U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: **INSTALLATION OF ELECTRONIC DISPLAYS IN PART 23 AIRPLANES** **Date:** 3/12/99 **Initiated By:** ACE-100 **AC No:** 23.1311-1A **Change:**

1. PURPOSE.

This advisory circular (AC) provides an acceptable means, but not the only means, of showing compliance with Title 14 of the Code of Federal Regulations (14 CFR) applicable to the installation of electronic displays in Part 23 airplanes. This material is neither mandatory nor regulatory in nature and does not constitute a regulation.

2. CANCELLATION.

AC 23.1311-1, Installation of Electronic Display Instrument Systems in Part 23 Airplanes, dated June 11, 1993, is canceled.

3. RELATED REGULATIONS AND DOCUMENTS.

3.1 REGULATORY SECTIONS:

These acceptable means of compliance refer to the applicable sections of 14 CFR Part 23. The corresponding paragraphs of the former Civil Air Regulations (CAR) are shown in parenthesis for airplanes certificated under CAR, Paragraph 3.

§ 23.771 (3.381)	Pilot compartment.
§ 23.773 (3.382)	Pilot compartment view.
§ 23.777 (3.3841)	Cockpit controls.
§ 23.901 (3.411)	Powerplant: Installation.
§ 23.1301 (3.651 and 3.652)	Equipment: Function and installation.

§ 23.1303 (3.655(a))	Flight and navigation instruments.
§ 23.1305 (3.655(b))	Powerplant instruments.
§ 23.1309	Equipment, systems, and installations.
§ 23.1311	Electronic display instrument systems.
§ 23.1321 (3.661 and 3.662)	Arrangement and visibility.
§ 23.1322	Warning, caution, and advisory lights.
§ 23.1323 (3.663)	Airspeed indicating system.
§ 23.1326	Pitot heat indication systems.
§ 23.1331 (3.668)	Instruments using a power source.
§ 23.1335 (3.669)	Flight director systems.
§ 23.1337 (3.6.71, (3.672, 3.673, and 3.674)	Powerplant instruments installation.
§ 23.1351 (3.681, 3.682, and 3.685)	Electrical Systems and Equipment: General.
§ 23.1353 (3.683)	Storage battery design and installation.
§ 23.1357 (3.690, 3.691, and 3.692)	Circuit protective devices.
§ 23.1359	Electrical system fire protection.
§ 23.1361	Master switch arrangement.
§ 23.1365 (3.693)	Electric cables and equipment.
§ 23.1367 (3.694 and 3.695)	Switches.
§ 23.1381 (3.696 and 3.697)	Instrument lights.
§ 23.1431 (3.721)	Electronic equipment.
§ 23.1501 (3.735 and 3.737)	Operating Limitations and Information: General.
§ 23.1529	Instructions for Continued Airworthiness.
§ 23.1541 (3.755)	Markings and Placards: General.
§ 23.1543 (3.756)	Instrument markings: General.
§ 23.1545 (3.757)	Airspeed indicator.
§ 23.1549 (3.759)	Powerplant and auxiliary power unit instruments.
§ 23.1551 (3.760)	Oil quantity indicator.
§ 23.1553 (3.761)	Fuel quantity indicator.
§ 23.1555 (3.762)	Control markings.
§ 23.1559	Operating limitations placard.
§ 23.1581 (3.777)	Airplane Flight Manual and Approved Manual Material: General.

§ 23.1583 (3.761 and 3.778)	Operating limitations.
§ 91.205	Powered civil aircraft with standard category U.S. airworthiness certificates: Instrument and equipment requirements.
§ 121.305	Flight and navigational equipment.
§ 135.149	Equipment requirements: General.
§ 135.159	Equipment requirements: Carrying passengers under VFR at night or under VFR over-the-top conditions.
§ 135.163	Equipment requirements: Aircraft carrying passengers under IFR.

Note: Part 23 contains many sections that indicate the need for an indicator or a warning. These sections may be met with lights, mechanical, or electro-mechanical means, to which this AC would not apply. However, these sections could also be met by electronic displays. If so, then this AC would apply to those electronic displays.

3.2 ADVISORY CIRCULARS AND RELATED DOCUMENTS:

Copies of current editions of the following publications may be obtained free of charge from the U.S. Department of Transportation, Subsequent Distribution Office, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785:

AC 20-115B	Radio Technical Commission for Aeronautics (RTCA), Inc., RTCA/DO-178B
AC 20-136	Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning
AC 21-16D	RTCA, Inc. Document DO-160C
AC 23-15	Small Airplane Certification Compliance Program
AC 23.1309-1C	Equipment, Systems, and Installations in Part 23 Airplanes
AC 25-11	Transport Category Airplane Electronic Display Systems
DOT/FAA/CT-96/1	Human Factors Design Guide
DOT/FAA/AAR-95/3	FAA Aircraft Certification Human Factors and Operations Checklist for Standalone GPS Receivers

Copies of current editions of the following AC's may be purchased from the Superintendent of Documents, P. O. Box 371954, Pittsburgh, PA l5250-7954. Make check or money order payable to the Superintendent of Documents:

AC 20-88A	Guidelines on the Marking of Aircraft Powerplant Instruments (Displays)
AC 23-8A and AC 23-8A, Change 1	Flight Test Guide for Certification of Part 23 Airplanes

3.3 TECHNICAL STANDARD ORDER:

A copy of the current edition of the following publication may be obtained from the Federal Aviation Administration, Aircraft Certification Service, Aircraft Engineering Division, Technical Programs and Continued Airworthiness Branch—AIR-120, 800 Independence Avenue, SW, Washington, DC 20591:

TSO-C113	Airborne Multipurpose Electronic Displays

3.4 INDUSTRY DOCUMENTS:

Copies of current editions of the following publications may be obtained as follows and are an excellent resource material for additional information, guidance, and standards:

3.4.1 The RTCA documents are available from RTCA, Inc., Suite 1020, 1140 Connecticut Avenue, NW, Washington, DC 20036-4001:

RTCA/DO-160D	Environmental Conditions and Test Procedures for Airborne Equipment
RTCA/DO-178A/B	Software Considerations in Airborne Systems and Equipment Certification
RTCA/DO-187	Minimum Operational Performance Standards for Airborne Area Navigation Equipment using Multi-Sensor Inputs

