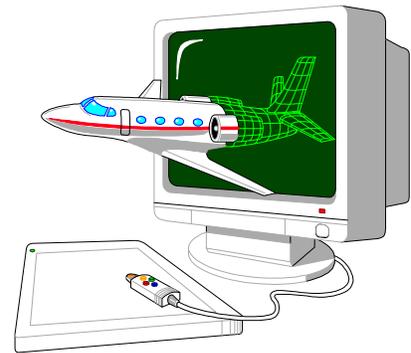


Integrated Modular Avionics (IMA)

An Interactive Video Teletraining Course

IVT course # 62834

Self-Study Video #25834



Developed and Presented by:

Leanna Rierson

FAA, Chief Scientific and Technical Advisor

For Aircraft Computer Software

**Aircraft Certification Service
Federal Aviation Administration**

October 23-24, 2002

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How Do You Use This IVT Guide?

This Interactive Video Teletraining (IVT) Guide provides you with an orientation to the IVT presentation, support materials for use during the broadcast, and the course evaluation.

Follow these steps to complete your study:

1. Review the *IVT Presentation Orientation* before the broadcast, if possible, or before you watch the self-study videotape. It provides the purpose of the presentation, the target audience, information about the instructors, what you will learn, and topics covered.
2. Turn to Appendix A, *IVT Presentation Visuals*, and refer to it during the broadcast/videotape. You can use these visuals to take notes and follow along when viewing the presentation/ self-study video.
3. Review the Technical Standard Order (TSO) – C153 on IMA hardware elements (Appendix B) before the broadcast, if possible, or before you watch the self-study videotape.
4. Review the Advisory Circular (AC) on IMA systems (Appendix C) before the broadcast, if possible, or before you watch the self-study videotape.
5. Complete the *IVT Presentation Evaluation Form* in Appendix D and send it to your Directorate/Division Training Manager (ATM). Your comments are very important to us and will help to enhance the quality of the IVT lesson.

NOTE: The IVT broadcast will be videotaped so that it may be used as a self-study package for those who were unable to participate in the broadcast, or for those who wish to refresh their knowledge of the content presented. This IVT Guide may also be used with the self-study videotape.

What Is IVT?

Interactive Video Teletraining, or IVT, is instruction delivered using some form of live, interactive television. This course originates from the television studio at the FAA Academy in Oklahoma City. Through the IVT broadcast facility, the instructor is able to use a variety of visuals, objects, and media formats to support the instruction.

Participants are located at various receive sites around the country and can see the instructor and his/her materials on television sets in their classrooms. The participants can communicate with the instructor either through a microphone and/or the simple-to-use Viewer Response System keypads. During the live presentation, when a participant has a question or the instructor asks for specific participant responses to questions, the participant(s) can signal to the instructor using the keypad.

The collective participant responses, or the name of a specific participant signaling a question, are immediately visible to the instructor on the console at the broadcast site. The instructor can then respond as needed. When the instructor calls on a specific participant to speak from a site, participants at each of the other sites can simultaneously hear the participant who is speaking.

Who Is the Target Audience?

Aviation safety engineers and inspectors who are responsible for approving integrated modular avionics systems.

What Is In This Guide?

This guide provides you with a framework for this course as well as the following three appendices to be used during the course:

- Appendix A contains copies of the actual slides used by the instructor during the broadcast. You can use these visuals to follow along with the broadcast or when you watch the tape and to record notes directly on the pages.
- Appendix B contains the Technical Standard Order (TSO) – C153, entitled “INTEGRATED MODULAR AVIONICS HARDWARE ELEMENTS,” that will be discussed throughout the broadcast.
- Appendix C contains draft 12 of the Advisory Circular (AC) entitled GUIDANCE FOR INTEGRATED MODULAR AVIONICS (IMA) THAT IMPLEMENT TSO-C153 AUTHORIZED HARDWARE ELEMENTS” that will be discussed throughout the broadcast.
- Appendix D contains the IVT/Self-study Evaluation Form. Please fill out this form after the IVT/self study course is finished. If taking the course “live” please fax the form to 405-954-0317. If taking this course via self-study, send the form to your Directorate/Division Training Manager (ATM) in order to get course credit.

What Will You Learn?

At the end of the training, participants will be able to:

- Describe TSO-C153 for IMA hardware elements.
- Explain the advisory circular (AC) on IMA and its relationship to TSO-C153.
- Describe the technical topics addressed in the IMA AC.
- Explain keys to approving IMA systems.
- Discuss future trends in IMA technology.
- Describe the “hot topics” in IMA approvals.

Who Is the Instructor?



Leanna Rierson is the FAA's Chief Scientific and Technical Advisor for Aircraft Computer Software. She has 14 years of experience in the computer/aviation industry. These positions include: national software program manager of the FAA Avionics Branch (AIR-130), avionics/electrical engineering specialist at the Wichita ACO, and software positions with industry at NCR and Cessna Aircraft Company. Leanna graduated summa cum laude from Wichita State University and has a Master's degree in Software Engineering from Rochester Institute of Technology. Leanna has led numerous national and international software teams. She is the co-lead of the FAA's Integrated Modular Avionics (IMA) team and is a member of the RTCA Special Committee #200 on modular avionics.

Self-Assessment

Pre- & Post-Course Self-Assessment Questions

If you are taking this course via IVT and you are logged on to a keypad, you will be asked before and after the broadcast to complete this self assessment, using your keypads. If you are taking this via self-study video, please complete manually and return with your end of course evaluation to your directorate/division training manager (ATM).

Rate your confidence level for each of the following statements before and after completing the course.

1. I can describe TSO-C153 for IMA hardware elements.

	<u>Very Confident</u>	<u>Moderately Confident</u>	<u>Not Confident</u>
BEFORE THE COURSE:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
AFTER THE COURSE:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2. I can explain the IMA AC and its relationship to TSO-C153.

	<u>Very Confident</u>	<u>Moderately Confident</u>	<u>Not Confident</u>
BEFORE THE COURSE:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
AFTER THE COURSE:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

3. I can describe the technical topics addressed in the IMA AC.

	<u>Very Confident</u>	<u>Moderately Confident</u>	<u>Not Confident</u>
BEFORE THE COURSE:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
AFTER THE COURSE:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

4. I can explain keys to approving IMA systems.

	<u>Very Confident</u>	<u>Moderately Confident</u>	<u>Not Confident</u>
BEFORE THE COURSE:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
AFTER THE COURSE:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

5. I can explain future trends in IMA systems.

	<u>Very Confident</u>	<u>Moderately Confident</u>	<u>Not Confident</u>
BEFORE THE COURSE:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
AFTER THE COURSE:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

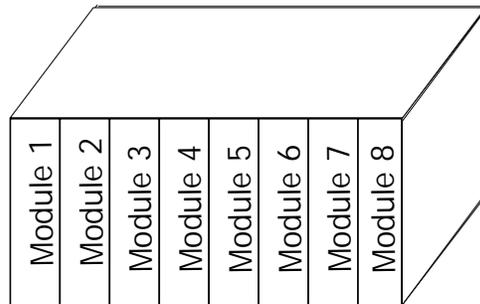
6. I can describe the “hot topics” in IMA systems approval.

	<u>Very Confident</u>	<u>Moderately Confident</u>	<u>Not Confident</u>
BEFORE THE COURSE:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
AFTER THE COURSE:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Presentation Visuals

Appendix A

Integrated Modular Avionics (IMA)



Leanna Rierson

October 23-24, 2002

E-mail: Leanna.Rierson@faa.gov

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Course Objectives

- ◆ Describe TSO-C153 for IMA Hardware elements.
- ◆ Explain the advisory circular (AC) on IMA and its relationship to TSO-C153.
- ◆ Describe the technical topics addressed in the IMA AC.
- ◆ Explain keys to approving IMA systems.
- ◆ Explain future trends in IMA technology.
- ◆ Discuss some of the “hot topics” in IMA approvals.



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Course Overview



◆ Day 1:

- IMA Background
- TSO-C153
- Keys to Granting TSO-C153 Authorization
- Introduction to IMA AC



◆ Day 2:

- IMA AC
- Keys to IMA System Approval
- Hot Topics in IMA
- RTCA's New IMA Committee
- Summary

3

IMA Background

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What is IMA?

- ❖ **Defining “IMA” is difficult**
- ❖ **The RTCA modular avionics team created the following definition:**
 - **Modular avionics is defined as a shared set of flexible, reusable, and interoperable hardware and software resources that create a platform that provides services, designed and verified to a defined set of safety and performance requirements, to host applications performing aircraft-related functions.**

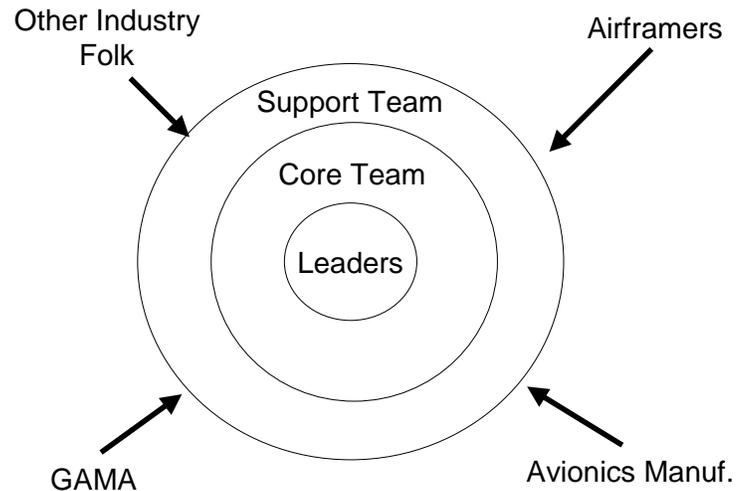
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IMA Team

- ❖ **IMA has been a difficult technology to address**
- ❖ **RTCA & EUROCAE created DO-255, “Avionics Computer Resource Requirements” in 2000**
- ❖ **The FAA’s IMA team was kicked off in March 2001**
 - **IMA team’s purpose: to create a TSO and AC to address IMA hardware elements**

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IMA Team (cont)



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IMA Team (cont)

- ◆ **Leaders:**
 - Leanna Rierson, John Lewis, and Dennis Wallace
- ◆ **Core Team:**
 - Kirk Baker, Jim Treacy, Connie Beane, Todd Dixon, Tom Dean, Jorge Castillo, Colleen Donovan, Kevin Dowling, Dave Gollings, John Philbin, Joe Miess, Erv Dvorak, Dave Walen, Kim Wolfley, Chris duff-Cole
- ◆ **Support Team:**
 - Gregg Bartley, Will Struck, Tony Lambreghts, Kathy Abbott, Jozef van Baal, Pippa Moore, John Vincent

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IMA Team Progress

- ❖ **May 2001 – Kick-off Meeting**
- ❖ **May 2002- Completed TSO C153**
- ❖ **Nov 2002 – Goal to Complete IMA AC**



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TSO-C153

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TSO Title and Date

- ❖ **Title:**
 - “TSO-C153, INTEGRATED MODULAR AVIONICS HARDWARE ELEMENTS”
- ❖ **Completion Date:**
 - May 6, 2002



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TSO Overview

- | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none">❖ Section 1 – Purpose❖ Section 2 – Applicability❖ Section 3 – Requirements❖ Section 4 – Marking❖ Section 5 – Application data requirements❖ Section 6 – Manufacturer data requirements❖ Section 7 – Furnished data | <ul style="list-style-type: none">❖ Section 8 – Manufacturer data sheet❖ Section 9 – Availability of references❖ Appendix 1 – MPS criteria❖ Appendix 2 – Example format for data sheet❖ Appendix 3 - Definitions |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

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Some Unique Things About TSO-C153



- ❖ TSO is for “Brain Dead Hardware”
- ❖ Manufacturer Develops and Submits MPS to FAA
- ❖ TSO Provides Criteria to Be Addressed in the MPS
- ❖ Software Functionality is Limited
- ❖ TSO’d Hardware Elements May Support Functional TSOs
- ❖ Manufacturer Creates a Data Sheet to Aid Users

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Section 1 – Purpose of TSO-C153

Two-Fold Purpose

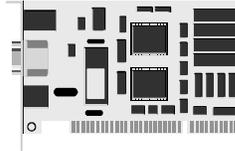
(1)
Requirements
For TSO-C153
Authorization

(2)
Criteria for
Hardware
Element MPS

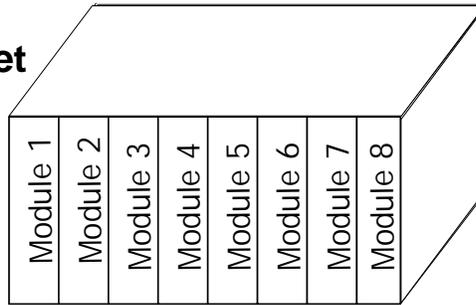
14

Section 2 – Applicability of TSO-C153

- ◆ Hardware modules



- ◆ Rack/cabinet to host hardware modules



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Section 2 – Applicability of TSO-C153 (cont)

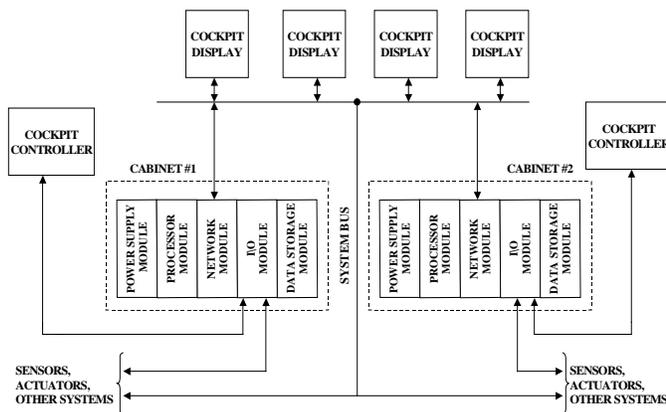


Table 1 in Appendix 1 gives examples of hardware elements.

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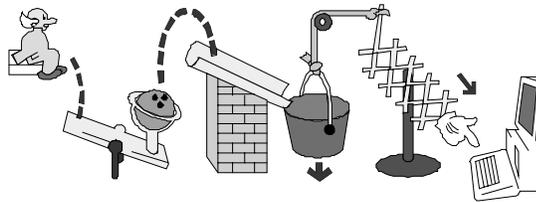
Section 3 – Requirements of TSO-C153

- 
- a. **Functionality**
 - b. **Functional Limitations**
 - c. **Failure Condition Classification**
 - d. **Functional Qualification**
 - e. **Environmental Qualification**
 - f. **Software Design Assurance**
 - g. **Hardware Design Assurance**
 - h. **Configuration Management**
 - i. **Quality Control**
 - j. **Deviations**

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Section 3a – Functionality

- ❖ **a) Document hardware element functionality in the form of MPS and meet the MPS**
 - **Appendix 1 provides criteria for MPS**



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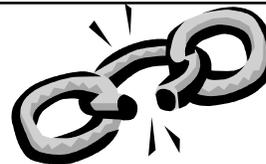
Section 3b – Limitations

- **No intentional transmitters**
- **Only software to enable software loading and/or electronic part marking**



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Section 3c – Failure Condition Classification



- ❖ **Failure conditions are typically dependent on the specific installation**
- ❖ **Hardware element manufacturer must state and include in installation limitation or instructions:**
 - **Software and hardware levels**
 - **Any assumptions about aircraft installation, software & hardware interface, operation to maintain the software and hardware levels**

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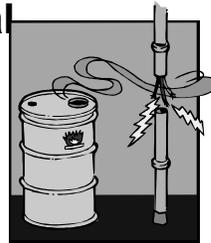
Section 3d – Functional Qualification

- ❖ The MPS must specify the functionality and configuration for the hardware element
- ❖ Appendix 1, Section 5 provides criteria for MPS regarding functional qualification
- ❖ Table 1 in Appendix 1 gives typical characteristics to be included in the MPS

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Section 3e – Environmental Qualification

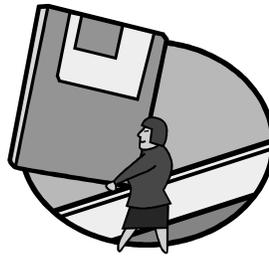
- ❖ Hardware element must meet DO-160D, change 2
- ❖ Appendix 1, Section 6 provides criteria for MPS regarding environmental qualification
- ❖ Table 2 in Appendix 1 provides environmental qualification testing guidance



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Section 3f – Software Design Assurance

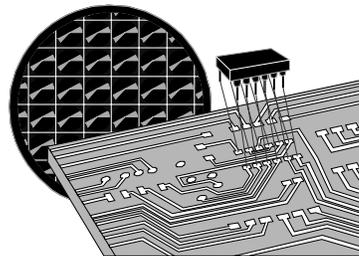
- ❖ Software is limited to software that enables field loading or electronic part marking
- ❖ Software must be developed to appropriate DO-178B level



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Section 3g – Hardware Design Assurance

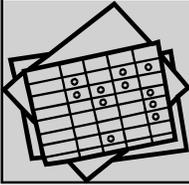
- ❖ Electronic devices that cannot be feasibly evaluated by test and/or analysis (e.g., complex electronic hardware) must comply with DO-254



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Section 3h – Configuration Management

- ❖ Hardware elements that will later be loaded with field-loadable software must support a “robust automatic configuration management function”
- ❖ The hardware elements will not be able to fully implement the configuration management function but should be designed to support it
- ❖ More on configuration management in the Advisory Circular



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Section 3i – Quality Control

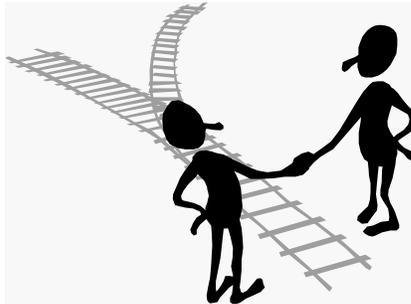


- ❖ Quality control data items must be provided
- ❖ Must meet § 21.143 – Quality control data requirements; prime manufacturer

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Section 3j – Deviations

- ❖ As with any TSO, deviations may be requested
- ❖ Deviations should be coordinated with AIR-100



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Section 4 - Marking

- ❖ Must comply with § 21.607(d)

§ 21.607 General rules governing holders of TSO authorizations.

Each manufacturer of an article for which a TSO authorization has been issued under this part shall—

(d) Permanently and legibly mark each article to which this section applies with the following information:

- (1) The name and address of the manufacturer.
- (2) The name, type, part number, or model designation of the article.
- (3) The serial number or the date of manufacture of the article or both.
- (4) The applicable TSO number.

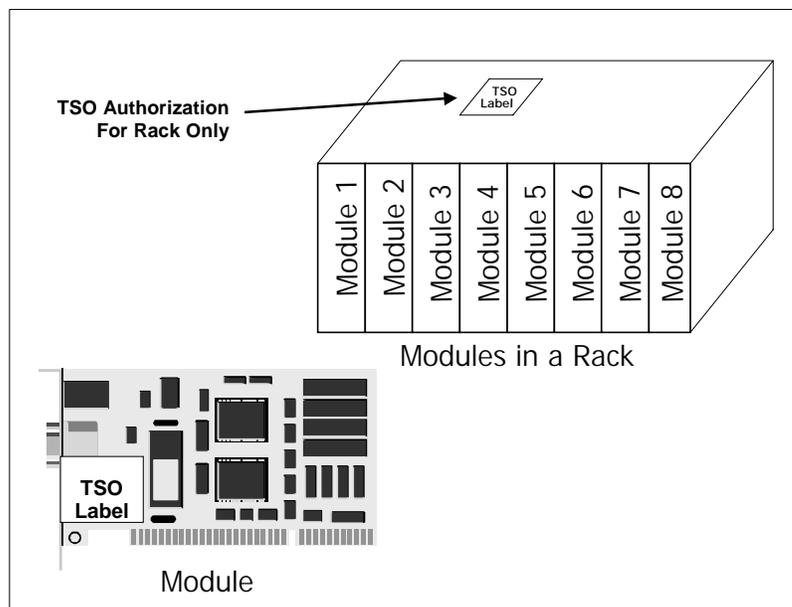
28

Section 4 - Marking

- a) May mark hardware element with P/N in multiple places
- b) May support electronic part marking
- c) Hardware element may have software to enable field loading of software and/or electronic part marking
- d) If (c) is true, may have separate hardware and software P/N
- e) Must have unique part identification
- f) Mark cabinet/rack with “TSO authorization for cabinet/rack only”

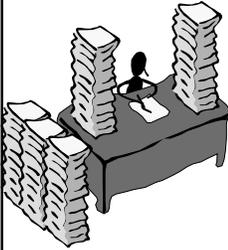
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Section 4 – Marking (cont)



Section 5 – Application Data (submitted to ACO)

- a. Operating instructions
- b. Installation procedures & limitations
- c. Schematic drawings
- d. Wiring diagrams
- e. List of components that comprise the hardware element
- f. Component Maintenance Manual
- g. Material and process specifications list
- h. DO-160D env qual form
- i. *Data sheet (Appendix 2)*



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Section 5 – Application Data (submitted to ACO) (cont)

- j. *MPS for each hardware element (Appendix 1)*
- k. TSO qualification test report
- l. Nameplate drawing
- m. List of drawings and processes to define hardware element design
- n. Quality control system design
- o. Software data (per DO-178B)
- p. Hardware data (per DO-254)
- q. *Instructions for viewing TSO-related electronic part identification*

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Section 6 – Manufacturer Data Requirements (available to ACO)

- a. Detailed spec and functional test for each hardware element**
- b. Equipment calibration procedures**
- c. Corrective maintenance procedures**
- d. Schematic drawings**
- e. Material and process specifications**
- f. Environmental qual test results**
- g. All data to support DO-178B compliance**
- h. All data to support DO-254 compliance**



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Section 7 – Furnished Data

- ❖ **Provide to each purchaser of one or more TSO'd hardware elements:**
 - **Data listed in 5.a through 5.i**
 - **Any additional information needed for proper installation, certification, use, or continued airworthiness of the hardware element**

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Section 8 – Manufacturer's Data Sheet



- ❖ Each hardware element should have a data sheet to summarize its characteristics
- ❖ Example format shown in Appendix 2
- ❖ Data sheet will become part of TSO authorization letter
- ❖ Data sheet will be supplied to all purchasers of the hardware element

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Section 9 – Availability of Reference Documents

- ❖ Provides information for manufacturers to obtain:
 - DO-160D
 - DO-178B
 - DO-254
 - Part 21
 - Advisory Circulars
 - SAE document – ARP 4754

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Appendix 1

- ◆ Appendix 1 is entitled:
 - “Development Criteria For Integrated Modular Avionics Hardware Element Minimum Performance Standards”
- ◆ It is the meat of the TSO
- ◆ It represents a “non-traditional” approach to TSO – the manufacturers develop their own MPS
- ◆ It documents detailed criteria of what manufacturers should include in their MPS

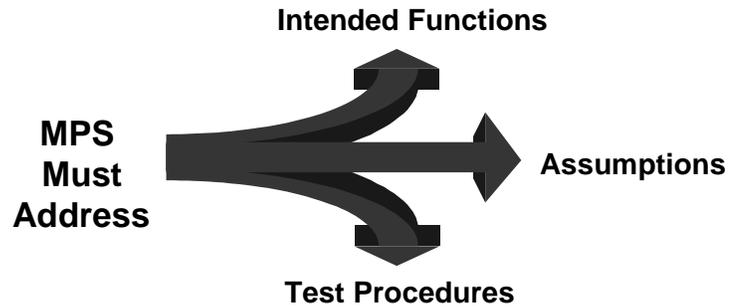
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Appendix 1 Contents

1. Appendix Layout
- Intro { 2. Introduction
3. MPS Overview
- MPS Guidance { 4. General MPS Requirements
5. Equipment Performance – Standard Conditions
6. Equipment Performance – Environmental Conditions
7. Equipment Test Procedures
- Installation & Operational { 8. Installed Equipment Performance
9. Equipment Operational Performance Characteristics

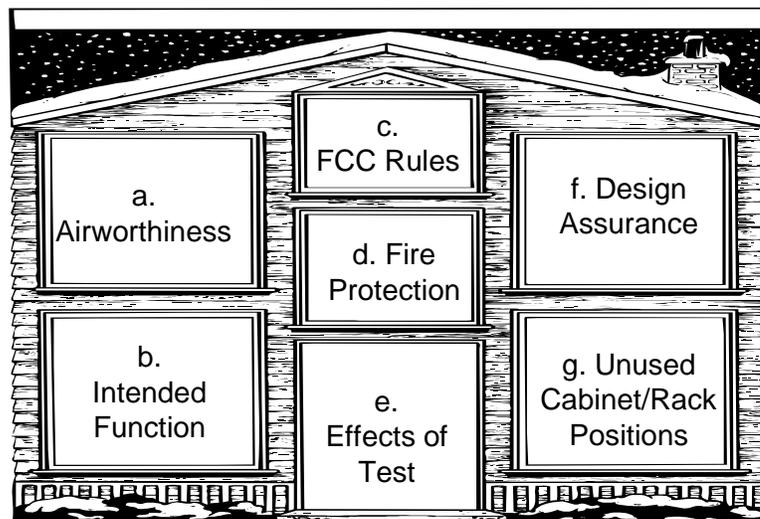
38

Appendix 1 – Section 3 – MPS Overview



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Appendix 1 – Section 4 – General MPS Requirements



