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Test Setup Strategy for Environmental Tests of Aircraft Systems

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Abstract. *As the aircraft critical systems has increased its complexity and the integration among their components over the years, and since their control and monitoring are implemented using electronic components, the concern whether those complex systems would continuing respond as required when exposed to an electromagnetic environment (EME) is also growing. In that sense, a great effort (in terms of cost, time and human resources) is required from the aerospace industry in order to prepare a representative test setup to be used to assure that the aircraft systems will behave as specified during and after the exposure of an EME. The definition of the test setup that will be used plays an important role and may impact significantly the overall project. This paper compares two different test setups strategies and, in the end, presents a guideline to help choosing the test strategy that best fits the program needs.*

Keywords: Electromagnetic Environment; Test Setup, Complex System.

1. Introduction

As the aircraft systems increased its complexity and integration over the years and based on the fact that their control and monitoring are implemented on electronic components, it also increased the concern whether those complex systems would continuing respond as required when exposed to an electromagnetic environment (EME). In that sense, a great effort (in terms of cost, time and human resources) is required from the industry in order to assure that the aircraft systems will operate properly during and after the exposure of an EME. There is always a big concern whether the system will behave in an unpredicted way because not only the internal electrical signal will appear on the circuitry, but also another unexpected inputs may appear due to the electromagnetic field coupling into the wires, rails, components leads and electrical junctions.

According to [ARP5583A 2010], which is collection of industry best practices for the Certification of Aircraft in a High-Intensity Radiated Field (HIRF) Environment, in the recent years the concern for protection of aircraft electrical and electronic systems have increased substantially due to the following reasons:

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

2) Reduced electromagnetic shielding afforded by some composite materials used in aircraft designs;
3) 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) Increased severity of the HIRF environment because of an increase in the number and radiated power of radio frequency (RF) transmitters (radar, radio, television, and other ground-based, shipborne, or airborne RF transmitters); and
6) Adverse effects experienced by some aircraft when exposed to HIRF.

Aligned with the concerns pointed above, the [ECSS 2010] defines that testing is considered the preferred method to provide evidence that a system meets its required (or specified) design and performance. As the aircraft critical systems (e.g., Flight Control System, Engine Control System) are commonly implemented on electronic platforms that are not Fully Analyzable and Testable (FAT), testing is indeed the method that better fulfill the requirements to verify that the those systems are still capable of performing its intended function when exposed to High-Intensity Radiated Fields (HIRF) Environment, which is one kind of the EME.

In order to define the most appropriated Test Setups we discuss two strategies. The paper is organized as follows. Section 2 presents the background; section 3 describes the test setups types discussed in this paper; section 4 presents a Test Setup Strategy; and section 5 concludes the paper.

2 Background

2.1 Test Setup - Representativeness

The representation of the system during the test is materialized in the form of a Test Setup, which has the goal to represent with a high degree of fidelity all the aspects of the system that may influence its behavior when exposed to an specific test environment (e.g., interconnection using the same harness from the real installation, same bonding features as used in the real installation). However, the definition of the test setup requires some compromise between:

a) Feasibility: for example, it may not be feasible to run the test in all possible modes of operation specified for the system. In that case, an analysis is mandatory to demonstrate that the test will be performed in only few modes of operation and the remaining modes will be covered by similarity analysis;
b) Space available at the test facility: due to the physical space available at the test facility, it may be required to define a boundary for the representation of the system in the test setup, where the system under test (SUT) will be “inside” this boundary. Everything outside this boundary will be not be representative of the real installation;

c) Cost: in order to assembly the representative test setup, it is required real system units, test bench for data recording during the tests, technical staff to run the test, etc.;

d) Time: from the moment the test setup is defined until the test execution starts, it is necessary to consider time to have the units available and additional time to assembly and integrate the test setup;

e) Knowledge of the system architecture: in order to reach the compromise of representativeness, feasibility and physical dimension of the test setup, it is necessary to have a deep understanding of the system architecture and its possible communication with other systems.

2.2 Complex electronic computers - an Hypothetical Aircraft System

According to [DO254 2000], a hardware item is identified as simple only if a comprehensive combination of deterministic test and analysies can ensure the correct functional performance under all foreseeable operating conditions with no anomalous behavior. When a hardware item cannot be classified as simple, it should be classified as complex.