3.4.2 The documents are available from Society of Automotive Engineers (SAE), Inc., 400 Commonwealth Drive, Warrendale, PA 15096-0001:

ARP 268G	Location and Actuation of Flight Deck Controls for Transport Aircraft
ARP 450D	Flight Deck Visual, Audible, and Tactile Signals

ARP 571C	Flight Deck Controls and Displays for Communication and Navigation Equipment for Transport Aircraft
ARP 926A/B	Fault/Failure Analysis Procedure
ARP 1068B	Flight Deck Instrumentation, Display Criteria and Associated Controls for Transport Aircraft
AIR 1093	Numeral, Letter and Symbol Dimensions for Aircraft Instrument Displays
ARP 1161	Crew Station Lighting—Commercial Aircraft
ARP 1782	Photometric and Colorimetric Measurement Procedures for Airborne Direct View CRT Displays
ARP 1834/A	Fault/Failure Analysis for Digital Systems and Equipment
ARP 1874	Design Objectives for CRT Displays for Part 25 (Transport) Aircraft
ARP 4032	Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays
ARP 4033	Pilot System Integration
ARP 4067	Design Objectives for CRT Displays for Part 23 Aircraft
ARP 4101	Flight Deck Layout and Facilities
ARP 4102	Flight Deck Panels, Controls, and Displays
ARP 4102/7	Electronic Displays
ARP 4103	Flight Deck Lighting for Commercial Transport Aircraft
ARP 4105	Abbreviations and Acronyms for Use on the Flight Deck (Revision A)
ARP 4256	Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft
ARP 4260	Photometric and Colorimetric Measurement Procedures for Airborne Flat Panel Displays (When Released)

ARP 4754	Certification Considerations for Highly Integrated or Complex Aircraft Systems
ARP 4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
AS 8034	Minimum Performance Standard for Airborne Multipurpose Electronic Displays
AS 8055	Minimum Performance Standard for Airborne Head Up Display (HUD)
ARP 5287	Optical Measurement Procedures for Airborne HUD

3.4.2.1 NOTE: Aerospace Recommended Practice's (ARP) 926A and 1834 have historically provided appropriate guidance for safety assessment of Part 23 airplanes. ARP's 926A and 1834 have been revised by ARP's 926B and 1834A, respectively. The scope sections of ARP's 926B and 1834A state that ARP 4761 provides updated methods and processes for use on civil aircraft safety assessment. When performing civil aircraft safety assessments, we recommend using ARP 4761, instead of ARP's 926B or 1834A. If ARP's 926B and/or 1834A are used, consider specific processes addressed in ARP 4761.

3.4.2.2 ARP's 4754 and 4761 state that these documents describe guidelines and methods of performing the safety assessment for certification of civil aircraft. They further state the guidance material in these Aerospace Recommended Practices (ARP's) were developed in the context of 14 CFR Part 25 and the Joint Aviation Requirements 25 (JAR 25). It is primarily associated with showing compliance with Part 25, § 25.1309/JAR 25.1309. A subset of this material may be applicable to non-25.1309 equipment. However, some of the processes included are not necessary or appropriate for Part 23 airplanes. ARP 4754 contains tutorial information on applying specific engineering methods that an applicant may wish to utilize in whole or in part.

NOTE: This AC is not intended to constrain the applicant to the use of these documents in the definition of their particular methods of satisfying the objectives of this AC. However, these documents do contain material and methods of performing the System Safety Assessment that an applicant may choose to use.

3.5 The Underwriter's Laboratories (UL), Inc., document listed below can be obtained from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112:

UL 1418	Implosion Protected Cathode Ray Tubes for Television Type Appliances, Revised 1992

4. BACKGROUND.

Title 14 CFR Part 23 was amended by Amendment 23-41, effective November 26, 1990. This amendment established airworthiness standards, in § 23.1311, for the installation of electronic display instrument systems in normal, utility, acrobatic, and commuter category airplanes. At the time the first electronic displays were developed, they were direct replacements for the conventional electromechanical components. Extensive integration of information is found in later designs. Prior to Amendment 23-41, most electronic display instrument systems were approved for installation in Part 23 airplanes by means of special conditions. Title 14 CFR Part 23 was further amended by Amendment 23-49, effective March 11, 1996, to harmonize the Federal Aviation Regulations with the Joint Aviation Requirements (JAR). The last revision of § 23.1311 removed redundant requirements and clarifies which secondary instruments are required, including the visibility requirements for those instruments.

5. APPLICABILITY.

This AC is generally applicable only to an applicant seeking issuance of a type certificate (TC), an amended type certificate (ATC), or a supplemental type certificate (STC) for the approval of a new type design or a change in the type design.

6. DEFINITIONS.

Refer to AC 23.1309-1C for the appropriate definitions.

7. DISPLAY DESCRIPTION.

The following paragraphs give a very brief description of an electronic display. They do not cover all the capabilities and details of these displays or the information presented on them.

7.1 General:

7.1.1 Electronic displays have replaced many of the traditional electromechanical and analog instruments, which provide flight and powerplant information. The major display technologies now used are multicolor cathode-ray tubes (CRT's), liquid crystal displays (LCD's), electroluminescence, plasma, and light emitting diodes (LED's). The initial electronic displays mimicked the electromechanical flight and powerplant instruments. Colors, symbols, and formats resemble the conventional instruments.

7.1.2 Human Factors (HF) Considerations for Design of Electronic Displays. Electronic displays can be programmed to provide many innovative display flexibilities and features. Technology improvements in display design and integration can enhance pilot performance and improve situation awareness provided that these innovations are

designed using sound processes and appropriate design criteria that adequately account for human performance. The process should to be in place at the beginning of the design effort to be of benefit. An example of an acceptable process can be found in SAE ARP 4033, Pilot System Integration. This document provides an example of a structured approach that will ensure development, verification, and application of all human factors requirements to enhance overall system performance and integration. An example of appropriate human factors design criteria can be found in a multitude of places; however, one good source of data generated by the FAA is the "Human Factors Design Guide," document number DOT/FAA/CT-96/1. This document contains appropriate human factors guidance for displays and human computer interface and is available on the internet through the FAA website. An example of an appropriate HF evaluation for electronic equipment can be found in FAA report DOT/FAA/AAR-95/3, titled "FAA Aircraft Certification Human Factors and Operations Checklist for Standalone GPS Receivers."