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Appendix 1 - Section 5 – Equipment Performance – Standard Conditions

- a. Performance requirements of the hardware element should be defined in the MPS.
- b. Test configuration must include:
 - ❖ All cooling and power supplies/modules
 - ❖ Appropriate processing modules
 - ❖ Appropriate communication modules
 - ❖ Appropriate fillers for unused slots
 - ❖ The cabinet or rack for installation
 - ❖ If field-loadable, special purpose test or functional software
 - ❖ Appropriate electrical & mechanical connectors

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Appendix 1 - Section 5c – Equipment Performance Requirements (Table 1)

- ❖ **9 Equipment Performance Categories**
 - General information
 - Analog input specs
 - Analog output specs
 - Discrete input specs
 - Discrete output specs
 - Processing specs
 - Power supplies
 - Digital communications
 - Racks or cabinets
- ❖ **Each of these categories should be characterized and specified in the MPS**

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Appendix 1 - Section 6 – Equipment Performance – Environmental Conditions

- ◆ **Manufacturer must specify environmental test categories per DO-160D**
- ◆ **Test configuration must include:**
 - All cooling and power supplies/modules
 - Appropriate processing modules
 - Appropriate communication modules
 - Appropriate fillers for unused slots
 - The cabinet or rack for installation
 - If field-loadable, special purpose test or functional software
 - Appropriate electrical & mechanical connectors

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Appendix 1 - Section 6f – Environmental Qual Testing

Not performed for TSO (mark with “X”)

- Temperature (4.5)
- Temperature variation (5.0)
- Shock (operational) (7.0)
- Vibration (8.0)
- Power input (16.0)
- Induced signal susceptibility (19.0)
- Radio frequency susceptibility (20.0)
- Emission of radio frequency energy (21.0)
- Lightning induced transient susceptibility (22.0)
- Lightning direct effects (23.0)

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Appendix 1 - Section 6f – Environmental Qual Testing (cont)

May be performed for TSO

- Altitude (4.6)
- Humidity (6.0)
- Shock (crash safety) (7.3)
- Explosion (9.0)
- Waterproof (10.0)
- Fluids susceptibility (11.0)
- Sand & dust (12.0)
- Fungus Resistance (13.0)
- Salt spray (14.0)
- Magnetic effect (15.0)
- Voltage spike conducted (17.0)
- Audio frequency conducted (18.0)
- Icing (24.0)
- Electro static discharge (25.0)

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Appendix 1 – Section 7 – Equipment Test Procedures

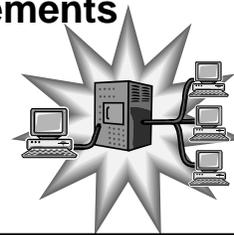
- a. Manufacturers must prepare detailed functional & environmental test procedures to demonstrate compliance to MPS.
- b. The required test equipment must be specified as part of the procedures.
- c. Terms & conditions of the test must be documented



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Appendix 1 – Section 8 – Installed Equipment Performance

- ❖ **Hardware element performance and compliance to regulations must be evaluated in the installed environment**
- ❖ **This is a responsibility of the aircraft or engine manufacturer using the hardware elements**



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Appendix 1 – Section 9 – Equipment Operational Performance Characteristics

- ❖ **Operational performance is typically evaluated in the installed environment**
- ❖ **The installed system must annunciate to crew, when any hardware element can't perform its intended function**

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TSO-C153

KEYS



Some Helpful Hints For ACO Engineers

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1. Remember the Uniqueness of TSO-C153

- ◆ **TSO is for “Brain Dead Hardware”**
- ◆ **Manufacturer Develops and Submits MPS to FAA**
- ◆ **TSO Provides Criteria to Be Addressed in the MPS**
- ◆ **Software Functionality is Limited**
- ◆ **TSO’d Hardware Elements May Support Functional TSOs**
- ◆ **Manufacturer Creates a Data Sheet to Aid Users**

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2. Coordinate With the ACOs that Will be Granting TC/STC/ATC/ASTC

- ❖ **The installation aspects of the TSO should be considered**
- ❖ **It helps for the ACO granting TSO and the ACO granting TC/STC/ATC/ASTC to communicate frequently**

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3. Ensure that Data Package Meets TSO-C153 Requirements

- ❖ **Ensure that all of the data listed in section 5 is provided**
- ❖ **Ensure that the MPS for each hardware element has been submitted**
- ❖ **Ensure that the MPS meets the Appendix 1 criteria**
- ❖ **Ensure that the data sheet has been completed**

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4. When Satisfied With The Data Package, Write TSO Authorization Letter

- ❖ **TSO authorization letter will contain the standard verbiage**
- ❖ **The letter should specify the hardware element configuration and type**
- ❖ **A copy of the data sheet should be attached to the authorization letter.**

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The logo for IMA AC is displayed in a 3D, blocky font. The letters 'I', 'M', and 'A' are grouped together on the left, and 'A' and 'C' are on the right. The letters are white with black outlines and shadows, giving them a three-dimensional appearance as if they are floating or standing on a surface.

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AC Status

- ◆ ***“GUIDANCE FOR INTEGRATED MODULAR AVIONICS (IMA) THAT IMPLEMENT TSO-C153 AUTHORIZED HARDWARE ELEMENTS”***
- ◆ **Draft 12 (in participant’s guide) addresses all public comments received before Oct 7, 2002.**
- ◆ **Final AC targeted for Nov 2002.**

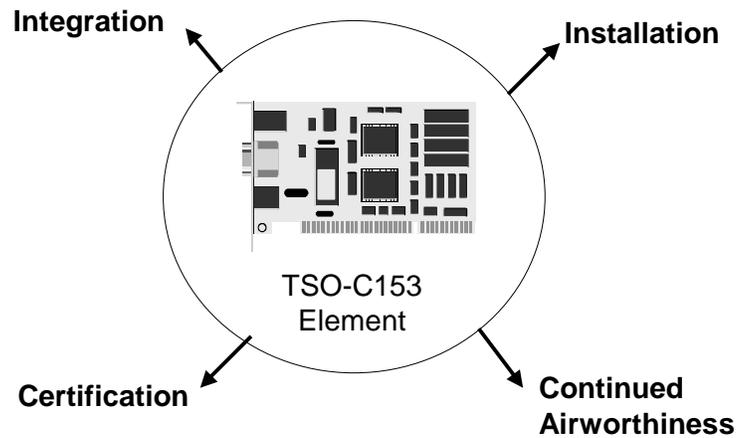
55

AC Overview

- | | |
|--------------------------------|----------------------------------------------|
| ◆ 1 – Purpose | ◆ 12 – Software |
| ◆ 2 – Related Docs | ◆ 13 – Complex Hardware |
| ◆ 3 – Definitions | ◆ 14 – Design Guidance |
| ◆ 4 – Acronyms | ◆ 15 – Environmental Qual |
| ◆ 5 – Scope | ◆ 16 – Human Factors |
| ◆ 6 – Background | ◆ 17 – Testing (multiple levels) |
| ◆ 7 – Document Overview | ◆ 18 – Roles & Responsibilities |
| ◆ 8 – IMA System Cert Overview | ◆ 19 – Third Party Guidance |
| ◆ 9 – Safety Assessment | ◆ 20 – Airworthiness |
| ◆ 10 – Configuration Mgt | ◆ 21 – Maintenance & Continued Airworthiness |
| ◆ 11 – Electronic ID | |

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Section 1 - Purpose



57

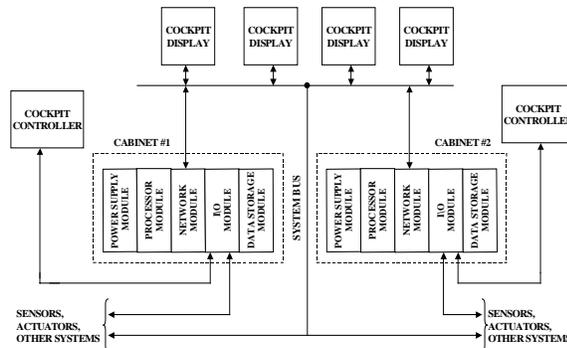
Section 3 - Definitions

- ❖ **Functional TSOs** – A TSO with functionality
- ❖ **Functional Software** – Software that's approved as part a functional TSO or type certificate effort
- ❖ **Hardware Element** – hardware module, cabinet, or rack with TSO-C153 authorization
- ❖ **Stakeholders** – all entities involved in development, integration, and certification of an IMA system

58

Section 3 – Definitions (cont)

- ❖ **IMA System – all components that interface with hardware elements to make the system functional**



59

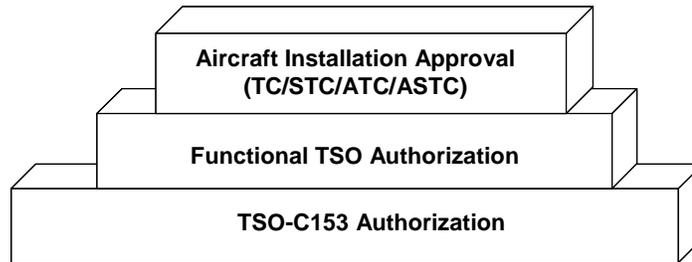
Section 5 & 6 – Scope and Background

- ❖ **AC focuses on IMA systems that use TSO-C153 hardware elements**
- ❖ **Guidance may also be useful for IMA systems that don't use TSO-C153 hardware elements**
- ❖ **Guidance addresses multiple stakeholders (i.e., C153 TSO applicants, Functional TSO applicants, TC/STC/ATC/ASTC applicants)**
- ❖ **Guidance needed for compliance to regs when using C153 TSO'd hardware elements**
- ❖ **Guidance addresses the IMA system**

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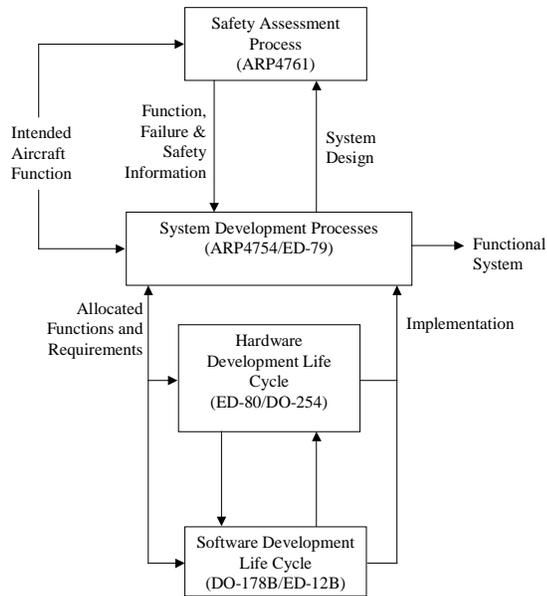
Section 8 – Approvals and Authorizations

Three Levels of Approval



61

Section 9 – Safety Assessment Guidance



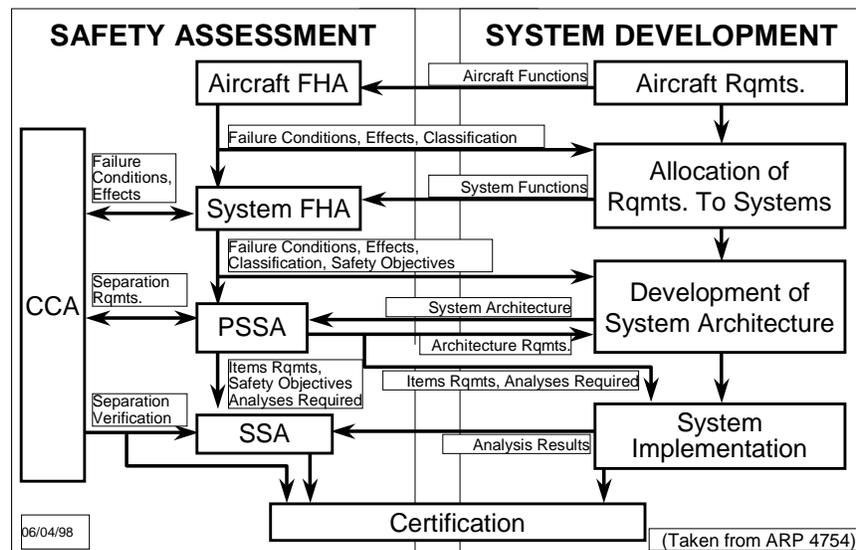
62

Safety Assessment Process (Section 9.b)

- Functional Hazard Assessment (FHA)
- Preliminary System Safety Assessment (PSSA)
- System Safety Assessment (SSA)
- Common Cause Analysis (CCA)

63

Safety Assessment Process Model



64

PSSA

- ◆ **Establishes safety requirements for each component in the IMA system.**
- ◆ **Establishes isolation features and reliability.**
- ◆ **Considers fail-safe design techniques.**
- ◆ **Considers common-cause failures.**
- ◆ **Addresses zonal analysis and risk assessments per ARP 4761.**
- ◆ **Establishes software levels and hardware design assurance levels.**
- ◆ **Addresses protection mechanisms.**

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SSA Process Flow

- **Generally a bottom-up verification that shows the following safety requirements meet what is delineated in the PSSA process:**
 - **Architectural**
 - **Hardware reliability**
 - **Hardware and software development assurance levels**
 - **Separation/segregation**

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Typical SSA Documentation

- System description
- List of failure conditions
- Classification of failures
- Qualitative and quantitative analysis
- Common-cause analysis results
- Confirmation that hazards are addressed
- Test data to support crew recognition of failure conditions
- Protection assurance
- Software and complex hardware assurance



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Section 10 - Configuration Management

- ◆ a) Many potential configuration management (CM) issues
- ◆ b) Robust automated CM system required:
 - Guarantee proper SW load
 - Identify improper system configuration
 - Annunciate “out of config” or “no dispatch” to crew
 - Means to verify proper SW & HW load
- ◆ e) Verification of correct SW load should not rely on a single action

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Section 10 - Configuration Management (cont)

- ◆ f) Changes to IMA SW or HW:
 - All SW changes to be tracked by automatic CM system
 - Major HW changes to be tracked by automatic CM system



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Section 11 – Electronic ID

- ◆ b) SW P/N must be verifiable through electronic query
- ◆ b) Improper config of SW should annunciate “no dispatch” to crew
- ◆ c) Electronic TSO nameplate meets 21.607 when:
 - P/N is stored in non-volatile memory
 - P/N is verifiable on ground at any geographic location

70

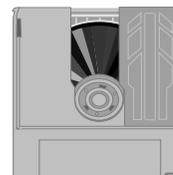
Section 11 – Electronic ID (cont)

- ❖ f) All HW elements that support a functional TSO must have a physical nameplate (either C153 or functional TSO)
- ❖ h) Separate process to record IMA configuration is required

71

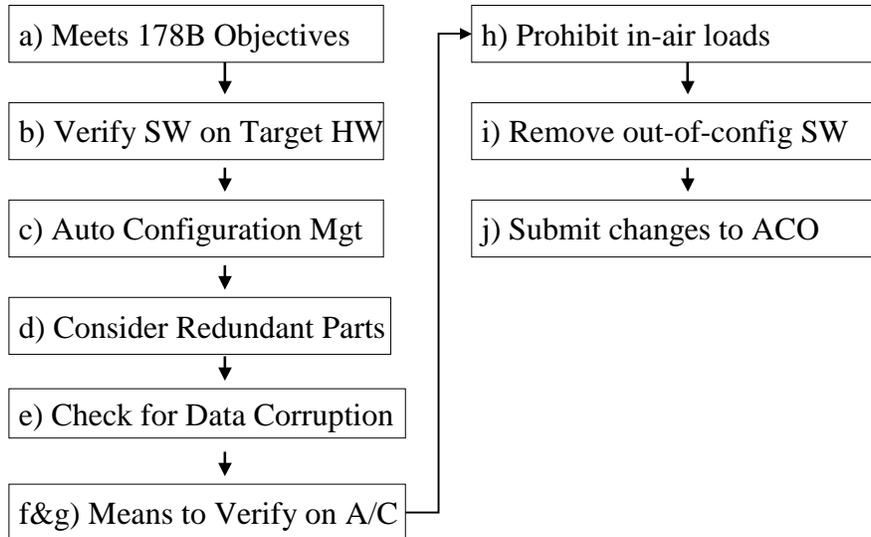
Section 12 - Software

- ❖ a & b. Use DO-178B for software assurance (or an equivalent alternate)
- ❖ c. Field-Loadable Software (FLS)
 - Based on Notice 8110.77 & 8110.95
- ❖ d. Partitioning and Protection
 - Based on CAST paper and DO-248B discussion paper
- ❖ e. Software reuse
 - Based on Notice 8110.97



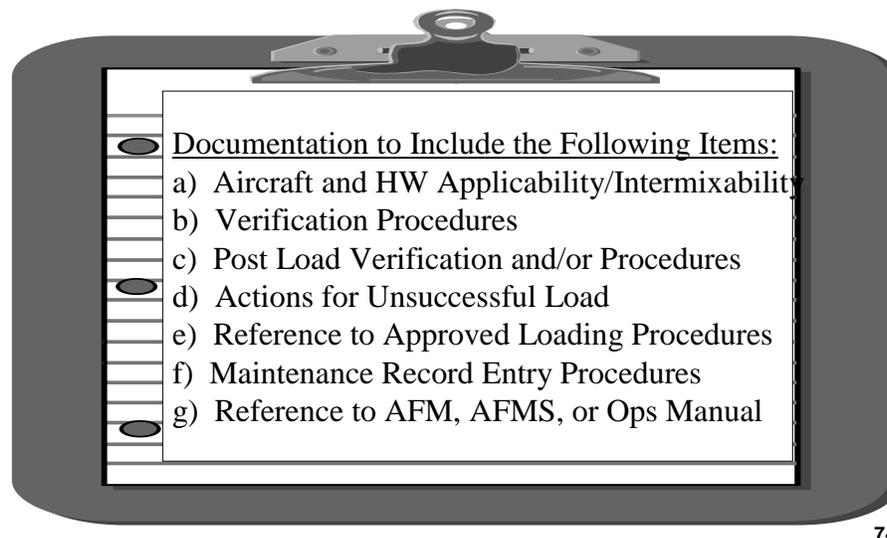
72

Section 12.c(1) – FLS Development



73

Section 12.c(2) – FLS Installation Documents



74

Section 12.d – Partitioning & Protection

- ◆ DO-178B and partitioning/protection
 - 2.3.1 “. . . a technique for providing isolation between functionally independent software components.”
 - 2.3.1 “. . . a technique . . . to contain and/or isolate faults.”
 - 2.3.1 “. . . a technique . . . to . . . potentially reduce the effort of the software verification process . . .”

75

Section 12.d – Partitioning & Protection (cont)

- ◆ DO-178B and partitioning/protection (cont)
 - Glossary—“The process of separating, usually with the express purpose of isolating one or more attributes of the software to prevent specific interactions and cross-coupling interference.”
 - A-4, Objective 13 (ref 6.3.3f)
 - Explicitly mentions partitioning in Annex A
 - Review/analyze SW architecture for prevention/isolation of partitioning breaches
 - A-6, Objective 1-5 (ref 6.4.3a)
 - Indirect link to partitioning in Annex A
 - Test to reveal any violations of SW partitioning

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DO-178B and Partitioning/Protection (cont)

- ❖ **Glossary—“The process of separating, usually with the express purpose of isolating one or more attributes of the software to prevent specific interactions and cross-coupling interference.”**
- ❖ **A-4, Objective 13 (ref 6.3.3f)**
 - **Explicitly mentions partitioning in Annex A**
 - **Review/analyze SW architecture for prevention/isolation of partitioning breaches**
- ❖ **A-6, Objective 1-5 (ref 6.4.3a)**
 - **Indirect link to partitioning in Annex A**
 - **Test to reveal any violations of SW partitioning**

77

Why do we need partitioning?

- ❖ **Increasing interactions in the integrated avionics architecture**
- ❖ **Fault containment is the main objective of partitioning**
- ❖ **The goal is to control the hazards created when a function shares resources with other functions**
- ❖ **Protection from loss of function is addressed by redundancy**

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Partitioning Characteristics

- ❖ **Partitioning in space and time is required in modern integrated architecture**
- ❖ **Partitioning could allow the software to be divided into components of different criticality levels**
- ❖ **Partitioning reduces/eliminates impact of fault in one partition on functionality and performance of another partition**
- ❖ **With no partitioning the highest criticality level must extend to the entire system**

79

Partitioning and Criticality

- ❖ **For varying levels of criticality, partitioning may reduce the certification effort**
- ❖ **One of the main concerns is when data is sent from a partition of lower criticality to a partition of higher criticality**
- ❖ **Shared resources introduce new paths and potential propagation of unintended effects**
- ❖ **Partitioning is sometimes advised, even for the same criticality level**

80

Section 12.d – Partitioning and Protection Issues

Time	Space
<ul style="list-style-type: none">• Interrupts• Loops• Real-time correspondence• Control flow defects• Memory and I/O contention• Data flags• Software traps	<ul style="list-style-type: none">• Loss of I/O data• Corruption of I/O data• Corruption of internal data• Delayed data• Program overlays• Buffer sequence• Control flow defects• External drive interaction



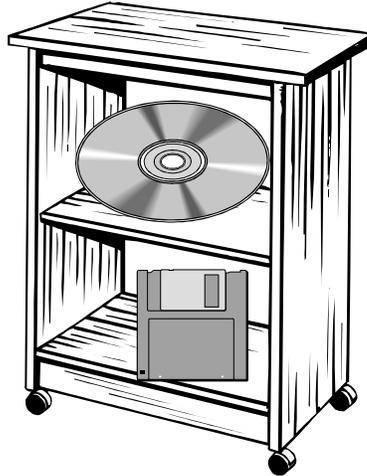
81

Partitioning/Protection Strategies

- ◆ Reasonableness checks (pre/post condition)
- ◆ Dissimilar source comparison (2-way)
- ◆ Watchdogs (reset, alternative logic trigger)
- ◆ Partitioning (physical, logical)
- ◆ Message authentication (cyclic redundancy checks)
- ◆ Wrappers (preventing invocation of unwanted feature)

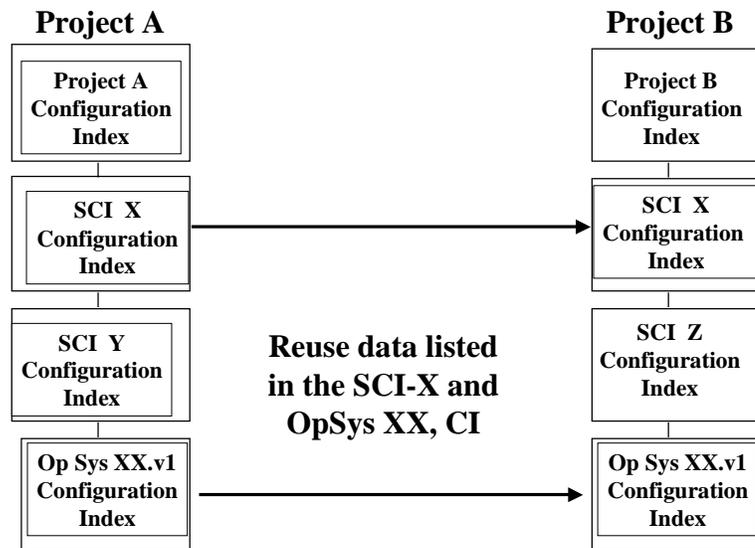
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Section 12.e – Software Reuse



83

Conceptual Framework



84

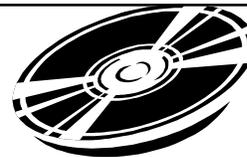
Reuse Guidelines



- ❖ Data to be reused is unchanged.
- ❖ The software level is equivalent to (or less than) software level of the previous approval.
- ❖ Range & data type of inputs are equivalent to previous approval.
- ❖ Configuration items are used on the same target environment and in same operational way.

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Reuse Guidelines (cont)

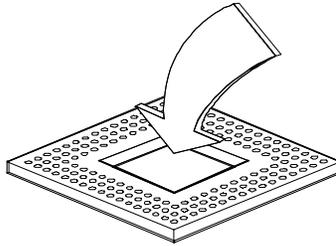


- ❖ Equivalent software/hardware integration and system testing conducted on same target and system as previous approval.
- ❖ Applicant addressed safety considerations.
- ❖ Open problem reports and in-service problems have been analyzed for affect on safety.
- ❖ Reuse rationale is documented in “Additional Considerations” portion of the PSAC.

86

Section 13 – Electronic Hardware Guidance

- ❖ Invokes RTCA/DO-254 (or other acceptable means of compliance) for electronic devices whose functions cannot feasibly be evaluated by test and/or analysis.



