears at the equipment interface circuits because of the external environment. This level may be less than or equal to the transient control level but should not be greater.

Aperture: an electromagnetically transparent opening.

Attachment point: a point where the lightning flash contacts the aircraft.

Automatically recover: return to normal operations without pilot action.

Channel: a subset of a system consisting of equipment, components, elements and electrical interconnections, which performs an aircraft function provided by the system. A system could be composed of redundant similar or dissimilar channels in order to maintain the function at aircraft level in case of failure on one or several channels.

Component damage: a condition in which transients permanently alter the electrical characteristics of a circuit. Because of this, the component can no longer perform to its specifications.

Continued safe flight and landing: the capability for continued controlled flight and landing at a suitable location, possibly using emergency procedures, but without requiring exceptional piloting skill or strength. For CS-25 aeroplanes, the pilot must be able to land safely at a suitable airport. For CS-23 aeroplanes, it is not necessary to land at an airport. For rotorcraft, the rotorcraft must continue to cope with adverse operating conditions, and the pilot must be able to land safely at a suitable site. Some aircraft damage may be associated with a failure condition during flight or upon landing.

Direct effects: physical damage to the aircraft or to its electrical and electronic systems. Direct attachment of lightning to the system's hardware or components causes the damage. Examples of direct effects include tearing, bending, burning, vaporisation, or blasting of aircraft surfaces and structures, and damage to the electrical and electronic systems.

Electrical and electronic system: an electrical or electronic system includes all electrical and electronic equipment, components, elements, and the electrical interconnections that are required to perform a particular function.

Equipment: a component of an electrical or electronic system with interconnecting electrical conductors.

Equipment electrical interface: a location on a piece of equipment where an electrical connection is made to the other equipment in a system of which it is a part. The electrical interface may consist of individual wires or wire bundles that connect the equipment.

Equipment transient design level (ETDL): the peak amplitude of transients to which equipment is qualified.

Function: the specific action of a system, equipment, and flight crew performance aboard the aircraft that, by itself, provides a completely recognisable operational capability. For example, 'display aircraft heading to the pilots' is a function. One or more systems may perform a specific function, or one system may perform multiple functions.

External environment: the natural lightning environment, outside the aircraft, for design and certification purposes. See SAE ARP 5412B / EUROCAE ED-84A, which references documents that provide additional guidance on aircraft lightning environments and the related waveforms.

Immunity: the capacity of a system or piece of equipment to continue to perform its intended function, in an acceptable manner, in the presence of RF fields.

Indirect effects: electrical transients induced by lightning in aircraft electrical or electronic circuits.

Internal environment: the electric and magnetic fields, currents, and voltages on and within the aircraft produced by a lightning strike to the aircraft.

Lightning flash: the total lightning event. It may occur in a cloud, between clouds, or between a cloud and the ground. It can consist of one or more return strokes, plus intermediate or continuing currents.

Lightning strike: attachment of the lightning flash to the aircraft.

Lightning strike zones: aircraft surface areas and structures that are susceptible to lightning attachment, dwell times, and current conduction. See SAE ARP 5414B / EUROCAE ED-91A, which references documents that provide additional guidance on aircraft lightning zoning.

Lightning stroke (return stroke): a lightning current surge that occurs when the lightning leader (the initial current charge) makes contact with the ground or another charge centre. A charge centre is an area of high potential of opposite charge.

Margin: the difference between the equipment transient design levels and the actual transient level.

Multiple burst: a randomly spaced series of bursts of short duration, low-amplitude current pulses, with each pulse characterised by rapidly changing currents. These bursts may result as the lightning leader progresses or branches, and are associated with the cloud-to-cloud and intra-cloud flashes. The multiple bursts appear most intense when the initial leader attaches to the aircraft. See SAE ARP 5412B / EUROCAE ED-84A.

Multiple stroke: two or more lightning return strokes during a single lightning flash. See SAE ARP 5412B / EUROCAE ED-84A.

Non-normal situation: any situation that requires non-normal, abnormal, emergency, or unusual procedures, or configurations for operating an aircraft.

Normal operation: a status where the system is performing its intended function. When addressing compliance with CS 23.1306/2515(a)(2), 25.1316(a)(2), 27.1316(a)(2), and 29.1316(a)(2), the function whose failure would prevent the continued safe flight and landing should be in the same undisturbed state as before exposure to the lightning threat while other functions, performed by the same system, subject to CS 23.1306/2515(b), 25.1316(b), 27.1316(b), and 29.1316(b), are not required to be recovered. The system that performs the function may be nevertheless in a different state as long as the function is not adversely affected.

Timely manner: timely recovery has been introduced to account for the necessary period for complex systems to reconfigure safely after a disruption. The meaning of 'in a timely manner' depends upon the function performed by the system to be evaluated, the specific system design, interaction between that system and other systems, and interaction between the system and the flight crew, or the phase of flight, which must be considered in the safety assessment. Therefore, the definition of 'in a timely manner' must be determined for each specific function performed by the system. The applicable definition could be included in the lightning compliance plan for review and concurred with the Agency.

Transient control level (TCL): the maximum allowable level of transients that appear at the equipment interface circuits because of the defined external environment.

Upset: impairment, either permanent or momentary, of the system's operation. For example, a change of digital or analogue state that may or may not require a manual reset.

b. Acronyms

14 CFR:	Title 14 of the Code of Federal Regulations
AC:	advisory circular
AMC:	acceptable means of compliance
ARP:	aerospace recommended practice
ATL:	actual transient level
CS:	certification specification
DAL:	development assurance level (ED-79A / ARP 4754A) / design assurance level (ED-80 / DO-254, ED-12C / DO-178C)
DEL:	direct effect of lightning
ETDL:	equipment transient design level
EASA:	European Union Aviation Safety Agency
EUROCAE:	European Organisation for Civil Aviation Equipment
FAA:	Federal Aviation Administration
ICAs:	instructions for continued airworthiness
IEL:	indirect effect of lightning
TCL:	transient control level

Appendix 2 to AMC 20-136A — Examples of lightning safety assessment considerations — Level A systems on large aeroplanes

a. Establishing appropriate pass/fail criteria for complying with CS 25.1316(a) could only be achieved through a comprehensive review of the system design using an acceptable lightning functional hazard assessment process. The following paragraphs summarise approaches whereby pass/fail criteria for compliance with CS 25.1316(a) could be specified on the merit of specific system architecture attributes.

b. For the purposes of discussion and evaluation of the examples, the architectural strategies used in the system implementation need to be defined. Therefore, the additional definitions below should be considered:

(1) *similar redundant channels*: the multiple channels consist of equipment, components, electrical interconnections and configurations that are similar, typically with equipment that has identical part numbers. The channels should be independent. They may be configured in active, active-backup, or passive-backup modes.

(2) *dissimilar redundant channels*: each channel is unique and independent of the others. They may be configured in active, active-backup, and passive-backup modes.

(3) *combination of similar and dissimilar redundant channels*: the combination of similar and dissimilar channels, as defined above, with independence between channels. They may be configured in active, active-backup, and passive-backup modes.

Notes:

(1) *Active mode* means the channel performs the aircraft function in normal operation.

(2) *Active-backup mode* means the channel is operational but not used to perform the aircraft function until switched to active mode either automatically or by flight crew action.

(3) *Passive-backup mode* means the channel is not operational; switching to active mode is either automatic or by flight crew action upon failure recognition.

(4) Combination of electrical/electronic and mechanical, hydraulic and/or pneumatic channels: certain architectures combine electrical and electronic channels with mechanical, hydraulic and/or pneumatic channels. These combinations of electrical/electronic and mechanical, hydraulic or pneumatic channels may be configured in active, active-backup, and passive-backup modes.

(5) These examples are theoretical and intended to facilitate a discussion from which universal guidelines may be derived to help develop useful guidance material. It is not the intention to account for all possible configurations, but only to represent the common system architectures or some that present unique challenges.

c. This Appendix presents examples of large aeroplane systems with multiple independent and redundant channels performing a function whose failure would prevent continued safe flight and landing.

These examples could also be used for other types of aircraft.

Example 1			
Function	**25.1316(a) System**		
	Channel	**Channel**	**Channel**
Display of attitude, altitude, and airspeed information to the pilots during IFR operations (e.g. primary display system and associated sensors, with dissimilar standby display system and sensors)	Active (Pilot displays and associated sensors)	Active (Co-pilot displays and associated sensors)	Active-backup (Dissimilar standby display and associated sensors)
Requirements for compliance demonstration (CS 25.1316)	(a)(1), (a)(2)	(a)(1), (a)(2)	(b)
Discussion: This example depicts the requirement of CS 25.1333 for independent displays of information essential to the safety of flight at each pilot station. The standby display is required in order to achieve the safety objectives of CS 25.1309. Either the pilot or the co-pilot can be the pilot flying (PF) or pilot monitoring (PM) during normal operations, so both the pilot and co-pilot display systems should be considered as active systems. Compliance with CS 25.1316(a)(1) and (a)(2) should demonstrate that neither pilot display of aircraft attitude, altitude, and airspeed is adversely affected and that each of them recovers normal operation of these Level A functions when the aircraft is exposed to lightning. It is acceptable that the dissimilar standby display demonstrates compliance with the CS 25.1316(b) requirements with LCL B. The adverse effects must include both a loss of, and hazardously misleading, attitude, altitude, and airspeed information.			

Example 2			
Function	**25.1316(a) System**		
	Channel	**Channel**	**Channel**
Full authority control of pitch, yaw, and roll using electrical and electronic flight control systems	Active or active-backup (Flight control system #1)	Active or active-backup (Flight control system #2)	Active or active-backup (Flight control System #3)
Requirements for compliance demonstration (CS 25.1316)	(a)(1), (a)(2)	(a)(1), (a)(2)	(a)(1), (a)(2)

Discussion:

This example depicts an electronic flight control system comprising three independent channels to meet the safety objectives of CS 25.1309. At any time, any one of the three channels can operate as the active channel.

Only one channel operates in an active mode while the others are in active-backup mode. Any channel can perform the control function at any time; therefore, all the channels must comply with CS 25.1316(a)(1) and (a)(2).

Example 3			
Function	**25.1316(a) System**		
	Channel	**Channel**	**Channel**
Provide engine overspeed protection	Active (Electronic engine control system) (Normal speed control)	Active or active-backup (Electronic engine control system) (Overspeed protection)	Active (Independent mechanical overspeed protection)
Requirements for compliance demonstration (CS 25.1316)	(b)	(b)	Not subject to CS 25.1316

Discussion:

This example depicts the function of engine overspeed protection performed by a combination of active electrical and electronic control and mechanical system control. The mechanical channel must provide overspeed protection during normal operations, and be independent of the active electronic control channels. The mechanical channel must not rely on electrical or electronic components to assist, augment, or monitor the overspeed protection. If the mechanical channel is independent of the electronic engine control speed control and overspeed protection, and has no electrical or electronic components that have failure modes that could prevent overspeed protection, then the engine overspeed protection function is not adversely affected when the aircraft is exposed to lightning. The system is, therefore, not subject to CS 25.1316(a). The electronic engine control channels should comply with CS 25.1316(b) with LCL B.

This example only considers the overspeed protection feature implemented by the system. Other functions whose failure may be classified as catastrophic, like the loss of thrust control function where the function may be implemented by electronic control channels, should comply with CS 25.1316(a).

Example 4			
Function	**25.1316(a) System**		
	Channel	**Channel**	**Channel**
Provide electrical power for electrical and electronic systems including those with catastrophic failure conditions	Active (Left engine generator system)	Active (Right engine generator system)	Passive-Backup (Emergency power supply system driven by a ram-air turbine)
Requirements for compliance demonstration (CS 25.1316)	(a)(1), (a)(2)	(a)(1), (a)(2)	(b)

Discussion:

This example depicts a typical transport category aircraft electrical system on a twin-engined aircraft where two or more independent sources of electrical power are required by CS 25.1307(b) and a ram-air turbine is necessary to meet the safety objectives of CS 25.1309 and CS 25.1351(d).

For this example, the electrical system consists of two active channels provided by a single main engine-driven generator on each engine with the associated distribution and controls, and a third passive-backup channel provided by a ram-air turbine electrical power system. The ram-air turbine electrical power system is stowed during normal operation and deployed either automatically and/or manually when power from the two main engine-driven generators is lost.

The active engine generator system channels must not be adversely affected when the aircraft is exposed to lightning, and comply with CS 25.1316(a)(1) and (a)(2). The passive-backup ram-air turbine electrical power system does not mitigate adverse effects for compliance with CS 25.1316(a). It is acceptable that the ram-air turbine electrical power system demonstrates compliance with the CS 25.1316(b) specifications with LCL B.

Example 5				
Function	**25.1316(a) System**			
	Channel	**Channel**	**Channel**	**Channel**
Provide electrical power for electrical and electronic systems including those with catastrophic failure conditions	Active (Left engine generator system)	Active (Right engine generator system)	Active (APU-driven generator system required for ETOPS flight beyond 180')	Passive-backup (Emergency power supply driven by a ram-air turbine)
Requirements for compliance demonstration (CS 25.1316)	(a)(1), (a)(2)	(a)(1), (a)(2)	(a)(1), (a)(2)	(b)

Discussion:

This example depicts a twin-engined transport category aircraft electrical system where two or more independent sources of electrical power are required by CS 25.1307(b), and an alternate source (driven by a ram-air turbine) is necessary to meet the safety objectives of CS 25.1309 and CS 25.1351(d). This configuration includes a third electrical power source driven by an auxiliary power unit (APU). This third source is required (active channel) for ETOPS beyond 180 minutes. As in Example 4, the emergency power source is a passive-backup channel provided by a ram-air turbine that remains stowed during normal flight and is deployed either automatically and/or manually when power from all other channels is lost.

All active electrical power generation channels should comply with CS 25.1316(a)(1) and (a)(2). The passive-backup electrical power generation channel does not mitigate the adverse effects due to lightning exposure to meet the intent of the lightning requirement. It is acceptable that the passive-backup channel demonstrates compliance with the CS 25.1316(b) requirements with LCL B.

Note: For non-ETOPS or for ETOPS up to 180' aircraft, the APU LCL should be defined based on the specific aircraft safety assessment.

Example 6				
Function	**25.1316(a) System**	**25.1316 System**	**25.1316 System**	**System**
	Channel	**Channel**	**Channel**	**Channel**
Reduce aircraft speed on ground in a controlled manner using thrust reverser control system, spoiler deployment system, wheel braking system	Active Main brake system (Electro-mechanical)	Active (Electronic engine thrust reverse control with associated sensors)	Active (Electronic spoiler deployment control with associated sensors)	Active (Independent mechanical wheel braking)
Requirements for compliance demonstration (CS 25.1316)	(a)(1), (a)(2)	25.1316(a) or (b) depending on specific aircraft safety assessment	25.1316(a) or (b) depending on specific aircraft safety assessment	Not subject to CS 25.1316

Discussion:

This example depicts an aircraft-level function that is performed by a combination of independent systems each contributing in part to the function during a specific phase of flight. In this case, each system implements very distinct aircraft-level functions that serve in a complementary manner to decelerate the aircraft during the landing roll. The mechanical wheel braking system is assumed to be independent of the other channels, with no associated electrical or electronic equipment to assist, augment, or monitor the mechanical wheel braking system.

In this example, it is assumed that the main brake system includes failure conditions that are catastrophic. For the electronic engine thrust reverser control and the electronic spoiler control systems, the applicable parts of CS 25.1316 would depend on the specific failure conditions. The effectiveness, authority, and malfunctions associated with each system should be considered. Additionally, the interaction between the systems has also to be considered. Issues such as asymmetrical thrust reverser activation or spoiler deployment could adversely affect the main brake and mechanical wheel braking functions and could affect the safety classification for the thrust reverser and spoiler controls.

An aircraft safety assessment must be carried out for each of these systems performing a specific aircraft-level function to identify and classify their failure conditions. The failure hazard classifications and the decomposition of each system into the constituent channels would then dictate which paragraphs of CS 25.1316 are needed.

Example 7			
Function	**25.1316(a) System**		
	Channel	**Channel**	**Channel**
Provide altitude information to be displayed in IFR flight, using air-data computer connected to the primary flight display (PFD), and pneumatic standby instrument with alternate static port	Active (Air-data computer 1 with static port)	Active (Air-data computer 2 with static port)	Active-Backup (Pneumatic standby altimeter with alternate static port)
Requirements for compliance demonstration (CS 25.1316)	(a)(1), (a)(2)	(a)(1), (a)(2)	Not subject to CS 25.1316

Discussion:

This example depicts the function to provide altitude information in IFR. The main sources are two air-data computers (ADCs) coupled to static ports and a backup source from a standby pneumatic altimeter coupled to an alternate static port independent from the main static ports.

In such a case, the standby altimeter does not mitigate compliance with CS 25.1316(a) for the active ADC channels. The standby altimeter does not mitigate the common hazardously misleading altitude information from the active ADC channels for compliance with CS 25.1316(a).

Example 8			
Function	25.1316(a) System		
	Channel	Channel	Channel
Control and protection of the aircraft pneumatic (bleed) system (Top-level failure condition classification: catastrophic)	Active (Pneumatic system controller #1) FDAL B / IDAL B	Active (Pneumatic system controller #2) FDAL B / IDAL B	Passive-backup (High pressure switch + valve) FDAL C / IDAL C
Requirements for compliance demonstration (CS 25.1316)	(a)(1), (a)(2)	(a)(1), (a)(2)	(b)

Discussion:

This is a generic example with the objective to show that it is not uncommon for the LCL of a given system to be different from the functional development assurance level (FDAL) and item development assurance level (IDAL), defined according to SAE ARP 4754A / EUROCAE ED-79A *Guidelines for Development of Civil Aircraft and Systems*.

Therefore, it is important to use the proper nomenclature and avoid using the SAE ARP 4754A / EUROCAE ED-79A *DAL* or similar terms when referring to the LCL.

In this example, the pneumatic control system is composed of two main active controllers and a simpler passive-backup channel that can perform the function, preventing the catastrophic event from occurring in case of failure of both controllers.

The FDAL for each channel or member (SAE ARP 4754A / EUROCAE ED-79A nomenclature) was defined for a catastrophic top-level failure condition based on the 'Option 2' column 4 of Table 3 *DEVELOPMENT ASSURANCE LEVEL ASSIGNMENT TO MEMBERS OF A FUNCTIONAL FAILURE SET* of SAE ARP 4754A / EUROCAE ED-79A, which allows the combination of FDALs B+B+C for independent channels. In contrast, the respective LCLs would be A+A+B.

Considering that lightning can simultaneously affect all channels, the considerations used for the IDAL assignment cannot be used, and compliance with CS 25.1316(a) is required for both the active channels performing a function with the catastrophic top-level failure condition.

In this example, the IDAL for the passive-backup channel may be C. However, for lightning, the applicable part of CS 25.1316 is (b), similarly to Example 5.

AMC 20-158A Aircraft electrical and electronic system high-intensity radiated fields (HIRF) protection

1. PURPOSE

a. This AMC describes an acceptable means, but not the only means, for demonstrating compliance with the applicable certification specifications (CSs) related to high-intensity radiated fields (HIRF) protection (CS 23.1308, 25.1317, 27.1317, and 29.1317). Compliance with this AMC is not mandatory, and an applicant may elect to use an alternative means of compliance. However, the alternative means of compliance must meet the relevant requirements, ensure an equivalent level of safety, and be approved by EASA on a product or ETSO article basis.

b. The modal verb 'must' is used to indicate which means are necessary to demonstrate compliance with the applicable CSs by using this AMC. The modal verb 'should' is used when following the AMC to indicate that an action is recommended but is not necessary to demonstrate compliance with the applicable CSs when using this AMC.