7.1.3 A Functional Hazard Assessment (FHA) should be performed to identify and classify failure conditions including determining probable combinations of failures. Guidelines and reference material that can be used in performing an FHA can be found in AC 23.1309-1C.

7.2 Configuration:

Electronic displays may be installed in several configurations. A basic electronic display may provide only one flight or powerplant parameter, while more sophisticated systems integrate many parameters on one electronic display. One of the major design goals for these systems is the elimination of separate conventional gauges, instruments, and annunciators. Recent installations show a trend toward a higher degree of integration, which reduces visual scanning requirements. For example, an integrated primary flight display provides several parameters such as attitude, direction (heading), airspeed, and altitude. Other parameters are also being placed on the primary flight displays, including vertical speed, flight mode annunciators, and other types of guidance cues.

8. FLIGHT, POWERPLANT, AND NAVIGATION DISPLAYS.

8.1 Required Parameters:

Sections 23.1303, 23.1305, 23.1311, and 23.1321, in conjunction with the applicable operating rules (14 CFR Part 91 and Part 135), incorporate flight and powerplant instrument requirements for Part 23 airplanes. The navigation equipment requirements are given in operational rules specified in §§ 91.205, 135.161, and 135.165. Display requirements for navigation information are dependent on the navigation system installed in the aircraft. Instruments and equipment required for flights under Part 91 and Part 135 may be affected by the electronic display installation. These instruments and equipment

include gyroscopic bank and pitch, gyroscopic direction, gyroscopic rate-of-turn, slip-skid instruments, and other required communication and navigational equipment. Electronic displays permit presentation of this information on one display. Under these conditions, a failure in the electronic display may affect more than one required display parameter.

8.2 Instrument Function:

8.2.1 Regulations promulgated prior to Amendment 23-41 were based on single-fault or fail-safe concepts. A single failure would cause the loss of only one primary instrument function. Only mechanical or electromechanical instruments that function independently for the primary parameter display were envisioned; that is, flight and powerplant instruments were isolated and independent. In some cases, several other instrument functions (indication of the function, display, or indicator) are housed in a common case. Section 23.1309, Amendment 23-41, approved more advanced, complex systems which perform critical functions. Amendment 23-41 also incorporated § 23.1311 into 14 CFR Part 23, which provides the standards for electronic displays. Section 23.1311, Amendment 23-49 revised and clarified the secondary instruments and the visibility requirements.

8.2.2 Section 23.1311(b) states that "the electronic display indicators, including their systems and installations, and considering other airplane systems, must be designed so that one display of information essential for continued safe flight and landing will remain available to the crew, without need for immediate action by any pilot for continued safe operation, after any single failure or probable combination of failures." In general, without considering specific characteristics of an airplane design, information essential to continued safe flight and landing are attitude, airspeed, altitude, direction (track or heading) and any applicable propulsion parameter(s). Major common-mode failures should be addressed. These include such failures induced by software errors, lightning effects, electromagnetic interference, power transients, etc., that could simultaneously affect the display of more than one parameter.

8.3 Aircraft Electrical Power Source:

8.3.1 Each electronic display instrument system should be installed so that it receives electrical power from a bus that provides the necessary reliability per the § 23.1309 safety assessment without jeopardizing other essential or critical electrical loads connected to that bus. The applicant should provide a means indicating when adequate power is available for proper operation of the instrument.

8.3.2 Electronic displays may be sensitive to momentary power interruptions. Use techniques that reduce the momentary power interruptions or design the equipment so momentary power interruptions will not adversely affect the availability or integrity of essential information required for continued safe flight and landing. The category selected from RTCA/DO-160D for momentary power interruptions should be appropriate for the intended use. The attitude display being used by the pilot during the takeoff phase of

flight should be usable within one second after a momentary power interruption resulting from an engine failure. Large electrical loads required to restart an engine (e.g., turboprops and small jets) should not affect the availability or integrity of essential information required for continued safe flight and landing.

8.3.3 Each reversionary display should be powered from a source that is independent of the source for the primary display and should function independently from the primary display. The power source for each reversionary display should provide for uninterrupted operation for at least 30 minutes after failure of the power source for the primary display. The independent power source may be provided by manual or automatic means. Section 23.1353(h) requires a minimum supply of 30 minutes of electrical power to the essential loads for continued safe flight and landing of the airplane should a complete loss of the primary electrical power generating system occur, including the reversionary displays. The airplane's primary electrical power includes the airplane's electrical generating system and the airplane's starter battery when only one battery is installed.

8.4 FLIGHT DISPLAYS:

8.4.1 Primary Flight Parameters:

Attitude, airspeed, altitude, and direction (track or heading) are the primary flight parameters required in § 23.1311(a)(3) and (5). The primary flight parameters should be continuously displayed in the pilot's primary field-of-view. For the purpose of this paragraph, the acceptable primary field-of-view is approximately +/- 30° horizontally from the centerline of the pilot's seat forward, with the seat adjusted for the pilot's nominal eye position. Minimal head and eye movement is allowed to evaluate display positions that may fall outside this criterion. Pilot evaluation is required to determine if display positions that fall outside the criterion are acceptable. For additional guidance refer to SAE ARP 1068B listed in paragraph 3.4.2 of this AC. Secondary displays of primary flight parameters may be placed outside the primary field-of-view.

8.4.2 Reversionary Flight Displays (Modes*)*:

Reversionary flight displays are additional displays that can provide a secondary means to provide primary flight parameters.

8.4.2.1 Reversionary flight parameters should be presented by an independent (secondary) display to prevent complete loss of primary flight parameters due to a single failure. Reversionary flight parameters need not be continuously displayed as long as the parameters are available without crewmember action for any single failure or probable combination of failures. Primary parameters displayed continuously on the reversionary displays during critical phases of flight (e.g., example, takeoff, landing, and missed or final approach) are acceptable. Manual activation of reversionary displays through single action by the pilot is acceptable when procedures to activate them are accomplished prior to entering critical phases of flight.

8.4.2.2 Display of primary flight parameters on reversionary (secondary) displays need not be arranged in the basic T-configuration. However, the displays should be legible and usable from the pilot's position with minimal head movement.

8.4.3 Secondary Instrument:

A secondary instrument is an instrument that provides an additional means of information to the pilot in a different manner than the primary flight information. The secondary instrument, or combination thereof, provides the equivalent information. For additional information see the requirements cited in the reversionary flight displays in paragraph 8.4.2.