87

Section 14 - IMA Design Guidance

- ❖ a. Electrical power
- ❖ b. Recovery features
- ❖ c. Built-in-test
- ❖ d. Maintenance diagnostics
- ❖ e. Failure detection and annunciation
- ❖ f. Functional partitioning
- ❖ g. Functional isolation
- ❖ h. Intentional transmitters
- ❖ i. Alerts and aural warnings

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Section 15 – Environmental Qualification Guidance

- ❖ Some credit from TSO-C153 may be carried over to the installation approval
 - See Figure 15-1 in the AC
- ❖ Environmental qual tests excluded from TSO-C153 must be performed as part of functional TSO or installation certification.



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Section 16 – Human Factors & Flight Crew Interface Guidance

Section 16.c – Numerous H.F. Issues in IMA Systems

Electronic Checklists



Cursor-Based Controls

Accessibility of Functions

90

Section 16 – Human Factors & Flight Crew Interface Guidance (cont)

- ❖ **Cursor-base controls pose several human factors issues:**
 1. **Numerous functions**
 2. **Performance in motion**
 3. **Control labeling**
 4. **Failures of cursor-based controls**
 5. **Replacement of discrete control panels**

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Section 16 – Human Factors & Flight Crew Interface Guidance (cont)

- ❖ **Section 16.d addresses testing aspects for human factors evaluation**
- ❖ **Section 16.e provides guidance for complying with the control regulations, with a focus on human factors**

92

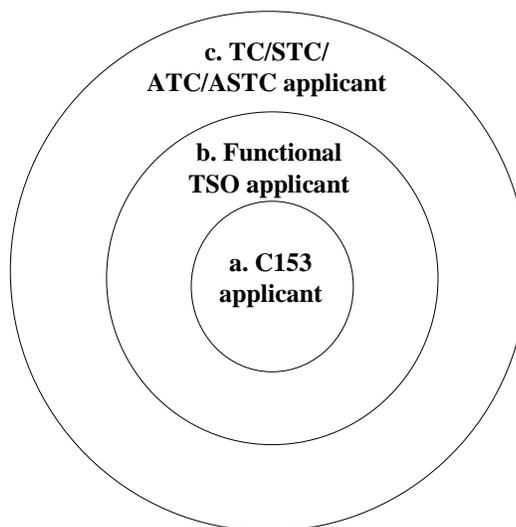
Section 17 - Testing Practices

- ◆ Focuses on IMA-unique aspects of testing
- ◆ a. IMA Hardware Element Testing
- ◆ b. Individual System Testing
- ◆ c. IMA System Integration Testing
- ◆ d. Aircraft Ground Testing
- ◆ e. Aircraft Flight Testing
- ◆ f. Configuration Control During Flight Testing



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Section 18 - Roles & Responsibilities



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Section 18 - Roles & Responsibilities (cont)

- ❖ **C153 Applicant**
 - Develop MPS (using Appendix 1 of TSO-C153)
 - Show compliance to MPS
- ❖ **Functional TSO Applicant**
 - Design system to comply with applicable TSOs
 - Address integration issues
 - Test to meet functional TSO

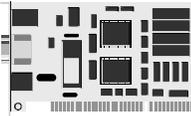


Section 18 - Roles & Responsibilities (cont)

- ❖ **TC/STC/ATC/ASTC applicant**
 - Bulk of AC is their responsibility
 - Sections 9-17 & 19-20
 - TC/STC/ATC/ASTC applicant is responsible for pulling it all together

Section 19 – Guidance for Third Party Manufacturers

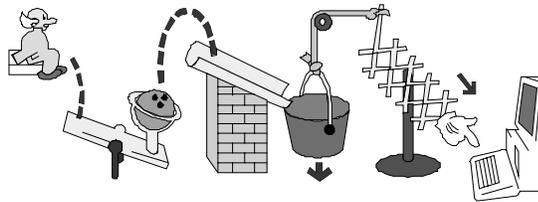
- ❖ Third party modules are those installed in C153 authorized rack/cabinet that are developed by a different manufacturer than the rack/cabinet
- ❖ Third party modules must meet environmental, interoperability, configuration management, & regulatory requirements
- ❖ Third party modules must participate in automatic configuration management system
- ❖ Data sheets should be provided for all third party modules



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Section 20 – Airworthiness Considerations

- ❖ Addresses Change Impact Analysis
 - Based on Notice 8110.85 concept
- ❖ Limits Usage of FAA Form 337 for IMA systems



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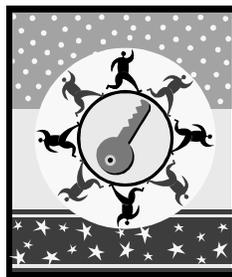
Section 21 – Maintenance & Continued Airworthiness



- Maintenance instructions to address handling, storage, shipping, & installation of hardware elements.
- MMEL should be developed and justified by applicant.

99

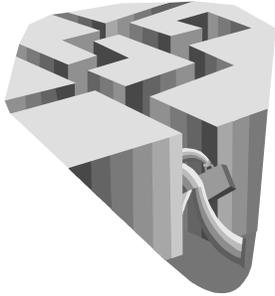
Keys For IMA System Approval



Some Helpful Hints For ACO Engineers

100

1. Understand the “big picture”



- ❖ Work with all stakeholders to get a thorough understanding of the system being proposed.
- ❖ Participate in familiarization meetings.
- ❖ View mock-ups and system benches to get an understanding of the system.

101

2. Coordinate with appropriate certification authorities

- ❖ There may be a number of different certification authorities involved in an IMA system approval. E.g.,
 - International cert authorities
 - Different ACOs that handle TSOs and certifications
- ❖ Identify the roles and responsibilities of each cert authority and applicant as early in the program as possible.

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3. Identify issues early

- ❖ **Identify issues as early as possible.**
- ❖ **Document those issues via issue papers or other appropriate means.**
- ❖ **Work with certification authorities to get a unified cert position, as soon as possible.**
- ❖ **Coordinate the applicant's response and solution to the issues at hand.**

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4. Ensure that the applicant(s) follows the IMA AC

- ❖ **When applicants are using TSO-C153 hardware elements in their IMA systems, the guidance of this AC should be followed.**
- ❖ **If the applicant opts to follow another means of compliance than the AC, work with the appropriate FAA experts to ensure compliance.**

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5. Identify areas where additional guidance is needed

- ❖ As you work with the IMA systems, you will likely find areas where the AC and/or TSO are unclear.
- ❖ Coordinate uncertainties with FAA HQ and other IMA team members.
- ❖ Issue papers or revisions to the AC may be needed to address the problematic area.



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6. Consider all levels of certification

- ❖ Make sure that all levels of certification are addressed:
 - TSO-C153 Authorizations
 - Functional TSO Authorizations
 - TC/STC/ATC/ASTC Installations
- ❖ Ensure that the interfaces and integration between these levels are thoroughly handled.



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7. Involve specialists as needed

- ❖ The IMA AC involves a number of specialized technical areas.
- ❖ Involve the directorate specialists, headquarters specialists, and national resource specialists, as needed.



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**Hot Topics &
Lessons Learned**

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Hot Topics



- ❖ **Functional TSOs**
- ❖ **Robust Automatic Configuration Management**
- ❖ **Who's Doing What**
- ❖ **Third Party Modules**
- ❖ **Partitioning/Protection**
- ❖ **Multiple Developers**
- ❖ **Multiple Certification Authorities**

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Lessons Learned



**Let's Hear From
Other IMA Team
Members**

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RTCA Special Committee #200 (SC-200)

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SC-200 Status

- ◆ **3/02 - SC-200 Approved by RTCA**
- ◆ **5/02 - First SC-200 Meeting**
- ◆ **8/02 - Became joint with EUROCAE Working Group #60 (WG-60)**
- ◆ **3/04 – Goal for Draft Guidance Document**
- ◆ **10/04 – Goal for Final Guidance Document**

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SC-200 Terms of Reference

- ◆ **Propose and document means to support the certification (or approval) of modular avionics, systems integration, and hosted applications, including considerations for installation and continued airworthiness in all categories and classes of aircraft.**
- ◆ **Define and document the key characteristics of modular avionics.**
- ◆ **Identify specific modular avionics issues in current regulatory materials and industry practices, and make recommendations to the document sponsor.**
- ◆ **Propose and document means for the stand-alone approval of modular avionics separate from the applications.**

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SC-200 Terms of Reference (cont)

- ◆ **Propose and document means for transfer and reuse of an accepted process, data, product, demonstration, or qualification.**
- ◆ **Create guidance to address the following safety and performance issues (at a minimum):**
 - **Partitioning & Resource Management**
 - **Fault Management & Health Monitoring**
 - **Safety & Security**
 - **Flight Operations & Maintenance**
 - **Environmental Qualification**
 - **Configuration Management**
 - **Design/Development Assurance**
- ◆ **Coordinate with cert authorities and other industry groups.**

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Summary

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Summary

- ◆ There is a lot going on related to IMA
- ◆ The TSO-C153 and IMA AC are intended to address the hardware element approach to IMA
- ◆ Additional activities are underway to expand upon the hardware element approach
- ◆ Connie Beane is the FAA point of contact for Epic systems:
 - Connie.Beane@faa.gov
- ◆ John Lewis is the point of contact for TSO-C153 and IMA AC questions.
 - John.Lewis@faa.gov

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TSO-C153, INTEGRATED MODULAR AVIONICS HARDWARE ELEMENTS

Appendix B



Department of Transportation
Federal Aviation Administration
Aircraft Certification Service
Washington, DC

TSO-C153

Effective
Date: 5/6/02

Technical Standard Order

**Subject: TSO-C153, INTEGRATED MODULAR AVIONICS HARDWARE
ELEMENTS**

1. PURPOSE. This Technical Standard Order (TSO) prescribes the minimum performance standards (MPS) criteria that an Integrated Modular Avionics (IMA) hardware element must meet to be identified with the applicable TSO markings.

2. APPLICABILITY.

a. This TSO is effective for new applications submitted after the effective date of this TSO. The standards of this TSO apply to the following hardware elements:

- (1) Hardware modules, and
- (2) Cabinets or racks that host hardware modules.

b. The hardware elements manufactured to comply with this TSO may be used to support functional TSOs (such as, a Global Positioning System, TSO-C129a) or systems approved under Title 14 of the Code of Federal Regulations (14 CFR) parts 21, 23, 25, 27, 29, 33 or 35 (for example, a braking system approved as part of a type certificate). Functional TSO authorizations and aircraft-level approvals are not covered by this TSO.

c. Appendix 3 provides a summary of the terminology applicable to hardware elements.

3. REQUIREMENTS. Hardware elements identified and manufactured on or after the effective date of this TSO must meet the MPS for hardware elements. Appendix 1 of this document provides the criteria for developing these MPS.

a. Functionality. This TSO applies to equipment intended to meet MPS developed to the criteria of Appendix 1. This TSO does not specify the aircraft functions that the system is intended to perform. It does, however, provide environmental qualification testing requirements for hardware that supports the generic capability to receive, process, and output data. Elements that the Federal Aviation Administration (FAA) authorizes under this TSO may also meet the functional requirements of other TSOs when loaded with the appropriate software applications. The combination of hardware and software would then be granted additional functional TSO authorizations by the FAA for all applicable TSOs. Functions performed by the equipment or systems without TSO authorization must be evaluated and approved by the FAA as part of the aircraft installation.

b. Functional Limitations.

(1) Equipment used to generate radio frequency signals for intentional transmitters is not covered by this TSO.

(2) Software functionality under this TSO is limited to software that enables electronic part marking and/or future loading of functional software.

c. Failure Condition Classification. The failure condition classification(s) will depend on the implemented functions and their intended use in a specific aircraft environment. This classification is beyond the scope of this TSO and must be determined by the safety assessment conducted as part of the installation approval. The manufacturer must state the hardware design assurance and software levels to which each hardware element was developed. Any assumptions about the aircraft installation, interfacing software and hardware, or operation required to maintain the hardware design assurance and software levels should also be stated and included in the installation limitations or instructions.

d. Functional Qualification. The manufacturer must define MPS for each hardware element. The functional qualification configuration must be specified in the MPS per Appendix 1, Section 5. The required performance of each hardware element must comply with the manufacturer's MPS developed per the Appendix 1 criteria.

Note: If software that enables software loading and/or electronic part marking capability is being approved under this TSO, then that software functionality must be validated by the FAA during installation approval of the IMA system.

e. Environmental Qualification. The manufacturer must test equipment per the conditions specified in Section 6 of Appendix 1. This section refers to RTCA/DO-160D, *Environment Conditions and Test Procedures for Airborne Equipment*, dated July 29, 1997 (Change 2, dated June 12, 2001).

f. Software Design Assurance. Hardware elements may include software to enable software loading and/or electronic part marking. The FAA will approve only this kind of software under this TSO. If such software is included, it must be developed in accordance with RTCA/DO-178B, *Software Considerations in Airborne Systems and Equipment Certification*, dated December 1, 1992, to the software level determined by the hardware element manufacturer.

g. Hardware Design Assurance. If the hardware element contains electronic devices whose functions cannot be feasibly evaluated by test and/or analysis, the electronic devices must comply with RTCA/DO-254, *Design Assurance Guidance for Airborne Electronic Hardware*, dated April 19, 2000, to the design assurance level determined by the hardware element manufacturer.

h. Configuration Management. Manufacturers must include design features in each hardware element that support a robust automatic configuration management function. This functionality may not be fully operational until actual installation. The manufacturer must be able to show that, by either mechanical means or automatic electronic monitoring of the integrated assemblies, the higher-level assemblies will only be assembled according to the

intended design or that incorrect assembly can be detected at power-up. Furthermore, for individual hardware elements that require interfaces to other system equipment through a mechanical or electrical connector(s), the manufacturer must be able to show that each element, by either mechanical means or automatic electronic monitoring of the higher level assembly, will either prevent an incorrect connection or that an incorrect connection will be detected before any dispatch. The manufacturer must consider failure of the configuration management design features in the safety assessment performed on the installed IMA system in each unique aircraft configuration.

i. Quality Control. To comply with the standards of this TSO for a hardware element, the manufacturer must be able to provide the quality control data items and meet the requirements of 14 CFR § 21.143. Additionally, each hardware element manufactured must conform to the approved type design.

j. Deviations. The FAA has provisions for alternative or equivalent means of compliance to the criteria in this TSO. Manufacturers invoking these provisions must demonstrate that they maintain an equivalent level of safety and must apply for a deviation per 14 CFR § 21.609.

4. MARKING. The information specified in 14 CFR § 21.607(d) shall be legibly and permanently marked on each hardware element manufactured under this TSO. Additionally:

a. To support maintenance, the hardware element's part number may also be marked in multiple places on the element.

b. Each separate hardware element that is manufactured under this TSO may also support a means by which the required information can be determined using an external means (for example, an electronic display).

c. Each hardware element approved under this TSO may contain software to enable electronic part marking and/or future loading of functional software.

d. If the hardware element includes software (that is, software to enable loading and/or electronic part marking), separate part numbers may be utilized for hardware and software.

e. Each part number must uniquely identify the configuration (including modification status).

f. Each rack or cabinet approved under this TSO must be marked with a note "TSO authorization for rack only" or "TSO authorization for cabinet only". This note should be on the TSO nameplate or in close proximity to the nameplate.

5. APPLICATION DATA REQUIREMENTS. Under 14 CFR § 21.605(a)(2), a manufacturer must furnish the manager of the Aircraft Certification Office (ACO) responsible for the manufacturer's facilities, one copy of each of the following technical data to support FAA design and production approval:

a. Operating instructions and equipment limitations, including description of the robust automatic configuration management design features.

b. Installation procedures and limitations. The limitations must ensure that the hardware element, when installed according to the installation procedures, continues to meet the requirements of this TSO.

(1) The limitations must also identify any unique aspects of the installation and must include the following note: “The conditions and tests required for TSO authorization of this hardware element are minimum performance standards. Those installing this hardware element either on or within a specific type or class of aircraft are responsible for determining that the installation conditions are within the TSO standards. This hardware element may be installed only if evaluation by the applicant (i.e., the user/installer) documents an acceptable installation per Title 14 of the Code of Federal Regulations part 43 (or the applicable airworthiness requirements) and is approved by the FAA Administrator.”

(2) If software to enable future software loading and/or electronic part marking is included in the hardware element, the software level applied under this TSO must be commensurate with the installation safety assessment and documented in the installation procedures and limitations.

- c.** Schematic drawings, applicable to the installation procedures.
- d.** Wiring diagrams, applicable to the installation procedures.
- e.** List of the components (by part number) that make up the hardware element complying with this TSO.
- f.** Instructions, in the form of a Component Maintenance Manual (CMM). These instructions contain information on the periodic maintenance, calibration, and repair to support the continued airworthiness of installed hardware elements, including recommended inspection intervals and service life. These instructions for continued airworthiness must be in accordance with 14 CFR § 21.50.
- g.** Material and process specifications list.
- h.** An environmental qualifications form as described in RTCA/DO-160D (Change 2) for each hardware element.
- i.** The manufacturer’s data sheet described in section 8 of this TSO.
- j.** The MPS for each hardware element. (See Appendix 1 for MPS development criteria.)
- k.** Manufacturer's TSO qualification test report.
- l.** Nameplate drawing providing the information required by section 4 of this TSO.
- m.** A list of all the drawings and processes, including revision level, necessary to define the hardware element's design.

n. The quality control system description required by 14 CFR § 21.605(a)(3) and § 21.143(a). This should include functional test specifications used on each production hardware element to ensure compliance with the MPS.

o. A Plan for Software Aspects of Certification (PSAC), Software Configuration Index, and Software Accomplishment Summary (if the hardware element includes software).

NOTE: The FAA recommends submittal of the PSAC early in the software development process.

p. A Plan for Hardware Aspects of Certification (PHAC), Hardware Configuration Index, and Hardware Accomplishment Summary (if the hardware element includes electronic devices whose functionality cannot be feasibly evaluated by test and/or analysis).

NOTE: The FAA recommends submittal of the PHAC early in the electronic device development process.

q. Instructions for viewing TSO-related electronic part identification.

6. MANUFACTURER DATA REQUIREMENTS. In addition to the above application data, each manufacturer must have available for review by the responsible ACO manager, the following technical data:

a. The detailed hardware element specification and functional test specification for each hardware element used to qualify each production element.

b. Equipment calibration procedures.

c. Corrective maintenance procedures.

d. Schematic drawings.

e. Material and process specifications.

f. The results of the environmental qualification tests conducted per RTCA/DO-160D (Change 2).

g. All data supporting the applicable objectives found in Annex A of RTCA/DO-178B (if the hardware element includes software).

h. The appropriate documentation, as defined in RTCA/DO-254, for the hardware design assurance level (if the hardware element contains electronic device(s) whose functions cannot be feasibly evaluated by test and/or analysis).

7. FURNISHED DATA. One copy of the data and information specified in sections 5.a through 5.i of this TSO must be provided to each purchaser of one or more hardware elements manufactured under this TSO. Any other data or information necessary for proper installation, certification, use, and/or continued airworthiness of the hardware element(s) must also be provided to each purchaser.

8. MANUFACTURER'S DATA SHEET. The TSO manufacturer must submit a data sheet to the FAA and to each purchaser of the hardware element manufactured under this TSO. This data sheet summarizes and communicates the hardware element design details to the FAA and the purchaser. The FAA will attach the data sheet to the TSO authorization letter upon approval. Appendix 2 of this TSO contains a sample data sheet format with the essential information to include. A manufacturer can submit data in a different format, but it must contain all of the information listed in Appendix 2. If a particular portion of the data sheet does not apply, mark it "Not Applicable."

9. AVAILABILITY OF REFERENCED DOCUMENTS.

a. Copies of RTCA/DO-160D (change 2), RTCA/DO-178B, and RTCA/DO-254 may be purchased from the RTCA Inc., 1828 L Street, N.W., Suite 807, Washington, DC 20036.

b. Title 14 of the Code of Federal Regulations, Part 21, may be purchased from the Superintendent of Documents, Government Printing Office, Washington, DC 20402-9325.

c. Advisory Circular 20-110, Index of Aviation Technical Standard Orders, may be obtained from the U.S. Department of Transportation, General Services Section, M-443.2, Washington, DC 20591.

d. Aviation Recommended Practice number ARP 4754 may be obtained from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, PA 15096-0001.

Kimberly K. Smith
Acting Manager, Aircraft Engineering Division
Aircraft Certification Service

APPENDIX 1

FEDERAL AVIATION ADMINISTRATION
DEVELOPMENT CRITERIA FOR
INTEGRATED MODULAR AVIONICS HARDWARE ELEMENT
MINIMUM PERFORMANCE STANDARDS

1. **APPENDIX LAYOUT.** This appendix is organized as follows:

a. **Sections 2 and 3** provide an introduction and overview of the hardware element minimum performance standards (MPS) criteria.

b. **Sections 4 through 7** provide guidance for developing the MPS and test conditions for hardware elements.

c. **Sections 8 and 9** address installation and operational performance aspects that should be considered when developing the MPS.

2. **INTRODUCTION.**

a. This appendix sets forth the criteria that a manufacturer must address in the MPS for an Integrated Modular Avionics (IMA) hardware element intended to receive Technical Standard Order (TSO)-C153 authorization. The appendix addresses the relevant characteristics of hardware performance that a manufacturer must consider and specify in the MPS and summarize in the data sheet (reference section 8 of this TSO).

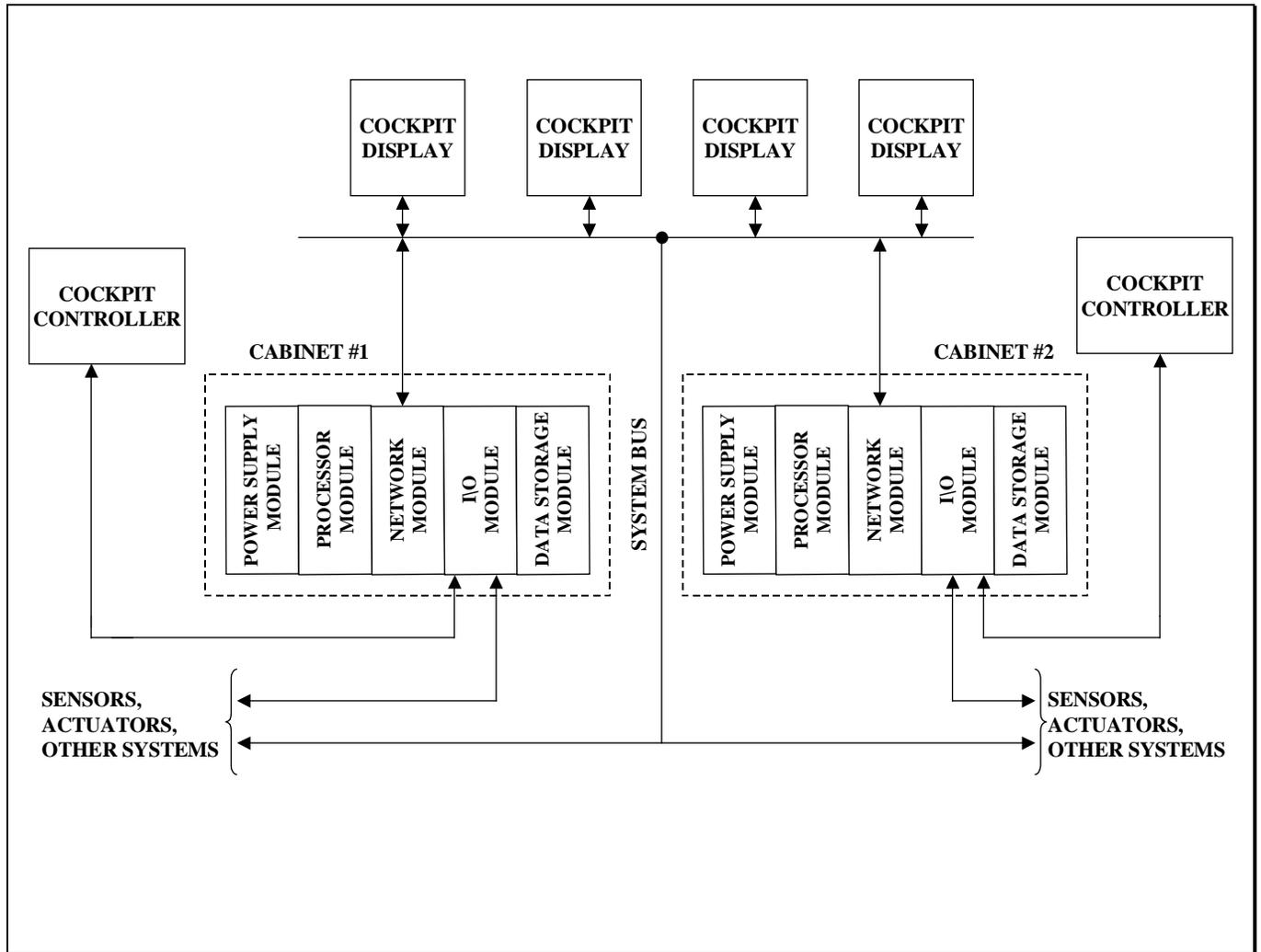
b. For this TSO, hardware elements include the following:

(1) **Modules** which may (or may not) contain software to enable electronic part marking and/or future loading of functional software. These modules will not function until they are installed in specific cabinets or racks. Module types may include data processing modules, power supply modules, communication and data bus modules, or others.