2. SCOPE AND APPLICABILITY

This AMC provides possible means to demonstrate compliance with CS 23.1308/23.2520, 25.1317, 27.1317, and 29.1317 for the effects of HIRFs. This AMC may be used by applicants for a new type certificate (TC) or a change to an existing TC when the certification basis requires to address the above-mentioned CSs.

Note: For CS-23 Amendment 5 and higher, a new HIRF specification, i.e. CS 23.2520, which differs from the previous CS 23.1308, is included. The associated AMC to CS 23.2520 are published separately in the AMC & GM to CS-23, based on ASTM F3061 / F3061M-17 and F3236-17. This AMC could nevertheless be used as guidance for demonstrating compliance with CS 23.2520.

3. DOCUMENT HISTORY

This AMC supersedes AMC 20-158, *Aircraft Electrical and Electronic System High-Intensity Radiated Fields (HIRF) Protection*, dated 15 July 2015.

4. RELATED MATERIAL

a. European Union Aviation Safety Agency (EASA) (in this document also referred to as 'the Agency')

Certification Specifications:

1. CS 23.1308, CS 25.1317, CS 27.1317, and CS 29.1317, *High-intensity Radiated Fields (HIRF) Protection;*
2. CS 23.1309, CS 25.1309, CS 27.1309, and CS 29.1309, *Equipment, systems, and installations;* and
3. CS 23.1529, CS 25.1529, CS 27.1529, and CS 29.1529, *Instructions for Continued*

Airworthiness.

EASA Certification Specifications (CSs) and Acceptable Means of Compliance (AMC) may be downloaded from the EASA website at www.easa.europa.eu.

b. FAA Advisory Circulars (ACs)

1. AC 23.1309-1E, *System Safety Analysis and Assessment for Part 23 Airplanes;*
2. AC 25.1309-1A, *System Design and Analysis*;
3. AC-27-1B, *Certification of Normal Category Rotorcraft;*
4. AC-29-2C, *Certification of Transport Category Rotorcraft*, or later revisions;
5. AC 20-158A, *The Certification of Aircraft Electrical and Electronic Systems for Operation in the High-Intensity Radiated Fields (HIRF) Environment*.

Applicants can view and download copies from the web-based FAA Regulatory and Guidance Library (RGL) at www.airweb.faa.gov. On the RGL website, the applicant should select 'Advisory Circular', then select 'By Number'. ACs are also available on the FAA website at http://www.faa.gov/regulations_policies/advisory_circulars/.

c. European Organisation for Civil Aviation Equipment (EUROCAE)

Copies of these documents can be requested from EUROCAE, 102 rue Etienne Dolet, 92240 Malakoff, France; Telephone: +33 1 40 92 79 30; Fax: +33 1 46 55 62 65; Website: http://www.eurocae.net.

1. EUROCAE ED-107A, *Guide to certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment*;
2. EUROCAE ED-14G, *Environmental Conditions and Test Procedures for Airborne Equipment;*
3. EUROCAE ED-79A, *Guidelines for Development of Civil Aircraft and Systems*;
4. EUROCAE ED-234, *User Guide Supplement to EUROCAE ED-14G*.

EUROCAE documents may be purchased from:

European Organisation for Civil Aviation Equipment
9-23 rue Paul Lafargue
"Le Triangle" building
93200 Saint-Denis, France
Telephone: +33 1 49 46 19 65
(Email: eurocae@eurocae.net, website: www.eurocae.net)

d. Radio Technical Commission for Aeronautics (RTCA)

RTCA/DO-160G, *Environmental Conditions and Test Procedures for Airborne Equipment*. This document is technically equivalent to EUROCAE ED-14G.

RTCA documents may be purchased from:

RTCA, Inc., 1150 18th Street NW, Suite 910, Washington D.C. 20036, USA
(Email: info@rtca.org, website: www.rtca.org)

e. Society of Automotive Engineers (SAE International)

1. SAE Aerospace Recommended Practice (ARP) 5583A, *Guide to Certification of Aircraft in a High Intensity Radiated Field (HIRF) Environment*. SAE ARP 5583A and ED-107A are technically equivalent and either document may serve as the 'User's Guide' referred to in this AMC.

2. SAE ARP 4754A, *Guidelines For Development Of Civil Aircraft And Systems*, dated December 2010. This document is technically equivalent to EUROCAE ED-79A.

3. SAE ARP 4761, *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment*, dated December 1996.

SAE International documents may be purchased from:

SAE Customer Service
400 Commonwealth Drive
Warrendale, PA
15096-0001, USA
Website: http://www.sae.org

5. BACKGROUND

a. Aircraft protection. The need for the protection of aircraft electrical and electronic systems has increased substantially in recent years for the following reasons:

1. greater dependence on electrical and electronic systems performing functions required for continued safe flight and landing of an aircraft;

2. the reduced electromagnetic shielding afforded by some composite materials used in aircraft designs;

3. the increased susceptibility of electrical and electronic systems to HIRF because of increased data bus and processor operating speeds, higher-density integrated circuits and cards, and greater sensitivities of electronic equipment;

4. expanded frequency usage, especially above 1 gigahertz (GHz);

5. the increased severity of the HIRF environment because of an increase in the number and radiated power of radio frequency (RF) transmitters; and

6. the adverse effects experienced by some aircraft when exposed to HIRF.

b. HIRF environment. The electromagnetic HIRF environment exists because of the transmission of electromagnetic RF energy from radar, radio, television, and other ground-based, shipborne, or airborne RF transmitters. The User's Guide (SAE ARP 5583A / EUROCAE

ED-107A) provides a detailed description of the derivation of these HIRF environments.

6. APPROACHES TO COMPLIANCE

a. **General.** The following activities should be elements of a proper HIRF certification programme. Adherence to the sequence shown is not necessary. More detailed information on HIRF certification compliance is provided in the User's Guide (ED-107A).

The applicant should:

1. identify the systems to be assessed;
2. establish the applicable aircraft external HIRF environment;
3. establish the test environment for installed systems;
4. apply the appropriate method of HIRF compliance verification;
5. verify the effectiveness of the HIRF protection; and
6. take corrective measures (if needed).

More detailed information on these activities is proposed in Sections 7 and 8 of this AMC.

b. **Identify the systems to be assessed**

1. General. The applicant should identify the aircraft systems requiring a HIRF safety assessment. The applicant should define the elements of the system performing a function, considering similar and/or dissimilar redundant channels that make up the system. The process used for identifying these systems should be similar to the process for demonstrating compliance with CS 23.1309, 25.1309, 27.1309, and 29.1309, as applicable. These paragraphs address any system failure that may cause or contribute to an effect on the safety of flight of an aircraft. The effects of a HIRF encounter should be assessed to determine the degree to which the safety of the aircraft and its systems may be affected.

The operation of the aircraft systems should be assessed separately and in combination with, or in relation to, other systems. This assessment should cover:

(a) all normal aircraft operating modes, phases of flight, and operating conditions;

(b) all HIRF-related failure conditions and their subsequent effects on aircraft operations and the flight crew; and

(c) any corrective actions required by the flight crew during or after the occurrence of a HIRF-related failure.

2. HIRF safety assessment. A safety assessment related to HIRF must be performed to establish and classify the equipment or system failure condition. Table 1 provides the corresponding failure condition classification and system HIRF certification level (HCL) for the appropriate HIRF requirements. The failure condition classifications and terms used in this AMC are similar to those used in AC 23.1309-1E, AMC 25.1309, AC-27-1B, and AC-29-2C, as applicable. Only those systems identified as performing or contributing to functions whose failure would result in catastrophic, hazardous, or major failure conditions are subject to HIRF requirements. Based on the safety classification of the failure condition classification by the safety assessment, the systems should be assigned appropriate HCLs, as shown in Table 1. The HIRF safety assessment should consider the common-cause effects of HIRF, particularly for highly integrated systems and systems with redundant elements. The HIRF safety assessment determines the consequences of failures for the aircraft functions that are performed by the system. The system HCL classification assigned to the systems and functions can be different from the development assurance level (ED-79A) or the design assurance level (ED-80) assigned for equipment redundancy, software, and airborne electronic hardware (AEH). This is because HIRF is an environment that can cause common-cause effects. The term 'DAL' should not be used to describe the system HCL because of the potential differences in assigned classifications for software, AEH, and equipment redundancy. The HIRF safety assessment must include all electrical and electronic equipment, components and electrical interconnections, assuming that they are potentially affected by HIRF. It is not appropriate to use the HIRF immunity data for electrical and electronic equipment, components and electrical interconnections as information input for the HIRF safety assessment. This information should only be used in the next phase, to show compliance with the applicable subpart of the HIRF requirements, after the required HCL for the system is defined by the HIRF safety assessment. The HIRF safety assessment must have input and be coordinated between the safety specialist, the system specialist, and the HIRF/lightning specialist. This process may vary from applicant to applicant. Further guidance on performing the safety assessment can be found in AC 23.1309-1E, AMC 25.1309, AC-27-1B, AC-29-2C, SAE ARP 4754A / EUROCAE ED-79A, SAE ARP 4761, and ARP 5583A / EUROCAE ED-107A.

Note: Considering that HIRF and lightning environments may have similar effects on electro-electronic systems (disturbing electrical signals, causing upsets or damage to circuits), and that the applicable certification specifications are similarly structured, in many cases the system HCL and corresponding LCL (see AMC 20-136A) should be the same.

Table 1: HIRF most severe failure conditions of the function and system HIRF certification levels

HIRF REQUIREMENTS EXCERPTS FROM CS 23.1308, CS 25.1317, CS 27.1317, AND CS 29.1317	MOST SEVERE FAILURE CONDITION OF THE FUNCTION	SYSTEM HIRF CERTIFICATION LEVEL (HCL)
(a) Each electrical and electronic system that performs a function whose failure would prevent the continued safe flight and landing of the aircraft.	Catastrophic	A
(b) Each electrical and electronic system that performs a function whose failure would significantly reduce the capability of the aircraft or the ability of the flight crew to respond to an adverse operating condition.	Hazardous	B
(c) Each electrical and electronic system that performs a function whose failure would reduce the capability of the aircraft or the ability of the flight crew to respond to an adverse operating condition.	Major	C

3. **Level A systems.** The specifications in CS 23.1308(a), 25.1317(a), 27.1317(a), and 29.1317(a) address adverse effects on the aircraft functions and systems that perform functions whose failure would prevent the continued safe flight and landing of the aircraft. When demonstrating compliance with CS 23.1308(a), 25.1317(a), 27.1317(a), and 29.1317(a), the electrical and electronic system is the one required to perform the function whose failure would prevent continued safe flight and landing. This electrical and electronic system must also automatically recover normal operation of the Level A functions in a timely manner to comply with CS 23.1308(a)(2), 25.1317(a)(2), 27.1317(a)(2), and 29.1317(a)(2). If all equipment and components of the system required for the normal operation of the Level A functions are not susceptible when complying with paragraphs (a)(1), (a)(2) and (a)(3), then it is acceptable that the equipment and components required only for non-normal situations do not show compliance with the requirements of paragraph (a). In this case, it is considered acceptable that the equipment and components of the system required only for non-normal situations show compliance at least with the requirements of paragraph (b).

4. **Level B or Level C systems.** The specifications in CS 23.1308(b)(c), 25.1317(b)(c), 27.1317(b)(c), and 29.1317(b)(c) address adverse effects on systems that perform functions whose failure would reduce the capability of the aircraft or the ability of the flight crew to respond to an adverse operating condition when all equipment, components and electrical interconnections of the Level B or Level C system are exposed to HIRF test Level 1 or 2, or 3 respectively.

If some of the electrical and electronic equipment of a Level A system perform Level B or Level C functions, and effects on these equipment items are noted when the system is submitted to Level A HIRF environments, these effects should be reassessed when the system is submitted to HIRF test Level 1 or 2, or 3 respectively.

5. **Failure conditions.** The HIRF safety assessment should consider all potential adverse effects due to system failures, malfunctions, or misleading information. The HIRF safety assessment may show that some systems have different failure conditions in different phases of flight; therefore, the system HCL corresponds to the most severe failure condition. For example, an automatic flight control system may have a catastrophic failure condition for autoland, while automatic flight control system operations in cruise may have a hazardous failure condition.

c. **Establish the applicable aircraft external HIRF environment.** The external HIRF Environments I, II, and III, as published in CS 23.1308, 25.1317, 27.1317, and 29.1317, are shown in Tables 2, 3, and 4 respectively. The field strength values for the HIRF environments and test levels are expressed in root-mean-square (rms) units measured during the peak of the modulation cycle.

Table 2: HIRF Environment I

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10 kHz–2 MHz	50	50
2–30 MHz	100	100
30–100 MHz	50	50
100–400 MHz	100	100
400–700 MHz	700	50
700 MHz–1 GHz	700	100
1–2 GHz	2 000	200
2–6 GHz	3 000	200
6–8 GHz	1 000	200
8–12 GHz	3 000	300
12–18 GHz	2 000	200
18–40 GHz	600	200
In this table, the higher field strength applies at the frequency band edges.		

Table 3: HIRF Environment II

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10–500 kHz	20	20
500 kHz–2 MHz	30	30
2–30 MHz	100	100
30–100 MHz	10	10
100–200 MHz	30	10
200–400 MHz	10	10
400 MHz–1 GHz	700	40
1–2 GHz	1 300	160
2–4 GHz	3 000	120
4–6 GHz	3 000	160
6–8 GHz	400	170
8–12 GHz	1 230	230
12–18 GHz	730	190
18–40 GHz	600	150
In this table, the higher field strength applies at the frequency band edges.		

Table 4: HIRF Environment III

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10–100 kHz	150	150
100 kHz–400 MHz	200	200
400–700 MHz	730	200
700 MHz–1 GHz	1 400	240
1–2 GHz	5 000	250
2–4 GHz	6 000	490
4–6 GHz	7 200	400
6–8 GHz	1 100	170

8–12 GHz	5 000	330
12–18 GHz	2 000	330
18–40 GHz	1 000	420
In this table, the higher field strength applies at the frequency band edges.		

d. Establish the test environment for installed systems

1. **General.** The external HIRF environment will penetrate the aircraft and establish an internal RF environment to which installed electrical and electronic systems will be exposed. The resultant internal RF environment is caused by a combination of factors, such as aircraft seams and apertures, reradiation from the internal aircraft structure and wiring, and characteristic aircraft electrical resonance.

2. **Level A systems.** The resulting internal HIRF environments for Level A systems are determined by aircraft attenuation of external HIRF Environment I, II, or III, as defined in CS-23 Appendix K, in CS-25 Appendix R, in CS-27 Appendix D, and in CS-29 Appendix E, as applicable. The attenuation is aircraft- and zone-specific and should be established by aircraft test, analysis, or similarity. The steps for showing Level A HIRF compliance are presented in Section 8 of this AMC.

3. **Level B systems.** The internal RF environments for Level B systems are defined in CS-23 Appendix K, in CS-25 Appendix R, in CS-27 Appendix D, and in CS-29 Appendix E, as applicable, as equipment HIRF test Levels 1 or 2. The steps for showing Level B HIRF compliance are presented in Section 9 of this AMC.

4. **Level C systems.** The internal RF environment for Level C systems is defined in CS-23 Appendix K, in CS-25 Appendix R, in CS-27 Appendix D, and in CS-29 Appendix E, as applicable, as equipment HIRF test Level 3. The steps for showing Level C HIRF compliance are also presented in Section 9 of this AMC.

e. Apply the appropriate method of HIRF compliance verification

1. **General.** Table 5 summarises the relationship between the aircraft performance requirements in the HIRF requirements (paragraphs (a), (b) and (c)), and the HIRF environments and test levels.

2. **Pass/fail criteria.** Establish specific HIRF compliance pass/fail criteria for each system corresponding to the applicable HIRF requirements performance criteria. The definitions of 'normal operation' and 'automatically recover' in paragraph 5 of this AMC are provided in the context of CS 23.1308(a)(2), 25.1317(a)(2), 27.1317(a)(2), and 29.1317(a)(2). These pass/fail criteria should be presented to the Agency for approval. The means for monitoring system performance relative to these criteria should be

established by the applicant and approved by the Agency. All effects defining the pass/fail criteria should be the result of identifiable and traceable analysis that includes both the separate and interdependent operational characteristics of the systems. The analysis should evaluate the failures, either singularly or in combination, which could adversely affect system performance. This should include failures which could negate any system redundancy or influence more than one channel performing the same function.

Table 5: Summary of the HIRF certification requirements

HIRF FAILURE CONDITION FROM CSs 23.1308, 25.1317, 27.1317, AND 29.1317	PERFORMANCE CRITERIA	ITEM THE ENVIRONMENT OR TEST LEVEL APPLIES TO	HIRF ENVIRONMENT OR TEST LEVEL
Each electrical and electronic system that performs a function whose failure would prevent the continued safe flight and landing of the aircraft/rotorcraft must be designed and installed so that:	Each function is not adversely affected during or after the time…	…the aircraft …	…is exposed to HIRF Environment I.
	Each electrical and electronic system automatically recovers normal operation of that function, in a timely manner after…	…the aircraft…	…is exposed to HIRF Environment I, unless this conflicts with other operational or functional requirements of that system.
	Each electrical and electronic system is not adversely affected during or after…	…the aircraft…	…is exposed to HIRF Environment II.
	Each function required during operation under visual flight rules (VFR) is not adversely affected during or after…	…the rotorcraft…	…is exposed to HIRF Environment III (CS 27 and CS 29 only).
Each electrical and electronic system that performs a function whose failure would significantly reduce the capability of the aircraft/rotorcraft or the ability of the flight crew to respond to an adverse operating condition must be designed and installed so that:	The system is not adversely affected when…	…the equipment providing these functions…	…is exposed to equipment HIRF test Level 1 or 2.
Each electrical and electronic system that performs a function whose failure would reduce the capability of the aircraft/rotorcraft or the ability of the flight crew to respond to an adverse operating condition must be designed and installed so that:	The system is not adversely affected when…	…the equipment providing these functions…	…is exposed to equipment HIRF test Level 3.

f. Verify compliance with the applicable requirements

1. The applicant should demonstrate that the systems comply with the applicable specifications of CS 23.1308, 25.1317, 27.1317, and 29.1317.

2. The applicant should show that the RF currents on system and equipment wire bundles and the RF fields on the system, created by the HIRF environment, are lower than the equipment or system HIRF qualification test levels.

3. Verification may be accomplished by tests, analyses, or by demonstrating similarity to previously certified aircraft and systems. The certification process for Level A systems is contained in Section 7. The certification process for Level B and Level C systems is contained in Section 8.