8.4.4 Display Usability:

Displays should be located in a position so the pilot(s) can monitor them with minimal head and eye movement between displays. Flight information should be legible, accurate, easily interpreted, sufficiently free of visual cutoff (viewing angle), parallax and distortion, for the pilot to correctly interpret it. The required secondary display(s) for attitude, airspeed, and altitude may be located at the co-pilot's position if usable from the pilot's position with minimal head movement.

8.4.5 Display of Attitude:

For flights under IFR conditions in Part 91 and Part 135 operations and under VFR at night for Part 135 operations, attitude information is required. The loss of all attitude information or the presentation of misleading attitude information could result in conditions where the pilot could not continue safe flight and landing of the airplane.

8.4.6 Display of Direction (heading or track):

The loss of direction (heading or track) information could result in reduced capability of the pilot to cope with adverse operating conditions. For flights under IFR conditions, the primary display of the direction parameter may be provided by a stabilized heading indicator. The reversionary display of direction may be provided by a non-stabilized magnetic direction indicator (compass).

8.4.7 Display of Altitude, Airspeed, and Magnetic Compass Information:

When the requirements of § 23.1303 (a), (b), and (c) were adopted into CAR, paragraph 3 and Part 23, it was envisioned that airspeed, altitude, and magnetic compass information would remain available to the pilot upon the loss of the airplane's primary electrical power. Airspeed and altitude functions were provided by pneumatically driven displays. For electronic displays, § 23.1311(a)(3) requires that the primary display of attitude, airspeed, and altitude not be inhibited in any normal mode of operation. Section 23.1311(a)(5)

requires an independent magnetic direction indicator, and either an independent secondary mechanical altimeter, airspeed indicator, and attitude instrument or individual electronic display indicators for the altitude, airspeed, and attitude. Guidance provided in paragraph 8.3 of this AC provides a means of compliance to satisfy the regulatory requirements for reversionary display power sources. Primary altitude or airspeed displays that require electrical power are acceptable, if means are provided for their continued operation upon loss of the airplane's primary electrical power, or if pneumatically driven instruments are available for the pilot's use.

8.4.8 Other Flight Parameters:

8.4.8.1 Rate-of-Turn Instrument:

In accordance with §§ 91.205 and 135.159, a rate-of-turn instrument is not required if a third attitude instrument usable though flight attitudes of 360° of pitch-and-roll is installed in accordance with the instrument requirements prescribed in § 121.305(j).

8.4.8.2 Slip-Skid Instrument:

The slip-skid information is required by §§ 91.205(d)(4) and 135.159(b), as applicable. It is suggested that the slip-skid display be located directly below the rate-of-turn instrument or the attitude display.

8.5 Powerplant Displays:

This section defines a means of presenting powerplant performance and condition information pertaining to the airplane’s operation, and provides guidelines as to when these functions should be displayed to the pilot. In general, there have been two methods used to accomplish this: (1) display raw engine parameters to the pilot for interpretation, or (2) collect powerplant data and have an automatic monitoring system interpret and report the powerplant condition to the pilot. The following evaluation criteria should be used when considering incorporating electronic powerplant displays.

8.5.1. Each airframe, engine, and airframe/engine interface with the operational characteristics of these systems needs to be evaluated by the FAA to determine the primary powerplant parameter requirements. For this evaluation, and as used in this section, a primary powerplant parameter is one needed to start the engine and set and monitor engine power within powerplant limitations.

8.5.2 For multiengine airplanes, arrange the display of powerplant parameters (function) so they are isolated from each other (electronically or mechanically). A failure or malfunction affecting the display or accuracy of any propulsion system parameter for one engine should not cause the loss of display or accuracy of any parameter for the remaining engine(s). If multiple propulsion parameters are integrated on one display, and the display fails, it is acceptable to provide a secondary propulsion parameter display.

8.5.3 No single failure, malfunction, or probable combinations of failures should result in the loss of powerplant information, or an erroneous display of powerplant parameters that would jeopardize continued safe flight and landing of the airplane. In most cases, for engines with limit protections, loss of powerplant displays with no additional failures will not cause immediate jeopardy to continued safe flight and landing.

8.5.3.1 A secondary display providing powerplant parameters may be used for cases of loss of a primary powerplant display provided the secondary display is located so the pilot can adequately view the powerplant parameters.

8.5.3.2 Throttle or power lever position may be used in place of lost powerplant display parameters. This would apply if throttle position or power lever position provides a positive indication of powerplant power level required to maintain safe flight to a landing, and has a means to preclude exceeding powerplant operating limits.

8.5.3.3 Each proposed airframe, engine, and airframe/engine interface, including appropriate human factors considerations, needs to be evaluated by the FAA to determine its adequacy. Appropriate procedures for operation of an integrated electronic powerplant display system should be in the Airplane Flight Manual (AFM).

8.5.4 Requirements for Continuous Display of Powerplant Information:

8.5.4.1 Display primary powerplant parameters continuously in the pilot's primary field-of-view when they are required. For example, a parameter defined as primary for engine start, but not for other normal engine operation, may only have to be displayed continuously during engine start. All parameters that are determined to be primary for other engine operations should be displayed continuously during these engine operations.

8.5.4.2 Prior to reaching or exceeding any operating limit, the required powerplant parameters should be indicated without pilot action. Crew attention to flight instrument displays required for continued safe flight and landing takes precedence over the continuous display of powerplant information that is not required for continuous safe flight and landing.

8.5.4.3 When a required display parameter is not displayed full time, adequate monitoring of the function should be provided. In addition, provide a manual select option for the pilot to display the information.

8.5.4.4 When any operating limit is reached or exceeded for the required powerplant parameter, the alerts for each phase of flight should be provided in a timely manner, and in a form that enables the flight crew to identify and carry out the necessary remedial actions.

8.5.4.5 The required powerplant information should be displayed continuously during a critical takeoff and landing phase of flight to minimize pilot distraction until an established rate of climb or minimum altitude is achieved.

8.5.5 Displays which provide multiple powerplant parameters should be such that any parameter, display, or alert will not suppress another display or alert that also requires immediate crew awareness necessary to conduct safe operation of the aircraft and engine(s). Alerts that could cause subsequent activation of other displays or alerts should be presented in a manner and form to ensure appropriate identification and prioritization of all significant hazards and required crew actions.