(2) **Cabinets or Racks** for hosting IMA modules. These cabinets or racks may be simple mechanical enclosures, or they may incorporate active cooling elements, power supplies, communication interfaces, backplanes for data and power, or any combination of these features.

c. Historically, avionics systems consisted of dedicated Line Replaceable Units (LRUs) which performed specific functions such as autoflight, flight management, and flight deck display. The Federal Aviation Administration (FAA) has traditionally written TSOs for these LRUs and their functions. Advancements in digital technology have caused a trend toward higher levels of integration. Software now determines functionality, while the hardware has become a platform for input, output, data storage, and software execution. Since these basic attributes tend to be similar for various applications, the manufacturer can gain efficiencies by using various types of generic airborne hardware elements to execute these functions. Figure 1 shows an example block diagram of an integrated avionics system. Depending upon the requirements of the system application, the types and number of hardware elements chosen and the number of each element type may differ. Figure 1 illustrates an example where the racks or cabinets are populated with modules of various types. Typical module types are processor, power supply, database, and input/output modules. In addition to the racks or cabinets, a complete system may consist of various controllers, displays, and sensors. Any combination of analog signals, dedicated communications busses, or system-level bi-directional communication databuses can provide IMA system communications. Manufacturers may distribute functionality among the modules of one or more racks or cabinets and other equipment.

Figure 1. Example IMA System With Hardware Elements



d. The specific system application function(s) hosted in each hardware element may not be determined or operational until after the manufacturer delivers it, and the user integrates the hardware and software. As a result, the descriptions of aircraft-level functions, their failure condition classifications, and the effects of their loss or malfunction will not be included in the hardware element MPS. Instead, those functions, classifications, and integration will be addressed by pertinent regulations, TSOs, Minimum Operational Performance Specifications (MOPS), and Advisory Circulars. However, the manufacturer's MPS must state the hardware design assurance and software levels to which each element is developed. The manufacturer must also include in the MPS and data sheet any interfacing hardware and software constraints needed to preserve the stated hardware design assurance and software levels.

e. Hardware elements may include software to enable software loading and/or electronic part marking. Only this kind of software may be approved under this TSO. If such software is included, it must be developed per RTCA/DO-178B, *Software Considerations in Airborne*

Systems and Equipment Certification, dated December 1, 1992, to the software level determined by the hardware element manufacturer.

3. **MPS OVERVIEW.** The MPS developed for each hardware element must address:

a. **Intended Function.** The manufacturer must specify the intended function of the hardware element in terms of relevant performance requirements over the applicable environments.

b. **Assumptions.**

(1) Each hardware element by itself may not be capable of performing any function on an aircraft. Aircraft functionality is not realized until multiple hardware elements are integrated and functional software is loaded. Individual hardware elements are intended to be manufactured and shipped separately with only enough software resident to facilitate software loading of the functional software application(s) and/or electronic part marking.

(2) The individual hardware elements should be tested and qualified independent of aircraft functionality. Each element will require its own test procedure to verify that the element performs its intended function over the various environmental conditions. Assurance that the hardware element correctly executes the functional software is not addressed in this TSO, but must be addressed during the type certificate (TC), supplement type certificate (STC), amended TC (ATC), or amended STC (ASTC) process, or when obtaining functional TSO authorization.

c. **Test Procedures.**

(1) **Hardware Element Performance Tests.** The hardware element manufacturer must develop a test procedure to demonstrate compliance of each applicable hardware element to its MPS, as specified in Section 5 of this Appendix. This test procedure can be performed in a laboratory environment to demonstrate that the hardware element meets the MPS.

(2) **Environment Tests.** The hardware element manufacturer must develop test procedures to demonstrate compliance of each hardware element to its MPS during each of the applicable environments specified in Section 6 of this Appendix. Several test procedures may be required for different environmental tests. The hardware element manufacturer's equipment specification or test report must detail the test procedures used in environmental testing and must also provide rationale that any use of abbreviated functional tests provides adequate coverage of the performance requirements over the specified operational range.

(3) **Installed Hardware Element Tests.** The hardware element manufacturer may develop a test procedure used when the hardware element is installed in the aircraft during ground or flight tests. Since the specific aircraft system function(s) hosted by the hardware element is not covered by this Appendix, refer to the respective MPS and/or MOPS for the functional TSO test requirements and/or to the manufacturer's test requirements for any additional aircraft system functions.

(4) **Operational Tests.** Each hardware element must include design features that support operational tests to determine that it is functioning properly when installed in the aircraft.

4. **GENERAL MPS REQUIREMENTS.** Each hardware element MPS must address the following requirements:

a. **Airworthiness.** The design and manufacture of each hardware element, when integrated with other hardware elements and the functional software for a particular aircraft, must provide a means of installation that does not impair or degrade the airworthiness of the aircraft.

b. **Intended Function.** Each hardware element must perform its intended function, as defined by the manufacturer, when installed in the aircraft or engine.

c. **Federal Communications Commission Rules.** As a matter of information, if applicable, all equipment must separately comply with the applicable rules of the Federal Communication Commission.

d. **Fire Protection.** Except for small parts (such as knobs, fasteners, seals, grommets, and small electrical parts) that would not contribute significantly to the propagation of a fire, all material used must be self-extinguishing.

e. **Effects of Test.** The design of the hardware element and test procedures must be such that the application of the specified test procedures must not result in any discernible condition that would be detrimental to the performance and reliability of the hardware element manufactured in accordance with such design.

f. **Design Assurance.** Each hardware element must be developed to the design assurance level(s) appropriate to the failure condition classifications of its hosted function(s) and the system architecture. An acceptable means for the determination of development assurance levels for systems and design practices can be found in Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 4754, *Certification Considerations for Highly-Integrated or Complex Aircraft Systems*. If the hardware element contains electronic devices whose functions cannot be feasibly evaluated by test and/or analysis, the hardware element must comply with RTCA/DO-254, *Design Assurance Guidance for Airborne Electronic Hardware*. If the hardware element contains software to enable software loading and/or electronic part marking, the software must be developed to the appropriate software level(s) of RTCA/DO-178B, *Software Considerations in Airborne Systems and Equipment Certification*.

Note: The design assurance level(s) chosen by the TSO manufacturer must be compatible with the level(s) assigned to the hardware element software and hardware by the preliminary system safety assessment (PSSA) necessary for the installation of the IMA system.

g. **Unused Cabinet or Rack Positions.** The manufacturer must define the method and parts to be used to provide the appropriate covers or position fillers for unused cabinet or rack positions. If required, these parts must be approved as part of the cabinet or rack TSO authorization.

5. EQUIPMENT PERFORMANCE – STANDARD CONDITIONS.

a. Hardware element performance requirements shall be specified by the manufacturer in the MPS. However, aircraft functionality is typically not realized until multiple hardware elements are integrated, functional software is loaded, and system integration is accomplished. Additional performance at the aircraft level must also be specified and verified during an aircraft certification program. It is at this higher level that TSO specifications will be evaluated for compliance. Since this level of performance specification is beyond the scope of this TSO, it is mentioned here only for completeness. The hardware element manufacturer must prepare MPS for each type of hardware element to which this TSO is being applied. The contents of each MPS must include all minimum performance requirements for the hardware element. The requirements must be stated in measurable terms. Tolerances must be included in the MPS (where applicable), thereby enabling better test procedure development.

b. Equipment Configuration for Equipment Performance Tests.

(1) The test configuration for cabinet or rack performance tests must include, as a minimum, the cabinet or rack with all integrated cooling and power supplies, the appropriate power supply modules (if not integrated into the cabinet or rack), the appropriate processing module(s), and the appropriate data communication modules (if not integrated into the cabinet or rack). The test configuration for a module must include, as a minimum, a cabinet or rack that is designed for this module, appropriate power supply modules (if required by the module to function), and appropriate data communication and processing modules (if required by the module to function). All unused module positions in the cabinet or rack must have the appropriate covers or position fillers installed.

(2) The cabinet or rack and module configurations must include the appropriate interfacing electrical and mechanical connectors intended for the cabinet or rack and modules.

(3) If the hardware elements that are manufactured under this TSO can be loaded with software to perform aircraft functions, the manufacturer should use special purpose test software or functional software to demonstrate operation of the hardware element functions. The manufacturer must verify, validate, and control the configuration of the software to ensure the validity of the testing.

c. Equipment Performance Requirements. As a minimum, the MPS must address the appropriate hardware characteristics selected from the items in Table 1 below. The functional composition of any specific hardware element will dictate the items to be addressed and the actual content of the hardware element MPS.

Table 1. Hardware Characteristics by Performance Category

Equipment Performance Category	Characteristics
General Information For Each Element	<ul style="list-style-type: none"> • Backplane Interface. • Power Requirements. • Power Dissipation. • Thermal Requirements. • Cooling Requirements. • Size and Weight. • Input and Output (I/O) Connectors. • Mating Connectors. • Form and Fit. • Mechanical Interface.
Analog Input Specifications For Each Analog Input	<ul style="list-style-type: none"> • Range. • Accuracy. • Resolution. • Null and Offset. • Filtering. • Input Impedance. • Analog-to-Digital Conversion Speed. • Digital-to-Analog Conversion Speed. • Steady State Voltage Rating. • Transient Voltage Rating. • Circuit Protection Techniques. • Multiplexing.
Analog Output Specifications For Each Analog Output	<ul style="list-style-type: none"> • Range. • Accuracy. • Null. • Linearity. • Current Capacity. • Output Impedance. • Analog/Digital Conversion Speed. • Steady State Voltage Rating. • Transient Voltage Rating. • Circuit Protection Techniques. • Multiplexing.
Discrete Input Specifications For Each Discrete Input	<ul style="list-style-type: none"> • Trip Point. • Hysteresis. • Filtering. • Input Impedance. • Logic Sense. • Maximum Logic-High Level. • Maximum Logic-Low Level. • Minimum Logic-High Level.

	<ul style="list-style-type: none"> • Minimum Logic-Low Level. • Steady State Voltage Rating. • Transient Voltage Rating. • Circuit Protection Techniques. • Multiplexing.
Discrete Output Specifications For Each Discrete Output	<ul style="list-style-type: none"> • Voltage Levels. • Current Source Capacity. • Current Sink Capacity. • Output Impedance. • Circuit Protection Techniques. • Multiplexing.
Processing Specifications for Processing Hardware	<ul style="list-style-type: none"> • Software Functions Included. • Software/Hardware Interface Mechanisms and Protocol(s). • Integration Requirements. • Limitations of Software. • Central Processing Unit (CPU) Bus(es) and Core Clock Frequencies. • Memory Size(s) and Type(s). • Interrupts. • Reset Structure. • Memory Management, such as cache and MMU. • Monitors. • Backplane Interface. • CPU Type. • CPU Throughput. • Timing Specifications.
Power Supplies	<ul style="list-style-type: none"> • Regulation. • Input Voltage & Current. • Maximum Start-up (In-rush) Current Rating. • Output Current Capacity. • Hold-up Capacity. • Restart. • Transient Immunity. • Voltage Outputs & Tolerances. • Power Monitors & Status Outputs. • Short Circuit Management. • Power Resets and Recovery. • Circuit Protection Techniques.
Digital Communications For Each Input and Output	<ul style="list-style-type: none"> • Data Rates. • Integrity Checks. • Signal Levels. • Current Sink and Source.

	<ul style="list-style-type: none"> • Input Impedance. • Output Impedance. • Signal Rise and Fall Times. • Filtering. • Stub Length Limits. • Input and Output Capacitance. • Isolation. • Maximum Bit Error Rates. • Circuit Protection Techniques. • Resets. • Monitors. • Multiplexing.
Racks or Cabinets	<ul style="list-style-type: none"> • Mounting Mechanism. • Clearance Requirements. • Air Flow Requirements. • Module Mounting Scheme. • Inter-Element Interfaces. • Inter-Element Connections. • Grounding and Shielding Provisions. • Separation and/or Isolation Provisions. • Module Installation and Extraction Means.

6. EQUIPMENT PERFORMANCE – ENVIRONMENTAL CONDITIONS.

a. The hardware element manufacturer must specify applicable environmental test categories found in RTCA/DO-160D (change 2) that are representative of expected conditions which may be encountered by that hardware element in actual installations. The manufacturer must specify the hardware element performance requirements for each applicable test procedure in RTCA/DO-160D (change 2). The manufacturer may elect to specify a different set of pass and/or fail criteria and/or test tolerances at environmental extremes, if appropriate. Once the applicable RTCA/DO-160D (change 2) test conditions and categories have been specified, the hardware element manufacturer must write a qualification test plan by which testing will be conducted. It may be necessary to combine elements during testing to more closely represent actual operating conditions.

b. If a manufacturer desires to qualify an element for multiple categories of an environmental test, then applicable tests must also be performed for each category.

c. It must be the joint responsibility of the hardware element manufacturer and the TC, STC, ATC, or ASTC applicant for aircraft certification to design the installation to be compatible with the environmental envelope for which the equipment is to be certified. It must also be determined that adequate aircraft performance and safety can be ensured as long as the environment remains within that envelope.

d. The manufacturer may use Category X on any environmental test procedure to indicate that compliance with the hardware element MPS has not been demonstrated under the environmental conditions of that section.

e. **Equipment Configuration for Environmental Tests.**

(1) The test configuration for cabinet or rack environmental tests must include, as a minimum, the cabinet or rack with all integrated cooling and power supplies, the appropriate power supply modules (if not integrated into the cabinet or rack), the appropriate processing module(s), and the appropriate data communication modules (if not integrated into the cabinet or rack). The test configuration for a module must include, as a minimum, a cabinet or rack that is designed for this module, appropriate power supply modules (if required by the module to function), and appropriate data communication and processing modules (if required by the module to function). All unused module positions in the cabinet or rack must have the appropriate covers or position fillers installed.

(2) The cabinet or rack and module configurations must include the appropriate interfacing electrical and mechanical connectors, including shielding, backshells, and strain relief, intended for the cabinet or rack and modules. The equipment configuration must include interfacing wires and cables specified by the installation procedures in RTCA/DO-160D (change 2).

(3) If the hardware elements that are manufactured under this TSO can be loaded with software to perform aircraft functions, the manufacturer should use special purpose test software or functional software to demonstrate operation of the hardware element functions. The manufacturer must verify, validate, and control the configuration of the software to ensure the validity of the testing.

f. **Environmental Qualification Testing.** Table 2 below summarizes guidance for environmental qualification testing. The table lists environmental tests, the applicable RTCA/DO-160D (change 2) section, and applicable guidance.

Table 2. Environmental Qualification Testing Guidance

Environmental Test	RTCA/DO-160D Section	Guidance
Temperature	4.5	<ul style="list-style-type: none"> • This testing is not performed as part of this TSO. • Mark the TSO environmental qualification form Category X (not tested) for this section. • Perform these tests as part of a functional TSO application or as part of a type certification program.

Altitude	4.6	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> • The equipment must be subjected to these test conditions. • The manufacturer must define the appropriate minimum performance standard that the equipment will satisfy when subjected to these tests.
Temperature Variation	5.0	<ul style="list-style-type: none"> • This testing is not performed as part of this TSO. • Mark the TSO environmental qualification form Category X (not tested) for this section. • Perform these tests as part of a functional TSO application or as part of a type certification program.
Humidity	6.0	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> • The equipment must be subjected to these test conditions. • The manufacturer must define the appropriate minimum performance standard that the equipment will satisfy when subjected to these tests.
Shock (Operational)	7.0	<ul style="list-style-type: none"> • This testing is not performed as part of this TSO. • Mark the TSO environmental qualification form Category X (not tested) for this section. • Perform these tests as part of a functional TSO application or as part of a type certification program.
Shock (Crash safety)	7.3	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> • The manufacturer must install equivalent weights or actual modules in all module positions. • Since applying crash safety tests may damage equipment under test, this test may be conducted last.
Vibration	8.0	<ul style="list-style-type: none"> • This testing is not performed as part of this TSO. • Mark the TSO environmental qualification form Category X (not tested) for this section. • Perform these tests as part of a functional TSO application or as part of a type certification program.
Explosion	9.0	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> • For Environment 1, the explosion must not propagate outside the equipment. • For Environment 2, the equipment must not detonate the explosive mixture in the test chamber.

Waterproof	10.0	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> • The equipment must be subjected to these test conditions. • The manufacturer must define the appropriate minimum performance standard that the equipment will satisfy when subjected to these tests.
Fluids Susceptibility	11.0	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> • The equipment must be subjected to these test conditions. • The manufacturer must define the appropriate minimum performance standard that the equipment will satisfy when subjected to these tests.
Sand and Dust	12.0	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> • The equipment must be subjected to these test conditions. • The manufacturer must define the appropriate minimum performance standard that the equipment will satisfy when subjected to these tests.
Fungus Resistance	13.0	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> • The equipment must be subjected to these test conditions. • The manufacturer must define the appropriate minimum performance standard that the equipment will satisfy when subjected to these tests.
Salt Spray	14.0	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> • The equipment must be subjected to these test conditions. • The manufacturer must define the appropriate minimum performance standard that the equipment will satisfy when subjected to these tests.
Magnetic Effect	15.0	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> • Equipment must meet requirements of the appropriate instrument or equipment class specified.
Power Input	16.0	<ul style="list-style-type: none"> • This testing is not performed as part of this TSO. • Mark the TSO environmental qualification form Category X (not tested) for this section. • Perform these tests as part of a functional TSO application or as part of a type certification program.

Voltage Spike Conducted	17.0	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> The equipment must be subjected to these test conditions. The manufacturer must define the appropriate minimum performance standard that the equipment will satisfy when subjected to these tests.
Audio Frequency Conducted Susceptibility—Power Input	18.0	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> The equipment must be subjected to these test conditions. The manufacturer must define the appropriate minimum performance standard that the equipment will satisfy when subjected to these tests.
Induced Signal Susceptibility	19.0	<ul style="list-style-type: none"> This testing is not performed as part of this TSO. Mark the TSO environmental qualification form Category X (not tested) for this section. Perform these tests as part of a functional TSO application or as part of a type certification program.
Radio Frequency Susceptibility (Radiated and Conducted)	20.0	<ul style="list-style-type: none"> This testing is not performed as part of this TSO. Mark the TSO environmental qualification form Category X (not tested) for this section. Perform these tests as part of a functional TSO application or as part of a type certification program.
Emission of Radio Frequency Energy	21.0	<ul style="list-style-type: none"> This testing is not performed as part of this TSO. Mark the TSO environmental qualification form Category X (not tested) for this section. Perform these tests as part of a functional TSO application or as part of a type certification program.
Lightning Induced Transient Susceptibility	22.0	<ul style="list-style-type: none"> This testing is not performed as part of this TSO. Mark the TSO environmental qualification form Category X (not tested) for this section. Perform these tests as part of a functional TSO application or as part of a type certification program.
Lightning Direct Effects	23.0	<ul style="list-style-type: none"> This testing is not performed as part of this TSO. Mark the TSO environmental qualification form Category X (not tested) for this section. Perform these tests as part of a functional TSO application or as part of a type certification program.

Icing	24.0	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> • The equipment must be subjected to these test conditions. • The manufacturer must define the appropriate minimum performance standard that the equipment will satisfy when subjected to these tests.
Electro Static Discharge (ESD)	25.0	To mark the TSO environmental qualification form for this section: <ul style="list-style-type: none"> • The equipment must be subjected to these test conditions. • The manufacturer must define the appropriate minimum performance standard that the equipment will satisfy when subjected to these tests.

7. EQUIPMENT TEST PROCEDURES.

a. Detailed Test Procedures. The manufacturer must prepare detailed hardware element functional and environmental test procedures to demonstrate compliance with the MPS.

b. Required Test Equipment. The manufacturer must define the required test equipment in the hardware element functional and environmental test procedures.

c. Definitions of Terms and Conditions of Test. The following are terms and the conditions under which the tests described in this subsection must be conducted.

(1) **Power Input Voltage.** Unless otherwise specified, all tests must be conducted with the power input voltage adjusted to design voltage plus or minus 2%. The input voltage must be measured at the input terminals of the equipment under test.

(2) **Power Input Frequency.**

(a) With equipment designed for operation from an alternating current source of essentially constant frequency (such as 400 hertz), the input frequency must be adjusted to design frequency plus or minus 2%.

(b) With equipment designed for operation from an alternating current source of variable frequency (such as 300 to 1000 hertz), unless otherwise specified, tests must be conducted with the input frequency adjusted to within 5% of a selected frequency and within the range for which the equipment is designed.

(3) **Adjustment of Equipment.** The circuits of the equipment under test must be properly aligned and otherwise adjusted or calibrated per the manufacturer's recommended practices prior to application of the specified tests.

(4) **Test Equipment.** All equipment used in the performance of the tests must be identified by make, model, and serial number (where appropriate), and its latest calibration date.

When appropriate, test equipment calibration standards must be traceable to national and/or international standards.

(5) **Test Instrument Precautions.** Precautions must be taken during the tests to prevent the introduction of errors resulting from the connection of voltmeters, oscilloscopes, and other test instruments across the input and output impedance of the equipment under test.

(6) **Ambient Conditions.** Unless otherwise specified, all tests must be conducted under condition of ambient room temperature, pressure, and humidity. However, the room temperature must not be lower than 10 degrees Celsius.

(7) **Connected Loads.** Unless otherwise specified, all tests must be performed with the equipment connected to loads having the nominal impedance values for which it is designed.

8. INSTALLED EQUIPMENT PERFORMANCE. By nature of the architecture and application of individual hardware elements whose specifications comply with Sections 4 through 7 of this Appendix, these hardware elements typically must be installed and integrated with other equipment in order to provide system-level or aircraft-level functionality. When software is loaded into hardware elements to provide resources for system-level functionality, it is necessary to demonstrate hardware and software integration, integration of the system into the aircraft, and integration of the system with other interfacing aircraft systems. The applicant for the type certificate must demonstrate that hardware elements, as installed in the aircraft, meet the applicable regulations.

9. EQUIPMENT OPERATIONAL PERFORMANCE CHARACTERISTICS. To ensure that operations can be conducted safely and reliably in the expected operational environment, the individual hardware elements typically must be installed and integrated with other equipment in order to provide system-level or aircraft-level functionality. The installed system must annunciate to the flight crew, when any hardware element is not capable of performing its intended functions.

APPENDIX 2

**SAMPLE FORMAT FOR DATA SHEET FOR INTEGRATED MODULAR AVIONICS
(IMA)
HARDWARE ELEMENTS**

Sample Format for Data Sheet for Integrated Modular Avionics (IMA) Hardware Element

If the item does not apply, write "Not Applicable."

TSO Manufacturer Name:	
TSO Manufacturer Address:	
TSO Number:	
Element Description (e.g., I/O module, processing module) and Intended Use(s):	
Element Part Number(s) (include modification status and serial number effectivity):	
Software Level(s):	
Hardware Design Assurance Level(s):	
Environmental Qualification (summarize or attach RTCA/DO-160D (change 2) Environmental Qualification form):	
Backplane Interface:	
Power Requirements:	
Power Dissipation:	
Size and Weight:	
Input/Output Mating Connectors with Backshell Requirements:	
Backplane Mating Connectors:	
Module Mounting and Handling Scheme:	
Inter-Element Interfaces:	
Inter-Element Connections:	
Grounding and Shielding Provisions:	
Separation and/or Isolation Provisions:	

Mounting Mechanism (for rack or cabinet):	
Clearance Requirements (for rack or cabinet):	
Air Flow Requirements (for rack or cabinet):	
Module Extraction Means (for rack or cabinet):	
Special Installation Information: (see Note 1 below)	
Limitations: (see Note 2 below)	
Continued Airworthiness Information: (see Note 3 below)	

Note 1: Include the following kinds of information: (1) software loading instruction document number, (2) required cabinet or rack model number (for modules), (3) grounding/shielding requirements, (4) mounting requirements (including orientation in aircraft), (5) clearance requirements, (6) air flow requirements, (7) sub-assembly installation and mounting requirements (if applicable), (8) separation and isolation provisions, and (9) any other information needed by the installer or integrator.

Note 2: Include any limitations required by the TSO or MPS and additional limitations of which the user must be aware.

Note 3: Include any information for continued airworthiness that the user must consider.

APPENDIX 3

HARDWARE ELEMENT DEFINITIONS

This appendix summarizes the terminology applicable to this TSO, hardware element development, and application of Appendix 1 MPS development criteria. The terms are segregated into eight categories per the appropriate hardware element performance.

(1) **General Terms.**

Air Flow Requirements. Specific requirements to provide air movement into or onto a cabinet, LRU, or module (for example, air temperature, volume rate, and pressure)

Analog/Digital Conversion Speed. The time to perform one Analog-to-Digital (A-to-D) conversion. Typically, this is expressed as either the time for one analog conversion by the A-to-D converter device or the frequency at which all analog inputs are converted.

Circuit Protection Techniques. The electrical isolation or circuitry included on inputs or outputs to protect the functional circuits from external environments. An example is using transorbs to protect circuits from the indirect effects of lightning.