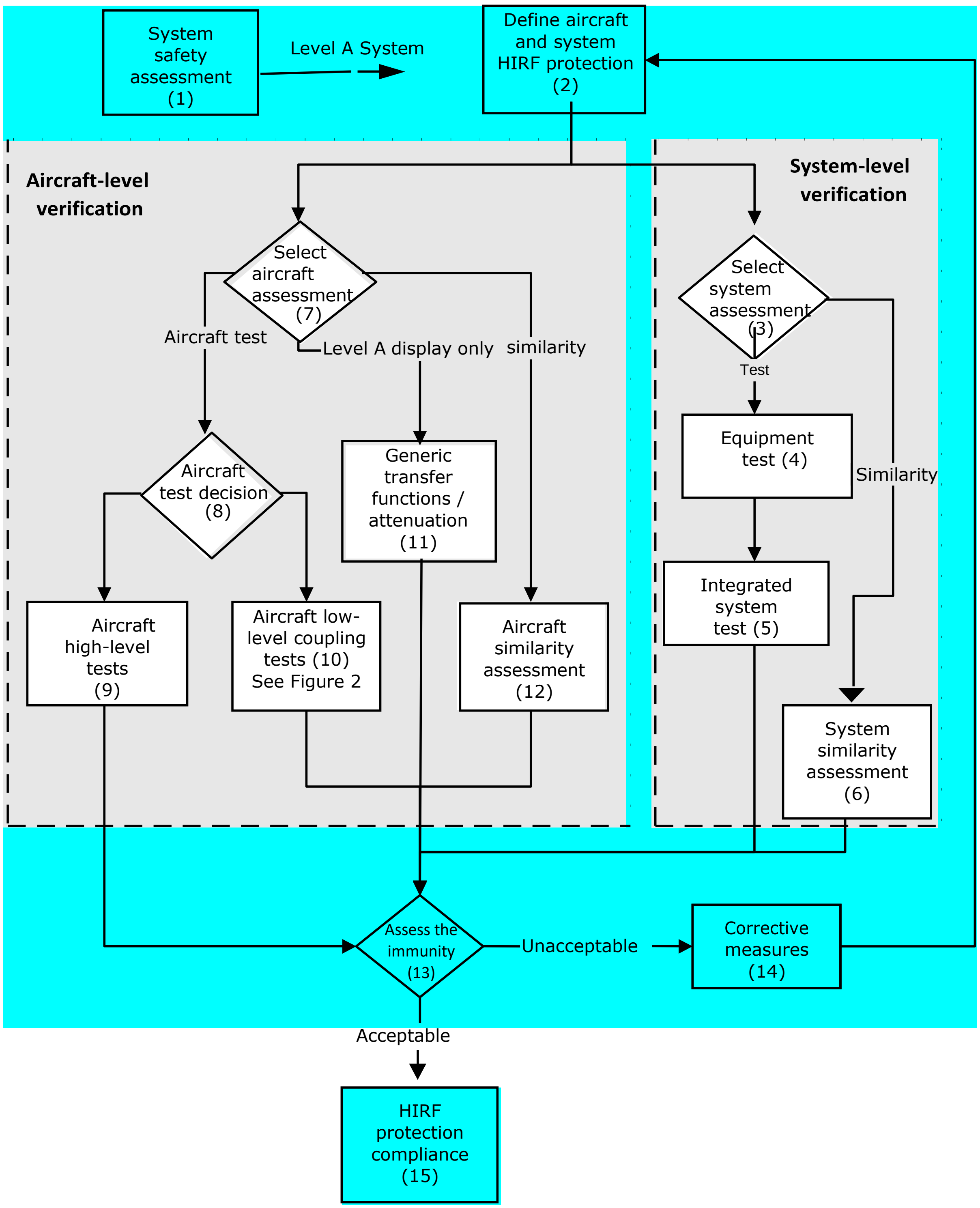
4. Margins are not required if HIRF compliance is based on tests of the specific aircraft model and system that undergo certification. Margins are also not required if HIRF compliance is based on analysis or similarity if the process validation is robust and the data well substantiated. Where data has limited substantiation, a margin may be required, depending on the available justifications. When a margin is required, the applicant should include a justification for the selected margin in the HIRF compliance plan, as discussed in Section 6(a).

5. The applicant should submit their compliance plan in the early stages of the certification programme to the Agency for review (see the details in Section 6(a)). Experience shows that, particularly with aircraft using new technology or those that have complex systems, early agreement on the compliance plan benefits both the applicant and the Agency. The plan should define acceptable ways to resolve critical issues during the certification process. Analyses and test results during the certification process may warrant modifications to the design or verification methods. When significant changes are necessary, the certification plan should be updated accordingly.

g. Take corrective measures (if needed)

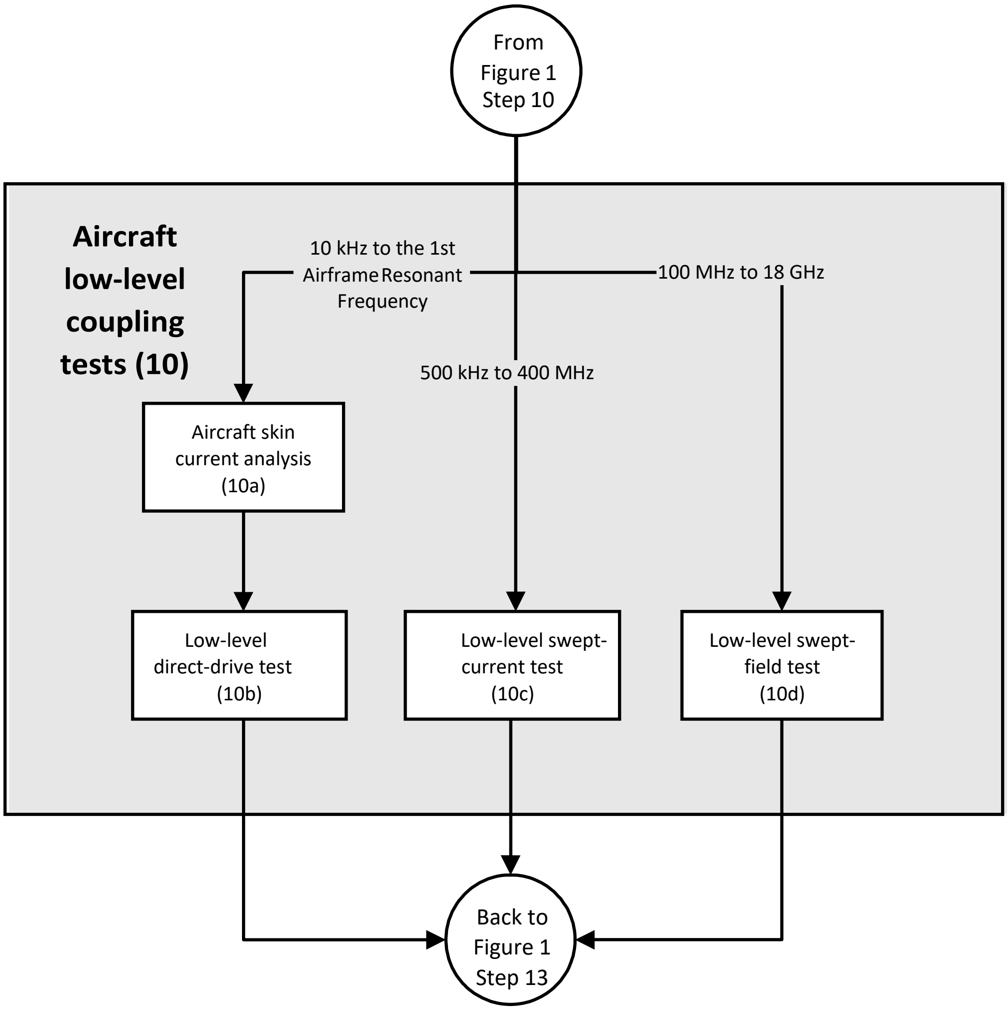
If tests and analyses show that the system did not meet the pass/fail criteria, the applicant should review the aircraft, installation or system design, and improve the protection against HIRF.

Figure 1: Routes to HIRF compliance — Level A systems



(n) = Step number as described in Section 7 of this AMC

Figure 2: Aircraft low-level coupling tests — Level A systems



(n) = Step number as described in Section 7 of this AMC

7. STEPS TO DEMONSTRATE 'LEVEL A' SYSTEM HIRF COMPLIANCE

Figures 1 and 2 illustrate a process that the applicant can use to demonstrate that their Level A system complies with CS 23.1308(a), 25.1317(a), 27.1317(a), and 29.1317(a).

a. Step 1 — HIRF safety assessment

1. The applicant should determine the system failure condition classification for the systems to be certified on their aircraft, using a system safety assessment as discussed in Section 6(b)(2). For systems classified with catastrophic failure conditions (Level A systems), the applicant should follow compliance steps 2 to 15 listed below, as appropriate. These compliance steps are also depicted in Figures 1 and 2 of this AMC, and are not necessarily accomplished sequentially. Applicants for systems

classified with hazardous or major failure conditions (HIRF certification Level B and Level C systems) should follow the compliance steps outlined in Section 8 of this AMC.

2. The system defined for paragraph (a) of CS 23.1308, 25.1317, 27.1317, and 29.1317 is not required to include:

   (a) equipment, components and electrical interconnections required only for non-normal situations; or

   (b) equipment, components and electrical interconnections required only for dispatching under master minimum equipment lists (MMELs) (when operational suitability data (OSD) is applicable).

3. Some systems include mechanical, hydraulic, and/or pneumatic channels as well as electrical and electronic channel(s) to perform functions whose failure would prevent continued safe flight and landing. The HIRF safety assessment for CS 23.1308(a), 25.1317(a), 27.1317(a), and 29.1317(a) only applies to functions performed by electrical and electronic systems. The HIRF safety assessment should consider electrical or electronic failures that would adversely affect the function of the mechanical, hydraulic, and/or pneumatic channel(s). If electrical or electronic equipment and components, as well as electrical interconnections are used to assist, augment, or monitor for control loop feedback, the mechanical, hydraulic, and/or pneumatic channels in performing the normal operation of the functions with failures that would prevent continued safe flight and landing, then the electrical and electronic channel(s) must comply with CS 23.1308(a), 25.1317(a), 27.1317(a), and 29.1317(a).

4. CS 23.1308(a), 25.1317(a), 27.1317(a), and 29.1317(a) do not require the applicant to assume pre-existing failure conditions when classifying the functional failure conditions and the scope of Level A systems. The applicant should consider total or partial loss of the systems and malfunctions of the systems, including hazardously misleading information presented to the flight crew during and after the aircraft is exposed to HIRF.

5. CS 23.1308(a)(2), 25.1317(a)(2), 27.1317(a)(2), and 29.1317(a)(2) require that Level A systems automatically recover normal operation of the Level A functions in a timely manner after exposure to HIRF Environment I. Automatic recovery applies to all redundant active channels of the Level A system required for normal operation unless its recovery conflicts with other operational or functional requirements of the system. The exception for automatic recovery conflicts must be based on aircraft operational or functional requirements independent of HIRF exposure. The exception should not be a mitigation for Level A system effects observed after exposure to HIRF Environment I.

6. Appendix 3 *Examples of HIRF safety assessment considerations — Level A systems* provides examples of systems' scope based on the guidance above.

b. **Step 2 — Define aircraft and system HIRF protection.** The applicant should define the HIRF protection features to be incorporated into the aircraft and system designs, based on the HIRF environments that are applicable to their aircraft and its Level A systems. Equipment, system, and aircraft HIRF protection design may occur before aircraft-level tests are performed, and before the actual internal HIRF environment is determined. Therefore, the equipment, system and aircraft HIRF protection design should be based on an estimate of the expected internal HIRF environment. The applicant should consider all aircraft configurations that may affect HIRF protection, such as open landing gear doors (see Step 7).

c. **Step 3 — System assessment decision.** The applicant should determine whether to perform integrated system HIRF tests on the Level A system, or to base the system verification on previous integrated system HIRF tests performed on a similar system. Aircraft and system tests and assessments need not be performed for HIRF environments above 18 GHz if data and design analysis show the integrated system test results (see Step 5) satisfy the pass/fail criteria from 12 GHz to 18 GHz, and the systems have no circuits that operate in the 18 GHz to 40 GHz frequency range.

d. **Step 4 — Equipment test**

1. Radiated and conducted RF susceptibility laboratory tests of RTCA / DO-160G / EUROCAE ED-14G (or latest version) Section 20 may be used to build confidence in the equipment's HIRF immunity before conducting integrated system laboratory tests in Step 5. The equipment should be specified and tested in accordance with the test levels (wire bundle currents injection and RF field illumination) of RTCA / DO-160 / EUROCAE ED-14 Section 20 or to a level estimated for the aircraft and equipment installation using the applicable external HIRF environment.

2. Equipment HIRF tests may be used to augment the integrated system HIRF tests where appropriate. For equipment whose HIRF immunity is evaluated as part of the integrated system-level HIRF tests discussed in Step 5, the individual equipment's HIRF testing described in this step is optional.

e. **Step 5 — Integrated system test**

1. Radiated and conducted RF susceptibility laboratory tests on an integrated system should be performed for Level A systems. The HIRF field strengths and wire bundle currents selected for this test should be based on the attenuated external HIRF environment determined in the aircraft assessment (see Steps 10, 11, or 12). In many cases, the integrated system test is performed before the aircraft assessment is complete. In these cases, the integrated system test field strengths and currents should be selected based on the expected aircraft attenuation or transfer function.

2. The installation details for the laboratory integrated system tests should be similar to the installation in the aircraft. For example, the bonding and grounding of the system, wire size, routing, arrangement (whether parallel or twisted wires), connector types, wire shields, and shield terminations, and the relative position of the elements to each

other and the ground plane in the laboratory should closely match the system installation on the aircraft to be certified. For this reason, the laboratory integrated system rig should have an Agency conformity inspection prior to conducting any Agency certification credit testing.

3. The integrated system should be tested with the system operating, to include connected displays, sensors, actuators, and other pieces of equipment. Applicants should place the system in various operating modes to ensure the integrated system is tested when operating at its maximum sensitivity. If the connected equipment is not related to the functions with catastrophic failures, these items may be simulated by test sets, if the test sets accurately represent the terminating circuit impedance of the sensor. However, the connected equipment should meet the appropriate HIRF requirements required for its failure condition classification.

4. The test levels should be selected based on the expected aircraft internal HIRF environment determined through aircraft tests (see Step 10), generic transfer functions 'for Level A display systems only' and attenuation (see Step 11), or aircraft similarity assessment (see Step 12), using the applicable external HIRF environment. Integrated system test procedures are described in detail in the User's Guide (SAE ARP 5583A / EUROCAE ED-107A).

5. Wire bundle current injection should be used for frequencies from 10 kHz to 400 MHz. RF currents are injected into the integrated system wiring via a current transformer. Each wire bundle in the system should be injected and the induced wire bundle current measured. If a system wire bundle branches, then each wire bundle branch should also be tested. Simultaneous multi-bundle current injection may be necessary on systems with redundant or multi-channel architectures.

6. High-level radiated susceptibility tests should be used at frequencies greater than 100 MHz. The radiating antenna should be far enough away to ensure the total volume of the equipment and at least half a wavelength of the wiring is simultaneously and uniformly illuminated during the test.

7. The applicant should define appropriate pass/fail criteria for the system, based on the system safety assessment and the appropriate HIRF requirements. Any system susceptibility, including system malfunctions such as displaying hazardously misleading information, upsets, or damage, should be recorded and evaluated based on these previously defined pass/fail criteria.

8. Using only the modulation to which the system under evaluation is most sensitive may minimise the test time. The User's Guide (SAE ARP 5583A / EUROCAE ED-107A) provides guidance on modulation selection and suggested default modulations and dwell times.

9. The equipment tests in Step 4, using the techniques in RTCA / DO-160G / EUROCAE ED-14G (or latest version) Section 20, normally are not sufficient to show HIRF

compliance for Step 5 and Step 6. However, these standard RTCA / DO-160G / EUROCAE ED-14G Section 20 tests may be sufficient if paragraph 7(e)(2) and (3) of this step are met.

10. If the Level A System consists of multiple similar channels, the applicant may propose using one or more channels in the laboratory test set-up for the integrated system, instead of all similar channels. The applicant should demonstrate that the laboratory test set-up adequately performs the functions that must demonstrate compliance with CS 23.1308(a), 25.1317(a), 27.1317(a), and 29.1317(a). The applicant should ensure that the laboratory test set-up represents and monitors any cross-channel interactions, such as cross-channel data links, redundancy management, and system health monitoring.

    Note: Similar channels are composed of equipment that has the same hardware but not necessarily the same part number; in case of use of pin programming and/or software to identify or configure equipment of similar channels, it must be assessed whether these differences have an impact on the functions performed.

f. Step 6 — System similarity assessment

1. The integrated system HIRF tests performed for a system previously certified on a given aircraft model may be used to demonstrate system verification for a similar system. Each system considered under the similarity approach needs to be assessed independently even if it may use equipment and installation techniques from previous certification projects.

2. The system used as the basis for similarity must have successfully completed integrated system HIRF tests. A similarity assessment requires a comparison of both the equipment and installation differences that could adversely affect HIRF immunity. The assessment should evaluate the differences between the previously HIRF certified system and the equipment circuit interfaces, wiring, grounding, bonding, connectors, and wire-shielding practices of the equipment that is part of the new system.

3. If the assessment finds only minimal differences between the previously certified system and the new system to be certified, similarity may be used as the basis for system-level verification without the need for additional integrated system tests, provided there are no unresolved in-service HIRF problems related to the previously certified system. If there is uncertainty about the effects of the differences, additional tests and analyses should be conducted, as necessary and appropriate, to resolve the uncertainty. The amount of additional testing should be commensurate with the degree of difference identified between the new system and the system previously certified. If significant differences are found, similarity should not be used as the basis for system-level verification.

g. Step 7 — Aircraft assessment decision

1. Level A systems require an aircraft assessment. The aircraft assessment should determine the actual internal HIRF environment where the Level A systems are installed in the aircraft. The applicant should choose whether to use aircraft tests, previous coupling/attenuation data from similar aircraft types (similarity). For Level A display systems only, applicants should use the generic transfer functions and attenuation in Appendix 1 to this AMC. Alternately, the aircraft assessment may be a test that exposes the entire aircraft with operating Level A systems to external HIRF Environment I, II, or III (Tables 2, 3, and 4 respectively), as appropriate, to demonstrate acceptable Level A system performance.

2. Level A display systems include the display equipment, control panels, and the sensors that provide information to the displays. These sensors could also provide information to Level A non-display systems, so in that case, the applicant should determine the real transfer function and attenuation curves of these sensors when demonstrating compliance for this Level A non-display system. For example, for air data systems and inertial reference systems, which send information to the EFIS and flight controls, the transfer function and attenuation should be determined by aircraft low-level coupling testing or an aircraft similarity assessment as defined in Steps 10 and 12.

3. Other methods for aircraft HIRF assessment, such as analysis, may be acceptable. However, comprehensive modelling and analysis for RF field coupling to the aircraft structure is an emerging technology. Therefore, analysis alone is currently not adequate to show HIRF compliance for Level A systems and should be augmented by testing.

4. If analysis is used to determine aircraft attenuation and transfer function characteristics, test data should be provided to support this analysis. Any analysis results should take into account the quality and accuracy of the analysis. Significant testing, including aircraft-level testing, may be required to support the analysis.

5. Aircraft and system tests and assessments need not be performed for the HIRF environments above 18 GHz if data and design analysis show the integrated system test results (see Step 5) satisfy the pass/fail criteria from 12 to 18 GHz, and the systems have no circuits operating in the 18 to 40 GHz frequency range.

h. Step 8 — Aircraft test decision

1. Various aircraft test procedures are available and accepted for collecting data for aircraft HIRF verification. The two main approaches to aircraft testing are the aircraft high-level test (see Step 9) and the aircraft low-level coupling test (see Step 10). The aircraft high-level field-illumination test involves radiating the aircraft at test levels equal to the applicable external HIRF environment in the HIRF requirements. Aircraft low-level coupling tests involve measuring the airframe attenuation and transfer

functions, so that the internal HIRF electric fields and currents can be compared with the integrated system test levels.