8.5.6 Direct-reading alphanumeric-only displays are most valuable when integrated with an analog display by adding a precise, quantitative indication to compliment an analog display's qualitative indication. Direct-reading alphanumeric powerplant displays should not be used in place of analog instruments to indicate values of engine parameters where trend or rate-of-change information is important. Direct-reading alphanumeric displays limit the flight crew's ability to assess trend information and result in reduced crew awareness. Direct-reading alphanumeric displays are also limited in their ability to provide a comparison of parameters from multiple engines or to check the general proximity of differing parameters against their individual limits. While these shortcomings can be compensated for with additional design provisions, the use of direct-reading alphanumeric displays should be made with care and evaluated for each airframe, engine, and airframe/engine integration. The required § 23.1305 powerplant instruments referred to as "indicators" should have the ability to provide trend or rate-of-change information, unless a finding of equivalence is made for direct-reading alphanumeric displays. The finding of equivalence should consider the following factors:

8.5.6.1 The visibility and relative location of the indicated parameter should be reviewed, including appropriate conditions of lighting and instrument panel vibration.

8.5.6.2 The ability to assess necessary trend or rate-of-change information quickly, including if and when this information may be needed during in-flight engine restarts.

8.5.6.3 The ability to assess how close the indicated parameter is relative to a limit.

8.5.6.4 For multiengine aircraft, the value to the crew of quickly and accurately comparing engine-to-engine data.

8.5.6.5 Compensating engine design features or characteristics that would forewarn the crew prior to the parameter reaching the operating limit (e.g., redline).

8.5.7 Marking of electronic displays on powerplant parameters is not always the most efficient or effective when performed in accordance with § 23.1549. AC 20-88A provides alternate methods of marking electronic powerplant displays. A finding of equivalence for

other methods of marking the displays may be performed. However, this should be evaluated on a case-by-case basis, which is dependent upon each airframe, engine, integration, and appropriate human factors considerations.

8.6 ELECTRONIC DISPLAYS OF NAVIGATION INFORMATION:

8.6.1 Guidance Information:

Information used by the pilot for steering commands, to monitor deviation from a navigation path, and information needed for immediate control of the airplane (pitch and roll attitude, altitude, airspeed and heading) must be in the pilot's primary field-of-view. Other data including identification of displayed information, alert flags and mode status indications must also be in the primary field-of-view. Secondary display of this information may be placed outside the primary field-of-view. For additional guidance, refer to specific TSO's and AC's.

8.6.2 Other Navigation Information:

Many navigation systems provide advisory information not immediately required by the pilot. This information is typically an aid to situation awareness, determination of system status, and reduction of pilot workload. The display for this data may be provided outside the pilot's primary field-of-view.

8.6.3 Display Integration:

8.6.3.1 Navigation guidance information may be integrated with the primary flight displays. Common examples are horizontal situational indicators (HSI's) that combine inputs from a directional gyro along with a course deviation indicator, or a flight director integrated with the attitude direction indicator (ADI). Additionally, information from more than one navigation source may be displayed separately or simultaneously.

8.6.3.2 In an integrated display, a failure in the navigation system should not inhibit the continued display of primary flight information.

8.6.3.3 If information from more than one navigation source can be displayed, the selected source should be continuously indicated to the pilot. If multiple sources can be displayed simultaneously, the display should indicate unambiguously what information is provided by each source and which is for guidance. Distinctive scales or points should differentiate between angular deviations (e.g., ILS, VOR) and linear deviations (e.g., GPS, FMS).

8.6.3.4 If the airplane is equipped with an autopilot, which is coupled to the guidance system, the input to the autopilot should coincide with the navigation source selected for guidance as described in paragraph 8.6.3.3 of this AC.

8.6.3.5 If other information is included on the guidance display, designers should exercise good human factors concepts, such as those outlined in Section 7 and 8 of the "HF Design Guide," Document No. DOT/FAA/CT-96/1.

8.6.4 Reversionary Navigation Displays:

8.6.4.1 Reversionary navigation displays are additional displays that can provide a secondary means to primary flight parameters. Reversion requirements for navigation display information are dependent upon the rules under which the aircraft is operated and the hazards associated with the loss of the display. No reversionary display is required for advisory navigation information not required by any rule or standard. Applicants should recognize that this paragraph applies only to navigation information, and that integration of other non-navigation information (for example, traffic, weather or flight parameters) may affect the hazards associated with the loss of the display. In these cases, the applicant should perform an FHA in accordance with AC 23.1309-1C. Reversionary displays may be either electronic or analog displays.

8.6.4.2 The reversionary (secondary) guidance display, if required, may be outside the pilot's primary field-of-view, if it is usable from the pilot's position with minimum head movement. See paragraph 8.4.2 of this AC.

8.7 Electronic Checklist:

Policy and guidance on electronic checklist displays are contained in AC 23-8A. If installed, an electronic checklist certification should include an FAA approved AFM or a Pilot's Operating Handbook (POH) which fulfills the requirements of an AFM.

9. AIRWORTHINESS CONSIDERATIONS.

9.1 GENERAL CRITERIA:

Evaluations of the electronic display system should consider airworthiness regulations, recommended practices, and standards from industry documents as listed in paragraph 3.4 of this AC. SAE documents AS 8034, ARP's 4067 and 1068B, and other documents listed in paragraph 3.4 may be used as guidelines for evaluating the visual performance parameters of the electronic displays relative to viewing, photocolorimetric, luminance characteristics, etc. The certification basis should include the regulatory sections, as appropriate, listed in paragraph 3.1 of this AC. Efforts should be made by the applicant to ensure that human performance considerations were adequately addressed throughout the design process. The applicant is encouraged to develop human performance considerations, including evaluation plans, and present them to the FAA early in the certification process.

9.2 CONTROLS AND DISPLAYS:

Controls and displays should be clearly visible and usable by the pilot, with the least practicable deviation from the normal position and from the line of vision when the pilot is looking forward along the flight path. Controls should have an appropriate amount of tactile feel (for example, detents, friction, stops or damping, etc.) so that they can be changed without undue concentration, which minimizes the potential for inadvertent changes. Controls need to be designed for the pilot to use intuitively. The controls should be easily identified and located in all lighting conditions, allow differentiation of one control from another, and have feedback through the system appropriate for the function being controlled.