Current Source/Sink. The maximum current drawn by the output while pulling the signal to a zero volt (ground) level.

Current Source. The maximum current supplied by the output while driving the signal to a voltage level.

Clearance Requirements. Additional spacing requirements in specific directions from the cabinet or rack beyond the outline dimensions. One example of this additional clearance is the area to allow proper airflow.

Design Assurance. All planned and systematic actions and data used to substantiate that hardware correctly performs its intended function(s) and that design errors have been identified and corrected such that the hardware satisfies the applicable certification basis.

Development Assurance. All planned and systematic actions and data used to substantiate that the system performs its intended function and that development errors have been identified and corrected such that the system satisfies the applicable certification basis.

Functional Software. Software applications that will be approved as part of a functional TSO authorization or as part of a type certification effort. This software is sometimes referred to as operational software, application software, or flight software.

Functional TSO. A TSO with a defined functionality (for example, a Global Positioning System, TSO-C129a). TSO-C153 is not considered a functional TSO, because IMA hardware elements typically do not have system-level functionality.

Grounding / Shielding Provisions. The electrical and/or mechanical details of the design which provide grounding of the element or which provide shield connections. These are the design details usually associated with the Radio Frequency emission and susceptibility

protection of the system.

Hardware Element. In this TSO, a hardware element is: (1) a hardware module, or (2) cabinets or racks that host hardware modules.

Note: This definition may differ from terminology in other documents (for example, RTCA/DO-254).

Inter-Element Connections. The connector type specification and connector pin assignments specified to allow modules to be installed interchangeably in the cabinets or racks.

Inter-Element Interfaces. The definition of the electrical signals, timing requirements, and protocols used to communicate among modules or elements with the cabinet or system.

Module Extraction Means. The details of the mechanical design to enable removal of the module from the cabinet.

Module Mounting Scheme. The details of the mechanical design used to secure each module into the cabinet or rack.

Mounting Mechanism. The details of the mechanical mechanism(s) used to secure the module into the cabinet or rack on the aircraft.

Multiplexing. The design technique where multiple inputs are individually switched to one receiver (for example, multiple digital communication buses switched to serial receiver) or multiple outputs are individually supplied by the same circuit (for example, multiple analog outputs driven by one Digital-to-Analog converter through multiple sample-and-holds).

Separation/Isolation Provisions. The electrical and/or mechanical details of the design which provide physical or electrical means of reducing interference from one element to another.

Steady State Voltage Rating. The maximum voltage range that can be applied continuously to an input or output without resulting in damage.

Transient Voltage Rating. The maximum voltage that can be applied for a short period of time to an input or output without resulting in damage. The maximum duration of the transient must be included.

(2) Analog Input/Output Terms.

Accuracy. The degree of conformity to the true value of the signal. This is usually expressed as a percentage of the reading or a percentage of the full-scale value of the signal.

Current Capacity. The maximum amount of current that can be sunked or sourced by the circuit.

Linearity. The error from the directly proportional expected value of the signal as the signal values vary over the entire range.

Null. The values of the signal for which a value of zero is identified. This is usually shown as positive and negative voltage values.

Offset. The indicated value of the signal (usually non-zero) when zero volts is applied.

Range. The least and greatest operating voltage extremes (full scale) of the signal; the voltage extremes between which the value of the signal is valid.

Resolution. The smallest measurable division of the numerical expression of the signal. This is usually identified as the number of binary bits used to express the value of the signal and/or the value in volts of the least significant binary bit (LSB).

(3) Discrete Input/Output Terms.

Discrete Input. This is an input with only two states. Typical examples are “ground or open” and “28 volt and open” inputs.

Discrete Output. An output with only two states. Typical examples are “ground or open” and “28 volt and open” outputs.

(4) Input Terms.

Hysteresis. The value of the input voltage lag when changing states. For example, if an input circuit has 0.2 volts of hysteresis and if the trip point is 2.0 volts then the circuit will change state as the input voltage reaches 2.0 volts but will not revert back to the original state until the input voltage drops below 1.8 volts.

Logic Sense. This is the functional interpretation of the discrete input states. A true or positive logic sense may identify the “ground” state as a ‘low’ or binary “0”. An inverse or negative logic sense may identify a “ground” state as a “high” or binary “1”.

Maximum Logic-High Level. The largest voltage value that can be connected to the input for which the circuit will interpret as “high”.

Maximum Logic-Low Level. The largest voltage value that can be connected to the input for which the circuit will interpret as “low”.

Minimum Logic-High Level. The smallest voltage value that can be connected to the input for which the circuit will interpret as “high”.

Minimum Logic-Low Level. The smallest voltage value that can be connected to the input for which the circuit will interpret as “low”.

Trip Point. This is the input voltage value at which the input circuitry changes state.

(5) **Output Terms.**

Current Sink Capacity. The maximum current drawn by the output while pulling the signal to a zero volt (ground) level (current flowing in the direction from the load to the element output).

Current Source Capacity. The maximum current supplied by the output while driving the signal to a voltage level (current flowing in the direction from the element output to the load).

Voltage Levels. The minimum and maximum voltages for each state of the output. The ground point that is to be used as the reference must be identified.

(6) **Processor Terms.**

Backplane Interface. The definition of the electrical signals, buses, timing requirements, and protocols used to communicate among elements installed in a cabinet or rack.

Interrupts. The signals to the processor that stops execution of an ongoing process or application. These announce that a higher priority or asynchronous event is occurring.

Memory Management Unit. A specialized control circuitry, sometimes integrated within the microprocessor, which performs predictive reads of instruction (pre-fetch) for use by the processor. It also may perform structured or prioritized control of specific sections of memory.

Monitors. Specific circuits which observe the normal operation of the processing system and alert the processor or user of an abnormal condition. Examples are power supply monitors, which reset the processor when a voltage is outside of its tolerance, and activity monitors which reset the processor when the processor is not performing a prescribed sequence.

Reset Structure. The architectural details of the various signals that stops execution of an ongoing process, or software application. They then restart the processor at a known state.

Central Processing Unit (CPU) Throughput. A measure of the number of processor instructions completed by the CPU per unit of time.

(7) **Power Supply Terms.**

Hold-up Capacity. The capacity of the power supply to continue supplying output current after the input voltage drops below the minimum level. This is usually expressed as the time from the input voltage drop to the reset generated by the power supply to the processor.

Input Voltage & Current. The input voltage is specified as nominal and acceptable variation values. The input current is specified as maximum steady state current. For peak current see “in-rush current” below.

Maximum Start-up (In-rush) Current Rating. The maximum input current when the power supply is first becoming active as a result of the input voltage increasing to the minimum level.

Output Current Capacity. The continuously operating maximum current supplied for each output voltage.

Power Monitors & Status Outputs. Separate circuitry which checks the output voltage levels and current loading of the power supply. This circuitry will generate one or more binary signals that may be connected to the processor to alert it to the “out of spec” condition. These binary signals may also force the power supply to shut-down to prevent damage to power supply components.

Power Resets. A binary signal output from the power supply that is asserted when the output voltages are outside acceptable tolerances.

Regulation. The percentage of variation of the output voltages when subjected to changes in load, changes in temperature, and all input voltage transients and deviations.

Restart. The ability of the power supply or other circuit to return to the normal operating mode when the input voltage returns to or above the minimum level or when the tripped monitor indicates the “out-of-spec” condition has returned to normal.

Short Circuit Management. The circuitry that monitors for short circuits or over-current conditions in the power supply outputs. The results from this circuitry may shut down the affected output or the entire power supply.

Transient Immunity. The ability of the power supply to continue operating normally during variations in the input voltage. This is usually expressed as the length of time and the voltage level of the transient.

Voltage Outputs & Tolerances. The voltage levels and tolerances of the outputs produced by the power supply.

(8) **Digital Communication Terms.**

Data Rates. The number of data bits transmitted in a time period. This is usually expressed in thousands of bits per second (Kbps) or millions of bits per second (Mbps).

Integrity Checks. The process that uses additional data accompanying the message information to validate that the message data was received without corruption or contamination. Examples are parity checks, checksums, data validity checks, and cyclic redundancy checks.

Maximum Bit Error Rates. The largest number of bit errors allowed in a message transmission before the receiver invalidates its ability to receive data from that source.

Monitors. Separate circuitry that checks either the continuing operation of a transmitter, or

checks that the receiver responds to input data. This circuitry will generate one or more binary signals that may be connected to the processor, alerting it to the “failed” condition.

Resets. Conditions that result in the receiver or transmitter stopping operation, clearing all data, and restarting.

Signal Levels. The minimum and maximum voltages for each state of the input or output. Typically, tolerances, thresholds, and reference ground point are also identified.

Signal Rise and Fall Times. The signal rise time is the time for the output to transition from 10% of the amplitude to 90% of the amplitude. The signal fall time is the time for the output to transition from the 90% level to the 10% level.

Stub Length Limits. The minimum and maximum length requirements of the wiring connector from the main bus to the inputs of the element.

ADVISORY CIRCULAR:

***GUIDANCE FOR INTEGRATED
MODULAR AVIONICS (IMA) THAT
IMPLEMENT TSO-C153 AUTHORIZED
HARDWARE ELEMENTS***

Appendix C



U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

AC-IMA

**GUIDANCE FOR INTEGRATED MODULAR
AVIONICS (IMA) THAT IMPLEMENT TSO-C153
AUTHORIZED HARDWARE ELEMENTS**

DRAFT 12 - 10/08/02
**(Addresses public comments
received prior to 10/7/02)**

Date: XXXXXXXX

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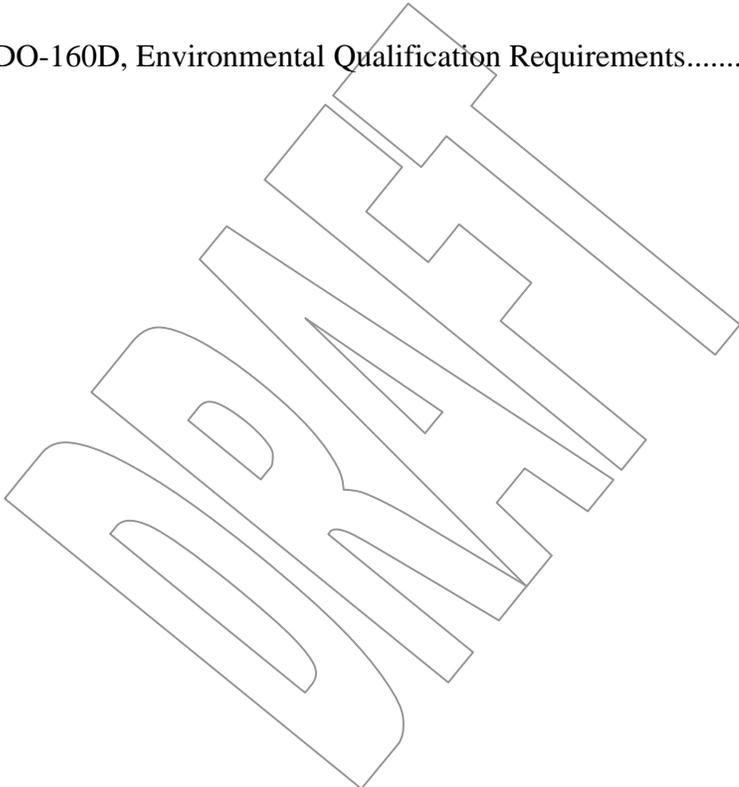
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U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

**Subject: GUIDANCE FOR
INTEGRATED MODULAR
AVIONICS (IMA) THAT
IMPLEMENT TSO-C153
AUTHORIZED HARDWARE
ELEMENTS**

Date: XXXXXXXX

AC No: XXXXX

DRAFT 12

10/08/02

Initiated By: AIR-100 Change:

1. PURPOSE.

a. This advisory circular (AC) establishes an acceptable means, but not the only means, to obtain Federal Aviation Administration's (FAA) airworthiness approval for the installation of an Integrated Modular Avionics (IMA) System that uses hardware elements authorized under Technical Standard Order (TSO)-C153, *Integrated Modular Avionics Hardware Elements*. The FAA's TSO process is a means for obtaining FAA design and production approval for an appliance, system, or product; however, the TSO authorization does not provide installation approval. This AC provides guidance for applicants involved in the integration, installation, certification, and continued airworthiness of IMA systems into an aircraft or engine, when the IMA system utilizes hardware elements that comply with TSO-C153. The guidance applies to the entire IMA system, not just the hardware elements. The guidance provided is specific to installations of these systems on aircraft or engines certificated under Title 14 of the Code of Federal Regulations (14 CFR) parts 23, 25, 27, 29, 33, and 35.

b. The means of compliance presented in this AC is not mandatory; therefore, the term "must" used in this AC only applies to an applicant who follows this particular means of compliance and TSO-C153.

2. RELATED DOCUMENTS.

a. Federal Aviation Regulations. 14 CFR parts 21, 23, 25, 27, 29, 33, 35, 91, 121, and 135.

b. FAA Technical Standard Orders (TSO). Copies of TSOs may be obtained from the Department of Transportation, FAA, Aircraft Certification Service, Aircraft

Engineering Division, AIR-100, 800 Independence Avenue, SW, Washington, D.C. 20591, or on the FAA's Aircraft Certification web site at <http://www.faa.gov/>. The following TSO is referenced in this AC:

- TSO-C153, *Integrated Modular Avionics Hardware Elements*.

c. FAA Policy Documents. Copies of orders may be obtained from the FAA web-site at <http://www.faa.gov/>. The following policy documents are relevant to this AC:

(1) Order 8150.1[], as amended, *Technical Standard Order Procedures*.

(2) Order 8110.4[], as amended, *Type Certification*.

(3) Policy Memo ANM-0103, *Factors to Consider When Reviewing an Applicant's Proposed Human Factors Methods of Compliance for Flight Deck Certification*. View this at website <http://av-info.faa.gov/software>. Select "Policy/Guidance," and scroll down to the yellow entries at the bottom of the page.

(4) Policy Memo ANM-99-2, *Guidance for Reviewing Certification Plans to Address Human Factors for Certification of Transport Airplane Flight Decks*. View this at website <http://av-info.faa.gov/software>. Select "Policy/Guidance," and scroll down to the yellow entries at the bottom of the page.

(5) Proposed Policy Memo PS-ACE100-2001-004, *Guidance for Reviewing Certification Plans to Address Human Factors for Certification of Part 23 Airplane*. View this at website www.faa.gov/certification/aircraft/small airplane directorate advisory.htm.

d. FAA Advisory Circulars (AC). Copies of ACs may be obtained from the Department of Transportation, Subsequent Distribution Office, SVC-121.23, Ardmore East Business Center, 3341 Q 75th Ave, Landover, MD 20785. The AC checklist (AC 00-2) is available at <http://www.faa.gov/>. The AC checklist contains status and order information for the FAA ACs. The following ACs are referenced in this AC:

(1) AC 20-88, *Guidelines on the Marking of Aircraft Powerplant Instruments (Displays)*;

(2) AC 20-115, *Radio Technical Commission for Aeronautics, Inc. Document RTCA/DO-178B*;

(3) AC 21-16, *RTCA Document DO-160D*;

(4) AC 21-40, *Application Guide for Obtaining a Supplemental Type Certificate*;

(5) AC 23.1309-1, *Equipment, Systems, and Installations in Part 23 Airplanes*;

- (6) AC 23.1311-1, *Installation of Electronic Displays in Part 23 Airplanes*;
- (7) AC 25-11, *Transport Category Airplane Electronic Display Systems*;
- (8) AC 25.1309-1, *System Design and Analysis*;
- (9) AC 27-1, change 1, *Certification of Normal Category Rotorcraft*;
- (10) AC 29-2, change 1, *Certification of Transport Category Rotorcraft*;
- (11) AC 33.28-1, *Compliance Criteria for 14 CFR §33.28, Aircraft Engines, Electrical and Electronic Engine Control Systems*; and
- (12) AC 120-64, *Operational Use and Modification of Electronic Checklists*.

NOTE: Other ACs may be applicable, depending on the functions being implemented in the IMA system.

e. RTCA, Inc. Documents. Copies of RTCA documents may be purchased from RTCA, Inc., 1828 L Street, NW, Suite 805, Washington, D.C. 20036. Alternatively, copies may be purchased on-line at <http://www.rtca.org/>. RTCA documents referenced in this AC are:

- (1) RTCA/DO-160D, change 2, *Environmental Conditions and Test Procedures for Airborne Equipment*;
- (2) RTCA/DO-178B, *Software Considerations in Airborne Systems and Equipment Certification*;
- (3) RTCA/DO-254, *Design Assurance Guidance for Airborne Electronic Hardware*; and
- (4) RTCA/DO-257, *Minimum Operational Performance Standards for the Depiction of Navigation Information on Electronic Maps*.

f. SAE Documents. Copies of Society of Automotive Engineers (SAE) documents may be purchased from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001. The following SAE documents are referenced in this AC:

- (1) ARP 4754, *Certification Considerations for Highly-Integrated or Complex Aircraft Systems*; and
- (2) ARP 4761, *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment*.

3. DEFINITIONS.

a. Cognizant Aircraft Certification Office (ACO). The ACO granting the certificate or TSO authorization for the specific product or appliance.

b. Design Assurance. All planned and systematic actions and data that substantiate that hardware correctly performs its intended function(s) and that design errors have been identified and corrected such that the hardware satisfies the applicable certification basis.

c. Development Assurance. All planned and systematic actions used to substantiate that development errors have been identified and corrected such that the system satisfies the applicable certification basis.

d. Functional Software. Software applications that will be approved as part of a functional TSO authorization or as part of a type certification effort. This software is sometimes referred to as operational software, application software, or flight software.

e. Functional TSO. A TSO with a defined functionality. Examples of functional TSOs are listed in Appendix 1 of this AC. TSO-C153 is not considered a functional TSO, because hardware elements typically do not have system-level functionality.

f. Functional TSO Applicant. The applicant seeking functional TSO authorization.

g. Hardware Element. A hardware element (as defined in TSO-C153) is (1) a hardware module, or (2) cabinets or racks that host hardware modules. A hardware element with TSO-C153 authorization is not considered a functional TSO authorization.

NOTE: This definition may differ from terminology in other documents (for example, RTCA/DO-254).

h. IMA System. For this AC, an IMA system encompasses all components (such as, hardware elements, software, displays, control devices, sensors, receivers, and transmitters) needed to make the aircraft or engine system functional and operational.

i. Partitioning. One means to implement protection.

j. Protection. The process of separating, usually with the express purpose of isolating one or more attributes of a function, to prevent specific interactions and cross-coupling interference.

k. Red Label Unit. For this AC, a red label unit is one that contains hardware and/or software that does not yet have FAA approval.

l. Software component. A functional software file that is loaded into the IMA system.

m. Stakeholders. All the entities involved in the development, integration, and certification of the IMA system. Stakeholders mentioned in this AC are the hardware element manufacturer, the functional TSO applicant, the IMA system integrator, the type certification applicant, the FAA, and any other manufacturer involved in the IMA system development or integration.

n. System configuration file. A data file loaded into the IMA system. It defines the IMA system, rack, or cabinet configuration; provides means of checking that the system is correctly configured and that the correct software has been successfully loaded; provides parameters for checking that system and card resource management protection features are functioning properly; and performs other similar purposes.

o. Third Party Manufacturer. For this AC, a third party manufacturer is a developer of a hardware module to be installed into a rack or cabinet that has TSO-C153 authorization, and who is not the rack or cabinet manufacturer nor the IMA system integrator. The hardware module may or may not have an associated TSO authorization.

p. TSO-C153 Applicant. The applicant seeking TSO-C153 authorization.

q. Type Certificate (TC), Supplemental TC (STC), Amended TC (ATC), or Amended STC (ASTC) Applicant. The applicant seeking type certification approval using the TC, STC, ATC, or ASTC process. For purpose of this document, the TC, STC, ATC, or ASTC applicant is denoted as TC/STC/ATC/ASTC applicant.

4. ACRONYMS. The following acronyms are used in this AC:

AC	Advisory Circular
ACO	Aircraft Certification Office
AEG	Aircraft Evaluation Group
AFM	Aircraft Flight Manual
AFMS	Aircraft Flight Manual Supplement
APU	Auxiliary Power Unit
ARP	Aerospace Recommended Practice
ASTC	Amended Supplemental Type Certificate
ATC	Amended Type Certificate
BIT	Built-In-Test
CCD	Cursor Control Device
CD	Compact Disk
CFR	Code of Federal Regulations
CRC	Cyclic Redundancy Check
CRM	Crew Resource Management
DOA	Delegation Option Authorization
DAS	Designated Alteration Station
EMC	Electro-Magnetic Compatibility

EMI	Electro-Magnetic Interference
EQT	Environmental Qualification Tests
FAA	Federal Aviation Administration
FHA	Functional Hazard Assessment
FLS	Field-Loadable Software
FMS	Flight Management System
GPS	Global Positioning System
HIRF	High Intensity Radiated Fields
I/O	Input and/or Output
ILS	Instrument Landing System
IMA	Integrated Modular Avionics
MCDU	Multi-function Control and Display Unit
MLS	Microwave Landing System
MMEL	Master Minimum Equipment List
MPS	Minimum Performance Standard
PSCP	Project Specific Certification Plan
PSSA	Preliminary System Safety Assessment
RF	Radio Frequency
SAE	Society of Automotive Engineers
SSA	System Safety Assessment
STC	Supplemental Type Certificate
TAS	Traffic Advisory System
TAWS	Terrain Awareness Warning System
TC	Type Certificate
TCAS	Traffic Alert and Collision Avoidance System
TSO	Technical Standard Order

5. SCOPE.

a. IMA systems using the TSO-C153 require consideration by all stakeholders involved (for example, the hardware element manufacturer, the functional TSO applicant, the IMA system integrator, the type certification applicant, and the FAA). This AC provides guidance for applicants involved in the integration, installation, certification, and continued airworthiness of IMA systems that use TSO-C153 authorized hardware elements in aircraft or engines. The guidance of this AC is focused on applicants who implement or interface with hardware elements that comply with TSO-C153. It should be noted that TSO-C153 authorization does not provide functional approval nor installation approval. This AC applies to the installation, integration, certification, and continued airworthiness of the entire IMA system, including the hardware elements. This AC provides guidance for an IMA system installed on an aircraft to provide aircraft or engine system functions. It addresses the integration of hardware elements, software, displays, sensors, control devices, etc. needed to ensure the aircraft or engine systems operate properly and safely.

b. The TC/STC/ATC/ASTC applicant is ultimately responsible for showing compliance to the applicable Title 14 CFRs for their aircraft or engine. The IMA system may include sub-systems that may or may not have TSO authorization. The applicability of TSO authorization to various portions of the IMA system should be handled like any other TSO application and authorized accordingly by the FAA. The IMA system must be approved as part of the TC/STC/ATC/ASTC project.

c. While this AC is focused on IMA systems that use TSO-C153 authorized hardware elements, much of the guidance may also be useful for IMA systems that do not use these hardware elements.

6. BACKGROUND.

a. IMA systems, depending on the specific aircraft or engine application, can combine many functions that have historically been contained in functionally and physically separated systems. The integration of many functions and the implementation of hardware elements present numerous obstacles for compliance to the regulations. This AC provides a means of compliance to the regulations for applicants involved in the integration, installation, certification, and continued airworthiness of IMA systems for an aircraft or engine.

b. TSO-C153 identifies two types of hardware that are considered hardware elements: (1) hardware modules, and (2) cabinets/racks that host hardware modules. The hardware elements that do not have TSO-C153 authorization can also be integrated into IMA systems, if they meet the environmental, interoperability, and regulatory requirements of the installation (that is, they are approved as part of the TC/STC/ATC/ASTC).

c. Hardware elements authorized under TSO-C153 may contain software to enable electronic part marking and/or future loading of functional software. The hardware

elements manufactured to comply with TSO-C153 may be used in support of functional TSOs (for example, a Global Positioning System, TSO-C129) or systems approved under 14 CFR Parts 23, 25, 27, 29, 33, or 35 (for example, a braking system approved as part of a type certificate).

7. DOCUMENT OVERVIEW. The following sections are included in this AC:

a. Sections 8 through 17 provide guidance on specific technical areas to be addressed by integrators and installers of IMA systems.

b. Section 18 provides guidance on the roles and responsibilities of the multiple stakeholders in the certification, integration, and installation process.

c. Section 19 provides guidance to third party manufacturers.

d. Section 20 provides guidance regarding the airworthiness considerations of IMA systems.

e. Section 21 provides guidance regarding the maintenance and continued airworthiness of IMA systems.

8. IMA SYSTEM APPROVALS AND AUTHORIZATIONS. Integration, installation, and certification of an IMA system on an aircraft may use hardware and software that has undergone several levels of design and approval. Three types of authorization or approval will typically be applicable:

a. TSO-C153 Authorization. In order to receive TSO-C153 authorization, the applicant must demonstrate that the hardware element being authorized meets the minimum hardware performance standards and the defined subset of RTCA/DO-160D environmental qualification requirements in TSO-C153. **TSO-C153 authorization does not provide functional approval nor installation approval.**

b. Functional TSO Authorization.