2. Some test procedures may be more appropriate than others because of the size of the aircraft and the practicality of illuminating the entire aircraft with the appropriate external HIRF environment. The aircraft low-level coupling tests (see Step 10) may be more suitable for testing large aircraft than the high-level field-illumination test in Step 9, which requires illumination of the entire aircraft with the external HIRF environment.

i. Step 9 — Aircraft high-level tests

1. The aircraft high-level field-illumination test requires generating RF fields external to an aircraft at a level equal to the applicable external HIRF environment.

2. At frequencies below 400 MHz, the distance between the aircraft and the transmitting antenna should be sufficient to ensure the aircraft is illuminated uniformly by the external HIRF environment. The transmitting antenna should be placed in at least four positions around the aircraft. For aircraft, the antenna is typically placed to illuminate the nose, tail, and each wing tip. For rotorcraft, the antenna is typically placed to illuminate the nose, tail, and each side. The aircraft should be illuminated by the antenna at each position while sweeping the frequency range. Perform separate frequency sweeps with the transmitting antenna oriented for horizontal and vertical polarisation. The RF field should be calibrated by measuring the RF field strength in the centre of the test volume before the aircraft is placed there.

3. At frequencies above 400 MHz, the RF illumination should be localised to the system under test, provided all parts of the system and at least one wavelength of any associated wiring (or the total length if less than one wavelength) are illuminated uniformly by the RF field. The applicant may need reflection planes to illuminate relevant apertures on the bottom and top of the aircraft.

4. To ensure the systems are tested when operating at their maximum sensitivity, Level A systems should be fully operational, and the aircraft should be placed in various simulated operating modes.

5. The test time can be minimised by using only the modulation to which the system under evaluation is most sensitive. If the applicant does this, the rationale used to select the most sensitive modulation should be documented in the HIRF test plan as discussed in Section 6(b)(1). The User's Guide (SAE ARP 5583A / EUROCAE ED-107A) provides guidance on modulation selection and suggested default modulations and dwell times.

6. As an alternative to testing at frequencies below the first airframe resonant frequency, it is possible to inject high-level currents directly into the airframe using aircraft high-level direct-drive test methods. Aircraft skin current analysis should be performed as

described in the User's Guide, or low-level swept-current measurements should be made to determine the skin current distribution that will exist for different RF field polarisations and aircraft illumination angles so that these can be simulated accurately during this test. Aircraft high-level direct-drive testing, although applicable only from 10 kHz to the first airframe resonant frequency, is advantageous because it is possible to test all systems simultaneously.

j. Step 10 — Aircraft low-level coupling tests

1. General

(a) The aircraft low-level coupling tests include three different tests that cover the frequency range of 10 kHz to 18 GHz (see Figure 2). Detailed descriptions are available in the User's Guide. Other techniques may be valid, but must be discussed with and accepted by the Agency before being used.

(b) The low-level direct-drive test (see Step 10b, Figure 2) and the low-level swept-current test (see Step 10c) are used for frequencies at or below 400 MHz. The low-level swept-field test (see Step 10d) is used for frequencies at and above 100 MHz. There is an overlap of test frequencies from 100 to 400 MHz in the low-level swept-current test and the low-level swept-field test. The division at 100 MHz is not absolute and depends on the aircraft to be tested and the resonance of the wiring and instrumentation limitations. The division at 400 MHz is not absolute either, and depends on when HIRF penetration of the equipment case becomes a significant factor.

2. Steps 10a and 10b — Aircraft skin current analysis and low-level direct-drive test. Low-level direct-drive tests in conjunction with skin current analysis should be used to determine the transfer function between the skin current and individual equipment wire bundle currents. The low-level direct-drive test is typically used for frequencies from 10 kHz to the first airframe resonant frequency. For the low-level direct-drive test to be applied successfully, a three-dimensional model of the aircraft should be derived using aircraft skin current analysis. The three-dimensional model can then be used to derive the aircraft's skin current pattern for the applicable external HIRF environment. Guidance on skin current analysis is in the User's Guide. If the relationship between the external HIRF environment and the skin current is known for all illumination angles and polarisation, either because of aircraft skin current analysis or the use of the low-level swept-current test, the skin current can be set up by direct injection into the airframe. The resultant currents on the system wire bundles are measured with a current probe and normalised to 1 V/m electric field strength so they can be scaled to the appropriate external HIRF environment. The low-level direct-drive test is more effective than low-level swept-current tests for frequencies from 10 kHz to the first airframe resonant frequency, and may be necessary for small aircraft or aircraft with high levels of airframe shielding.

3. **Step 10c — Low-level swept-current test.** The low-level swept-current test involves illuminating the aircraft with a low-level external HIRF field to measure the transfer function between the external field and the aircraft and equipment wire bundle currents. This test is typically used in the frequency range of 500 kHz to 400 MHz. The transfer function is resonant in nature and is dependent on both the aircraft structure and the system installation. Because the transfer function relates wire bundle currents to the external field, the induced bulk current injection test levels can be related to an external HIRF environment.

   The transmitting antenna should be placed in at least four positions around the aircraft, with the distance between the aircraft and the transmitting antenna sufficient to ensure the aircraft is illuminated uniformly. For aircraft, the antenna is typically placed to illuminate the nose, tail, and each wing tip. For rotorcraft, the antenna is typically placed to illuminate the nose, tail, and each side. The aircraft should be illuminated by the antenna at each position while sweeping the frequencies in the range of 500 kHz to 400 MHz. The applicant should perform separate frequency sweeps with the transmitting antenna oriented for horizontal and vertical polarisation, and measure the currents induced on the aircraft wire bundles.

   The applicant should calculate the ratio between the induced wire bundle current and the illuminating antenna field strength, and normalise this ratio to 1 V/m. This provides the transfer function in terms of induced current per external field strength unit. Then the current induced by the applicable external HIRF environment can be calculated by multiplying the transfer function by the external HIRF field strength. The calculated HIRF currents for all transmitting antenna positions for each aircraft wire bundle to be assessed should be overlaid to produce worst-case induced current for each wire bundle. These worst-case induced currents can be compared with the current used during the integrated system test in Step 5.

4. **Step 10d — Low-level swept-field test.** Low-level swept-field testing is typically used from 100 MHz to 18 GHz. The test procedures for the low-level swept-field test are similar to those used for the low-level swept-current test; however, in the low-level swept-field test, the internal RF fields in the vicinity of the equipment are measured instead of the wire bundle currents. Various techniques can be used to ensure the maximum internal field in the vicinity of the equipment is measured. Depending on the size of the aircraft and the size of the aircraft cabin, flight deck, and equipment bays, multipoint measurement or mode stirring can be used to maximise the internal field in the vicinity of the equipment. See the User's Guide (SAE ARP 5583A / EUROCAE ED-107A) for detailed low-level swept-field test procedures.

k. Step 11 — Generic transfer functions and attenuation — Level A display systems only

1. Level A displays involve functions for which system information is displayed directly to the pilot. For Level A display systems, the aircraft attenuation data may be determined using generic attenuation and transfer function data. This approach should not be used

for other Level A systems, such as control systems, because failures and malfunctions of those systems can more directly and abruptly contribute to a catastrophic failure event than display system failures and malfunctions; therefore, other Level A systems should have a more rigorous HIRF compliance verification programme.

2. The integrated system test levels specified in Step 5 may be derived from the generic transfer functions and attenuation for different types of aircraft. Acceptable transfer functions for calculating the test levels are given in Appendix 1 to this AMC. Appendix 1 to this AMC also contains guidelines for selecting the proper generic attenuation. The generic transfer functions show the envelope of the currents that might be expected to be induced in the types of aircraft in an external HIRF environment of 1 V/m. The current levels should be multiplied linearly by HIRF Environment I, II, or III, as appropriate, to determine the integrated system test levels.

3. The internal HIRF electric field levels are the external HIRF environment divided by the appropriate attenuation, in linear units. For example, 20 dB or a 10:1 attenuation means the test level is the applicable external HIRF environment electric field strength reduced by a factor of 10.

4. The internal HIRF environments for Level A display systems can also be measured using on-aircraft low-level coupling measurements of the actual system installation (see Step 10). This procedure should provide more accurate information to the user, and the test levels may be lower than the generic transfer functions or attenuation, which are worst-case estimates.

l. Step 12 — Aircraft similarity assessment

1. The aircraft attenuation and transfer function tests performed for a previously certified aircraft may be used to support aircraft-level verification for a similar aircraft model. The aircraft used as the basis for similarity must have been previously certified for HIRF compliance, using HIRF attenuation and transfer functions determined by tests on that aircraft.

2. The similarity assessment for the new aircraft model should consider the aircraft differences that could impact on the internal HIRF environment affecting the Level A systems and the associated wiring. The comparison should consider equipment and wiring locations, airframe materials and construction, and apertures that could affect attenuation for the external HIRF environment.

3. If the assessment finds only minimal differences between the previously certified aircraft and the new aircraft to be certified, similarity may be used to determine the aircraft attenuation and transfer functions without the need for additional aircraft tests, providing there are no unresolved in-service HIRF problems related to the existing aircraft. If there is uncertainty about the effects of the differences, additional tests and analyses should be conducted as necessary and appropriate to resolve the uncertainty. The amount of additional testing should be commensurate with the degree of difference identified between the new aircraft to be certified and the aircraft previously certified. If significant differences are found, similarity should not be used as the basis for aircraft-level verification.

m. Step 13 — Assess the immunity

1. The applicant should compare the test levels used for the integrated system test of Step 5 with the internal RF current or RF fields determined by the aircraft low-level coupling tests (see Step 10), the generic transfer functions and attenuation (see Step 11), or the aircraft similarity assessment (see Step 12). The actual aircraft internal RF currents and RF fields should be lower than the integrated system test levels. The comparison method should be included in the HIRF compliance plan. The method should enable a direct comparison between the system test level and the aircraft internal HIRF environment at the equipment or system location, using current for frequencies from 10 kHz to 400 MHz, and using electric field strength for frequencies from 100 MHz through 18 GHz.

2. If the conducted RF susceptibility test levels used for the integrated system test (see Step 5) were too low when compared with the aircraft-induced currents determined in Steps 10b, 10c, 11 or 12, then corrective measures are needed (see Step 14). If the radiated RF susceptibility test levels used for integrated system tests (see Step 5) were too low when compared with the aircraft internal fields determined in Steps 10d, 11 or 12, then corrective measures are needed (see Step 14).

3. When comparing the current measured during low-level swept-current tests in Step 10c with the current used during the integrated system tests in Step 5, there may be differences. These differences may be due to variations between the actual aircraft installation and the integrated system laboratory installation, such as wire bundle lengths, shielding and bonding, and wire bundle composition. The worst-case current signature for a particular wire bundle should be compared with the current induced at the particular test level or equipment malfunction over discrete frequency ranges such as 50 to 500 kHz, 500 kHz to 30 MHz, and 30 to 100 MHz. This comparison should be broken into discrete frequency ranges because the resonant frequencies may differ between the integrated system tests and the aircraft tests.

4. If the applicant uses aircraft high-level tests (see Step 9) for aircraft HIRF verification, they should determine whether there were any Level A system susceptibilities. Any Level A system susceptibilities should be evaluated based on the pass/fail criteria as established in the test plan (see Section 8(b)(1)). If the HIRF susceptibilities are not acceptable, then corrective measures may be needed (see Step 14).

5. HIRF susceptibilities that were not anticipated or defined in the test plan pass/fail criteria may be observed during aircraft high-level tests or integrated system laboratory tests. The pass/fail criteria may be modified if the effects neither cause nor contribute to conditions that adversely affect the aircraft functions or systems in the HIRF requirements. The applicant should provide an assessment and the supporting rationale for any modifications to the pass/fail criteria to the Agency for acceptance. If the HIRF susceptibilities are not acceptable, then corrective measures may be needed (see Step 14).

6. If the Level A systems show no adverse effects when tested to levels derived from the applicable HIRF Environment I or III, this also demonstrates compliance of the system with HIRF Environment II.

7. If the integrated system test results (see Step 5) satisfy the pass/fail criteria from 12 to 18 GHz, and design analysis shows the system has no circuits operating in the 18 to 40 GHz frequency range, this demonstrates by analysis that the system is not adversely affected when exposed to HIRF environments above 18 GHz. If these conditions are satisfied, further aircraft and system tests and assessments above 18 GHz are not necessary.

8. The applicant should review the actual system installation in the aircraft and the system configuration used for the integrated system test (see Step 5). If significant configuration differences are identified, corrective measures may be needed (see Step 14).

9. Certain RF receivers with antennas connected should not be expected to perform without effects during exposure to the HIRF environments, particularly in the RF receiver operating band. Because the definition of adverse effects and the RF response

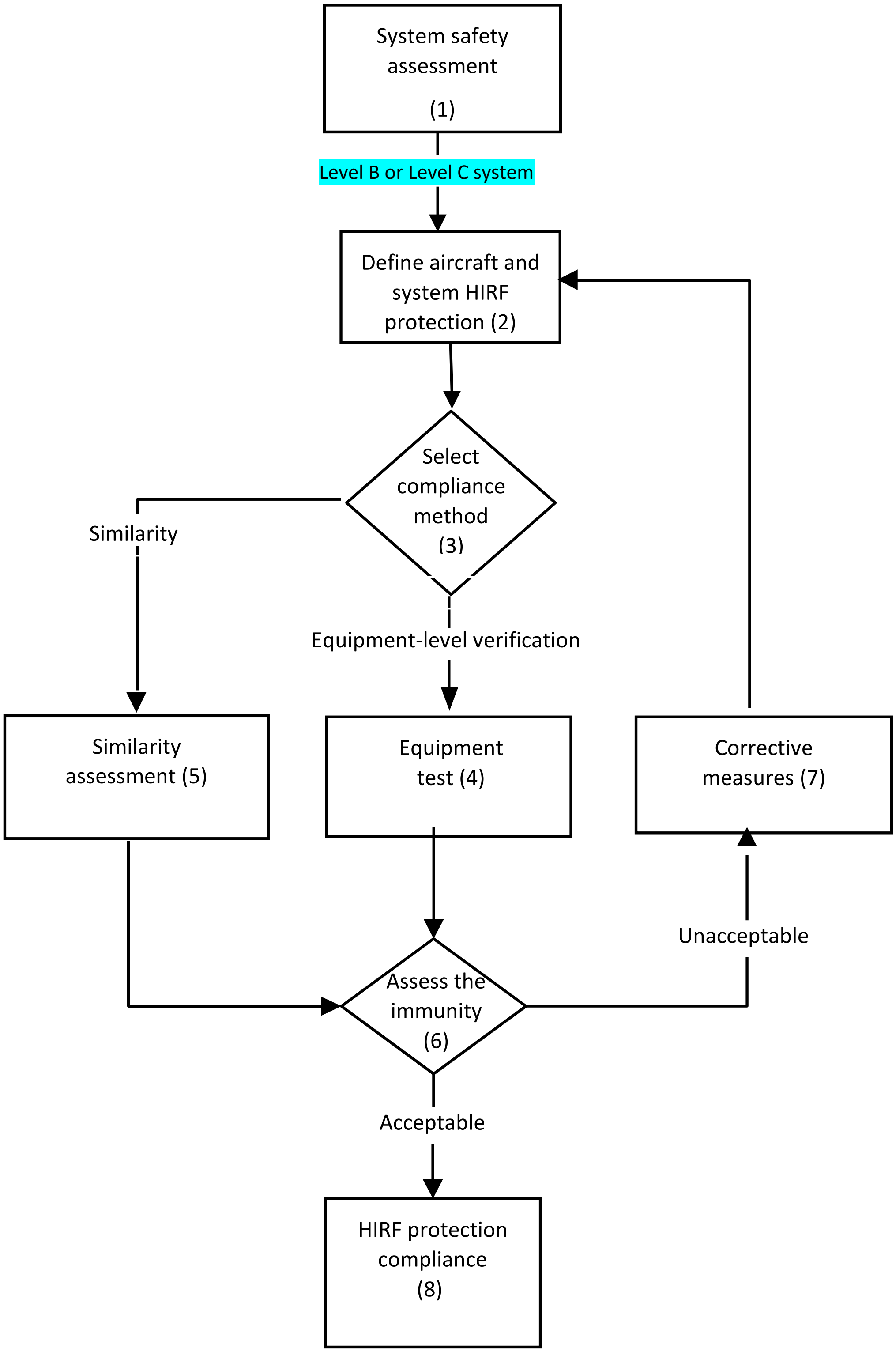
at particular portions of the spectrum depends on the RF receiver system function, the applicant should refer to the individual RF receiver minimum performance standards for additional guidance. However, because many RF receiver minimum performance standards were prepared before the implementation of the HIRF requirements, the RF receiver pass/fail criteria should be coordinated with the Agency.

10. The applicant should provide the similarity assessment and the supporting rationale to the Agency for acceptance.

n. **Step 14 — Corrective measures.** Corrective measures should be taken if the system fails to satisfy the HIRF immunity assessment of Step 13. If changes or modifications to the aircraft, equipment, system or system installation are required, then additional tests may be necessary to verify the effectiveness of the changes. The RTCA / DO-160G / EUROCAE ED-14G, or latest version, Section 20 equipment tests, integrated system tests, and aircraft tests, in whole or in part, may need to be repeated to show HIRF compliance.

o. **Step 15 — HIRF protection compliance.** The test results and compliance report should be submitted to the Agency for approval as part of the overall aircraft type certification or supplemental type certification process.

Figure 3: Routes to HIRF compliance — Level B and Level C systems



(n) = Step number as described in Section 10 of this AMC

8. STEPS TO DEMONSTRATE 'LEVEL B' AND 'LEVEL C' SYSTEM HIRF COMPLIANCE

Figure 3 illustrates a process that the applicant can use to demonstrate whether their Level B and Level C systems comply with CS 23.1308(b), 25.1317(b), 27.1317(b), and 29.1317(b), and with CS 23.1308(c), 25.1317(c), 27.1317(c), and 29.1317(c) respectively.

a. **Step 1 — HIRF safety assessment.** The applicant should determine the system certification level for the systems to be certified on their aircraft, using a system safety assessment as discussed in Section 6(b)(2). For systems classified with hazardous or major failure conditions (Level B and Level C systems), the applicant should follow compliance Steps 2 through 8 listed below, as appropriate. These compliance steps are also depicted in Figure 3 of this AMC and are not necessarily accomplished sequentially. For systems classified with catastrophic failure conditions (Level A systems), the applicant should follow the compliance steps outlined in Section 7.

b. **Step 2 — Define the aircraft and system HIRF protection.** The applicant should define the HIRF protection features incorporated into the aircraft and system designs, based on the HIRF test levels applicable to their aircraft and its Level B and Level C systems. Equipment, system, and aircraft HIRF protection design may occur before aircraft-level tests are performed, and before the actual internal HIRF environment is determined. Therefore, the equipment, system and aircraft HIRF protection design should be based on an estimate of the expected internal HIRF environment.

c. **Step 3 — Select the compliance method.** The applicant should determine whether to perform equipment HIRF tests on the Level B and Level C systems, or to base the compliance on previous equipment tests performed for a similar system.

d. **Step 4 — Equipment test**

1. Level B and Level C systems do not require the same degree of HIRF compliance testing as Level A systems and, therefore, do not require aircraft-level testing. RTCA / DO-160G / EUROCAE ED-14G, or latest version, Section 20 laboratory test procedures should be used, using equipment test levels defined in the applicable specifications. The test levels used depend on whether the system is categorised as Level B or Level C. Equipment HIRF test Level 1 or 2, as applicable, should be used for Level B systems. RTCA / DO-160 / EUROCAE ED-14 Section 20 Category RR (using the alternative modulation for radiated susceptibility) satisfies the requirements of equipment HIRF test Level 1. For equipment HIRF test Level 2, the applicant may use the approach in Section 9(k) to help determine the acceptable aircraft transfer function and attenuation curves for their Level B system. Equipment HIRF test Level 3 should only be used for Level C systems. RTCA / DO-160 / EUROCAE ED-14 Section 20 Category TT satisfies the requirements of equipment HIRF test Level 3. When applying modulated signals, the test levels are given in terms of the peak of the test signal as measured by

a root mean square (rms), indicating the spectrum analyser's peak detector. See the User's Guide (SAE ARP 5583A / EUROCAE ED-107A) for more details on modulation.