9.3 LOCATION OF PRIMARY DISPLAYS:

9.3.1 Use the basic T-configuration for airplanes certificated under § 23.1321, Amendment 23-14 or later amendment. The basic T-configuration is defined as an arrangement where the airspeed and altitude data are centered, respectively, directly to the left and right of the attitude data, with the direction data located directly below the attitude data. Deviations from the basic T-configuration are acceptable if the droop angle (angle below the § 23.1321(d) position) is 15° or less, or when the elevated angle is 10° or less. These angles are measured from a horizontal reference line, which passes through the center of the attitude reference data with lines passing through the center of the airspeed and altitude data.

9.3.2 Deviations from the limits of +10°, -15° could be approved through an equivalent level of safety finding when these limits have been substantiated based on satisfactory service experience or research. Flight instrument arrangements having deviations greater than +10°, -15° from a horizontal reference line passing through the attitude display would require an equivalent level of safety finding. These findings should be human factors substantiation, and a complete display installation evaluation, considering the following items (See paragraph 7.1.2 of this AC):

(1) the display arrangement and its alignment to the normal line of the pilot's vision,
(2) cockpit view,
(3) the integration of other functions within the displays,
(4) the data presented, format, symbology, etc. within the display, and
(5) the ease of manipulating controls associated with the displays.

This evaluation should consider the different types of operations under which the airplane may be operated as defined by § 23.1559(b).

9.3.3 Use of unique displays or arrangements for attitude, altitude, airspeed and navigation data, integration of combinations of these functions, or rearrangement of them from the basic T-configuration may be approved when an equivalent safety finding, and a human factors evaluation is provided. Coordination with the Small Airplane Directorate is required.

9.4 FAILURE ISOLATION:

Any probable failure of the electronic display system should not degrade the normal operation of other required equipment connected to it or cause a flight hazard. Likewise, the failure of other equipment should not result in a failure or degraded performance of the electronic display.

9.5 SAFETY ASSESSMENTS:

Safety assessment methods are described in AC 23.1309-1C for identifying and classifying each Failure Condition and choosing the method(s) of safety assessment. Certification of electronic display systems may involve new and complex technology that may not utilize traditional service-proven design concepts. In this case, technically qualified judgment can be enhanced when a quantitative analysis is included in the safety assessment, whether or not a quantitative analysis is required by § 23.1309.

9.6 ELECTROMAGNETIC PROTECTION:

Current trends indicate increasing reliance on electrical/electronic systems for safe operations. For systems that perform flight, propulsion, navigation, and instrumentation functions, electromagnetic effects should be considered. AC 23.1309-1C provides additional guidance.

9.7 ENVIRONMENTAL CONDITIONS:

9.7.1 The equipment environmental limits established by the manufacturer should be compatible with the operating environment of the airplane. Evaluation of the equipment installation should consider factors such as the maximum operating altitude of the airplane, and whether the equipment is located within a temperature and pressure-controlled area. Applicable methods for testing the performance characteristics of equipment for specified environmental conditions are provided in RTCA/DO-160D. Either test or analysis, or both, ensures the compatibility between the operational environment and the environmental equipment category of the laboratory tests.

9.7.2 Electronic systems reliability is strongly related to the temperature of the solid-state components in the system. Component temperatures are dependent on internal thermal design and external cooling. In evaluating the temperature environment, consider the additional heat generated by the equipment, especially in a location where airflow is restricted. For determining if adequate cooling is provided, the evaluation should make

maximum use of previous data from comparable installations, thus limiting ground or flight tests to those installations that cannot be verified conveniently by other means. When the equipment-operating environment cannot be verified from previous experience or from an evaluation of temperature values in that equipment location, a cooling test should be conducted.

9.7.3 Attitude information should continue to be presented for a minimum of 30 minutes after the in-flight loss of cooling for the primary instrument when operating in the normal operating environment (temperature/altitude). If proper performance of the flight instrument function(s) is adversely affected due to in-flight loss of cooling, such failure conditions should be annunciated. Automatic over-temperature shutdown of the system should be considered a Failure Condition. Subsequent pilot actions should be documented in the AFM or on placards. These actions may include procedures to allow possible recovery of a system that has an over-temperature shutdown condition.

9.7.4 Annunciation of in-flight loss of cooling or fan monitors may not be required if it is shown by a safety analysis or test demonstration that a Hazardous or Catastrophic Failure Condition does not occur. The safety analysis should consider the reliability of the fans, redundancies of the functions, reversionary features (such as the ability to transfer critical functions), the annunciation of over-temperature and its response time, and the availability of other flight instrumentation. In some systems, cooling fans may only be installed to extend the life of the components and not to prevent a Failure Condition or shutdown of the equipment. These types of installations do not require fan monitors or temperature sensors. If the cooling fans are needed to prevent a Hazardous or Catastrophic Failure Condition, install fan monitors or another method to determine the status of the cooling fan during preflight checks.

9.8 SOFTWARE QUALIFICATION:

AC 20-115B discusses how RTCA/DO-178B provides an acceptable means for showing that software complies with pertinent airworthiness requirements. AC 23.1309-1C provides additional guidance on determining the Software Development Assurance Levels.

9.9 ELECTROMAGNETIC INTERFERENCE:

The electronic display instrument system should not be the source of objectionable conducted or radiated interference; nor should it be adversely affected by conducted or radiated interference from other equipment or systems installed in the airplane.

9.10 LEGIBILITY:

9.10.1 All displayed symbols and graphics should be clearly differentiable from one another and legible under all ambient illumination conditions. These conditions range from the night environment to direct sunlight through any window with the operational brightness at the luminance expected at the displays useful end-of-life state. The end-of-life luminance level

represents the expected value of the display brightness or minimum acceptable output that is established by the manufacturers. The display luminance should sufficiently provide a comfortable level of viewing with rapid adaptation when transitioning from looking outside the cockpit.

9.10.2 The luminance level of some displays will gradually diminish over the life of the unit. As part of the continued airworthiness requirements of § 23.1529, consider establishing an operational in-flight evaluation or maintenance evaluation to determine the minimum luminance level appropriate for the type of display, flight deck location, method of format, symbology, color used, etc. Although an automatic luminance control compensation is not required, the incorporation of such a system may decrease pilot workload. Regardless of whether an automatic luminance control is incorporated, provide a manual luminance control that is not adversely affected by failure of any automatic luminance control. Luminance control should not result in some information disappearing while other information remains visible.