(1) A functional TSO authorization is a one with a defined functionality (for example, autopilot, TSO-C9c). Other examples of functional TSOs are listed in Appendix 1 of this AC. TSO-C153 is not considered a functional TSO, because hardware elements typically do not have system-level functionality. The TSO-C153 and functional TSO applicants may be different entities. The functional TSO applicant must demonstrate that the IMA system, when loaded with the functional software for the functional TSO, meets all requirements of the functional TSO. The environmental qualification may include selected environmental qualification tests performed as part of the TSO-C153.

(2) The configuration of all software components and hardware modules installed in TSO-C153 authorized cabinets or racks must be identified in the type design defined for

the particular aircraft or engine model. Additionally, the software and hardware must conform to that type design.

(3) Functional TSO authorization supported by hardware modules authorized under TSO-C153 is granted for the specific system configuration, not for individual modules. That is, a functional TSO may be comprised of multiple hardware elements with the appropriate functional software.

(4) A functional TSO authorization (for example, a GPS card that includes the functional software) may be obtained on a hardware element to be installed in a TSO-C153 authorized rack or cabinet. A hardware element without TSO-C153 authorization must be identified only with the functional TSO markings.

(5) TSO authorization is not an authorization to install either the TSO-C153 hardware element or a functional TSO authorized system in an aircraft.

c. Installation Approval.

(1) The TC/STC/ATC/ASTC applicant must demonstrate that the installed IMA system configuration (including hardware and software) and performance meets the appropriate aircraft and engine certification basis. This demonstration must include functional performance, interoperability, aircraft-level and system-level safety assessments, environmental qualification, system integration test, flight-test, software and hardware assurance, etc. (as required to show compliance to the regulations).

(2) The TC/STC/ATC/ASTC applicant may use TSO data to support airworthiness assessment if they show that the TSO requirements apply to the installation. Any change to an IMA element's hardware or software configuration must be controlled at both the TSO authorization and the aircraft installation level. Section 20.c of this AC provides additional guidance on changes.

NOTE: IMA systems often have generic software functions (for example, an operating system). These functions are approved as part of the functional TSO authorization or aircraft installation approval of the TC/STC/ATC/ASTC (that is, they are not approved as stand-alone components).

9. SAFETY ASSESSMENT PROCESS GUIDANCE.

a. Because of the high level of complexity and integration inherent in IMA systems, it is recommended that applicants conduct a structured formal analysis of these systems using the guidance contained in Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 4754 (*Certification Considerations for Highly-Integrated or Complex Aircraft Systems*) and ARP 4761 (*Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment*), or an acceptable alternative. IMA systems, depending on the specific airframe application, can combine

many functions that historically have been contained in functionally and physically separate systems into an IMA system. In the IMA system architecture, electrical power, computing hardware, memory, databuses, physical location, etc. may all be shared by multiple functions, some of which have little commonality with each other. All hosted functions may use common resources such as common processing, common operating system, common protection and partitioning mechanisms, common core services, and common interconnect buses. System and functional “hardware module” communications may be tied together using a bi-directional digital communication network that uses a standard interface circuit for each hardware module. Time and space software partitioning may rely on a common operating system that allows functions of mixed hazard categories, design assurance levels, and software levels to co-exist and execute on the same processing platform. These features raise several concerns, such as:

(1) Possible interference to critical systems (for example, fly-by-wire flight controls or electronic engine control) by functions of lower integrity.

(2) Failure conditions (either single or multiple) that could affect multiple functions, thereby reducing safety and causing increased flight crew workloads when attempting to determine the nature of the problem and the correct flight crew response.

b. The TC/STC/ATC/ASTC applicant should conduct an aircraft-level safety assessment for the installation of IMA systems, the failure of which could result in catastrophic, hazardous/severe-major, or major failure conditions. This assessment must specifically address systems integration issues and should be performed in addition to the system safety analyses performed for individual functions. Central to the aircraft-level safety assessment is the identification of the cross-functional effects of single and/or multiple failure combinations. Cascading or common-cause failures, and fault propagation effects, if they exist, should be identified, analyzed, and mitigated. Additional guidance is provided in SAE documents ARP 4754 and ARP 4761. The safety assessment should include the following:

(1) **Functional Hazard Assessment (FHA).** The intended functions of the IMA system should be identified and evaluated for their impact on aircraft and engine safety. A FHA should be conducted at the aircraft level to determine and classify the hazards associated with both the loss and malfunction of each function provided by the IMA system. The hazards associated with the simultaneous loss or malfunction of multiple functions provided by the IMA system must also be identified and classified. In addition, the loss and malfunction of functions provided by the IMA system should be considered in combination with the loss and malfunction of related functions provided by other aircraft and engine systems.

(2) **Preliminary System Safety Assessment (PSSA).**

(a) Based on the hazard classifications determined by the FHA, the proposed design and installation of the IMA system should be evaluated by a PSSA to establish the

specific safety requirements of each component in the IMA system (for example, cabinet, rack, hardware modules, buses, connectors, displays, sensors, control devices, and functional software).

(b) The PSSA should establish the number, isolation features and reliability of each component of the IMA system, including the power supplies, communication interfaces, displays, and controls that are required to protect the aircraft from the effects of random hardware failures. The system development assurance levels necessary to protect the aircraft and engine from design and development errors in the hardware and software of each hardware element should be determined. Unless extraordinary measures are provided (for example, physical and electrical isolation within a cabinet or rack) to protect an IMA cabinet or rack from common-cause failures (such as an electrical fire), all of the functions provided by a single IMA cabinet or rack should be assumed to fail as the result of a single failure. All functions that use any single hardware element (for example, printed wire board, connector, power supply, or wire bundle) should be assumed to fail as the result of a single failure. Loss of all functions in each IMA cabinet or rack and/or hardware module should be addressed in the safety analysis, including common-cause issues.

(c) PSSA should consider the fail-safe design techniques, as applicable for the aircraft type (for example, AC 25.1309-1[] for part 25 aircraft). The PSSA should ensure the effective use of design techniques in order to prevent single failures or other events from damaging or adversely affecting: (1) more than one IMA cabinet or rack, and/or (2) an IMA cabinet or rack and independent aircraft and engine systems performing operationally similar functions. To simplify the analysis, the IMA system should be installed to minimize the effects of its failures on other aircraft engine systems. When considering such common-cause failures or other events, consequential or cascading effects should also be addressed. Some examples of such potential common-cause failures or other events include:

1. Rapid energy released from concentrated sources such as uncontained failures of rotating parts (other than engines and propellers) or pressure vessels.
2. Pressure differentials.
3. Non-catastrophic structural failures.
4. Loss of environmental temperature control.
5. Disconnection of more than one sub-system or component by over-temperature protection devices.
6. Contamination by fluids.
7. Damage from localized fires.

8. Loss of power supply or return (for example, mechanical damage or deterioration of connections).
9. Excessive voltage.
10. Physical or environmental interactions among parts.
11. Errors (for example, design errors, operation errors, and maintenance errors).
12. Events external to the system or to the aircraft.
13. Uncontained engine and Auxiliary Power Unit (APU) rotorburst.
14. Uncontained propeller and propeller blade out.
15. Vibration due to engine or propeller blade out.
16. Tire burst.
17. Thrown tire tread.
18. Wheel rim release.
19. Runway debris.
20. Bird strike.
21. High Intensity Radiated Fields (HIRF).
22. Lightning.
23. Duct rupture.
24. Explosion (sabotage).
25. Release of stored energy (batteries, accumulators, and pressure bottles).

(d) See SAE ARP 4761 for more information on recommended methods for conducting a Zonal Safety Analysis and a Particular Risks Assessment.

(e) The software level should be determined for all installed software. The software level may be determined using the procedures described in RTCA/DO-178B. Additional guidance material for assigning software levels by aircraft category should be

consulted (for example, AC 23.1309-1C for part 23 airplanes). When the applicant uses system architectural features, as described in SAE ARP 4754, to propose a lower software level than the level determined by the guidance contained in RTCA/DO-178B, the applicant should consult with certification authorities early in the program and obtain concurrence.

(f) If the IMA system contains electronic devices that cannot feasibly be evaluated by test and/or analysis, hardware design assurance levels should be identified using a functional failure path analysis, as described in Appendix B of RTCA/DO-254, *Design Assurance Guidance for Airborne Electronic Hardware*, and the appropriate design assurance design assurance achieved for each complex electronic device to that guidance or other acceptable means of compliance.

(g) Failure probabilities of the protection scheme(s) must be commensurate with the failure condition classifications of the simultaneous malfunction of all IMA functions that it supports. The FAA recommends that design features that implement protection use both hardware and software means.

(3) System Safety Assessment (SSA). A systematic, comprehensive evaluation of the functions implemented by the IMA system, as installed in the aircraft, should be conducted to show that the relevant safety requirements identified in the PSSA have been met. This evaluation may include bench, ground, and flight tests to ensure assumptions made in the PSSA are correct. The SSA combines the results of a number of different analyses and tests to verify the safety of the overall system, as installed. The SSA should be conducted as described in SAE ARP 4761; a typical SSA includes:

- (a) A system description, including functions and interfaces.
- (b) A list of failure conditions.
- (c) The classification of each failure condition.
- (d) Qualitative analysis of each failure condition.
- (e) Quantitative analysis of each failure condition, as required.
- (f) The results of common-cause analyses.

(g) Confirmation that any hazards associated with failure of the functions implemented in the IMA system, combined with the failure of other aircraft systems, have been addressed.

(h) Laboratory, simulator, and aircraft test (ground and flight) data, as appropriate, that substantiates flight crew recognition and response to failure conditions.

(i) An assurance that any failure modes of lower criticality functions that could adversely affect higher criticality functions are addressed.

(j) Confirmation that all software has been developed to the appropriate software level identified in the PSSA using the guidance of RTCA/DO-178B or other acceptable means of compliance.

(k) Confirmation that electronic devices whose functions cannot be feasibly evaluated by test and/or analysis have been developed to the hardware design assurance levels identified in the PSSA using the guidance of RTCA/DO-254 or other acceptable means of compliance.

10. CONFIGURATION MANAGEMENT GUIDANCE.

a. Configuration management and control in an IMA system is especially necessary because the system may contain many hardware elements and software applications, with multiple approved configurations. Techniques to effectively manage and use the IMA architecture are necessary to safely provide system attributes, such as:

- (1) Hosting multiple software applications on a single processor.
- (2) Producing and distributing hardware elements without loading specific software applications.
- (3) Allowing electronic part numbering for software components, without the need to physically mark hardware elements with the software part number.
- (4) Allowing the electronic display of the TSO identification of hardware elements and software components of the IMA system.
- (5) Allowing the field-loading of hardware elements with functional software components for efficient maintenance and incorporation of approved design changes.
- (6) Allowing the stocking of generic, non-configured hardware elements for maintenance. A non-configured hardware element is one that does not already contain the functional software components needed to satisfy an aircraft, engine, or system function, and for installation. These hardware elements will be field-loaded with the appropriate software components, after being physically installed on the aircraft or engine.
- (7) Providing the ability to update and maintain IMA system configuration files without corruption.

b. The TC/STC/ATC/ASTC applicant is responsible for the overall aircraft configuration management. A robust automated configuration management scheme for the IMA system should be used to support aircraft configuration management by monitoring

incorrect assembly, configuration, or installation of hardware elements in the cabinet or rack. The robust automated configuration management system monitors correct configuration of hardware elements that implement field-loadable software used throughout the IMA system. IMA systems that do not include field-loadable software may not need a robust automated configuration management scheme when other means (such as mechanical interlocks, keyed connectors, etc.) are implemented.

c. When field-loadable software is loaded into the IMA system, a robust automated configuration management scheme is required to enable the safe operation and maintenance of an IMA system with some or all of the features described in 10.a above. This scheme, along with any necessary manual inspections, must guarantee that the configuration of the software components loaded is identical to what was approved under the TC, STC, ATC, or ASTC process. The scheme must also be able to identify improper configuration of the hardware elements and software components in the IMA system. Improper configurations of the hardware elements and software components in the IMA system must be annunciated to the flight crew at power-up. In addition, the automated configuration management scheme should provide a means to verify that the software components and hardware elements of the system are correctly configured for the aircraft on which they are installed (for example, the automated configuration management system should ensure that the correct software is loaded into the correct hardware element(s) and is installed in the correct rack or cabinet location). Any loss of functionality caused by the protection mechanisms of the configuration management system must be shown to be acceptable through the aircraft-level safety assessment and Master Minimum Equipment List (MMEL).

d. If individual hardware elements require direct interfaces to the aircraft, engine, or other equipment with mechanical connector(s), the applicant must show that each interface, by either mechanical means or automatic electronic monitoring, will prevent or detect an incorrect connection at power up.

e. TC/STC/ATC/ASTC applicants must provide appropriate field-loading procedures that ensure that the proper software is always correctly loaded on the aircraft. This procedure should not rely on a single action to verify that the correct software version has been loaded. For example, (1) a procedure may be added to the Aircraft Flight Manual (AFM) or Aircraft Flight Manual Supplement (AFMS) requiring the pilot to verify the part number of the IMA system, or (2) a procedure may be implemented to support critical maintenance items, per 14 CFR § 121.369, requiring duplicate inspection.

f. All changes to an IMA system, whether the change is major or minor (by either the TSO definition (14 CFR § 21.611) or the type certificate definition (14 CFR § 21.93)), should be evaluated and tracked by the TC/STC/ATC/ASTC holder. The results of the change evaluation should be included in the type design data package for the change. Additional guidance on the change process is included in Section 20.c of this AC. The following configuration management items should be considered when making changes:

(1) All software changes in the hardware elements, whether major or minor, should be tracked by the automated configuration management system.

(2) Hardware changes to hardware elements that do not affect weight, balance, structural strength, reliability, operational characteristics, or other characteristics affecting airworthiness of the aircraft (for example, change of resistor manufacturer) may be approved as a minor change to the TSO-C153 authorization. The change should at least result in a modification status update and should be tracked by the TC/STC/ATC/ASTC applicant.

(3) All major hardware changes to hardware elements should be tracked by the automated configuration management system. However, minor hardware changes to hardware elements need not be tracked by automated configuration management system.

11. ELECTRONIC IDENTIFICATION GUIDANCE.

a. Identification of software components field-loaded into hardware elements must be implemented by electronic means, unless the automated configuration management system is unnecessary per 10.b above. Electronic identification markings consist of identifying software components by electronically embedding the identification within software installed on the hardware element, rather than on the equipment nameplate.

b. Electronic software part numbers and versions must be verifiable through an electronic query, such as an electronic display. Software part number configuration errors must be annunciated to the flight crew at power-up and should result in a “no dispatch” indication.

c. 14 CFR § 21.607 requires TSO'd equipment to be permanently and legibly marked with specific information. Compliance to 14 CFR § 21.607 can be demonstrated when the information required to be included is provided by an electronic identification query system stored in non-volatile memory (this approach is commonly referred to as an “electronic TSO nameplate”). The electronic identification system must be verifiable on board the aircraft when the aircraft is on the ground at any geographic location and must provide the specific information required by 14 CFR § 21.607 for all applicable functional TSOs being integrated.

d. Electronic identification may also provide software component and hardware element revision or modification status information and RTCA/DO-178B software level which can be used to demonstrate conformity to type design configuration.

e. Information identifying the location of each hardware element must be included in the electronic identification since configuration is dependent on the specific location of each hardware element within the cabinet or rack. This requirement can be satisfied when the automatic configuration management scheme tracks and protects the IMA system configuration by ensuring hardware elements are properly located.

f. All hardware elements that support a functional TSO must have a physical TSO nameplate (either a C153 or a functional TSO nameplate). Even when electronic identification (that is, electronic nameplate) is used, a physical TSO nameplate (either functional TSO or C153) must be included on supporting hardware elements.

g. The verification of electronic identification information is an acceptable alternative to physical verification of hardware part number and revision/modification status. Electronic means may be used in lieu of verifying dataplates on each hardware element, if all required information is available electronically. Electronic identification does not replace hardware element and software conformity inspections that determine the elements and components are produced in conformity to type design.

h. Operators should establish a separate process that records the IMA system configuration (for example, identification and revision status of hardware elements and software components). This information should be kept up-to-date and maintained off-board the aircraft. The process should be defined by the TC/STC/ATC/ASTC applicant as part of their instructions for continued airworthiness (per 14 CFR § XX.1529, where XX may be 14 CFR Parts 23, 25, 27, or 29)). The operator should maintain the information as part of their maintenance program.

12. SOFTWARE GUIDANCE.

a. Software Assurance. All software used in IMA systems should be developed to the guidance of RTCA/DO-178B, *Software Considerations in Airborne Systems and Equipment Certification*, dated December 1, 1992 or another acceptable means of compliance, as agreed to between the applicant and the cognizant FAA Aircraft Certification Office (ACO).

b. Software Levels. The software levels for all software should be determined by the appropriate safety assessments (see section 9 above) and any additional requirements, such as those specified by functional TSOs.

c. Field-Loadable Software (FLS).

(1) Many IMA systems utilize Field-Loadable Software (FLS) as part of the TC/STC/ASC/ASTC installation. FLS is software that can be loaded without removal of the equipment from the aircraft installation. FLS might also include software loaded into a line replaceable unit (LRU) or hardware element at a repair station or shop. FLS can refer to either executable code or data. When obtaining certification approval for utilization of the FLS capability, the applicant should consider the following guidance:

(a) The FLS should meet the objectives and guidance of RTCA/DO-178B or another acceptable means of compliance, as agreed to between the applicant and the cognizant ACO.

(b) The software should be loaded on the target computer and hardware configuration that it was verified on for the software approval.

(c) To ensure that the FLS is loaded in the proper configuration, there must be a robust automatic configuration management scheme as described in paragraphs 10.b and 10.c above to ensure that the installation configuration (that is, software part number, the hardware part number, the aircraft model, and the aircraft serial number combination, as applicable) is the configuration approved during the TC, ATC, STC, ASTC, or TSO authorization process.

(d) If redundant functions of the IMA system are field-loadable, the applicant should ensure that the redundant functions have the same software configuration, unless intermixing of different software configurations is supported by the safety assessment and has been approved for the aircraft configuration and type design.

(e) There should be a process to assure that the software loaded is the software approved and that it has not been corrupted (for example, verification with an appropriate data transfer integrity check, such as a cyclic redundancy check (CRC)). Different data integrity algorithms give different assurances that the data transferred is correct. The applicant should assure that the algorithm used is commensurate with the integrity required for the software level of the data being loaded.

(f) If the applicant proposes more than one medium for loading of FLS (such as, diskette, mass storage device, or compact disk (CD)), loading from all mediums should comply with the guidance in this section.

(g) The applicant should demonstrate the ability to verify the airborne equipment software part numbers with onboard equipment, carry-on equipment, or other appropriate means.

(h) Loading protection mechanisms should be implemented to inhibit loading FLS during flight.

(i) If FLS is loaded onto a hardware element that previously had software loaded, the out-of-configuration software file(s) on the hardware element should be removed prior to loading the new FLS, in order to prevent the existence of unapproved or out-of-configuration code.

(j) All changes to FLS should be submitted to the cognizant ACO for review and approval.

(2) FLS installation documents should specify the following elements:

(a) The aircraft and hardware applicability and inter-mixability allowances for redundant systems software loading.

(b) Verification procedures to assure that the software was correctly loaded into an approved and compatible target computer and memory device(s).

(c) Any post load verification and/or test procedures required to show compliance to the guidelines specified in this AC.

(d) Actions to be taken in the event of an unsuccessful load (for example, prohibit dispatch of aircraft).

(e) Reference to an approved loading procedure.

(f) Maintenance record entry procedures required to maintain configuration control.

(g) Reference to Aircraft Flight Manual, Aircraft Flight Manual Supplement, or Operator's Manual, as appropriate.

d. Partitioning and Protection.

(1) IMA systems may combine many functions (that may have different software levels) of different software levels on the same target computer or hardware element. Per RTCA/DO-178B, higher level software must be partitioned and/or protected in such a way that lower level software cannot affect the memory locations allocated to the higher level software or otherwise interfere with the computation of its functions (that is, there must be both time and space protection). It should be noted that functions operating on the same hardware may need to be partitioned and/or protected to support fail-safe designs and safety requirements, even if they are the same software level. It is recommended that design features that implement protection and partitioning use both hardware and software means.

(2) IMA systems typically contain many functions, often using the same computer resources (for example, real-time operating systems, memory, and input/output devices). A function can affect the operation of other functions by affecting the timing or performance behavior or the space (that is, memory) of the other functions. When partitioning is used as the means of protection for the computer resources in an IMA system, the applicant should demonstrate the partitioning in both the time and space domains.

(3) As a minimum, when evaluating timing properties, the following items should be considered to demonstrate that functions either have no effect or that their effect is acceptable based on the identified safety parameters:

(a) Interrupts and interrupt inhibits (software and hardware).

(b) Loops (for example, infinite loops or indirect non-terminating call loops).

(c) Real-time correspondence (for example, frame overrun, interference with real time clock, counter/timer corruption, pipeline and caching, deterministic scheduling).

(d) Control flow defects (timing aspects) (for example, incorrect branching into a partition or protected area, corruption of a jump table, corruption of the processor sequence control, corruption of return addresses, unrecoverable hardware state corruption (for example, mask and halt)).

(e) Memory, Input, and/or Output contention.

(f) Data flags.

(g) Software traps (for example, divide by zero, un-implemented instruction, specific software interrupt instructions, unrecognized instruction, and recursion termination).

(h) Hold-up commands (i.e., performance hedges).

(4) As a minimum, when evaluating space properties, the following items should be considered to demonstrate that functions either have no effect or that their effect is acceptable based on the identified safety parameters:

(a) Loss of input or output data.

(b) Corruption of input or output data.

(c) Corruption of internal data (for example, direct or indirect memory writes, table overrun, incorrect linking, calculations involving time, corrupted cache memory).

(d) Delayed data.

(e) Program overlays.

(f) Buffer sequence.

(g) External device interaction (for example, loss of data, delayed data, incorrect data, protocol halts).

(h) Control flow defects (space aspects) (for example, incorrect branching into a partition or protected area, corruption of a jump table, corruption of the processor sequence control, corruption of return addresses, unrecoverable hardware state corruption).

NOTE: These lists are not all-inclusive of partitioning issues that may need to be addressed.

e. Software Reuse. IMA systems frequently implement reusable software. If software is reused, the following items should be assured:

(1) The software life cycle data being considered for reuse has not changed since its previous approval.

(2) The software required level of the software application(s) is equal to, or less than, the software level of the previous approval.

(3) The range and data type of inputs to the configuration item are equivalent to its approved predecessor.

(4) The configuration item being reused is resident on the same target computer and used in the same way operationally as it was for the previous approval.

(5) Equivalent software/hardware integration testing and system testing were conducted on the target computer and system as in the previous approval.

(6) Software life cycle data has been shown to (1) have no adverse effect on the original systems safety margins, and (2) have no adverse effect on the original operational capability, unless accompanied by a justifiable increase in safety. If software life cycle data intended for reuse adversely affects safety or exceeds a pre-approved range of data, parameters, or equipment performance characteristics, then it will not be approved for reuse. The software life cycle data would require design approval under the applicable paragraph of 14 CFR.

(7) All open problem reports and in-service problems associated with the software to be reused should be analyzed to ensure that there are no safety or operational issues.

13. ELECTRONIC HARDWARE GUIDANCE. If the IMA system contains electronic devices whose functions cannot feasibly be evaluated by test and/or analysis, the electronic devices should comply with RTCA/DO-254, or other acceptable means of compliance, as negotiated with the cognizant ACO.

14. IMA DESIGN GUIDANCE.

a. Electrical Power for IMA Systems.

(1) IMA cabinet or rack installations should show compliance with XX.1357 (where XX may be 14 CFR Parts 23, 25, 27, or 29) or provide supporting data to justify an equivalent level of safety finding. Circuits that do not directly comply with XX.1357(e) may be acceptable if the failure effects are minor.

(2) Design of the physical architecture should support the ability to manage smoke or fire without losing functions whose loss is catastrophic.

(3) The IMA cabinet or rack should not be powered with circuit protection features that are under control of that IMA cabinet or rack.