The Figure 1 represents a simplified view of an hypothetical aircraft system that implements a complex electronic computer (EUT #1). By definition, the EUT #1 is installed in the forward electronic bay, right below the aircraft cockpit and acts as the core of the system, performing the analog and digital computation of the commands send to the other units via electrical signals (current) and also performing the monitoring of those units based on feedback signals (voltage, current) received by the unit. The different colors represent the different routing of the wires that connects all the units of the system. Per design, the hypothetical system represented in Figure 1 exchange data through digital busses (e.g., ARINC 429) with other systems (System A, System B and System C). The complete interconnection of the Systems A, B and C are not represented in the Figure 1 for simplicity, but they are not really relevant for the scope of the analysis presented in this paper.

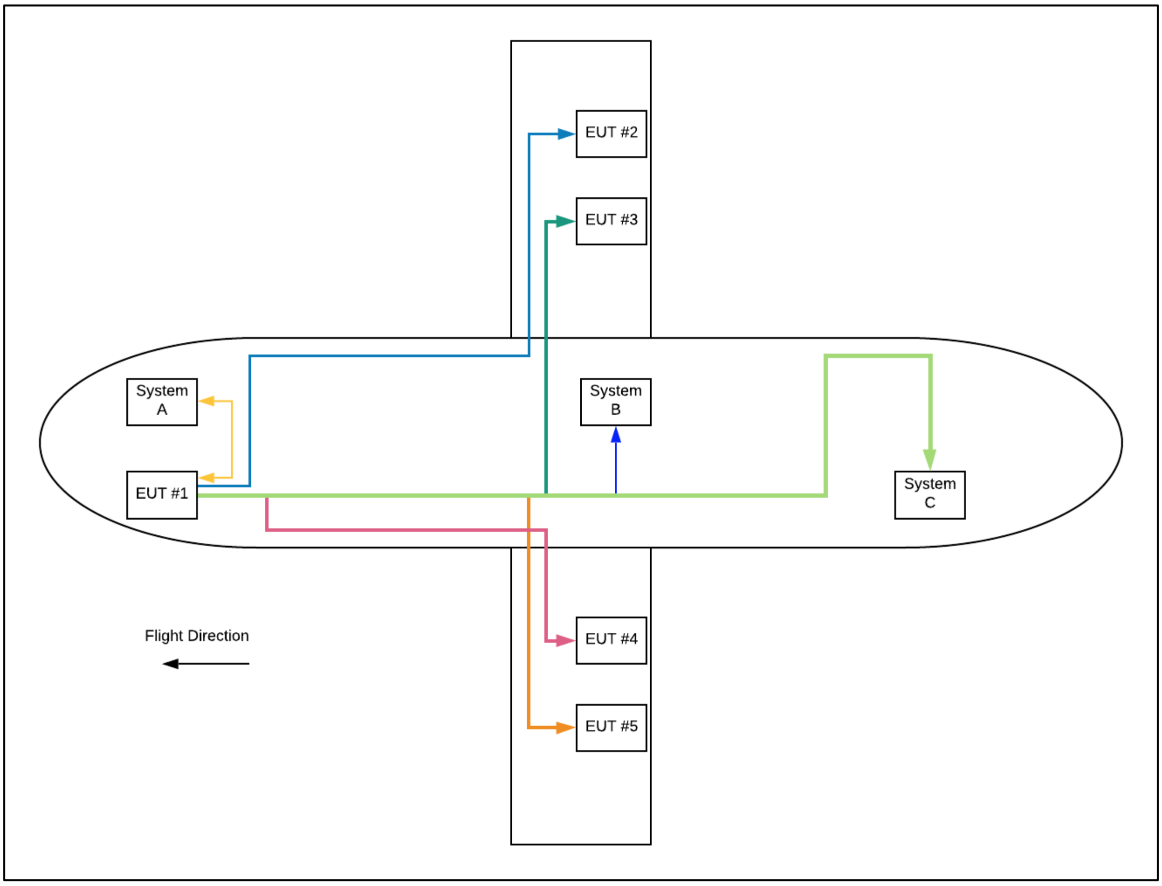

Figure 1 - Simplified view of the installation of a hypothetical aircraft system

2.3 HIRF Environment

Concerning the High Intensity Radio Frequency (HIRF) Environment that a civil aircraft (and consequently all its systems) may be exposed, [ARP5583A 2010] explains that the test levels used by the industry are based on the worst-case estimation of electromagnetic fields that a civil aircraft may encounter during its operation.