2. The applicant should define appropriate pass/fail criteria for the system, based on the system safety assessment and the appropriate HIRF requirements (see Section 6(b)(2)). Any susceptibility noted during the equipment tests, including equipment malfunctions, upsets, or damage, should be recorded and evaluated based on the defined pass/fail criteria.

e. Step 5 — Similarity assessment

1. The equipment HIRF tests performed for a system previously certified on a given aircraft model may be used to show compliance for a similar system. Each system considered for similarity needs to be assessed independently even if it used equipment and installation techniques from a previous certification.

2. The system used as the basis for certification by similarity must have successfully completed equipment HIRF tests and been previously certified for HIRF compliance on another aircraft model. Similarity assessment requires a comparison of both the equipment and installation differences that could adversely affect HIRF immunity. An assessment of a new system should consider the differences in the equipment circuit interfaces, wiring, grounding, bonding, connectors, and wire-shielding practices.

3. If the assessment finds only minimal differences between the previously certified system and the new system to be certified, similarity may be used for HIRF compliance without the need for additional equipment HIRF tests, provided there are no unresolved in-service HIRF problems related to the previously certified system. If there is uncertainty about the effects of the differences, additional tests and analyses should be conducted as necessary and appropriate to resolve the uncertainty. The amount of additional testing should be commensurate with the degree of difference identified between the new system and the system previously certified. If significant differences are found, similarity should not be used as the basis for HIRF compliance.

f. Step 6 — Assess the immunity

1. The applicant should review the results of the equipment test to determine whether the pass/fail criteria are satisfied. HIRF susceptibilities that were not anticipated or defined in the test plan pass/fail criteria may be observed during equipment HIRF tests. The pass/fail criteria may be modified if the effects neither cause nor contribute to conditions that adversely affect the aircraft functions or systems, as applicable, in the HIRF requirements. The applicant should provide an assessment of, and the supporting rationale for, any modifications to the pass/fail criteria to the Agency for approval. If the HIRF susceptibilities are not acceptable, then corrective measures may be needed (see Step 7).

2. The applicant should review the actual system installation in the aircraft and the configuration used for the equipment tests (see Step 4). If significant differences in grounding, shielding, connectors, or wiring are identified, corrective measures may be needed (see Step 7).

3. Certain RF receivers with antennas connected should not be expected to perform without effects during exposure to the HIRF environments, particularly in the RF receiver operating band. Because the definition of adverse effects and the RF response at particular portions of the spectrum depends on the RF receiver system function, applicants should refer to the individual RF receiver minimum performance standards for additional guidance. However, because many RF receiver minimum performance standards were prepared before the implementation of the HIRF requirements, the RF receiver pass/fail criteria should be coordinated with the Agency. Future modifications of the minimum performance standards should reflect the HIRF performance requirements.

g. **Step 7 — Corrective measures.** The applicant should take corrective measures if the system fails to satisfy the HIRF immunity assessment of Step 6. If changes or modifications to the equipment, system, or system installation are required, then additional tests may be necessary to verify the effectiveness of the changes. The RTCA / DO-160G / EUROCAE ED-14G, or latest version, Section 20 equipment tests, in whole or in part, may need to be repeated to show HIRF compliance.

h. **Step 8 — HIRF protection compliance.** The applicant should submit the test results and compliance report to the Agency for acceptance as part of the overall aircraft type certification or supplemental type certification process.

9. HIRF COMPLIANCE DEMONSTRATION

a. **HIRF compliance plan.** An overall HIRF compliance plan should be established to clearly identify and define HIRF certification requirements, HIRF protection development, and the design, test, and analysis activities intended to be part of the compliance effort. This plan should provide definitions of the aircraft systems, installations, and protective features against which HIRF compliance will be assessed. The HIRF compliance plan should be discussed with, and submitted to, the Agency for acceptance before initiating HIRF compliance activities. If the aircraft, system, or installation design changes after approval, a revised HIRF compliance plan should be submitted to the Agency for acceptance. The HIRF compliance plan should include the following:

1. a HIRF compliance plan summary;

2. identification of the aircraft systems, with classifications based on the safety assessment as it relates to HIRF (see Section 6(b)(2));

3. the planned or expected HIRF environment for the aircraft and installed systems; and

4. the verification methods, such as test, analysis, or similarity.

b. Methods of compliance verification

1. Various methods are available to aid in demonstrating HIRF compliance. Methods acceptable to the Agency are described in Sections 6 and 7 of this AMC. Figures 1 and 2 above outline the steps to HIRF compliance for systems that require Level A HIRF certification. Figure 3 above outlines the steps to HIRF compliance for systems that require Level B or Level C HIRF certification. The steps in these figures are not necessarily accomplished sequentially. Wherever a decision point is indicated on these figures, the applicant should complete the steps in that path as described in Sections 6 and 7 of this AMC.

2. Other HIRF compliance techniques may be used to demonstrate system performance in the HIRF environment; however, those techniques should be accepted by the Agency before using them.

c. HIRF verification test, analysis, or similarity plan. Test, analysis and similarity are all acceptable methods. The applicant must choose the method or the combination of methods most appropriate for their project. See Sections 6 and 7 of this AMC, and SAE ARP 5583A / EUROCAE ED-107A for additional guidance for selecting the appropriate method. Specific HIRF test, analysis, or similarity plans could be prepared to describe specific verification activities. A single verification plan combining various methods for all the selected systems or dedicated verification plans may be necessary. For example, there may be several systems or equipment laboratory test plans, an aircraft test plan, or a similarity plan for selected systems on an aircraft.

1. Test plan

(a) A HIRF compliance test plan may include the equipment, system, and aircraft test objectives for the acquisition of data to support HIRF compliance verification. The plan should provide an overview of the factors to be addressed for each system test requirement.

The test plan should include:

1. the purpose of the test;
2. a description of the aircraft and/or the system to be tested;
3. system configuration drawings;
4. the proposed test set-up and methods;
5. the intended test levels, modulations, and frequency bands;
6. pass/fail criteria; and
7. the test schedule and test location.

(b) The test plan should cover Level A, B, and C systems and equipment, as appropriate. Level A systems may require both integrated systems laboratory tests and aircraft tests. Level B and Level C systems and equipment require only equipment laboratory testing.

(c) The test plan should describe the appropriate aspects of the systems to be tested and their installation. Additionally, the test plan should reflect the results of any analysis performed in the overall process of the HIRF compliance evaluation.

2. **Analysis plan.** A HIRF compliance analysis plan should include the objectives, both at system and equipment level, for generating data to support HIRF compliance verification. Comprehensive modelling and analysis for RF field coupling to aircraft systems and structures is an emerging technology; therefore, the analysis plan should be coordinated with the Agency to determine an acceptable scope for the analysis.

The analysis plan should include:

(a) the purpose and scope of the analysis;

(b) a description of the aircraft and/or the system addressed by the analysis;

(c) system configuration descriptions;

(d) the proposed analysis methods;

(e) the approach for validating the analysis results; and

(f) pass/fail criteria, including margins to account for analysis uncertainty.

3. **Similarity plan.** A similarity plan should describe the approach undertaken to use the certification data from previously certified systems, equipment, and aircraft in the proposed HIRF compliance programme.

The similarity plan should include:

(a) the purpose and scope of the similarity assessment;

(b) the specific systems addressed by the similarity assessment;

(c) the data used from the previously certified systems, equipment, and aircraft;

(d) details of the significant differences between the aircraft and system to be certified and the similar aircraft and system from which the data will be used; and

(e) when data has limited substantiation, a description and justification for margins to account for similarity uncertainty; see Section 6(f)(3) for additional information on margins.

d. **Compliance reports.** One or more compliance reports may be necessary to document the results of test, analysis, or similarity assessments. For new or significantly modified aircraft, HIRF compliance reports include many system and equipment test reports, aircraft test reports, and HIRF vulnerability analysis reports. For these types of HIRF certification programmes, a compliance summary report may be useful to summarise the results of tests and analyses. For HIRF certification programmes of relatively simple systems, a single compliance report is adequate.

1. **Test reports.** Comprehensive test reports should be produced at the conclusion of HIRF compliance testing. The test reports should include descriptions of the salient aspects of equipment or system performance during the test, details of any area of non-compliance with HIRF requirements, actions taken to correct the non-compliance, and any similarity declarations. The applicant should also provide the supporting rationale for any deviations from system performance observed during testing.

2. **Analysis reports.** Analysis reports should describe the details of the analytical model, the methods used to perform the analysis, and the results of the analysis. The reports should identify any modelling uncertainty and justify the margins established in the analysis plan.

3. **Similarity reports.** Similarity reports should document the significant aircraft, system, equipment, and installation features that are common between the aircraft or system that is the subject of the similarity analysis and the aircraft or system that was previously certified for HIRF. The reports should identify all the significant differences encountered, along with the assessment of the impact of these differences on HIRF compliance. These reports should also justify the margins established in the similarity plan.

10. MAINTENANCE, PROTECTION ASSURANCE, AND MODIFICATIONS

a. The minimum maintenance required to support HIRF certification should be identified in the instructions for continued airworthiness (ICAs) as specified in CS 23.1529, 25.1529, 25.1729, 27.1529, and 29.1529, as appropriate. Dedicated devices or specific features may be required to provide HIRF protection for an equipment or system installation. Appropriate maintenance procedures should be defined for these devices and features to ensure in-service protection integrity. A HIRF protection assurance programme should be proposed in the certification plan to identify all actions necessary to justify or to verify that the maintenance procedures are adequate. This assurance programme may propose a surveillance programme based on a sampling of the fleet for monitoring the effectiveness of the protection features and/or maintenance procedures. The User's Guide (SAE ARP 5583A / EUROCAE ED-107A) provides further information on these topics.

b. The maintenance procedures should consider the effects of corrosion, fretting, flexing cycles, or other causes that could degrade these HIRF protection devices. Whenever applicable, specific replacement times of these devices and features should be identified.

c. Aircraft or system modifications should be assessed for the impact that any changes will have on the HIRF protection. This assessment should be based on analysis and/or measurement.

Appendix 1 to AMC 20-158A — Definitions and acronyms

1. Definitions

Adverse effect: a response of a system that results in an unexpected and unacceptable operation of an aircraft system, or unexpected and unacceptable operation of the function performed by the system.

Attenuation: the term used to denote a decrease in the electromagnetic field strength in the transmission from one point to another. Attenuation may be expressed as a scalar ratio ofthe input magnitude to the output magnitude, or in decibels (dB).

Automatically recover: a return to normal operations without pilot action.

Bulk current injection: a method of electromagnetic interference (EMI) testing that involves injecting current into wire bundles through a current injection probe.

Channel: a subset of a system consisting of equipment, components, and interconnections, which performs an aircraft function provided by the system. A system could be composed of redundant similar or dissimilar channels in order to maintain the function at the aircraft level in case of failure on one or several channels.

Continued safe flight and landing: the capability for continued controlled flight and landing at a suitable location, possibly using emergency procedures, but without requiring exceptional piloting skill or strength. For CS-25 aeroplanes, the pilot must be able to land safely at a suitable airport. For CS-23 aeroplanes, it is not necessary to land at an airport. For rotorcraft, the rotorcraft must continue to cope with adverse operating conditions, and the pilot must be able to land safely at a suitable site. Some aircraft damage may be associated with a failure condition during flight or upon landing.

Continuous wave: an RF signal consisting of only the fundamental frequency with no modulation in amplitude, frequency, or phase.

Coupling: the process whereby electromagnetic energy is induced in a system by radiation produced by an RF source.

Current injection probe: an inductive device designed to inject RF signals directly into wire bundles when clamped around them.

Direct drive test: an electromagnetic interference (EMI) test that involves electrically connecting a signal source directly to the unit to be tested.

Electrical and electronic system: an electrical or electronic system includes all the electrical and electronic equipment, components, elements and the electrical interconnections that are required to perform a particular function.

Equipment: a component of an electrical or electronic system with interconnecting electrical conductors.

Equipment electrical interface: a location on a piece of equipment where an electrical connection is made to the other equipment in a system of which it is a part. The electrical interface may consist of individual wires or wire bundles that connect the equipment.

External HIRF environment: electromagnetic RF fields at the exterior of an aircraft.

Field strength: the magnitude of the electromagnetic energy propagating in free space expressed in volts per metre (V/m).

Function: the specific action of a system, equipment, and flight crew performance aboard the aircraft that, by itself, provides a completely recognisable operational capability. For example, 'display aircraft heading to the pilots' is a function. One or more systems may perform a specific function, or one system may perform multiple functions.

HIRF environment: the electromagnetic environment created by the transmission of high-power RF energy into free space.

HIRF vulnerability: the susceptibility characteristics of a system that cause it to suffer adverse effects when performing its intended function as a result of having been subjected to a HIRF environment.

Immunity: the capacity of a system or piece of equipment to continue to perform its intended function, in an acceptable manner, in the presence of RF fields.

Interface circuit: an electrical or electronic device connecting the electrical inputs and outputs of a piece of equipment to other pieces of equipment or devices in an aircraft.

Internal HIRF environment: the RF environment inside an airframe, equipment enclosure, or cavity. The internal RF environment is described in terms of the internal RF field strength or wire bundle current.

Margin: the difference between the equipment susceptibility or qualification levels and the aircraft internal HIRF environment. Margin requirements may be specified to account for uncertainties in design, analysis, or test.

Modulation: the process whereby certain characteristics of a wave, often called the carrier wave, are varied in accordance with an applied function.

Non-normal situation: any situation that requires non-normal, abnormal, emergency, unusual procedures, or configurations for operating an aircraft.

Normal operation: a status where the system performs its intended function. When addressing compliance with CS 23.1308(a)(2), 25.1317(a)(2), 27.1317(a)(2), and 29.1317(a)(2), the function whose failure would prevent the continued safe flight and landing should be in the same undisturbed state as before exposure to the HIRF threat, while other functions, performed by the same system, subject to CS 23.1308(b) and (c), 25.1317(b) and (c), 27.1317(b) and (c), and 29.1317(b) and (c), are not required to be recovered. The system that performs the function may be nevertheless in a different state as long as the function is not adversely affected.

Radio frequency (RF): a frequency useful for radio transmission. The present practical limits of RF transmissions are roughly 10 kilohertz (kHz) to 100 gigahertz (GHz). Within this frequency range, electromagnetic energy may be detected and amplified as an electric current at the wave frequency.

Reflection plane: a conducting plate that reflects RF signals.

Similarity: the process of using existing HIRF compliance documentation and data from a system or an aircraft to demonstrate HIRF compliance for a nearly identical system or aircraft of equivalent design, construction, and installation.

Susceptibility: a property of a piece of equipment that describes its inability to function acceptably when subjected to unwanted electromagnetic energy.

Susceptibility level: the level where the effects of interference from electromagnetic energy become apparent.

Transfer function: the ratio of the electrical output of a system to the electrical input of a system, expressed in the frequency domain. For HIRF, a typical transfer function is the ratio of the current on a wire bundle to the external HIRF field strength, as a function of frequency.

Timely manner: timely recovery has been introduced to account for the necessary period for complex systems to reconfigure safely after a disruption. The meaning of 'in a timely manner' therefore depends upon the function performed by the system to be evaluated, the specific system design, the interactions between that system and other systems, and interactions between the system and the flight crew. The definition of 'in a timely manner' must be determined for each specific system and for the specific functions performed by the system. The applicable definition could be included in the HIRF compliance plan for review and concurred with the Agency.

Upset: an impairment, either permanent or momentary, of the system operation. For example, a change of digital or analogue state that may or may not require a manual reset.

User's Guide: this refers to SAE Document ARP 5583A or EUROCAE Document ED-107A.

2. Acronyms

AC:	advisory circular
AMC:	acceptable means of compliance
ARP:	aerospace recommended practice
CS:	certification specification
DAL:	development assurance level (ED-79A / ARP 4754A) / design assurance level (ED-80 / DO-254)
EASA:	European Union Aviation Safety Agency
EWIS:	electrical wiring interconnection systems
EUROCAE:	European Organisation for Civil Aviation Equipment
FDAL:	functional development assurance level (ED-79A / ARP 4754A)
HCL:	HIRF certification level

HIRF:	high-intensity radiated field
ICAs:	instructions for continued airworthiness
IDAL:	item development assurance level (ED-79A / ARP 4754A)
RTCA:	Radio Technical Commission for Aeronautics
SAE:	Society of Automotive Engineers

Appendix 2 to AMC 20-158A — Generic transfer functions and attenuation

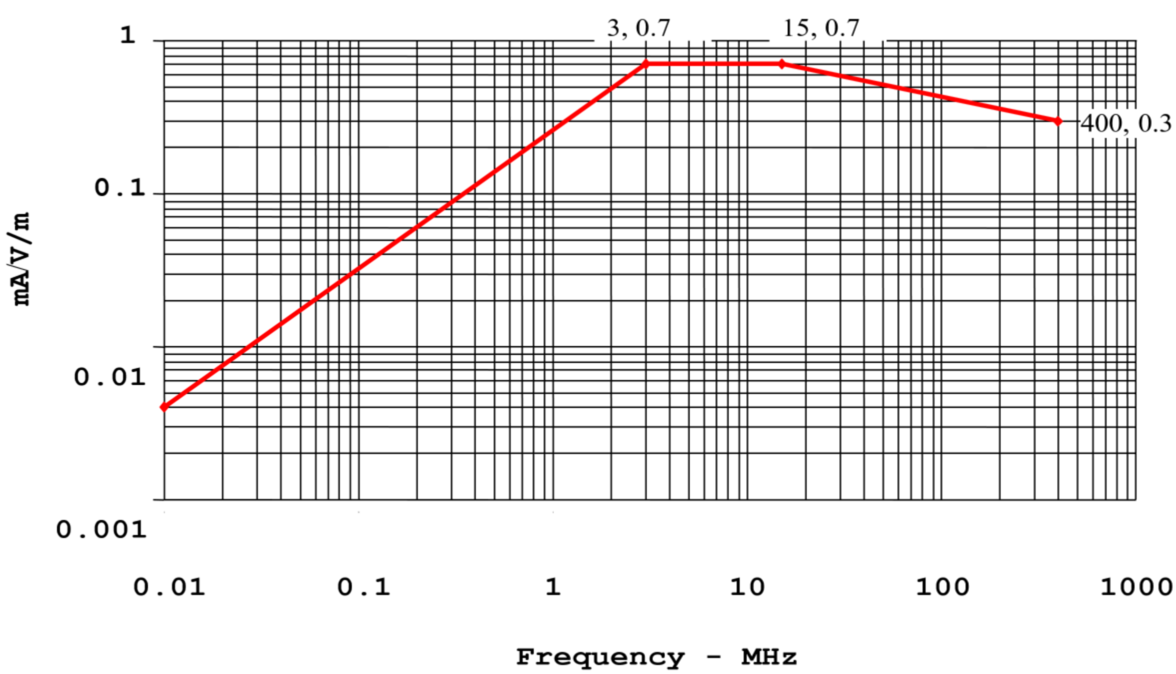
1. Generic transfer functions

a. Suitable transfer functions for calculating the bulk current injection test levels for Level A display systems (see Section 8(k)) are given in Figures A1-1 through A1-5. These are derived generic transfer functions acquired from test results obtained from a significant number of aircraft. The test results were processed to establish a 95 per cent population probability.

b. The transfer functions are normalised to a 1 V/m HIRF environment and may be multiplied linearly by the external HIRF environment to establish the bulk current injection test level requirements in the frequency range from 10 kHz up to 400 MHz. For example, if the HIRF environment is 100 V/m at 3 MHz, then using Figure A1-1, multiply 0.7 mA/V/m by 100 V/m to establish a test level of 70 milliamperes (mA).