(4) If redundant IMA hardware elements are used to provide functions, individual non-resettable fuses or circuit breakers may be provided for each IMA hardware element. The applicant should provide supporting data in the aircraft-level SSA to verify that operation of the circuit device does not cause a loss of a function. The applicant must provide an analysis to demonstrate appropriate availability in compliance with XX.1309 (where XX may be 23, 25, 27, or 29) to justify an equivalent level of safety finding.

b. Recovery Features. IMA systems should be designed to provide capabilities to initiate recovery of functions whose loss is catastrophic. IMA systems should be designed to avoid the need for crew-initiated recovery features. If crew-initiated recovery features are implemented, protective mechanisms and operational procedures should be in place to prevent accidental activation of the recovery feature. Effects of recovery feature activation in normal and failed conditions must be evaluated for all phases of flight.

c. Built-In-Test (BIT). BIT features are recommended to limit exposure time to latent failures. If pilot-initiated BIT features are provided, there should be provisions (for example, interlocks) to prevent interference with control functions (for example, flight controls, autopilots, and engine controls). Activation of BIT features intended only for ground operations should be inhibited during flight.

d. Maintenance Diagnostics. It is recommended that the IMA system provide means to detect and record failures of hardware elements and to isolate these failures to the IMA hardware module that has failed in order to facilitate maintenance of the IMA system. Procedures for isolating the problems to the module-level are recommended. Activation of maintenance diagnostic software intended for ground operations should be inhibited during flight.

e. Failure Detection and Annunciation. Failures that affect functions provided by the IMA system should be detected and annunciated to the flight crew with alerting and indication means for warning, caution, or advisory information appropriate for the failure effects.

f. Functional Partitioning. It is recommended that IMA systems that integrate multiple functions within a single processor implement partitioning among functions to reduce complexity and provide fault containment. This is recommended even if all of the software is developed to the same software level.

g. Functional Isolation. To enable continued use of the working IMA functions in the event of a failed function, it is recommended that IMA systems that integrate multiple functions implement a means to individually disable the failed function(s).

h. Intentional Transmitters. Intentional transmitters should not be installed in TSO-C153 authorized racks or cabinets.

i. Alerts and Aural Warnings. Because of the integrated nature of IMA systems, alert and aural warnings must be carefully designed and evaluated by the flight crew. For example:

- (1) Priorities of alerting system must be evaluated,
- (2) Nuisance and distracting alerts and aural warnings should be able to be disabled, and
- (3) Alerts and aural warnings should be evaluated by the flight crew.

15. ENVIRONMENTAL QUALIFICATION GUIDANCE.

a. Appendix 1 of TSO-C153 lists environmental qualification tests (EQT) that should be performed to satisfy the TSO. The TSO EQT are performed according to procedures and category levels defined in RTCA/DO-160D (Change 2). The category levels tested should be selected as appropriate for the aircraft installation and environment. The EQT performed as part of the TSO-C153 should be applicable to functional TSO environmental qualification and may be applied to the aircraft TC, STC, ATC, or ASTC environment qualification. Figure 15-1 below lists the RTCA/DO-160D environmental tests that can be accomplished under TSO-C153 authorization and how they may affect functional TSO authorization.

Figure 15-1. RTCA/DO-160D Environmental Qualification Requirements

RTCA/ DO-160D Section #	RTCA/DO-160D Section Title	TSO-C153 Requirement	Functional TSO Requirement
4	Temperature and Altitude - Temperature	Not tested	Yes
4	Temperature and Altitude - Altitude	Yes	Yes, TSO-C153 qualification data may be used by similarity
5	Temperature Variation	Not tested	Yes
6	Humidity	Yes	Yes, TSO-C153 qualification data may be used by similarity
7	Operational Shock and Crash Safety - Operational Shock	Not tested	Yes
7	Operational Shock and Crash Safety - Crash Safety	Yes	Yes, TSO-C153 qualification data may be used by similarity
8	Vibration	Not tested	Yes
9	Explosionproofness	Yes, if appropriate	Yes, TSO-C153 qualification data may be used by similarity
10	Waterproofness	Yes, if appropriate	Yes, TSO-C153 qualification data may be used by similarity
11	Fluid Susceptibility	Yes, if appropriate	Yes, TSO-C153 qualification data may be used by similarity
12	Sand and Dust	Yes, if appropriate	Yes, TSO-C153 qualification data may be used by similarity
13	Fungus Resistance	Yes, if appropriate	Yes, TSO-C153 qualification data may be used by similarity
14	Salt Spray	Yes, if appropriate	Yes, TSO-C153 qualification data may be used by similarity
15	Magnetic Effect	Yes	Yes, TSO-C153 qualification data may be used by similarity

16	Power Input	Not tested	Yes
17	Voltage Spike	Yes	Yes, TSO-C153 qualification data may be used by similarity
18	Audio Susceptibility – Power Inputs	Yes	Yes, TSO-C153 qualification data may be used by similarity
19	Induced Signal Susceptibility	Not tested	Yes
20	Radio Frequency Susceptibility	Not tested	Yes
21	Emissions of Radio Frequency Energy	Not tested	Yes
22	Lightning Induced Transient Susceptibility	Not tested	Yes
23	Lightning Direct Effects	Not tested	Yes
24	Icing	Yes	Yes, TSO-C153 qualification data may be used by similarity
25	Electrostatic Discharge	Yes	Yes, TSO-C153 qualification data may be used by similarity

NOTE: RTCA/DO-160D sections 20 and 22 may require more testing at aircraft installation (see section 17.c. (4) and (5) of this AC).

b. Certain EQT cannot be appropriately performed on the hardware elements as part of the TSO-C153. Those EQT can only be appropriately performed when the IMA system and hardware elements are arranged in the configuration specified for the applicable aircraft, as defined for the aircraft TC, STC, ATC, or ASTC. Also, those EQT can only be appropriately performed with the functional software components installed and operating. Therefore, certain RTCA/DO-160D EQT are excluded from the TSO-C153. These EQT must then be addressed as part of the functional TSO compliance, or as part of the TC/STC/ATC/ASTC environmental qualification. These tests are described below:

(1) The EQT for temperature (RTCA/DO-160D, Section 4) and temperature variation (RTCA/DO-160D, Section 5) should be performed with the cabinet or rack and modules in the hardware configuration intended for the functional TSO authorization or the TC/STC/ATC/ASTC approval. For temperature and temperature variation tests performed for the functional TSO or TC/STC/ATC/ASTC, the hardware module arrangement should represent the expected worst-case temperature conditions. As an alternate approach, the functional TSO or TC/STC/ATC/ASTC applicant may perform engineering analysis of the thermal characteristics of the expected cabinet or rack and module configuration variations to determine temperature test parameters that exceed the worst-case expected temperature

conditions. These temperature test parameters could be used instead of the standard RTCA/DO-160D Sections 4 and 5 temperature conditions.

(2) The EQT for operational shock (RTCA/DO-160D, Section 7) and vibration (RTCA/DO-160D, Section 8) should be performed with all cabinet or rack module positions (slots) occupied in the hardware configuration specified for the functional TSO or TC/STC/ATC/ASTC installation. An alternate approach would be to perform an engineering analysis of the characteristics of the expected cabinet or rack and module configurations to determine vibration and operational shock test parameters that exceed the worst expected conditions. These test parameters could be used instead of the standard RTCA/DO-160D Sections 7 and 8 conditions.

(3) The EQT for induced transients (RTCA/DO-160D, Section 19), Radio Frequency (RF) susceptibility (RTCA/DO-160D, Section 20), RF emissions (RTCA/DO-160D, Section 21), and lightning induced transients (RTCA/DO-160D, Section 22) are most appropriately performed with the hardware elements and software components loaded and active in the IMA system. This is because the response of the system may be highly dependent on the hardware element position and software component configuration. Therefore, these EQT should be performed as part of the functional TSO compliance or as part of the TC/STC/ATC/ASTC environmental qualification.

(4) IMA systems should have lightning and high intensity radiated fields (HIRF) protection EQT performed with the hardware elements and software components loaded in the configuration specified for the applicable aircraft, per the lightning regulations and ACs and the HIRF policy. The interface wiring and connected equipment must be representative of the wiring and connected equipment intended to be installed in the aircraft.

c. The EQT performed for a single functional TSO authorization or aircraft TC/STC/ATC/ASTC may be used to support other applications for functional TSOs or aircraft TC/STC/ATC/ASTCs with similar configurations. The TSO applicant may use similarity assessment and worst-case test conditions to minimize the EQT required for subsequent functional TSO applications or aircraft TC/STC/ATC/ASTC. Use of the environmental qualification data should be accompanied by a rational engineering analysis of the differences between hardware element and software component load configurations used during the original environmental tests and the proposed new configuration. The engineering analysis may consider the worst-case environmental limits developed above.

d. The functional TSO qualification data sheet should state explicitly the RTCA/DO-160D test categories and tests that are performed in the functional TSO configuration and the test categories and tests that are performed in the TSO-C153 configuration. This information should also be included in the installation instructions.

e. Hardware elements and software components providing a function that does not have an applicable functional TSO must meet the TC/STC/ATC/ASTC environmental requirements.

f. All hardware elements must be evaluated prior to installation to ensure that the TC/STC/ATC/ASTC environmental qualification requirements have been satisfied.

16. HUMAN FACTORS AND FLIGHT CREW INTERFACE GUIDANCE.

a. Human Factors Background.

(1) This section assists in the identification and, in some cases, resolution of human factors and flight crew interface issues of IMA systems. It includes issues with the design of TSO-C153 hardware elements and the installation and integration of such elements into the aircraft. The installation and integration of an end-state, fully-integrated IMA system is also addressed in this section.

(2) Because IMA systems contain many unique issues, applicants should develop a plan early in the program to address human factors and flight crew interface issues. The plan should document how issues will be identified, tracked, and resolved throughout the life cycle of the program. Typically, this information is documented through either a Human Factors Certification Plan or through a general certification plan in which the human factors components are identified. FAA Policy Memo ANM-99-2, *Guidance for Reviewing Certification Plans to Address Human Factors for Certification of Transport Airplane Flight Decks*, provides guidance for reviewing the human factors components of the certification plan for Transport Category Airplanes, as well as what should be included in these plans. FAA Policy Memo ANM-01-03, *Factors to Consider When Reviewing an Applicant's Proposed Human Factors Methods of Compliance for Flight Deck Certification*, provides guidance on factors to consider when reviewing an applicant's proposed method of compliance identified in a Human Factors Certification Plan or general certification plan. While these policy memos were tailored for part 25, much of the guidance is general and may prove useful for any aircraft type. Potential human factors and flight crew interface issues for all aircraft types are discussed below, as well as guidance related to finding compliance with the related regulations.

b. Existing Human Factors and Displays Guidance Material. The following is a partial list of guidance materials with information relevant to human factors and displays that may be particularly relevant to IMA systems:

(1) AC 20-88, *Guidelines on the Marking of Aircraft Powerplant Instruments (Displays)*;

(2) AC 23.1311-1, *Installation of Electronic Displays in Part 23 Airplanes*;

(3) AC 25-11, *Transport Category Airplane Electronic Display Systems*;

- (4) AC 27-1 (Change 1), *Certification of Normal Category Rotorcraft*;
- (5) AC 29-2 (Change 1), *Certification of Transport Category Rotorcraft*;
- (6) AC 120-64, *Operational Use and Modification of Electronic Checklists*;
- (7) FAA Policy Memo ANM-01-03, *Factors to Consider When Reviewing an Applicant's Proposed Human Factors Methods of Compliance for Flight Deck Certification*;
- (8) FAA Policy Memo ANM-99-2, *Guidance for Reviewing Certification Plans to Address Human Factors for Certification of Transport Airplane Flight Decks*;
- (9) FAA Policy Memo PS-ACE100-2001-004, *Guidance for Reviewing Certification Plans to Address Human Factors for Certification of Part 23 Airplanes*; and
- (10) RTCA/DO-257, *Minimum Operational Performance Standards for the Depiction of Navigation Information on Electronic Maps*.

c. Potential Human Factors and Flight Crew Interface Issues with IMA Systems.

(1) Displays and associated flight deck controls typically pose the greatest challenges for human factors and flight crew interfaces in IMA systems. This section addresses the most common issues, but does not comprehensively address all potential human factors and flight crew interface issues with an IMA system. IMA systems have many novel aspects; therefore, new issues arise with each new project.

(2) Guidance in this section is intended to supplement the previously published material (see section 16.b of this AC) and provide awareness of the issues to facilitate standardization with how the issues are identified and resolved across the various certification offices. Thus, where relevant regulatory or advisory material exists, they are referenced, and where none exists the issue is noted along with a recommended resolution path, where one has been established.

(3) Electronic Checklists.

(a) Initial electronic checklists were passive; that is, they only monitored system status and then allowed check-off (either manually or automatically) of the item when it was accomplished by the flight crew. In order to address the workload and task timeline issues with integration of utility system controls (including fuel, electrical, pneumatic, air conditioning, and pressurization) the applicant may use electronic checklists. These allow the flight crew to click on the checklist item (to call up the system synoptic display), move the cursor to the synoptic display, and position the cursor on required control function on that display. One good aspect of this approach is a reduction

in errors associated with selecting the wrong control. However, a significant potential human factors and flight crew interface issue is system awareness, because overloaded or complacent pilots may adopt a “click, click, click, ... checklist complete” habit and lose awareness of the consequences of the individual items. This is even more significant because of the small amount of display area that may have been reserved for the checklist, which may result in little room for expanded explanations of procedure steps.

(b) Flight Standard Service normally handles the post-type certificate approval of user-modifiable checklists without the need of a design change. However, it is recommended that checklists that interact with aircraft systems not be user-modifiable, because they may require design changes to other aircraft systems and additional human factors evaluations.

(c) Automatic control of aircraft functions through the checklist is not recommended.

(4) Accessibility of Functions.

(a) As more and more functions are being controlled using multi-purpose controls (such as, Cursor Control Device (CCD) or Multi-function Control and Display Unit (MCDU)), the flight crew must step through more menus to access functions that had previously been immediately accessible using dedicated controls.

(b) For example, applicants may propose to use the CCD to control all radios (with the MCDU as a backup). This may take several steps to do something that previously took only one control action (such as, turning a single knob). While some shortcuts have been developed for on-side radios, there can still be more steps than required for conventional radio control panels.

(c) Quick access to various functions can be an important issue, considering the many other functions may be performed using the CCDs and other multifunction controls.

(d) Increased sharing of the MCDU may also cause problems. For example, an applicant design may propose to use the MCDU as the control and display device for the solid state circuit breakers. This would require time-sharing with all of the other functions (Flight Management System (FMS), datalink, display of maintenance data, backup tuning of communication/navigation radios, and so forth) that currently are hosted on the MCDUs.

(e) It is important to evaluate this decrease in accessibility across all flight deck functions, in addition to evaluating it on a case-by-case basis. The cumulative effects on workload, task timelines, interference across functions, and flight crew coordination may be significant.

(5) **Cursor-Based Controls.**

(a) Controls used in IMA systems pose a number of potential human factors and flight crew interface issues. Specifically, a variety of cursor-based controls may be used with “point-and-click” graphical user interfaces for certain flight crew functions. Example cursor-based control technologies include touch-pads, joysticks, force-sensitive two-axis buttons (similar to those embedded in some laptop computer keyboards), and trackballs. A number of cursor-based control issues to be addressed are included below:

1. Numerous Functions. A number of functions are likely to be controlled by these cursor-based control devices, presenting the possibility of flight crew interface “choke points.” Rather than simply reaching for different discrete controls as needed, the flight crew may have to repeatedly work their way through menus in order to use the cursor-based control to perform various control functions.

2. Performance in Motion Environments. A related issue that needs to be evaluated when determining the acceptability of a cursor-based control is the performance in expected motion environments. This may be especially problematic using cursor-based controls to navigate through multiple nested menus, during time-critical activities, in turbulence, or when tasks are interrupted (for example, by Air Traffic Control).

3. Control Labeling. §25.1555(a) states the following: “Each cockpit control, other than primary flight controls and controls whose function is obvious, must be plainly marked as to its function and method of operation.” IMA system designs may use multifunction control devices that perform different functions under various conditions. Examples include cursor-based controls, multifunction rotary knobs (associated with the cursor-based controls), multifunction keyboards, and multifunction control and display units (MCDUs). These controls perform a variety of functions, depending on the context. In the case of cursor-based control devices, part of the control function, including the labeling, actually exists on the display (the cursor and the selectable items).

a. The flight crew must be able to quickly identify which function is currently active for cursor-based control functions. This means that the current location of the cursor should be easily identifiable, without searching the displays.

b. In some designs, certain of these controls are labeled (on the display) with icons (symbols) in lieu of text. While a limited number of control functions may have icons associated with them that one could reasonably assume the pilot could recognize, most functions may have no universally accepted icons. Therefore, the association between the icons and the function controlled will require flight crew training and memorization. The use of such icons in lieu of text should be kept to a minimum.

4. Cursor-Based Control Failures. Several types of cursor-based control failures need to be considered. One is the failure of a single cursor-based control, which

may disrupt the normal flow of flight crew tasks. The tasks on the flight deck are normally allocated based on which pilot is flying the aircraft. As tasks are performed, some will be accomplished by the Pilot-Flying, while others will be accomplished by the Pilot-Not-Flying. With the failure of one cursor-based control, there may be significant disruption in flight crew activities for the following two reasons:

a. In some designs, the pilot with a failed cursor-based control will be unable to use the other pilot's cursor-based control. In this case, flight crew procedures can be disrupted. For example, tasks that are normally allocated to the Pilot-Flying or Pilot-Not-Flying may need to be done by the flight crew with the remaining functional cursor-based control, regardless of who is flying.

b. Even if the remaining cursor-based control is usable by both pilots, it may be required by both pilots simultaneously. With some implementations, loss of both cursor-based controls can render significant numbers of important functions unavailable.

5. Replacement of Discrete Control Panels:

a. In some configurations, the IMA system and associated cursor-based controls (in conjunction with synoptic (schematic) system displays and electronic checklists) can be used to control a wide variety of functions. Those include fuel, electrical, pneumatic, air conditioning, pressurization, communication and navigation radios, and display systems. In such cases, many discrete or dedicated control panels may be eliminated. Pilots will "point and click" to bring up menus, select icons that represent system components (for example, valves, pumps, generators, and radios), and change system states. Significant human factors issues include workload, time to complete functions, system status awareness, and crew coordination. For example, with a conventionally designed flight deck, the flight crew could turn off a hydraulic pump by simply reaching up to the overhead panel and pushing a button. To do the same thing using an integrated CCD/IMA system that replaces the overhead panel, the flight crew may have to perform many more individual actions.

b. This sequence of individual actions is likely to take significantly longer than it would on a conventional design. This may also cause more difficulty in manipulating different systems in a sequence, particularly if the system requires the flight crew to navigate through various menus. Furthermore, these selections would be accomplished by very small finger motions on the cursor-based control, which are more likely to go unnoticed by the other crewmember, especially if cursor-based control activity is very routine and the selections occur on a multi-function display that is displaced to one side of the flight deck. Thus, the other flight crew member might not know that the status of the system has changed. Additionally, the flight crew may spend significantly more time "heads-down" while manipulating the cursor-based control and navigating the menu selections than they would if using a single dedicated control.

c. For IMA systems, applicants should present criteria and rationale to justify which functions will retain discrete or dedicated controls, and which ones will not.

d. Another consideration is the splitting of controls for a system. For a given system, a few of its controls may be in the overhead panel while the rest will be operated by the CCD. In conventional designs, there will typically be a control panel or area of the overhead panel devoted to each major system. In that way, for example, all controls for the electrical system will be grouped together. However, when some controls are moved from the discrete or dedicated control panels, some of the system's controls may now be accessed by the CCD and main displays, while other controls for that same system may remain in the overhead panel. For example, most electrical system controls (such as bus switching) would be controlled by the CCD, while the generator drive disconnect switches are likely to stay in the overhead panel due, in part, to the irreversible nature of the control. Thus, the flight crew would have to go to different locations for various electrical system controls. This scattering of system controls may result in flight crew confusion in critical, high workload/stress failure scenarios. Compliance with 14 CFR § XX.777a should be shown (where XX may be 23, 25, 27, or 29).

d. Testing Considerations for Human Factors and Flight Crew Interface Issues. Cursor-based control evaluations should include scenarios involving manual flight, emergencies, multiple failures, turbulence, vibration from sustained engine imbalance (blade-out), and so forth. Scenarios should involve testing of all cursor-based control functionality, including when the flight crew might use the cursor-based control to select displays, position the cursor, select from menus, and navigate through menu trees to access control functions (see also section 17 of this AC for testing considerations). Testing the acceptability of the IMA cursor-based control system should focus on each of the issues discussed in the section above, as well as on determining compliance with the regulations, as partially discussed in the following section.

e. Methods of Compliance with Controls Regulations.

(1) Policy Memo ANM-99-2 contains an appendix with a list of regulations typically associated with human factors and flight crew interface issues. It is important to check that the IMA system as a whole, as well as to check that the individual components comply with these and other applicable regulations. It is recommended that an IMA system applicant develop a Human Factors Certification Plan that will provide the certification office a structured approach to show how compliance will be determined with each of the applicable regulations (that is, test, analysis, and simulation). The certification plan should be organized in a way that shows the relationship between the specific human factors requirements and the method of compliance. Methods of compliance must be evaluated for the following regulations: 14 CFR §§ XX.771(a), XX.771(e), XX.777(a), XX.1523, XX.1555(a), XX.1301(a), XX.1309(b), XX.1309(d) (where XX may be 23, 25, 27, or 29). A subset of these are discussed below with emphasis on part 25, but must be evaluated for parts 23, 27, and 29 (as appropriate):

(a) To comply with 14 CFR §§ 25.777(a) and 25.1523, the applicant must show that the flight crew can conveniently access required controls in all expected flight scenarios, without unacceptable disruption of aircraft control, crew task performance, and Crew Resource Management (CRM). Since not all possible scenarios can be evaluated, the applicant should develop a set of worst-case scenarios for evaluation, along with proposed methods for evaluation (such as, analysis, test, and demonstration). Comparison to conventional controls is considered an important aspect of this evaluation, in order to determine if the use of cursor-based controls results in an increase in flight crew workload or task timelines. The evaluation plan should show how each of the factors identified in 14 CFR part 25, Appendix D will be evaluated. Operation of the cursor-based control with both the dominant and non-dominant hand should be included in the evaluations. Additionally, experience has shown that control-display response lag (time delay between movement of the control and response of the cursor) and control gain characteristics can be critical in the acceptability of a cursor-based control. Usability testing should therefore accurately replicate the response lag and control gain characteristics that will be present in the actual aircraft.

(b) To show compliance with 14 CFR § 25.771(e), the applicant should show by test and/or demonstration in representative motion environment(s) that the cursor-based control is acceptable for controlling all functions that the flight crew will access using the cursor-based control during these conditions. In addition to turbulence, vibration due to the loss of a fan blade and the subsequent damage to other rotating parts of the fan and engine must be considered in the definition of the motion environment.

(c) To show compliance with 14 CFR §§ 25.1309(b) and (d), the applicant must conduct an aircraft-level safety assessment to determine the hazards and failure conditions associated with the failure of one and of both cursor-based controls. Particular attention should be paid to the independence of the two cursor-based controls (that is, vulnerability to common-cause failures), and to the combined effects of the loss of control of multiple cursor-based systems and functions. The applicant should demonstrate that the failure of either cursor-based control does not unacceptably disrupt operation of the aircraft (that is, the allocation of flight crew tasks) in normal and emergency conditions. The failure condition classifications described in SAE ARP 4761 can be used to assess the severity of the effect on the aircraft and on flight crew operations of the loss or malfunction of a single cursor-based control or the loss or malfunction of both cursor-based controls, either by themselves or in combination with other failures. In conducting the safety assessment, the failure conditions that could result in the failure or anomalous behavior of a cursor-based control should include fluid contamination, unless it can be shown that spills of fluids expected to be present in the flight deck (for example, coffee and syrup) will not result in cursor-based control failure or anomalous behavior, or in degraded flight crew usability of the cursor-based control. The safety assessment should also include common mode failures such as physical damage, HIRF, lightning, fire, and electrical faults.

(d) To show compliance with 14 CFR § 25.1555(a), the following should be demonstrated:

1. That pilots are able to quickly and reliably identify what item on the display is “active” as a result of cursor positioning as well as what that function will be performed if the item is selected using the selector buttons and/or changed using the multifunction knob.

2. That pilots will correctly identify and select the control functions, at a speed and error-rate that is equivalent to or better than that of controls that are labeled with text formats. The data required to substantiate that the speed and error rate is equivalent need not be objective data; the applicant may collect subjective data from test subjects to show that the design meets this standard.

NOTE: Smoke-filled cockpit should be considered when evaluating compliance to 14 CFR § 25.1555(a).

17. TESTING PRACTICES. This section describes hardware element testing, individual system testing, IMA system integration testing, aircraft ground testing, aircraft flight-testing, and maintaining configuration control of test plans/procedures/results. The applicant(s) should develop test plans for each of the appropriate testing categories. The test plans should be coordinated with and approved by the cognizant ACO. In addition to normal certification testing, the following testing should be addressed for IMA systems. (Note: This is not an exhaustive list.)

a. IMA Hardware Element Testing.

(1) Testing of the hardware elements should be accomplished by TSO testing for the TSO-C153 and functional TSOs.

(2) Additional tests required for the installation of the hardware elements that were not performed for TSO compliance (for example, additional environmental qualification or hardware device testing) should be conducted.

(3) Hardware elements that have functionality not addressed by a functional TSO should be tested to the aircraft system performance and environmental specifications.

b. Individual System Testing.

(1) Individual functions (for example, Flight Management System, Braking System) within the overall IMA system should be tested with associated power, controls, sensors, and displays.

(2) System-level testing should focus on performance and functional testing. It is beneficial for the system integrator to provide several early opportunities for human factors and flight crew interface evaluations. Early evaluation allows a timely identification of human factors and flight crew interface issues so that changes can be made with acceptable

technical, schedule, and economic impacts. It also allows for FAA evaluation of the design to instill confidence in the applicant's design decisions and to potentially reduce certification risks. System-level testing is typically the earliest opportunity for this type of evaluation.