3 Test Setups for Verification

Figure 2 represents the System Under Test (SUT) highlighted in red (EUT's #1 trough #5). For simplicity, it is assumed that the interconnection of the System Under Test (SUT) with the other systems A, B and C are represented by one single box in the Figure 2.

Once the test is defined as the method to verify the complex system, the Test Owner (usually an Engineer involved in the design of the system, which is responsible for the technical aspects of the test) must define that is the strategy in terms of the kind of Test Setup that will be used: an Equipment Level Test Setup or an Integrated System Level Test Setup.

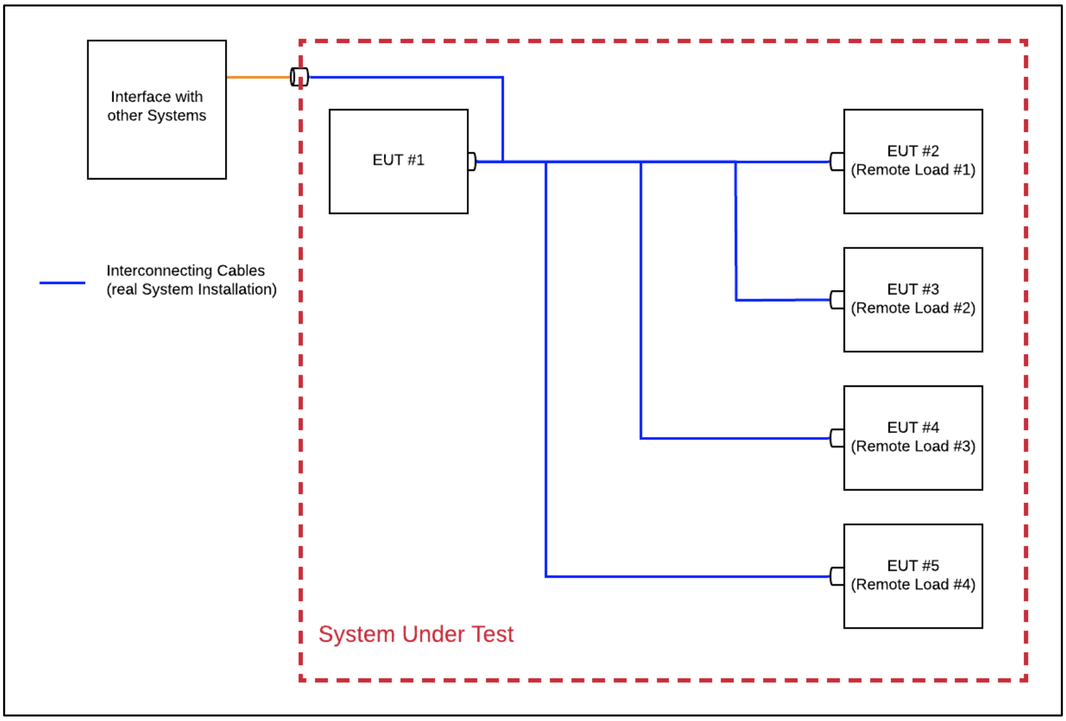

Figure 2 - Hypothetical System Under Test (based on the system represented in the Figure 1)

3.1 Equipment Level Test Setup

The [DO-160G 2010] is an Industry Standard that defines a series of minimum standard environmental test conditions (test levels and/or categories) and applicable test procedures for airbone equipment. The purpose of these tests is to provide means of determining the performance characteristics of airbone equipment in environmental conditions representative of those which may be encountered in airbone operation of the equipment.

The Figure 3 extracted from the revision G of reference [DO-160G 2010] presents a generic test setup that focus on Equipment Level Test. Note that the proposed test setup is focused in only one of the units (EUT) of the hypothetical system represented in the Figure 1. All the other the units (remote loads) and the other systems (Systems A, B and C) are not present in the test setup. They are all emulated by representative electric loads (see the block highlighted in RED) in the Figure 3.