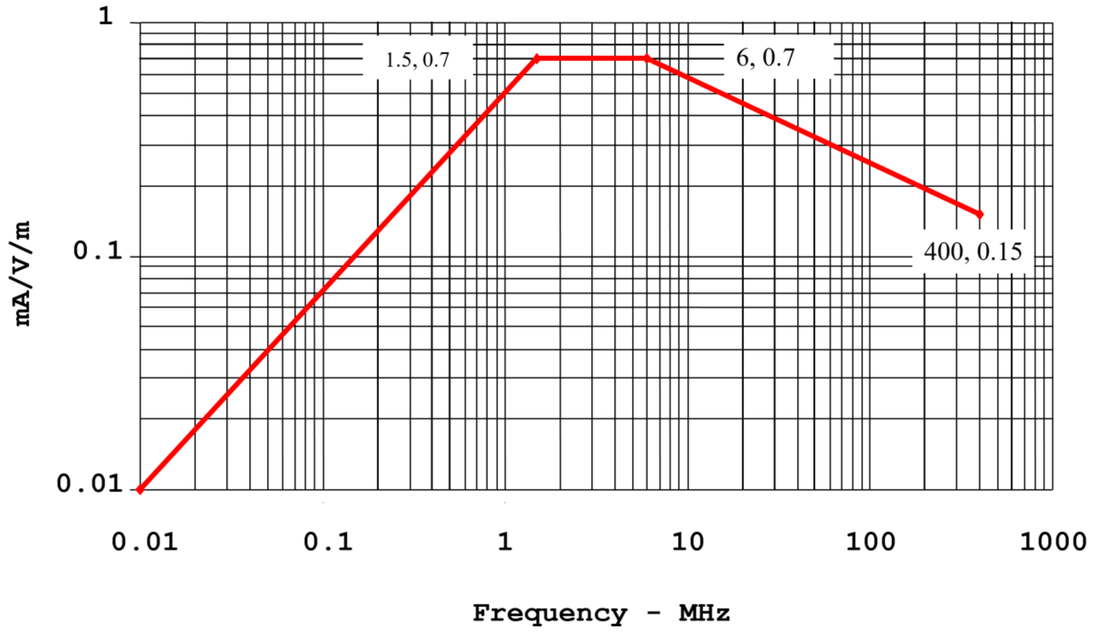
c. Consult the User's Guide (SAE ARP 5583A / EUROCAE ED-107A) for details on the use of generic transfer functions.

Figure A1-1: Generic transfer function — Aeroplanes



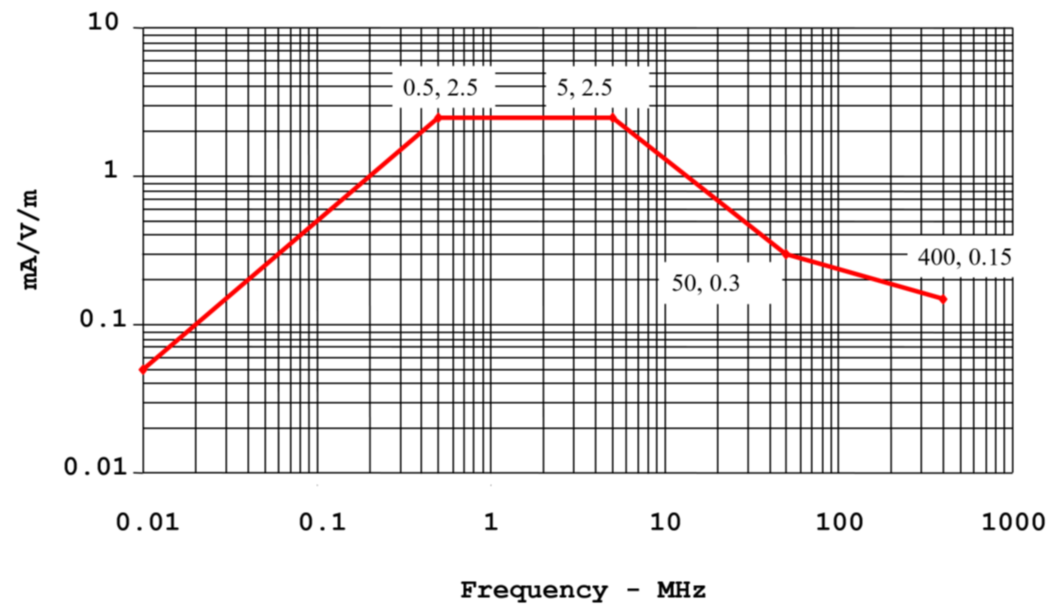
Note: Generic transfer function normalised to 1 V/m for an aircraft with a fuselage length of ≤ 25 m.

Figure A1-2: Generic transfer function — Aeroplanes



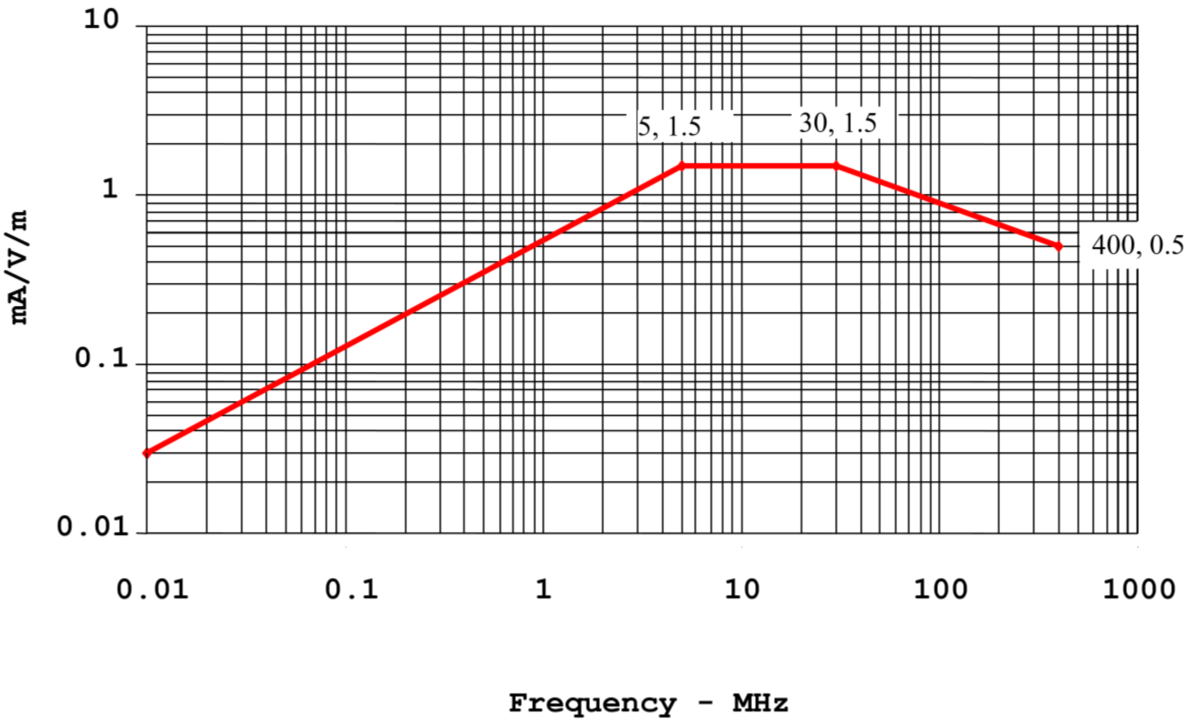
Note: Generic transfer function normalised to 1 V/m for an aircraft with a fuselage length of > 25 m and ≤ 50 m.

Figure A1-3: Generic transfer function — Aeroplanes



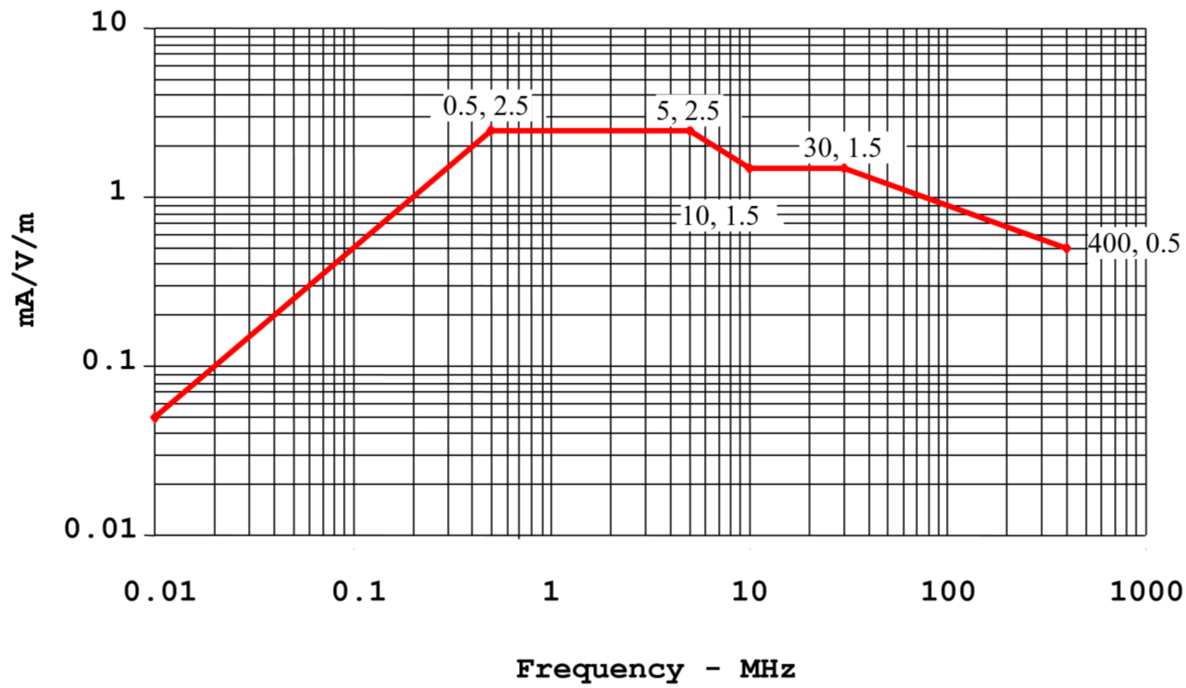
Note: Generic transfer function normalised to 1 V/m for an aircraft with a fuselage length of > 50 m.

Figure A1-4: Generic transfer function — Rotorcraft



Note: Generic transfer function normalised to 1 V/m for a rotorcraft.

Figure A1-5: Generic transfer function — All aircraft



Note: Generic transfer function normalised to 1 V/m for all aircraft.

2. Generic attenuation

a. Figure A1-6 shows the generic attenuation for frequencies from 100 MHz to 18 GHz that can be used for determining the internal HIRF environment where the equipment and associated wiring for Level A display systems (see Section 9(k)) are installed. This internal HIRF environment provides the test level for the integrated system radiated susceptibility laboratory test. The external HIRF environment should be divided by the appropriate attenuation, in linear units, to determine the internal HIRF environment. For example, 12 dB or a 4:1 attenuation means that the test level is the applicable external HIRF environment electric field strength reduced by a factor of 4.

b. Guidance on the use of the generic attenuation is given below:

1. *No attenuation*. No attenuation credit can be used when the Level A display equipment and the associated wiring are located in aircraft areas with no HIRF shielding, such as areas with unprotected, non-conductive composite structures, areas where there is no guarantee of structural bonding, or other open areas where no shielding is provided. The applicant may choose to use no attenuation for equipment that may be installed in a broad range of aircraft areas.

2. *6 dB attenuation*. This attenuation is appropriate when the Level A display equipment and the associated wiring are located in aircraft areas with minimal HIRF shielding,

such as a cockpit in a non-conductive composite fuselage with minimal additional shielding, or areas on the wing leading or trailing edges, or in wheel wells.

3. *12 dB attenuation*. This attenuation is appropriate when the Level A display equipment and the associated wiring are located entirely within aircraft areas with some HIRF shielding, in aircraft with a metal fuselage or a composite fuselage with shielding effectiveness equivalent to metal. Examples of such areas are avionics bays not enclosed by bulkheads, cockpits, and areas near windows, access panels, and doors without EMI gaskets. Current-carrying conductors in this area, such as hydraulic tubing, control cables, wire bundles, and metal wire trays, are not all electrically bonded to the bulkheads they pass through.

4. *20 dB attenuation*. This attenuation is appropriate when the Level A display equipment and the associated wiring are located entirely within aircraft areas with moderate HIRF shielding, in aircraft with a metal fuselage or a composite fuselage with shielding effectiveness equivalent to metal. In addition, wire bundles passing through bulkheads in these areas have shields electrically bonded to the bulkheads. Wire bundles are installed close to metal structure and take advantage of other inherent shielding characteristics provided by metal structure. Current-carrying conductors, such as hydraulic tubing, cables, and metal wire trays are electrically bonded to all the bulkheads they pass through.

5. *32 dB attenuation*. This attenuation is appropriate when the level A display equipment and all the associated wiring to and from equipment are located entirely within areas with very effective HIRF shielding to form an electromagnetic enclosure.

6. *Generic attenuation for rotorcraft*. Display units installed in rotorcraft typically have minimal attenuation unless specific shielding is provided in the bulkhead, glare shield, panel, and doors.

c. Different attenuation values may be appropriate for different frequency ranges. For example, 0 dB attenuation may be used for the frequency range of 100 to 400 MHz, 6 dB attenuation for the frequency range of 400 MHz to 1 GHz, and 12 dB attenuation for the frequency range of 1 to 18 GHz. If an applicant intends to use different attenuation values for various frequency ranges, then they should also provide the supporting rationale.

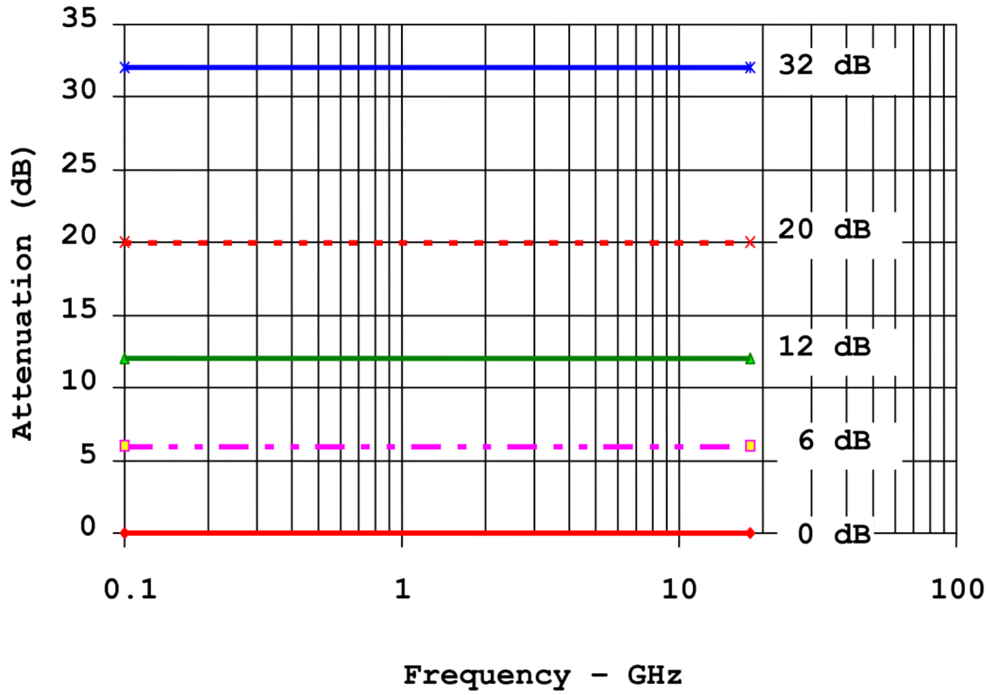
d. Consult the User's Guide (SAE ARP 5583A / EUROCAE ED-107A) for details on the use of generic attenuation.

3. Measured transfer functions or attenuation

The applicant may produce their own generic transfer functions and attenuation for their Level A display systems (see Section 9(k)) based on actual measurements on their aircraft models. These transfer functions and the attenuation can then be used in their HIRF compliance submission in place of the generic transfer functions and attenuation specified in this Appendix. The Agency encourages this approach because it provides a more accurate reflection of the true internal HIRF environment for aircraft models. However, if an applicant intends to produce their own generic transfer functions and attenuation, then this approach should also be addressed in the HIRF compliance plan (see Section 6(a)) that is submitted to the Agency for acceptance.

Figure A1-6: Generic attenuation values — All aircraft

100 MHz to 18 GHz



Appendix 3 to AMC 20-158A — Examples of HIRF safety assessment considerations — Level A systems on large aeroplanes

1. Establishing appropriate pass/fail criteria for complying with CS 25.1317(a) can only be achieved through a comprehensive review of the system design using an acceptable HIRF functional hazard assessment process in the form of a system HIRF certification level (HCL). The following paragraphs summarise the approaches whereby pass/fail criteria for compliance with CS 25.1317(a) are specified on the merit of specific system architecture attributes.

2. For the purposes of discussion and evaluation of the examples, the architectural strategies used in the system implementation need to be defined. Therefore, the additional definitions below should be considered:

a. *Similar redundant channels*: the multiple channels consist of equipment, components, electrical interconnections and configurations that are similar, typically with pieces of equipment that have identical part numbers. The channels should be independent. They may be configured in active, active-backup and passive-backup modes.

b. *Dissimilar redundant channels*: each channel is unique and independent of the others. They may be configured in active, active-backup and passive-backup modes.

c. *Combination of similar and dissimilar redundant channels*: the combination of similar and dissimilar channels, as defined above, with independence between channels. They may be configured in active, active-backup and passive-backup modes.