9.11 SYMBOLOGY AND FORMAT:

9.11.1 Electronic displays in the cockpit should have related symbology and format, and should be consistent with their intended use. Appendix A to SAE ARP 4102/7 provides recommended symbols for Electronic Attitude Direction Indicators (EADI) and Primary Flight Displays (PFD) used in the flight deck of transport aircraft.

9.11.2 Symbols should be distinctive to minimize misinterpretation or confusion with other symbols utilized in the displays. The type and function of symbology should be clearly defined and appropriately classified for pilot understanding. Symbols representing the same functions on more than one display should utilize the same shape and/or color-coding. Also, use of flashing letters such as an "X" should be consistent: flashing, when used, should not be a caution for one parameter and a warning for another. Although the use of different types of symbols and formats among displays is discouraged, it may be acceptable, if the pilot can quickly and consistently recognize, interpret, and respond correctly to the symbol or format without incurring excessive pilot workload. For example, to indicate bank angle on the attitude displays in the cockpit, the type of pointer, ground (fix) or sky (moveable), should be similar for ease of interpretation and to minimize confusion.

9.11.3 Powerful formats are possible with an electronic display system, but too much information could result in clutter and reduce the efficiency of the pilot cues. Density of the information on the display should be compatible with the pilot's ability to recognize essential information and to minimize misinterpretation. Symbols and markings that are displayed during specific phases of flight may be removed at other times to reduce clutter. Consider the minimum display size for suitable readability. In the reversionary or compacted modes, when combining essential information on a display after another display or unit fails, the display format should not be confusing and the information should still be usable. Determine whether the reversionary or compacted mode is usable in normal

operation or only under emergency/abnormal operating conditions. Attitude, altitude, and airspeed information on the primary electronic display should not be inhibited during these modes. The approved configuration (whether basic-T configuration or a new configuration) should be preserved.

9.11.4 Presentation of airspeed, altitude, attitude, or certain propulsion parameters (as applicable) should convey to the pilot a quick-glance sense of rate and trend information. For airspeed and altitude, direct-reading alphanumeric displays may not be adequate on the primary display or on the standby instruments, but it is acceptable on a display used as supplementary information. If the applicant proposes a direct-reading alphanumeric display, they should demonstrate that the pilot response is equal to or better than the response with analog data (symbology) using a human factors evaluation (see paragraph 7.1.2. of this AC). The application of direct-reading alphanumeric displays to propulsion parameters should be made with care and it is subject to evaluation on a case-by-case basis. See paragraph 8.5.6 of this AC.

9.11.5 The display of a round dial-moving pointer with a digital readout is acceptable. To accommodate a larger operating range on a linear tape, adopt a moving scale display with the present value on a digital readout. Since the moving scale display typically does not provide any inherent visual cue of the relationship of present value to low or high airspeed limits, quick-glance awareness cues may be needed.

9.11.5.1 It is important that airspeed displays with moving scales provide appropriate low-speed awareness cues. The low-airspeed awareness cues should include a caution cue at some multiple of the stall speed below the normal operating range, and a warning cue above the stall warning speed (reference § 23.207(c)). The low airspeed awareness cues should be accurate for any airplane weight and flap configuration (usually angle-of-attack based). The applicant may choose a single conservative speed value to account for various weight and flap configurations (reference § 23.1545(a)(4)). Also, airspeed moving scale displays should have low-speed markings displayed in the lower airspeed scale and high-speed markings at the upper part of the scale.

9.11.5.2 Linear tape altimeter displays should include enhancements denoting standard 500- and 1,000-foot increments, and convey unambiguously, at a glance, the present altitude.

9.11.6 The heading display should provide a clear and unmistakable display of aircraft symbol and heading. A Horizontal Situation Indicator (HSI) should provide a clear and unmistakable display of aircraft position, heading, and track relative to the desired course/track. Pilot computation or interpretation should be minimized. On the primary display, the heading scale should have a mode that presents at least 180° of arc (270° is recommended). Other display formats may be acceptable and have been previously approved, but they need to be evaluated for human factors effectiveness.

9.11.7 Alternative formats or arrangements to those described above should have an adequate human factors evaluation (see paragraph 7.1.2 of this AC) completed to show that pilot response is timely and accurate to at least the level of the existing conventional displays. Human factors criteria should be defined as part of the design process. Because displays are a function of the specific cockpit layout and configuration, human factors evidence needs to be provided during certification. Specific human factors evaluation/studies that have been performed may support the configuration of displays and their location in the cockpit. An alternative is validating these evaluations/studies on each airplane during the installation process of the certification.

9.11.8 Integration of a number of display parameters into one common display provides distinct benefits, but raises some certification issues. New approaches presenting data and commands to the pilot are encouraged. To overcome the issues that may occur as a result of this integration, present the data and commands in a simple format to alleviate any increase in pilot workload. Specific areas to address are more intuitive guidance commands, combination of various navigation sensors, and similar functions. An example would be where the pilot selects a destination point (that is, a runway, an altitude, a fix, etc.). The system commands would provide guidance to that point, which could integrate the attitude sensor information, navigation data, air data information, etc., in a common display command element without the raw data being provided to the flight crew. The overall goal of this effort is to meet or exceed the existing cockpit performance levels currently in operational use while maintaining pilot workload at acceptable levels.

9.12 ANNUNCIATION:

9.12.1 The electronic display system should provide the pilot with visibly discernible annunciators that will indicate to the pilot the system operating modes. The visual annunciators should be distinctive under all normal lighting conditions and consistent with cockpit warnings. Under night lighting with the display average brightness at the lowest usable level for prolonged flight, visual annunciators should be usable. Annunciations should be consistently located in a specific area of the electronic display, to ensure proper interpretation by the pilot. Except for a flight director display, use of the display selection control position as annunciation is acceptable only when the control position is in direct view of the pilot, without head movement, and when the control position is obvious under all lighting conditions. When a failure occurs or when reversionary modes are used, an annunciation of abnormal system status shall be provided per § 23.1311(a)(7). The display should not provide hazardously misleading information. Annunciations that require flight crew action should be evaluated to determine if the required actions can be accomplished in a timely manner without exceptional pilot skill.