The Equipment Level Test Setup presented as shown in the Figure 3 can be used whenever the representation of the complete real system installation is not required for the test. For example, for tests that aims to verify the effect of voltage transients in the power leads of the equipment (simulating a possible normal or abnormal surge voltage), or tests that expose the unit to extreme Temperature and/or Vibration conditions.

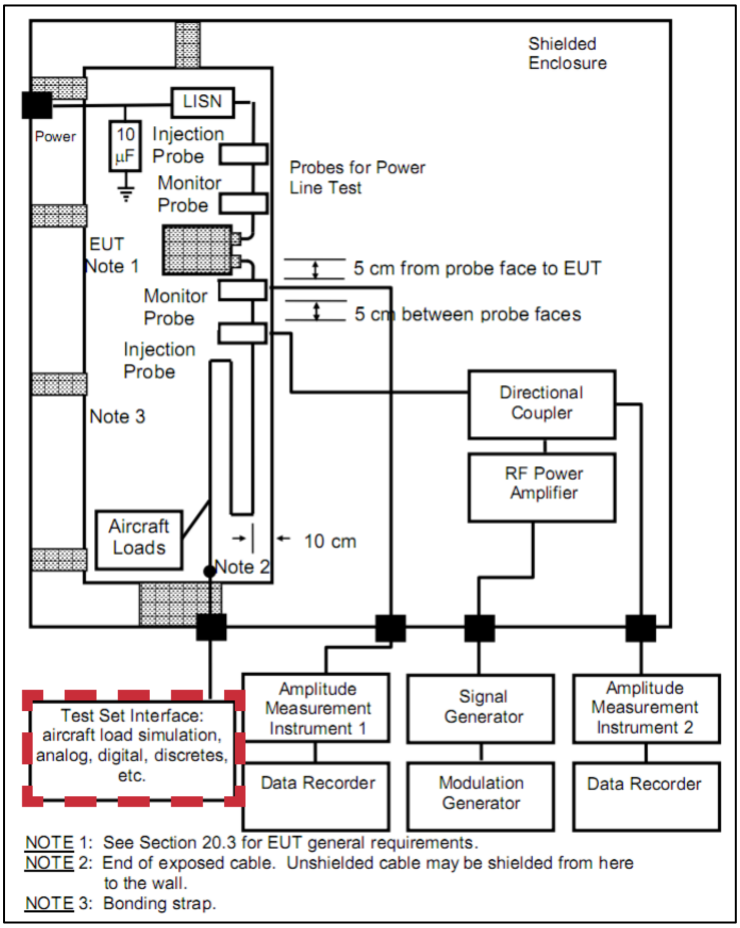

Figure 3 - Example of Equipment Levels Test (source: [DO-160G 2010])

Equipment Level Test Setup represents a more simple solution in terms of physical space occupied by the setup, quantity of system units, time spent for preparation and its complexity. This test setup is proven to be sufficient to assure that the hardware design of the EUT meets the environmental qualification requirements. However, it may present some "pitfalls" (or challenges) as noted below:

a) When the remote load provides a feedback to the EUT in order to perform a closed control loop, the representation of the electrical remote load may become more complex than actually adding the real remote load to the test setup.

b) The interconnecting wires may have a simplified configuration of the real system installation, in a way that all the physical interconnections of the EUT are represented, but the real bundle configuration of the entire path is not represented. Some reasons for that different configuration from the real system installation are: lack of maturity of the real harness design; lack of time to manufacture a cable harness that represents the complete real system installation.

3.2 Integrated System Level Test Setup

The reference [ARP5583A 2010] represents a collection of best engineering practices that have been used to certify aircraft HIRF protection, which is consistent with the guidance of [AC 20-158A 2014] to realize the Integrated System Test Setup.

Figure 4 presents a test setup for an Integrated System Test considering the hypothetical Complex System shown in the Figure 1. Although the system under test has interconnection with other systems, it is necessary to establish the boundary between the systems in order to define what will be the part of the test setup under test. That connection with the other systems A, B and C are represented in the Integrated Test Setup by the "Aircraft Load Simulation", shown in the box outside the Shielded Enclosure in the Figure 4.