Notes:

a. 'Active mode' means that the channel performs the aircraft function in normal operation.

b. 'Active-backup mode' means that the channel is operational but not used to perform the aircraft function until switched to active mode either automatically or by flight crew action.

c. 'Passive-backup mode' means that the channel is not operational; switching to active mode is either automatic or by flight crew action upon failure recognition.

d. 'Combination of electrical/electronic and mechanical, hydraulic and/or pneumatic channels': certain architectures combine electrical and electronic channels with mechanical, hydraulic and/or pneumatic channels. These combinations of electrical/electronic and mechanical, hydraulic or pneumatic channels may be configured in active, active-backup and passive-backup modes.

e. These examples are theoretical and intended to facilitate the discussion from which universal guidelines may be derived to help develop useful guidance material. It is not the intention to account for all possible configurations but only to represent the common system architectures or some that present unique challenges.

3. This Appendix presents examples of large aeroplane systems with multiple independent and redundant channels that perform a function whose failure would prevent continued safe flight and landing.

These examples could also be used for other types of aircraft.

Example 1			
Function	**25.1317(a) System**		
	Channel	**Channel**	**Channel**
Display of attitude, altitude, and airspeed information to the pilots during IFR operations (e.g. primary display system and associated sensors, with dissimilar standby display system and sensors)	Active (Pilot displays and associated sensors)	Active (Co-pilot displays and associated sensors)	Active-backup (Dissimilar standby display and associated sensors)
Requirements for compliance demonstration (CS 25.1317)	(a)(1), (a)(2), (a)(3)	(a)(1), (a)(2), (a)(3)	(b)

Discussion:

This example depicts the specification of CS 25.1333 for independent displays of information essential to the safety of flight at each pilot station. The standby display is required in order to achieve the safety objectives of CS 25.1309. Either the pilot or the co-pilot can be the pilot flying (PF) or pilot monitoring (PM) during normal operations, so both the pilot and the co-pilot display systems should be considered as active systems.

Compliance with CS 25.1317(a)(1), (a)(2), and (a)(3) should demonstrate that neither pilot display of aircraft attitude, altitude, and airspeed is adversely affected and recovers normal operation of these Level A functions when the aircraft is exposed to HIRF Environment I and II. It is acceptable that the dissimilar standby display demonstrates compliance with the CS 25.1316(b) requirements. The adverse effects must include both a loss of, and hazardously misleading, attitude, altitude, and airspeed information.

Example 2			
Function	**25.1317(a) System**		
	Channel	**Channel**	**Channel**
Full authority control of pitch, yaw, and roll using electrical and electronic flight control systems	Active or active-backup (Flight control system #1)	Active or active-backup (Flight control system #2)	Active or active-backup (Flight control system #3)
Requirements for compliance demonstration (CS 25.1317)	(a)(1), (a)(2), (a)(3)	(a)(1), (a)(2), (a)(3)	(a)(1), (a)(2), (a)(3)

Discussion:

This example depicts an electronic flight control system that comprises three independent channels to meet the safety objectives of CS 25.1309. At any time, any one of the three channels can operate as the active channel.

Only one channel operates in an active mode while the others are in active-backup mode. Any channel can perform the control function at any time; therefore, all the channels must comply with CS 25.1317(a)(1), (a)(2), and (a)(3).

Example 3			
Function	**25.1317(a) System**		
	Channel	**Channel**	**Channel**
Provide engine overspeed protection	Active (Electronic engine control system) (Normal speed control)	Active or active-backup (Electronic engine control system) (Overspeed protection)	Active (Independent mechanical overspeed protection)
Requirements for compliance demonstration (CS 25.1317)	(b)	(b)	Not subject to CS 25.1317

Discussion:

This example depicts the function of engine overspeed protection performed by a combination of active electrical and electronic control and mechanical system control. The mechanical channel must provide overspeed protection during normal operations, and be independent of the active electronic control channels. The mechanical channel must not rely on electrical or electronic components to assist, augment, or monitor the overspeed protection. If the mechanical channel is independent of the electronic engine control speed control and overspeed protection, and has no electrical or electronic components that have failure modes that could prevent overspeed protection, then the engine overspeed protection function is not adversely affected when the aircraft is exposed to HIRF Environment I and II. The system is, therefore, not subject to CS 25.1317(a). The electronic engine control channels should comply with CS 25.1317(b).

This example only considers the overspeed protection feature implemented by the system. Other functions whose failure may be classified as catastrophic, such as the loss of thrust control function where the function may be implemented by electronic control channels, should comply with CS 25.1317(a).

Example 4			
Function	**25.1317(a) System**		
	Channel	**Channel**	**Channel**
Provide electrical power for electrical and electronic systems including those with catastrophic failure conditions	Active (Left engine generator system)	Active (Right engine generator system)	Passive-backup (Emergency power supply system driven by ram-air turbine)
Requirements for compliance demonstration (CS 25.1317)	(a)(1), (a)(2), (a)(3)	(a)(1), (a)(2), (a)(3)	(b)

Discussion:

This example depicts a typical transport category aircraft electrical system on a twin-engined aircraft where two or more independent sources of electrical power are required by CS 25.1307(b) and a ram-air turbine is necessary to meet the safety objectives of CS 25.1309 and CS 25.1351(d).

For this example, the electrical system consists of two active channels provided by a single main-engine-driven generator on each engine with the associated distribution and controls, and a third passive-backup channel provided by a ram-air turbine electrical power system. The ram-air turbine electrical power system is stowed during normal operation and deployed either automatically and/or manually when power from the two main-engine-driven generators is lost.

The active engine generator system channels must not be adversely affected when the aircraft is exposed to HIRF Environment I and II, and comply with CS 25.1317(a)(1), (a)(2), and (a)(3). The passive-backup ram-air turbine electrical power system does not mitigate adverse effects for compliance with CS 25.1317(a). It is acceptable that the ram-air turbine electrical power system demonstrates compliance with the CS 25.1317(b) requirements.

Example 5				
Function	**25.1317(a) System**			
	Channel	**Channel**	**Channel**	**Channel**
Provide electrical power for electrical and electronic systems including those with catastrophic failure conditions	Active (Left engine generator system)	Active (Right engine generator system)	Active (APU-driven generator system required for ETOPS flight beyond 180')	Passive-backup (Emergency power supply driven by ram-air turbine)
Requirements for compliance demonstration (CS 25.1317)	(a)(1), (a)(2), (a)(3)	(a)(1), (a)(2), (a)(3)	(a)(1), (a)(2), (a)(3)	(b)

Discussion:

This example depicts a twin-engined transport category aircraft electrical system where two or more independent sources of electrical power are required by CS 25.1307(b) and an alternate source (driven by a ram-air turbine) is necessary to meet the safety objectives of CS 25.1309 and CS 25.1351(d). This configuration includes a third electrical power source driven by an auxiliary power unit (APU). This third source is required (active channel) for ETOPS beyond 180 minutes. As in Example 4, the emergency power source is a passive-backup channel provided by a ram-air turbine that remains stowed during normal flight and deployed either automatically and/or manually when power from all other channels is lost.

All active electrical power generation channels should comply with CS 25.1317(a)(1), (a)(2), and (a)(3). The passive-backup electrical power generation channel does not mitigate the adverse effects due to HIRF exposure to meet the intent of the HIRF requirements. It is acceptable that the passive-backup channel demonstrate compliance with CS 25.1316(b) requirements.

Note: For non-ETOPS or for ETOPS up to 180' aircraft, the APU HIRF certification level should be defined based on the specific aircraft safety assessment.

Example 6				
Function	**25.1317(a) System**	**25.1317 System**	**25.1317 System**	**System**
	Channel	**Channel**	**Channel**	**Channel**
Reduce aircraft speed on ground in a controlled manner using thrust reverser control system, spoiler deployment system, and wheel braking system	Active Main brake system (Electro-mechanical)	Active (Electronic engine thrust reverse control with associated sensors)	Active (Electronic spoiler deployment control with associated sensors)	Active (Independent mechanical wheel braking)
Requirements for compliance demonstration (CS 25.1317)	(a)(1), (a)(2), (a)(3)	25.1317(a), (b) or (c) depending on specific aircraft safety assessment	25.1317(a), (b) or (c) depending on specific aircraft safety assessment	Not subject to CS 25.1317

Discussion:

This example depicts an aircraft-level function that is performed by a combination of independent systems each contributing in part to the function during a specific phase of flight. In this case, each system implements a very distinct aircraft-level function that serves in a complementary manner to decelerate the aircraft during the landing roll. The mechanical wheel braking system is assumed to be independent of the other channels, with no associated electrical or electronic equipment to assist, augment, or monitor the mechanical wheel braking system.

In this example, it is assumed that the main brake system includes failure conditions that are catastrophic. For the electronic engine thrust reverser control and the electronic spoiler control systems, the applicable parts of CS 25.1317 would depend on the specific failure conditions. The effectiveness, authority, and malfunctions associated with each system should be considered. Additionally, the interaction between the systems has also to be considered. Issues such as asymmetrical thrust reverser activation or spoiler deployment could adversely affect the main brake and mechanical wheel braking functions and could affect the safety classification for the thrust reverser and spoiler controls.

An aircraft safety assessment must be carried out for each of these systems that perform a specific aircraft-level function to identify and classify their failure conditions. The failure hazard classifications and the decomposition of each system into the constituent channels would then dictate which paragraphs of CS 25.1317 are needed.

Example 7			
Function	**25.1317(a) System**		
	Channel	**Channel**	**Channel**
Provide altitude information to be displayed in IFR flight using air-data computer connected to the primary flight display (PFD), and pneumatic standby instrument with alternate static port	Active (Air-data computer 1 with static port)	Active (Air-data computer 2 with static port)	Active-backup (Pneumatic standby altimeter with alternate static port)
Requirements for compliance demonstration (CS 25.1317)	(a)(1), (a)(2), (a)(3)	(a)(1), (a)(2), (a)(3)	Not subject to CS 25.1317

Discussion:

This example depicts the function to provide altitude information. The main sources are two air-data computers (ADCs) coupled to static ports and a backup source from a standby pneumatic altimeter coupled to an alternate static port independent from the main static ports.

In such a case, the standby altimeter does not mitigate compliance with CS 25.1317(a) for the active ADC channels. The standby altimeter does not mitigate the common hazardously misleading altitude information from the active ADC channels for compliance with CS 25.1317(a).

Example 8			
Function	**25.1317(a) System**		
	Channel	**Channel**	**Channel**
Control and protection of the aircraft pneumatic (bleed) system (Top-level failure condition classification: catastrophic)	Active (Pneumatic system controller #1) FDAL B / IDAL B	Active (Pneumatic system controller #2) FDAL B / IDAL B	Passive-backup (High pressure switch + valve) FDAL C / IDAL C
Requirements for compliance demonstration (CS 25.1317)	(a)(1), (a)(2), (a)(3)	(a)(1), (a)(2), (a)(3)	(b)

Discussion:

This is a generic example with the objective to show that not rarely the HIRF certification level (HCL) of a given system will be different from the functional development assurance level (FDAL) and item development assurance level (IDAL), defined according to SAE ARP 4754A / EUROCAE ED-79A *Guidelines for Development of Civil Aircraft and Systems*.

Therefore, it is important to use the proper nomenclature and avoid SAE ARP 4754A / EUROCAE ED-79A 'DAL' or similar terms when referring to the HCL.

In this example, the pneumatic control system is composed of two main active controllers and a simpler passive-backup channel that can perform the function, preventing the catastrophic event in case of the failure of both controllers.

The FDAL for each channel or member (SAE ARP 4754A / EUROCAE ED-79A nomenclature) was defined for a catastrophic top-level failure condition based on the 'Option 2' column 4 of Table 3 *DEVELOPMENT ASSURANCE LEVEL ASSIGNMENT TO MEMBERS OF A FUNCTIONAL FAILURE SET* of SAE ARP 4754A / EUROCAE ED-79A, which allows the combination of FDALs B+B+C for independent channels. In contrast, the respective HCLs would be A+A+B.

Considering that HIRF can simultaneously affect all the channels, the considerations used for IDAL assignment cannot be used, and compliance with CS 25.1317(a) is required for both the active channels that perform a function with the catastrophic top-level failure condition.

In this example, the IDAL for the passive-backup channel may be C. However, for HIRF, the applicable part of CS 25.1317 is (b), similarly to Example 5.

AMC 20-193 Use of multi-core processors

1. Purpose

1.1 This AMC describes an acceptable means, but not the only means, for showing compliance with the applicable airworthiness specifications for aspects related to multi-core processors (MCPs) contained in airborne systems and equipment used in product certification or ETSO authorisation. Compliance with this AMC is not mandatory, and an applicant may elect to use an alternative means of compliance. However, the alternative means of compliance must meet the relevant requirements, ensure an equivalent level of safety, and be approved by the Agency on a product or ETSO article basis.

1.2 This AMC provides objectives for the demonstration of compliance with the applicable airworthiness specifications for airborne systems and equipment that contain MCPs, according to the applicability in Section 2 of this AMC.

2. Applicability

2.1. This AMC may be used by applicants, design approval holders, and developers of airborne systems and equipment, which contain MCPs, to be installed on type-certified aircraft, engines, and propellers. This also includes developers of ETSO articles.

This AMC applies to systems and equipment that contain MCPs with two or more activated cores for which the item development assurance level (IDAL) of at least one of the software applications hosted by the MCP or of the hardware item that contains the MCP is A, B, or C. The deactivation of cores is handled through the applicable airborne electronic hardware (AEH) guidance.

This AMC does not apply when the IDALs are all Level D or E.

If an applicant modifies the use of the MCP (such as by activating one or more additional cores or adding software of IDAL A, B, or C), then the applicant should reassess the applicability of this AMC.

Section 5.7 of this AMC describes the objectives that apply according to the assigned IDAL (A, B, or C) of the hosted software or of the hardware item that contains the MCP.

2.2. Aspects not covered by this AMC

The following aspects are not covered by this AMC. This does not constitute an exemption, i.e. the objectives of this AMC are still applicable if an applicant uses these features.

Any applicant who uses these features should describe how they are used so that the behaviour of the MCP is not altered, and determinism is still guaranteed.

In their planning activities, the applicant should present the methods employed to cover these aspects, and satisfy the objectives of this AMC or show compliance with the applicable airworthiness specifications if they propose an alternative to this AMC or part of it.

2.2.1. Dynamic allocation of software applications

An assumption in this AMC is that software applications are statically allocated to cores during the start-up of the MCP software, but not during the subsequent operation of the software.

This AMC does not cover MCP platforms on which software applications or tasks can be dynamically reallocated to a different core (or different cores) by the operating system, a software hypervisor, or by other means.

However, justification for using dynamic allocation features within the scope of this AMC may rely on robust and proven limitations that lead to deterministic behaviour, such as:

— restricted usage permitting the applicant to claim equivalence to the conditions expressed in this AMC (for example, multi-static allocation, i.e. selection of a prequalified configuration, instead of pure dynamic allocation).

2.2.2. Simultaneous multithreading support

This AMC does not cover simultaneous multithreading, as this issue is not specific to MCPs.

2.3. Exceptions

An MCP may contain multiple cores of different types, which may interact in different ways and some of the interactions do not produce interference. Therefore, the objectives of this AMC do not apply to the interactions between two or more activated cores of an MCP in the following cases:

— The activated cores are set up in lockstep mode (in lockstep processors with two or more activated cores, the cores host the same software and execute that same software in parallel so that their outputs, based on identical input data, can be compared for use in a safety-critical application); or

— The activated cores are only linked by the conventional databuses typically used in avionics systems, and not by any of the following: shared memory, shared cache, or a 'coherency fabric' / 'module interconnect'. This category includes the case where the cores only act as co-processors or graphics processors, each under the control of another core that executes software.

The objectives of this AMC apply to the interactions between all the other activated cores of an MCP.

3. Background

MCPs can execute several software applications at the same time by hosting them on different cores; therefore, several software applications and/or hardware functions may attempt to access the same shared resources of the MCP (such as memory, cache, 'coherency fabric' / 'module interconnect', or external interfaces) at the same time, causing contention for those resources.

Most MCPs have internal features to handle and arbitrate the concurrent demands for MCP resources, which may cause delays in access to the resources. These delays are a form of time interference between the software applications or tasks, which can cause the software applications to take much longer to execute than when executing on their own.

The execution of software applications may be different on MCPs than it is on single-core processors (due to parallelism and other MCP mechanisms, or software components such as operating systems or hypervisors). This may result in new or different data or control coupling paths, and functional interference between the software applications or tasks.

Interference between the software applications or tasks executing on an MCP could cause safety-critical software applications to behave in a non-deterministic or unsafe manner, or could prevent them from having sufficient time to complete the execution of their safety-critical functionality.

4. Definitions

Applicable airborne electronic hardware (AEH) guidance: AMC 20-152( ) and any project-specific guidance.

Applicable software guidance: AMC 20-115( ) and any project-specific guidance.

Asymmetric multi-processing (AMP): an MCP software architecture in which each individual functional task is permanently allocated to a specific core and each core has its own operating system (however, the operating systems may be multiple copies of the same operating system or be different from core to core).

Bound multi-processing (BMP): an MCP software architecture that restricts symmetric multi-processing (SMP) (see definition below) architecture by constraining tasks to be bound to specific cores while using a common operating system across all cores.

Determinism/deterministic: the ability to produce a predictable outcome generally based on the preceding operations and data. The outcome occurs in a specific period of time with repeatability (definition taken from ED-124/DO-297).

Integrated modular avionics (IMA) platform: in this AMC, this term refers to an integrated modular avionics MCP platform that provides both robust resource partitioning and robust time partitioning (as defined in this AMC).

Intended final configuration: the configuration of the software and hardware in which the set of the MCP resources has been defined by implementing the configuration settings and all software components have been installed on the target MCP.

Interference channel: a platform property that may cause interference between software applications or tasks.

Item: a hardware or software element that has bounded and well-defined interfaces (definition taken from ED-79A / ARP 4754A).

Item development assurance level (IDAL): the level of rigour of development assurance tasks performed on item(s), e.g. IDAL is the appropriate software level in ED-12C / DO-178C and design assurance level in ED-80 / DO-254 objectives that need to be satisfied for an item (definition taken from ED-79A / ARP 4754A).

MCP platform: it consists of the MCP itself and, in many cases, the platform software, such as an operating system and/or software hypervisor, which provides the interface between the software applications and the MCP.

MCP platform with robust partitioning: an MCP platform that complies with the objectives of this AMC and provides robust resource partitioning and robust time partitioning as defined in this AMC, not only between software applications hosted on the same core, but also between software applications hosted on different cores of an MCP or between software applications that have tasks hosted on several cores.

Multi-core processor (MCP): an AEH device that contains two or more processing cores. A core in an MCP is defined as a device that executes software. This includes virtual cores (e.g. in a simultaneous multithreading microarchitecture, although as stated in Section 2.2.2, the use of simultaneous multithreading is not covered by this guidance). An MCP is typically implemented in a device that may also include resources such as memory or peripheral controllers, internal memory, peripherals, and internal interconnects.

Robust partitioning: both robust resource partitioning and robust time partitioning.

Robust resource partitioning (adapted from ED-94C / DO-248C and ED-124 / DO-297): robust resource partitioning is achieved when:

— software partitions cannot contaminate the storage areas for the code, I/O, or data of other partitions;

— software partitions cannot consume more than their allocation of shared resources; and

— failures of hardware unique to a software partition cannot cause adverse effects on other software partitions.

Note: Software that provides partitioning should have at least the same IDAL as the highest IDAL of the software that it partitions.