9.12.2 Where multiple system configurations and more than one sensor input are available for source selection, the switching configuration by annunciation or by selector switch position should be readily visible, readable, and should not be hazardously misleading to the pilot using the system. Labels for mode and source selection annunciators should be compatible throughout the cockpit. To ensure that the flight crew can properly interpret the system status, cautionary annunciation methods should be consistent when numerous interface switching configurations are possible.

9.12.3 Alerting messages should differentiate between normal and abnormal indications. Abnormal indications should be clear and unmistakable, using techniques such as different shapes, sizes, colors, flashing, boxing, outlining, etc. Individual alerts should be provided for each function essential for safe operation.

9.13 IMPLOSION PROTECTION:

The display unit should be designed and constructed to prevent implosion when the unit is operating over the range of normal and abnormal operating environment in the airplane. When a display unit contains a component containing lower pressure than the ambient atmospheric pressure and it is susceptible to implosion, no incapacitation of the flight crew or adjacent equipment should result, if an implosion occurs. Test the display unit for the most severe environmental conditions of pressure and temperature levels, and for variations in both normal and abnormal operating conditions (including overpressure and decompression) specified by RTCA/DO-160D. To verify that the display unit is acceptable in the event of an implosion, the unit should meet the requirements in United Laboratories (UL) Document No. 1418 listed in paragraph 3.5 of this AC. Similarity of a particular display to a unit already tested may be used to comply with this requirement.

9.14 COLOR STANDARDIZATION:

9.14.1 Color is considered an enhancement for understanding the display information that leads to performance improvement. Select color to minimize display interpretation errors. A proliferation of color sets can ultimately reduce safety rather than increase it. Using contrast between basic colors provides a better differentiation of display elements than arbitrarily using colors near to each other in the color table. Prior to defining the color standard to be used in a specific display, establish a consistent color philosophy throughout the display. The FAA does not intend to limit electronic displays to the below listed colors, although these have been shown to work well. The following table depicts colors found acceptable for compliance with § 23.1322, and other recommended colors as related to their functional meaning for electronic display systems:

9.14.1.1 Display features should be color coded as follows:

Warnings	Red
Flight envelope and system limits	Red
Cautions, abnormal sources	Amber/Yellow
Earth	Tan/Brown
Scales and associated figures	White
Engaged modes	Green
Sky	Cyan/Blue
ILS deviation pointer	Magenta
Flight director bar	Magenta/Green

9.14.1.2 Specified display features should be allotted colors from one of the following color sets:

	Color Set 1	Color Set 2
Fixed reference symbols	White	Yellow*****
Current data, values	White	Green
Armed modes	White	Cyan
Selected data, values	Green	Cyan
Selected heading	Magenta******	Cyan
Active route/flight plan	Magenta	White

*****The extensive use of the color yellow for other than caution/abnormal information is discouraged.

******In color Set 1, magenta is associated with those analog parameters that constitute "fly to" or "keep centered" type information.

9.14.1.3 The depiction of weather precipitation and turbulence should be coded as follows:

Precipitation 0-1 mm/hr	Black
1-4 "	Green
4-12 "	Amber/Yellow
12-50 "	Red
Above 50 "	Magenta (other colors may be acceptable)
Turbulence "	White or Magenta

9.14.1.4 Background color (Gray or other shade) Background color may be used to enhance display presentation.

9.14.2 When the color assignments deviate from the above color set, the applicant should ensure that the chosen color assignments are not susceptible to confusion of symbol meaning and increased workload. Where appropriate, color assignment should be consistent with other color displays in the panel. Luminance and color differences

should not be confusing or ambiguous under any operating ambient illumination conditions. The specific colors should be consistent with change in brightness on the displays over the full range of ambient light conditions. Under high and low levels of lighting, color degradation should not prevent the pilot from properly interpreting display information. Where precipitation is integrated with other information, the precipitation colors can be presented at half intensity. Service experience has shown that this provides enhanced presentation and reduced ambiguity. Warnings should be at full intensity.

9.14.3 Color is an enhancement for understanding the display information that leads to performance improvement, but it should not be the sole means of discrimination of critical information. Color degradation should be obvious and should not preclude the pilot from interpreting the remaining display information. Displays should remain legible, stable, and unambiguous when operating in a degraded mode. The display format should allow the pilot to overlay multiple weather or other graphics relevant to the flight path on one display without ambiguity. Each new graphic should be evaluated both individually and with allowed combinations of other weather, terrain, and navigation symbology to guard against confusing the pilot or cluttering the screen.

9.14.4 For warnings and cautions, § 23.1322 provides specific requirements for the assignment of red and amber for visual annunciations.

9.14.4.1 Red should be used as the warning annunciation for emergency operational conditions when immediate flight crew recognition is required, and immediate correction or compensatory action may be required. Amber should be used for the cautionary annunciation for abnormal operational conditions when immediate flight crew awareness is required and subsequent flight crew action may be required. White or another unique color should be used for advisory annunciations of operational conditions which require flight crew awareness and action may be required. Green should be used for indication of safe operating conditions.

9.14.4.2 A complete list of warnings, cautions, and annunciation messages should be included in the AFM, supplemental AFM, and placards. If the manufacturer’s Pilot Operating Guide is found adequate and acceptable, it may be referenced in the AFM or supplemental AFM as a means to satisfy this requirement.

9.15 AIRPLANE FLIGHT MANUAL (AFM):

For equipment required for IFR approval, the AFM or supplemental AFM should contain the limitations, and operating and emergency procedures applicable to the equipment installed. Installations limited to VFR use only may require an AFM or supplemental AFM depending upon the complexity of the installation and the need to identify necessary limitation and operating procedures. Additional policy and guidance on AFM's are contained in AC 23-8A.

9.16 LAG TIME AND DATA UPDATE:

The display of information essential to the safety of flight should be thoroughly responsive and accurate to the operational requirements. Electronic display system delay effects of essential information, including attitude, airspeed, altitude, heading, and specific propulsion parameters, should not degrade the pilot's ability to control the airplane. SAE ARP's provide recommended lag times for display of the format and primary flight data, and minimum rates for data updates to meet symbol motion.

9.17 TEST FUNCTIONS:

The electronic display should incorporate a pilot selectable or automatic test mode that exercises the system to a depth appropriate to the system design. Alerting and annunciation functions that are necessary to alert the pilot of unsafe conditions should be exercised.

S/

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