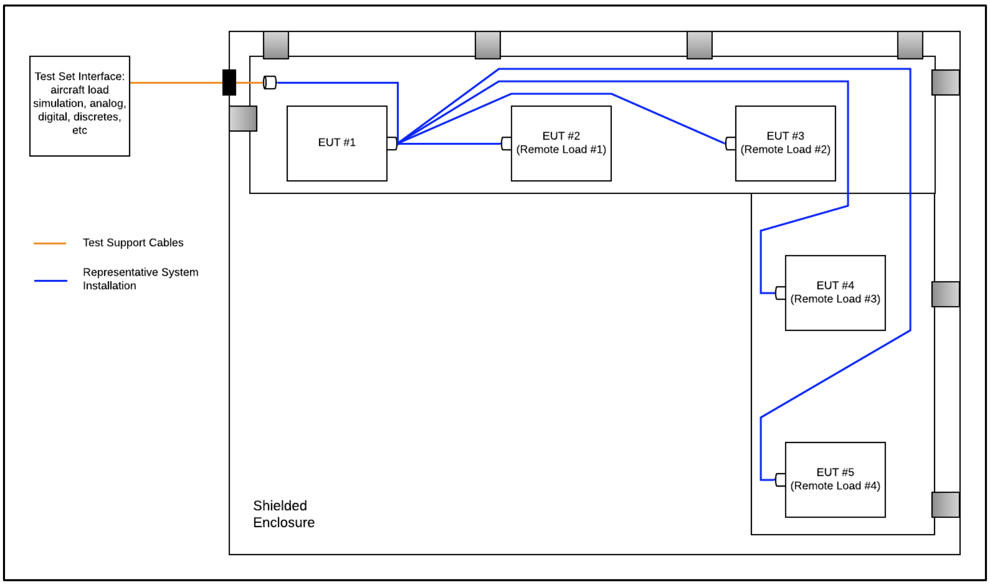

Figure 4 - Example of Integrated System Level Test Setup (based on the system represented in the Figure 1)

Although the Figure 4 presents only a simplified view of the test setup, it can be clearly noted that in this case the complete system is installed in the test setup (EUT #1 and its remote loads, and all its representative interconnecting cables).

This test setup is realized using more resources (harness, system units, physical space) than the test setup represented in the Equipment Level Test Setup (Figure 3). However, it is a better representation of the real system and its installation.

The Integrated System Level test setup is mandatory for tests where the system and its installation may affect the behavior of the system operation when it is exposed to certain environmental conditions (e.g., induced currents and voltage coupling in the interconnecting wires due to a lightning strike hitting the aircraft; or induced current/voltage coupling in the interconnecting wires or rails due to exposure to electric fields from antennas, radars and other radio frequency field emitters).

4. Equipment Level and Integrated System Tests – to guideline for decision

The decision to use one single test setup for both Equipment Level and Integrated System Tests may not be as straight forward as it look like: one could say that using an Integrated System Level Test Setup seems to be the most reasonable solution considering the best coverage and representativeness of the real system installation. The Table 1 summarizes the differences between Equipment Level and Integrated System Level Test Setups:

Item	Equipment Level Test Setup	Integrated System Test Setup
Complexity	Less complex	More complex
Physical dimension	Smaller	Larger
Number of Units Under Test	1	Many
Duration of Test Execution	Shorter	Longer
Time required for assembly	Smaller	Longer
Representativeness of real installation	Less representative	More representative
Purpose	Verification of the equipment design (hardware and functions)	Verification of the System design (hardware and functions)

Table 1 - Comparison between Equipment Level and Integrated System Level Test Setups

Before taking that decision, the Test Owner must keep in mind that it will require a lot of effort during a phase of the project that the system and its installation may still be under early stages of development. In other words, it means that:

- The system installation (interconnecting cables, or even the position of the units inside the aircraft) may be not mature enough, and a redesign made in the system installation after the test execution will affect the test setup and it will be necessary to repeat the execution of the test;
- The interface with other systems may change (e.g., new interfaces are added). That change will affect the system interconnecting cables used in the test setup and it will be necessary to repeat the execution of the test;
- Issues found during Design Reviews or documentation inspection that evidences flaws in the equipment hardware design.

All the points mentioned above have impact on the tests results. I.e., the test setup will have to be modified to incorporate both changes, and the penalty in this case is that the Integrated System Tests will have to be repeated. In this case, it the best strategy would be to use two test setups: one for Equipment Level tests (that will help improving the maturity for the equipment hardware design) and later one additional Integrated Test Setup that will be used for the tests that require a test setup representative of the real system installation.