Robust time partitioning (on an MCP): this is achieved when, as a result of mitigating the time interference between partitions hosted on different cores, no software partition consumes more than its allocation of execution time on the core(s) on which it executes, irrespective of whether partitions are executing on none of the other active cores or on one, more than one, or all of the other active cores.

Safety net: a safety net is defined as the employment of mitigations and/or protections at the appropriate level of aircraft and system design as a means to satisfy the safety objectives. The safety net methodology may be applied when it is assumed that part of a system will misbehave. The safety net is by nature independent of the source of misbehaviour. The safety net can include passive monitoring functions, active fault avoidance functions, and control functions for effective recovery of system operations from anomalous events.

Simultaneous multithreading: this is when virtual cores are used to execute more than one execution thread on a single physical core.

Software application: generally, it designates the software part of a function installed on an MCP.

Software component: any part of the software which may access MCP shared resources; it may designate either a software application or an operating system or a hypervisor.

Hardware component: any part of the hardware which may independently access MCP shared resources.

Symmetric multi-processing (SMP): an MCP software architecture in which a single operating system controls the execution of the software on multiple cores and may dynamically allocate tasks to cores at run-time.

Task: the smallest unit of software execution that can be managed independently by a scheduler. For the purposes of this AMC, this term encompasses 'threads' or 'processes' (in the sense of ARINC 653). For simplification in this AMC, when addressing interference, a task also represents any part of an application or any part of a software component that executes on one core.

5. Multi-core processor (MCP) guidance

This section takes stages of a typical life cycle of a project involving an MCP in turn, explains the important issues involved in each stage, and provides objectives for applicants to meet for each of those stages.

The applicant should meet the objectives of this AMC, with the exception of any objective or part of an objective that the applicant justifies as not being applicable to the MCP in their system or equipment (e.g. if the MCP mechanism addressed does not exist on the selected MCP). The applicant should state in the appropriate deliverable document which particular aspects do not apply and explain why they do not apply.

Some of the objectives have notes provided after them. These notes should be considered to be part of the objectives, as they provide additional information that is relevant to the objectives. Objectives and their included notes are formatted in italics to differentiate them from the rest of the text.

5.1. Planning

The additional planning objectives below clarify the information to be included in the applicable plans to achieve planning data [standardisation]/[standardization] for projects with MCPs.

Objective MCP_Planning_1

The applicant's plans or other deliverable documents:

1. *Identify the specific MCP, including the unique identifier from the manufacturer.*
2. *Identify the number of active cores.*
3. *Identify the MCP software architecture to be used and all the software components that will be hosted on the MCP.*
4. *Identify any dynamic features provided in software hosted on the MCP that will be activated, and provide a high-level description of how they will be used.*
5. *Identify whether or not the MCP will be used in an integrated modular avionics (IMA) platform to host software applications from more than one system.*
6. *Identify whether or not the MCP platform will provide robust resource partitioning and/or robust time partitioning as defined in this AMC.*
7. *Identify the methods and tools to be used to develop and verify all the individual software components hosted on the MCP so as to meet the objectives of this AMC and the applicable software guidance, including any methods or tools needed due to the use of an MCP or the selected MCP architecture.*

Notes:

a) *The MCP software architecture includes asymmetric multi-processing (AMP), symmetric multi-processing (SMP), or any other architecture used by the applicant.*

b) The software components identified should include any operating systems, hypervisors, software applications, and all functions that are provided in software. In the case of an MCP used in an IMA platform, the software components that are identified do not have to include the hosted software applications.

c) The dynamic features provided in software should include such aspects as the dynamic allocation of software applications or tasks to cores and any other software dynamic features that can affect the execution of the software while it is executing.

d) Where the applicable software and AEH guidance calls for independence in meeting the objectives, the plans should identify how verification independence will be applied.

Multiple software applications and/or hardware functions may use resources of the MCP and may cause contention for resources and interference between software applications or tasks. Even if there is no explicit data or control flow between software applications or tasks running concurrently on different cores, MCP resources (e.g. cache or interconnects) may be shared. Therefore, coupling may exist on the platform level which can cause interference between the software applications or tasks and cause increases in the worst-case execution times (WCETs) of the software applications. In addition, there could be interaction between software and hardware functions that would need to be considered (e.g. cases where there are multiple masters).

Objective MCP_Planning_2:

The applicant's plans or other deliverable documents:

1. Provide a high-level description of how MCP shared resources will be used and how the applicant intends to allocate and verify the use of shared resources (see Note a)) so as to avoid or mitigate the effects of contention for MCP resources and to prevent the resource capabilities of the MCP from being exceeded by the demands from the software applications and/or the hardware components of the MCP.

2. Identify the MCP hardware resources to be used to support the objectives in this AMC.

3. Identify any hardware dynamic features of the MCP that will be active, and provide a high-level description of how they will be used.

4. Identify the aspects of the use of the MCP that may require a safety net or other mechanisms to detect and handle failures in the MCP.

Notes:

a) The description of the use of shared resources should include any use of shared cache (taking into account the time interference it may cause due to cache misses or other effects) or shared memory (taking into account the time interference and the data and control flow effects it may cause, such as lockouts, race conditions, data starvation, deadlocks, live-locks, or excessive data latency). The description of shared resources should also include any use of shared interconnect and take into account the time interference due to arbitration for access to the shared interconnect.

b) Hardware dynamic features of the MCP include any features that can alter the behaviour of the MCP or the hosted software during execution — for example, energy-saving features (clock *enable / gating, frequency adaptations, deactivating one or more cores, or dynamic control of peripheral access).*

5.2. The setting of MCP resources

In the context of MCPs, some of the configuration settings are especially relevant to the MCP hardware and software architectures, such as:

— which cores are activated;

— the execution frequencies of the cores;

— the priorities and allocation of shared interconnect;

— which of the peripheral devices of the MCP are activated;

— whether shared memory or shared cache is used, and how each is allocated; and

— whether dynamic features that are built into some MCPs are allowed to alter the frequency of execution of the cores or to deactivate one or more cores in order to save energy (this might not be desirable for cores that host safety-critical software applications).

Objective MCP_Resource_Usage_1:

The applicant has determined and documented the MCP configuration settings that will enable the hardware and the software hosted on the MCP to satisfy the functional, performance, and timing requirements of the system.

Objective MCP_Resource_Usage_2:

RESERVED.

Covered by AMC 20-152A, Objective COTS-8.

5.3. Interference channels and resource usage

As stated above, the software applications or tasks that execute on different cores of an MCP share MCP resources; so, even if there is no explicit data or control flow between these software applications or tasks, coupling exists on the platform level, which can cause interference between them.

There may be software or hardware channels through which the MCP cores or the software hosted on those cores could interfere with each other, in addition to those channels specifically mentioned in this AMC. For instance, many MCPs include an ‘interconnect’ / ‘coherency fabric’, through which the demands for MCP resources (e.g. from the software applications hosted on the MCP) are channelled and the demands are arbitrated. This arbitration can cause interference effects such as jitter on data arrival times, data consistency issues, or it can change the order in which transactions requested by the software applications are executed.

Non-deterministic behaviour of the hosted software applications may occur due to such interference.

Moreover, the complexity of the MCP, executing tasks in parallel and the interference could lead to the demands for resources exceeding the available resources. For instance, if the demands for interconnect transactions are very high in MCPs with a very high level of external databus traffic, the interconnect can become overloaded, which can affect transactions on some MCPs.

MCP_Resource_Usage_3:

The applicant has identified the interference channels that could permit interference to affect the software applications hosted on the MCP cores, and has verified the applicant's chosen means of mitigation of the interference.

Notes:

a) This objective includes the identification of any interference caused by the use of shared memory, shared cache, an interconnect, or the use of any other shared resources, including shared peripherals, and the verification of the means of mitigation chosen by the applicant.

b) If the applicant identifies interference channels that cannot affect the software applications in the intended final configuration, then those interference channels do not need to be mitigated and no verification of mitigation is needed.

c) The applicant should handle any interference channel discovered at any time during the project in the same manner as in this objective and these explanatory notes.

d) If the highest IDAL of the MCP hardware and of all the software applications hosted on the MCP is C, and the hosted software applications are not required by the safety analysis to be robustly partitioned, then the applicant has the option to not conduct an interference analysis and, therefore, to not meet this objective. However, applicants should note that opting to not meet this objective affects the manner in which they are permitted to conduct their software verification (see Objective MCP_Software_1 *and* Note c) *of that objective.)*

MCP_Resource_Usage_4:

The applicant has identified the available resources of the MCP and of its interconnect in the intended final configuration, has allocated the resources of the MCP to the software applications hosted on the MCP, and has verified that the demands for the resources of the MCP and of the interconnect do not exceed the available resources when all the hosted software is executing on the target processor.

Note: The use of worst-case scenarios is implicit in this objective.

5.4. Software verification

The software verification processes in the applicable software guidance need to be adapted for use on an MCP to demonstrate that the hosted software applications function correctly and have sufficient time to execute in the presence of the interference that occurs when all the hosted software is executing on an MCP.

With an MCP, there may be data and control flows between software components or tasks hosted on different cores of the MCP. Therefore, the data and control coupling analysis performed on the software hosted on each separate core (as required by the applicable software guidance) may not reveal the improper software behaviour associated with features such as hardware runtime optimisations and memory models on MCPs.

The WCET of a software component or task may increase significantly when other software components or tasks are executing in parallel on the other cores of an MCP. This could cause some software applications to have insufficient time to complete the execution of their safety-critical functionality.

Interference and interactions between software applications or tasks occur via the proprietary internal mechanisms of an MCP. Any simulation of those mechanisms is, therefore, less likely to be representative in terms of functionality or execution time than testing conducted on the target MCP in the intended final configuration, and thus is less likely to detect errors.

To adapt the software verification guidance for different types of MCP platforms, the two following categories of MCP platforms are considered:

— MCP platforms with robust partitioning, and

— all other MCP platforms.

MCP_Software_1:

The applicant has verified that all the software components hosted by the MCP meet the objectives of the applicable software guidance. In particular, the applicant has verified that all the hosted software components function correctly and have sufficient time to complete their execution when all the hosted software and hardware of the MCP is executing in the intended final configuration.

The way in which the applicant should satisfy this objective depends on the type of the MCP platform:

— ***MCP platforms with robust partitioning:***

Applicants who have verified that their MCP platform provides both robust resource partitioning and robust time partitioning (as defined in this AMC) may verify software applications separately on the MCP and determine their WCETs separately.

— ***All other MCP platforms:***

Applicants may verify separately on the MCP any software component or set of requirements for which the interference identified in the interference analysis is mitigated or is precluded by design. Software components or sets of software requirements for which interference is not avoided or mitigated should be tested on the target MCP with all software components executing in the intended final configuration, including robustness testing of the interfaces of the MCP.

The WCET of a software component may be determined separately on the MCP if the applicant shows that time interference is mitigated for that software component; otherwise, the WCET should be determined by analysis and confirmed by test on the target MCP with all the software components executing in the intended final configuration.

Notes:

a) All the interfaces between the hosted software and the hardware of the MCP should be included in this testing.

b) The robustness testing mentioned above is intended to cover the specific aspects of an MCP that are not specifically covered by the standard verification activities described in the applicable software guidance.

c) If the highest IDAL of the MCP hardware and of all the software applications hosted on the MCP is C, and the hosted software applications are not required by the safety analysis to be robustly partitioned, then the applicant has the option to not conduct an interference analysis and therefore to not meet Objective MCP_Resource_Usage_3. In such a case where no interference *analysis has been performed, the hosted software components should be verified according to this objective as components for which interference is not avoided or mitigated and for which separate verification is, therefore, not permitted.*

d) To 'verify separately' and 'determine the WCET separately' mean to conduct these activities without all the software executing at the same time on other cores of the MCP.

e) Interference may occur between tasks of a single component when the tasks execute on different cores.

MCP_Software_2:

The applicant has verified that the data and control coupling between all the individual software components hosted on the same core or on different cores of the MCP has been exercised during software requirement-based testing, including exercising any interfaces between the software components via shared memory and any mechanisms to control the access to shared memory, and that the data and control coupling is correct.

Notes:

a) When this objective cannot be completely met during the software verification, applicants may propose to use system-level testing to exercise the data and control coupling between software components hosted on different cores.

b) Interference may occur between tasks of a single component when the tasks execute on different cores.

5.5. Error detection and handling, and safety nets

As well as the types of errors and failures normally detected and handled in a system that incorporates a single-core processor, additional types of errors and failures may need to be detected and handled in an MCP environment due to problems caused by the features of MCPs and due to the additional complexity of executing several software applications or tasks in parallel in real time.

Features of an MCP may, therefore, contain unintended functionality that may cause errors and produce unexpected behaviour. Applicants may, therefore, wish to consider the use of a 'safety net' independent from the MCP to detect and handle failures within the MCP and to contain any such failures within the equipment in which the MCP is installed.

MCP_Error_Handling_1:

The applicant has identified the effects of failures that may occur within the MCP and has designed, implemented, and verified means commensurate with the safety objectives, by which to detect and handle those failures in a fail-safe manner that contains the effects of any failures within the equipment in which the MCP is installed. These means may include a 'safety net' independent from the MCP.

5.6. Data to complement the accomplishment summaries

The applicant is expected to describe how the objectives of this AMC were satisfied.

MCP_Accomplishment_Summary_1:

In addition to providing the information requested by the applicable software and AEH guidance, the applicant has provided documentation that summarises how they have met each of the objectives of this AMC.

5.7. Applicability of the MCP objectives according to their IDALs

The column 'IDAL A or B' shows the objectives applicable when the highest IDAL of any of the software applications hosted by the MCP or of the MCP hardware device is A or B.

The column 'IDAL C' shows the objectives applicable when the highest IDAL of any of the software applications hosted by the MCP or of the MCP Hardware device is C.

MCP OBJECTIVES	**IDAL A or B**	**IDAL C**
MCP_Planning_1	**Yes**	**Yes**
MCP_Planning_2	**Yes**	**Yes**
MCP_Resource_Usage_1	**Yes**	**Yes**
MCP_Resource_Usage_2	Covered by AMC 20-152A Objective COTS-8	**n/a**
MCP_Resource_Usage_3	**Yes**	**Refer to Note d**
MCP_Resource_Usage_4	**Yes**	**No**
MCP_Software_1	**Yes**	**Yes**
MCP_Software_2	**Yes**	**Yes**
MCP_Error_Handling_1	**Yes**	**No**
MCP_Accomplishment_Summary_1	**Yes**	**Yes**

6. RELATED REGULATORY, ADVISORY, AND INDUSTRY MATERIAL

(a) Related EASA Certification Specifications (CSs)

(1) CS-23 *Certification Specifications and Acceptable Means of Compliance for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes*

(2) CS-25 *Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes*

(3) CS-27 *Certification Specifications and Acceptable Means of Compliance for Small Rotorcraft*

(4) CS-29 *Certification Specifications and Acceptable Means of Compliance for Large Rotorcraft*

(5) CS-E *Certification Specifications and Acceptable Means of Compliance for Engines* and AMC 20-3B *Certification of Engines Equipped with Electronic Engine Control Systems*

(6) CS-P *Certification Specifications for Propellers* and AMC 20-1A *Certification of Aircraft Propulsion Systems Equipped with Electronic Control Systems*

(7) CS-ETSO *Certification Specifications for European Technical Standard Orders*

(8) CS-APU *Certification Specifications for Auxiliary Power Units* and AMC 20-2B *Certification of Essential APU Equipped with Electronic Controls*

(b) EASA Acceptable Means of Compliance (AMC)

(1) AMC 20-115( ) *Airborne Software Development Assurance Using EUROCAE ED-12 and RTCA DO-178*

(2) AMC 20-152( ) *Development Assurance for Airborne Electronic Hardware (AEH)*

(c) FAA Advisory Circulars (ACs)

(1) AC 20-115 *Airborne Software Development Assurance Using EUROCAE ED-12( ) and RTCA DO-178( )*

(2) AC 20-152 *Development Assurance for Airborne Electronic Hardware (AEH)*

(3) AC 00-72 *Best Practices for Airborne Electronic Hardware Design Assurance Using EUROCAE ED-80( ) and RTCA DO-254( )*

(4) AC 20-170 *Integrated Modular Avionics Development, Verification, Integration and Approval using RTCA DO-297 and Technical Standard Order C-153*

(5) AC 27-1309 *Equipment, Systems, and Installations (included in AC 27-1, Certification of Normal Category Rotorcraft)*

(6) AC 29-1309 *Equipment, Systems, and Installations (included in AC 29-2, Certification of Transport Category Rotorcraft)*

(d) Industry Documents

(1) EUROCAE ED-12 *Software Considerations in Airborne Systems and Equipment Certification*, dated May 1982 (no longer in print)

(2) EUROCAE ED-12A *Software Considerations in Airborne Systems and Equipment Certification*, dated October 1985 (no longer in print)

(3) EUROCAE ED-12B *Software Considerations in Airborne Systems and Equipment Certification*, dated December 1992

(4) EUROCAE ED-12C *Software Considerations in Airborne Systems and Equipment Certification*, dated January 2012

(5) EUROCAE ED-79A *Guidelines for Development of Civil Aircraft and Systems*, dated December 2010

(6) EUROCAE ED-80 *Design Assurance Guidance for Airborne Electronic Hardware*, dated April 2000

(7) EUROCAE ED-94C *Supporting Information for ED-12C and ED-109A*, dated January 2012

(8) EUROCAE ED-124 *Integrated Modular Avionics (IMA) Development Guidance and Certification Considerations,* dated June 2007

(9) EUROCAE ED-215 *Software Tool Qualification Considerations*, dated January 2012

(10) EUROCAE ED-216 *Formal Methods Supplement to ED-12C and ED-109A,* dated January 2012

(11) EUROCAE ED-217 *Object-Oriented Technology and Related Techniques Supplement to ED-12C and ED-109A*, dated January 2012

(12) EUROCAE ED-218 *Model-Based Development and Verification Supplement to ED-12C and ED-109A*, dated January 2012

(13) SAE International Aerospace Recommended Practice (ARP) 4754A *Guidelines for Development of Civil Aircraft and Systems*, dated 21 December 2010

(14) RTCA DO-178 *Software Considerations in Airborne Systems and Equipment Certification,* dated January 1982 (no longer in print)

(15) RTCA DO-178A *Software Considerations in Airborne Systems and Equipment Certification*, dated March 1985 (no longer in print)

(16) RTCA DO-178B *Software Considerations in Airborne Systems and Equipment Certification*, dated 1 December 1992

(17) RTCA DO-178C *Software Considerations in Airborne Systems and Equipment Certification*, dated 13 December 2011

(18) RTCA DO-248C *Supporting Information for DO-178C and DO-278A*, dated 13 December 2011

(19) RTCA DO-254 *Design Assurance Guidance for Airborne Electronic Hardware*, dated 19 April 2000

(20) RTCA DO-297 *Integrated Modular Avionics (IMA) Development Guidance and Certification Considerations*, dated 8 November 2005

(21) RTCA DO-330 *Software Tool Qualification Considerations*, dated 13 December 2011

(22) RTCA DO-331 *Model-Based Development and Verification Supplement to DO-178C and DO-278A*, dated 13 December 2011

(23) RTCA DO-332 *Object-Oriented Technology and Related Techniques Supplement to DO-178C and DO-278A*, dated 13 December 2011

(24) RTCA DO-333 *Formal Methods Supplement to DO-178C and DO-278A*, dated 13 December 2011