(3) System-level testing may include:

- (a) Power-up testing.
 - (b) Verification of correct software part number.
 - (c) Hardware and software integration testing for the specific system and functions.
 - (d) Function and feature testing (for example, "functions" include things like Global Positioning System (GPS) navigation, while "features" are parts of the system, such as a zoom-in button).
 - (e) BIT versus external test equipment (for example, an Instrument Landing System (ILS) test set or a Traffic Alert and Collision Avoidance System (TCAS) test set) to assure correct interfacing.
- (4) Environmental qualification tests requiring functional software should typically be performed as part of the system-level environmental qualification testing.
- (5) Robustness testing to verify that the system responds correctly to abnormal conditions, such as corrupted or invalid data inputs, and to ensure that assumptions made during the safety assessment and system design are valid.

c. IMA System Integration Testing.

- (1) This testing addresses the integration of all hardware elements, functional software, displays, controls, sensors, and power sources representing the configuration intended for aircraft certification.
- (2) Typically, the same issues are addressed as in the individual system testing, plus the addition of functional compatibility and interoperability among systems.
- (3) Worst-case system testing or analysis should be performed to verify the performance of the functionality of the overall system (for example, data communication, throughput, design margins, cooling, and power consumption).
- (4) HIRF testing should be performed as part of the system integration tests for systems whose failures may contribute to catastrophic or hazardous failure conditions for the aircraft or engine.

(5) Lightning testing should be performed as part of the system integration tests for systems whose failures may contribute to major, hazardous, or catastrophic failure conditions for the aircraft or engine.

(6) System integration testing is another opportunity for human factors and flight crew interface evaluations. This enables a timely identification of human factors and flight crew interface issues so that changes can be made with acceptable technical, schedule, and economic impacts. It allows for FAA evaluation of the design to instill confidence in the applicant's design decisions and to potentially reduce certification risks.

(7) Integration testing should include evaluation of built-in-test functionality, fault isolation, detection and annunciation, and maintenance diagnostics. Integration testing should also be used to validate assumptions made in the aircraft level and IMA safety assessment, where possible.

(8) System testing should verify independence assumptions between or among functions supported by the IMA system, as documented in the SSA. Verification includes assurance that functions are not affected during malfunction and/or loss of other independent systems and hardware elements, including short-circuited power. Analysis to identify worst-case conditions may be used to minimize the testing effort. It is recommended that this testing be performed in the laboratory but may be performed as part of the aircraft ground test.

d. Aircraft Ground Testing.

(1) The applicant should submit a ground test plan. Hardware elements must be installed and software components loaded in the conformed configuration that represents the intended type design. Ground tests should evaluate the high temperature extremes and may evaluate the low temperature operating conditions.

(2) If system integration testing is not performed in a laboratory, then it must be performed on the aircraft.

(3) Typically, Electro-Magnetic Compatibility (EMC) testing is performed during the aircraft ground tests.

(4) Some human factors and flight crew evaluations may be performed on the ground (for example, night lighting, equipment location, and hazardous system malfunctions).

(5) Ground testing should also include IMA system testing with simulated malfunctions or losses, where possible. This testing should verify that functions are not affected during malfunction and/or loss of other independent systems and hardware elements, including loss of power (for example, that none of the non-GPS IMA systems are

affected by a GPS hardware module failure). These tests should be a subset of the integration testing addressed in paragraph 17.c.(8) above.

(6) Compliance of colors of advisories, cautions, and warnings with the regulations (such as, 14 CFR § XX.1322) and applicable guidance of advisory materials (for example, AC 25-11). (Portions of alerting system evaluation may be performed in flight-test.)

(7) Equipment cooling testing.

e. Aircraft Flight-Testing. Hardware elements must be installed and software components loaded in the conformed configuration that represents the intended type design. Situational awareness, human factors, and flight crew workload must be considered with respect to the certification requirements of the type design for both normal and abnormal operational requirements. Certain tests may not be able to be conducted during flight due to safety reasons and may be accomplished during ground testing or simulator testing, as agreed with the cognizant ACO. The fidelity of simulator testing must be commensurate with the complexity of the task and the degree of system integration at the aircraft level. The following areas of each installation should be evaluated by flight-testing for compliance with the applicable airworthiness regulations (for example, 14 CFR Parts 23, 25, 27, or 29) and impact on crew workload:

- (1) Evaluation of functions, features, and abnormal modes of the IMA system.
- (2) Evaluation of flight crew situational awareness of selected/deselected systems/modes during normal and degraded system scenarios.
- (3) Evaluation of the crew alerting system(s).
- (4) Evaluation of pilot visibility of each required instrument from each pilot station, to include normal and reversionary modes.
- (5) Human factors aspects of control system (for example, cursor-based control or other control devices, location and accessibility of controls).
- (6) Any tests unique to the new equipment or new/novel functions. This should include simulated IMA system failures and the capability of the backup systems to take over without interruption.
- (7) Electrical bus switching. Testing should include monitoring the response of the different IMA systems with buss interruptions and transients.

f. Configuration Control During Flight-Testing. Because of the dynamic and complex nature of IMA system configuration, "red label" units are often used during the certification flight-testing. The hardware elements and software configurations may change several times during the flight-test program. Therefore, the applicant should define

an IMA system configuration control process to use during the certification flight-test program. This process should include "flight-test conformity," as well as a means of assuring that the final product conforms to what was tested, and that the test results for configurations tested that were different than the final IMA system configuration are valid. Examples of items to be addressed in the process are:

- (1) Inclusion of the aircraft-level safety assessment and a summary of each functions's criticality and worst case failure conditions.
- (2) A process to identify and control the configuration of each hardware element and software component of the IMA system during the certification flight-test program.
- (3) A process for analyzing the interoperability effects of all changes during the flight-test program. For example, a process to determine how changes to some software components may affect other software components or functions in the IMA system.
- (4) A change impact analysis process for analyzing the effect of changes during the test program on the aircraft-level safety assessment and other systems, and the validity of previously conducted tests.
- (5) A process for analyzing the effect of every change on the overall functionality of the final IMA system and the validity of previous test results.

18. ROLES AND RESPONSIBILITIES OF IMA SYSTEM APPLICANTS. There are a number of different levels of roles and responsibilities that should be addressed in order for the overall IMA system certification to occur. This section identifies the major roles and responsibilities for the TSO-C153 applicant, the functional TSO applicant, and the TC/STC/ATC/ASTC applicant. All applicants are strongly encouraged to coordinate with the certification authorities throughout the entire IMA system development.

a. TSO-C153 Applicant Roles and Responsibilities:

- (1) Apply for TSO-C153.

NOTE: Due to the complexity of IMA projects, it is recommended that the TSO manufacturer coordinate with the FAA early in the program.

- (2) Build a minimum performance standard (MPS) in accordance with TSO-C153. Ensure that all the appropriate items in TSO-C153 Appendix 1 have been documented and approved by the FAA.

- (3) Develop and implement part identification and configuration management functionality into hardware elements. The configuration management and part identification approach should follow the guidance of sections 10 and 11 of this AC.

(4) Coordinate with TC/STC/ATC/ASTC applicants who will be integrating and installing the hardware elements on the aircraft to ensure that the relevant issues are identified and addressed as early as possible.

(5) Design and build hardware elements per TSO-C153 and the MPS.

(6) Perform the tests necessary to demonstrate compliance with the TSO-C153 and the MPS. If special purpose test software is used for environmental qualification testing, the manufacturer must verify, validate, and control the configuration of the hardware elements and software components to ensure the validity of the testing

(7) Submit the data package (that is, information in section 5 of TSO-C153, including the minimum performance standard) to the cognizant FAA ACO for review and issuance of TSO authorization.

(8) Apply for changes to TSO-C153 elements, as design changes occur. Notify TC, STC, ATC, ASTC holder and functional TSO holder of the design change.

NOE: During the manufacturing airworthiness determination of the hardware elements identified with TSO-C153 authorization, functional software must not be installed on the hardware element in order to comply with 14 CFR § 21.603.

b. Functional TSO Applicant Roles and Responsibilities.

(1) Apply for functional TSO.

(2) Design the system in accordance with the appropriate TSO standards.

(3) Identify and address all integration and installation issues with the TSO-C153 and TC/STC/ATC/ASTC applicants.

(4) Perform tests to demonstrate compliance to the functional TSO or functional performance standards. Some EQT may not have been accomplished for TSO-C153 authorization. The functional TSO applicant must demonstrate that all testing, including EQT, required for the functional TSO has been accomplished. If special purpose test software is used for environmental qualification testing, the applicant must verify, validate, and control the configuration of the software to ensure the validity of the testing. Credit may be applied for EQT that were conducted for the TSO-C153 authorization, if appropriate.

(5) Submit data package required by the functional TSO to the cognizant FAA ACO for review and issuance of TSO authorization.

(6) Apply for changes to functional TSOs, as design changes occur. Notify TC, STC, ATC, and ASTC holder of the design change.

c. TC, STC, ATC, ASTC Applicant Roles and Responsibilities.

(1) Develop and submit a Project-Specific Certification Plan (PSCP) for the IMA system to the cognizant ACO for approval. It is recommended the PSCP include a detailed conformity plan that addresses all hardware elements and software components' conformity and installation conformity inspections (including the plan for addressing any "red label" units). Additionally, the PSCP should address all integration and installation of all components of the IMA system (including, TSO-C153 and functional TSO hardware elements and software and any third party or non-TSO'd elements).

(2) Define aircraft system and performance requirements.

(3) Perform aircraft-level safety assessment per section 9 of this AC and submit to ACO.

(4) Integrate the IMA system into the aircraft or engine. (Note: The TC/STC/ATC/ASTC applicant is responsible for system integration in the aircraft or engine, IMA system-level testing, ground testing, and flight testing.)

(5) Ensure that all TSO assumptions are not violated in the installation (for example, relocation of GPS card does not invalidate environmental qualification credit for the GPS TSO).

(6) Integrate any third-party hardware modules or software.

(7) Verify software and complex electronic hardware issues were properly addressed for the installation per sections 12 and 13 of this AC.

(8) Determine appropriate aircraft environmental conditions and ensure that EQT were performed (reference section 15 of this AC).

(9) Perform necessary tests, including those addressed in section 17 of this AC.

(10) Perform human factors and flight crew evaluations of the IMA system, as described in section 16 of this AC.

(11) Ensure that IMA system meets all airworthiness requirements (see section 20 of this AC).

(12) Submit all appropriate certification data (for example, safety assessments, hardware design assurance data, software data, test plans, test results, compliance reports) to ACO for approval.

- (13) Maintain aircraft system configuration management per sections 10 and 11 of this AC.
- (14) Evaluate and document changes to IMA system and elements per 14 CFR § 21.93.
- (15) Ensure that aircraft design features address safety and comply with the regulations (see section 14 of this AC).
- (16) Evaluate third party hardware modules installed in the IMA system and demonstrate compliance to regulations (see section 19 of this AC).

NOTE: If a manufacturer desires production authority, the quality assurance, inspection, and test procedures data must be submitted for issuance of production approval.

19. ADDITIONAL GUIDANCE FOR THIRD PARTY MANUFACTURERS. For purposes of this section, a third party manufacturer is a developer of a hardware module to be installed into a TSO-C153 authorized rack or cabinet. However, this hardware module developer is not the developer of the rack or cabinet and is not the primary IMA system integrator. A third party manufacturer may have many approaches to integrating their hardware module into an IMA system. This section provides additional guidance to be considered by third party manufacturers and applicants of IMA systems using third party hardware modules.

a. Third party hardware modules may or may not obtain TSO-C153 authorization. In order to not violate the TSO-C153 authorization granted for the rack or cabinet, the third party manufacturer's hardware module must be shown to meet the environmental, interoperability, configuration management, and regulatory requirements of the installation. The third party hardware module must also participate in the robust automatic configuration management system by providing configuration identification information to the system. This requires close cooperation between all manufacturers involved.

b. Some third party manufacturers may seek functional TSO authorization on their hardware module as part of a TSO authorized system (for example, GPS or Terrain Awareness Warning System (TAWS) TSO authorization). Hardware modules seeking functional TSO authorization should be designed and tested to operate in an environment that is valid for the actual environment. During the functional TSO authorization, the configuration of all components needed for system operation should be specified. The expected installation approach and limitations should be documented when the TSO package is submitted to the FAA. During the actual installation of such hardware modules into IMA systems, TC/STC/ATC/ASTC applicants should ensure that the assumptions of the TSO authorization are not violated (for example, ensure that the actual environment is not harsher than the environment authorized by the TSO authorization).

c. Some third party hardware module manufacturers will not apply for any TSO authorization (neither TSO-C153 authorization nor a functional TSO authorization). This might happen because a functional TSO authorization doesn't exist (for example, braking system or power distribution system) or because a TSO authorization isn't desirable. Such hardware modules will be approved as part of the TC/STC/ATC/ASTC. The environmental, interoperability, configuration, and regulatory requirements must be demonstrated as part of the TC/STC/ATC/ASTC process. Regardless of the approach taken by the third party manufacturer, third party hardware modules should be evaluated at the installation level to verify that all requirements are met. Third party manufacturers are suppliers to the TC/STC/ATC/ASTC applicant and must be controlled during production by the TC/STC/ATC/ASTCs quality assurance organization.

d. Some third party hardware modules may be designed to install field-loadable software (FLS). The FLS should meet the criteria of sections 10, 11, and 12 of this AC and the requirements of any functional TSOs involved. Additionally, the FLS should be carefully controlled. Loading software into third party hardware modules may or may not be through the same port as other hardware modules in the IMA system. The loading approach must be carefully controlled to address configuration management, security, and verification of correct loads. There must be a robust loading process to ensure that incorrect software cannot be loaded and that other software cannot be inadvertently changed, when the third party hardware module is loaded.

e. All hardware modules installed into a C153 authorized rack or cabinet should have a data sheet, similar to the one shown in Appendix 2 of TSO-C153. A manufacturer can submit data in a different format, but it must contain all of the information listed in Appendix 2 of the TSO-C153. If a particular portion of the data sheet does not apply, mark it "Not Applicable."

20. AIRWORTHINESS CONSIDERATIONS.

a. **Initial Installation.** For initial approval of a particular equipment installation, the scope of the applicant's program should be directed toward airworthiness approval through the TC or STC process. This AC is also appropriate for applicants who exercise their Designated Organization Authority (DOA/ODAR) or Designated Alteration Station (DAS) authorization for STC approval. As part of the ATC or ASTC program, the applicant should determine if the changes to the type certificated aircraft constitute a significant change, but not one so extensive as to require a new TC in accordance with 14 CFR § 21.19. If the design change is considered significant, the certification program should be coordinated with the responsible FAA Directorate and cognizant ACO, as described in FAA Order 8110.4[.]

b. **Follow-on Installations.** For equipment that has already obtained initial installation approval by the TC or STC process, approval may be obtained using either the STC, ATC, ASTC, or FAA Form 337 (Major Repair and Alteration) process subject to the restrictions of paragraph (1) below.

(1) For installations on aircraft operated under 14 CFR part 91 and with the applicant providing acceptable IMA system installation or alteration instructions, approval for return to service can be accomplished using FAA Form 337. Because of the complexity of IMA systems, the FAA Form 337 should be limited to return to service. Installation variations acceptable for approval by FAA Form 337 must not impact system or aircraft operation (for example, slight location changes, minor fastener changes, and so forth, could use the FAA Form 337 process). Therefore, it is recommended that the FAA Form 337 process be limited to minor aircraft installation variations from a TC/STC/ATC/ASTC that approves an IMA system for that particular aircraft model. Any operational variation in installation should only be accomplished by STC or amended TC.

NOTE: Part 121 operators and Part 145 repair stations may not require FAA Form 337 for return to service because their return to service method is specified in their FAA approved manuals.

(2) When using the STC or ATC process, all required data pertaining to the installation should be submitted to the ACO. These data should include the manufacturer's operating and installation or alteration instructions, safety analysis for the installation or alteration, installation or alteration details, structural substantiation, system wiring diagrams, ground test plans, flight test plans, and test results as a minimum.

(3) Because of the complexity of IMA system installations and alterations, it is highly recommended that initial Designated Alteration Station (DAS) and Delegation Option Authorization (DOA/ODAR) IMA projects have significant ACO participation.

c. Change Impact Analysis. When a change is made to the IMA system, a change impact analysis should be performed. The change impact analysis should determine whether the change could adversely affect safe operation of the system or product. The following are examples of areas that could have an adverse impact on safety or operation:

(1) **Safety-related information is changed.** For example:

(a) Previous hazards, as identified by the system safety assessment, are changed.

(b) Failure condition categories, as identified by the system safety assessment, are changed.

(c) Software levels or electronic hardware device design assurance levels are changed.

(d) Safety-related requirements, as identified by the system safety assessment, are changed.

(e) Safety margins are reduced.

(f) Validity of the environmental qualification testing is affected.

(2) Operational or procedural characteristics of the aircraft are changed in a manner that could adversely affect flight safety as a result of the software change. For example:

(a) Aircraft operational or airworthiness characteristics are changed.

(b) Flight crew procedures are changed.

(c) Pilot workload is increased.

(d) Situational awareness, warnings, and alerts are changed.

(e) Displayed information to make flight decisions is changed.

(f) Assembly and installation requirements are changed.

(g) Changes that affect equipment interchangeability and/or interoperability with other equipment.

(h) Certification Maintenance Requirements are changed or added.

(3) New functions or features are added to the existing system functions that could adversely impact flight safety.

(4) Processors, interfaces, and other hardware components or the environment are changed in such a way that safety could be adversely affected. See RTCA/DO-178B, section 12.1.3, and RTCA/DO-254, sections 11.1 and 11.2.

(5) Life cycle data (for example, requirements, code, and architecture) is significantly changed in such a way that it could adversely affect safety.

d. Change Classification. The change impact analysis should be used to justify minor or major classification of the change. The major and minor change classification procedures should also evaluate the interoperability of the changed components. The TC/STC/ATC/ASTC holder must control all changes, regardless of the classification.

21. MAINTENANCE AND CONTINUED AIRWORTHINESS GUIDANCE.

a. Maintenance instructions. TC/STC/ATC/ASTC applicant should specify instructions for handling, storage, shipping, and installation of hardware elements in the IMA system.

b. Maintenance diagnostics. See paragraph 14.d of this AC.

c. Master Minimum Equipment List (MMEL). The applicant should develop a proposed MMEL with appropriate justification during the TC/STC/ATC/ASTC effort. Procedures for safely dispatching the aircraft using the MMEL should be developed. Any MMEL allowance should be determined with consideration given to the criticality of the IMA functionality. MMEL allowances should be substantiated based on the aircraft-level functional hazard assessment. The proposed MMEL, justification, and procedures should be submitted to the Flight Operations Evaluation Board Chairman in the Aircraft Evaluation Group (AEG) for FAA evaluation and approval. If modifications are made to the IMA system, the following guidance should be considered regarding the MMEL:

(1) The MMEL may need to be revised to address the IMA system hardware or software changes. Once the MMEL addresses the IMA equipment changes, it may be submitted to the FAA for approval.

(2) The FAA approving office (for example, Flight Standards District Office) should coordinate with ACO engineering when evaluating the revised MMEL.

d. Operational Approval. For Operational approval of IMA systems the applicant must address the requirements of 14 CFR 21.5(b) for Instructions for Continued Airworthiness.

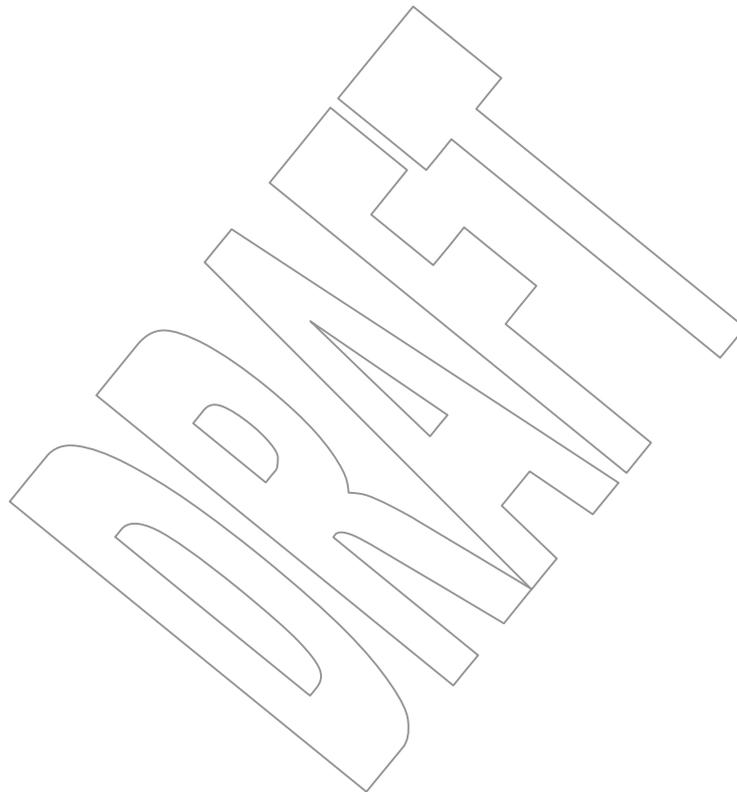
APPENDIX 1 – Partial List of Functional TSOs.

The following is a partial list of the FAA TSOs that might be considered as functional TSOs in IMA systems. Note that applicants may apply for a TSO that does not adequately address all of the functionality in the system. Alternatively, applicants may apply for multiple TSOs, since no single TSO applies to all functions. If the applicant applies for multiple TSOs for a single system, that combination of TSOs may result in the system being considered complex or integrated, even though the individual TSOs were not.

TSO NUMBER		SUBJECT TITLE
TSO-C2d	6/14/89	Airspeed Instruments (using electronic sensing)
TSO-C4c	4/1/89	Bank and Pitch Instruments
TSO-C9c	9/15/60	Automatic Pilots
TSO-C10b	9/1/59	Altimeter, Pressure Actuated, Sensitive Type
TSO-C52b	5/30/95	Flight Director Equipment
TSO-C92c	3/19/96	Airborne Ground Proximity Warning Equipment
TSO-C93		Airborne Interim Standard Microwave Landing System Converter Equipment
TSO-C101	2/19/87	Over Speed Warning Instruments
TSO-C104	6/22/82	Microwave Landing System (MLS) Airborne Receiving Equipment
TSO-C105	6/13/84	Optional Display Equipment for Weather and Ground Mapping Radar Indicators
TSO-C106	1/15/88	Air Data Computer
TSO-C110a	10/26/88	Airborne Passive Thunderstorm Detection Equipment
TSO-C115b	9/30/94	Airborne Area Navigation Equipment Using Multi-Sensor Inputs
TSO-C117a	8/1/96	Airborne Windshear Warning and Escape Guidance Systems for Transport Airplanes
TSO-C118	8/5/88	Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, TCAS I
TSO-C119a	4/9/90	Traffic Alert and Collision Avoidance System (TCAS) Airborne Equipment, TCAS II
TSO-C123	8/2/96	Cockpit Voice Recorder Systems
TSO-C129a	2/20/96	Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)
TSO-C146	10/6/99	Stand-Alone Airborne Navigation Equipment Using The Global Positioning System (GPS) Augmented By The Wide Area

		Augmentation System (WAAS)
TSO-C147	4/6/98	Traffic Advisory System (TAS) Airborne Equipment
TSO-C151a	11/29/99	Terrain Awareness and Warning System

Note: The revisions of TSOs may change. This list is only for reference purposes. Applicants should ensure that they are using the appropriate TSO.



IVT Course Evaluation Form

Appendix D

IVT or Self-Study Video

Evaluation Form

Integrated Modular Avionics (IMA) IVT course # 62834; Self-Study Video #25834

We want your candid opinion on the course you just completed. Your feedback will help us to provide the best possible products and services. Please respond to the questions below. If you have completed via IVT, your instructor will prompt you when to enter your answers in your keypad. If you have completed the video option, complete this form manually and return to your ATM. You must complete and return this evaluation form to your ATM in order to get credit for the video option.

A = Highly Satisfactory B = Satisfactory C = Somewhat Satisfactory
D = Not at all Satisfactory E = Not applicable

1. Clarity of objectives	A	B	C	D	E
2. Clarity of instructions	A	B	C	D	E
3. Ease of navigation	A	B	C	D	E
4. Relevance of content to your job	A	B	C	D	E
5. Relevance of exercises to your job	A	B	C	D	E
6. Effectiveness of presentation of content	A	B	C	D	E
7. Quality of feedback	A	B	C	D	E
8. Quality of instructor/student communication	A	B	C	D	E
9. Supervisor support in course completion	A	B	C	D	E
10. Overall quality of the course	A	B	C	D	E

*Integrated Modular Avionics (IMA)
IVT course # 62834; Self-Study Video #25834
October 23-24, 2002*

(This page is optional: complete manually)

What information was most useful to you and why?

What information was least useful to you and why?

Additional comments:

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