4.1 Test Setup Strategy Checklist

The checklist shown in the **Erro! Fonte de referência não encontrada.** presents a collection of questions that may guide the definition of the best Test Setup Strategy to be used. The proposed checklist collects some of the challenges that may be faced during the definition of the test setup used during for the system environmental tests as part of the system development.

Question #	YES	NO	Remarks
1 - All the units of the system are available?			The objective of this question is to highlight whether the System Units would be available if an Integrated System Test Setup would be assembled.
2 – The date when the complete set of units (based on question 1) will be available is consistent with the Program Schedule?			The objective of this question is to evaluate if the availability of the system units is consistent with the overall program schedule.
3 – Is it mandatory to use an Integrated System Level Test Setup to verify the performance of the unit in the required environmental test conditions?			The objective of this question is to evaluate if it is technically acceptable to execute an Equipment Test Level. If not, the Integrated System Level test setup is required.
4 – The Critical Design Review (CDR) of the system is already closed?			The objective of this question is to evaluate the risk of the system design may be changed in a way that the test should be repeated after the modification.
5 - The system installation is already frozen?			The objective of this question is to evaluate the risk of the system installation may be changed in a way that the test should be repeated after the modification.
6 – The time duration required to manufacture a representative harness is consistent with the Program Schedule?			The objective of this question is to evaluate if the manufacturing of the representative harness fits in the Program schedule.
7 – The chosen test facility has enough space to fit the complete system with the representative harness?			The objective of this question is to evaluate if the test facility will have enough space to assembly the Integrated System Test Setup.

Table 2 - Test Setup Strategy Checklist

4.2 Discussion

After answering the checklist presented in Table 2, the interpretation of the answers will guide the definition of the best setup strategy for Environmental Tests. We propose the following interpretation:

a) If all the questions of the checklist are filled with YES, then the Integrated System Test Setup is the best test strategy and will meet the Program needs.

b) If all the question are answered with NO, then it is an indication that the strategy should consider one Equipment Level Test Setup in order to acquire more maturity for the System Design and Installation, and later use an Integrated System Test Setup for the final Integration and Verification required for the system.

c) If only some of the questions are answered with NO, then it might be possible to evaluate if the specific can be focused and maybe find a way accomplish that and change that answer to an YES in an adequate time. And then use only one Integrated System Test Setup may be applicable.

5. Conclusion

The definition of the best Test Setup that will be used during the system's environmental tests is not as straight forward as it looks like. It involves aspects related to the maturity of the system and its installation (interconnecting wires), and other "non-technical" aspects like costs, resources, schedule. In that sense, the checklist defined in the Table 2 aims to guide the definition of the best test setup strategy that will be used to demonstrate that the systems is able to perform its intended functions during and after the exposure to an required environmental test condition.

If the Test Setup Strategy is not well substantiated or if erroneous assumptions are considered during its definition, it may affect substantially the overall program since it may drain resources and time. For example, if an Integrated System Test Setup is chosen but the system or its installation is not mature, all the changes applied to the system and/or to the system installation will affect the tests already performed and a repetition of the complete environmental test campaign may be required. Additionally, the Test Setup will have to be changed in order to accommodate all the improvements implemented in the system and/or in the system installation.

Since this paper presents only a qualitative analysis, one possible future work is to quantify the possible impacts at the Program Level (schedule, costs) may be incurred in case a wrong Environmental Test Setup strategy is chosen.

References

Federal aviation administration (FAA), Advisory circular 20-158 Revision A. USA, 2014

RTCA, Inc., Document No. RTCA/DO-160/EUROCAE ED14G, Environmental Conditions and Test Procedures for Airbone Equipment. RTCA DO160, Washington, D.C., USA, 2010

SAE Aerospace, Document No. ARP5583 Revision A, 2010

ECSS, Document No. ECSS-E-HB-10-02A, Space engineering Verification guidelines, 2010

RTCA, Inc., Document No. RTCA/DO-254/EUROCAE ED80, Design Assurance Guidance for Airborne Electronic Hardware. RTCA DO254, Washington, D.C., USA, 2000