U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: TRANSPORT CATEGORY AIRPLANE ELECTRONIC DISPLAY SYSTEMS

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1. PURPOSE. This advisory circular (AC) provides guidance for certification of cathode ray tube (CRT) based electronic display systems used for guidance, control, or decision-making by the pilots of transport category airplanes. Like all advisory material, this document is not, in itself, mandatory and does not constitute a regulation. It is issued to provide guidance and to outline a method of compliance with the rules.

2. SCOPE. The material provided in this advisory circular consists of guidance related to pilot displays and specifications for CRT's in the cockpit of commercial transport airplanes. The content of the circular is limited to statements of general certification considerations, including display function criticality and compliance considerations; color, symbology, coding, clutter, dimensionality, and attention-getting requirements; display visual characteristics; failure modes; information display and formatting; specific integrated display and mode considerations, including maps, propulsion parameters, warning, advisory, checklist, procedures and status displays.

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1. BACKGROUND.

a. The initial certification of CRT's as primary flight instruments, both in Europe and the United States, was coincident with major airframe certifications. The prime airframe manufacturers invested extensive preliminary laboratory work to define the system architecture, software design, colors, symbols, formats, and types of information to be presented, and to prove that these resulting displays would provide an acceptable level of safety. The flight test programs gave many hours exposure of the electronic display systems to company test pilots, FAA test pilots, and customer pilots. Certification of the displays came at the end of this process. Because of this precertification exposure, the FAA had a high degree of confidence that these displays were adequate for their intended function and safe to use in foreseeable normal and failed conditions.

b. The initial electronic display designs tended to copy the electromechanical display formats. As a result, pilots have evaluated the new displays using the electromechanical displays as a reference. As electronic display systems evolve, there is great potential for significant improvements in information interchange between the system (airplane) and the pilot. The FAA intends to allow a certification environment that will provide the greatest flexibility commensurate with safety.

2. GLOSSARY OF ACRONYMS.

AC	Advisory Circular
ADF	Automatic Direction Finder
ADI	Attitude Director Indicator
AFCS	Automatic Flight Control System
AFM	Airplane Flight Manual
AIR	Aerospace Information Report (SAE)
ARP	Aerospace Recommended Practice (SAE)
AS	Aerospace Standard (SAE)
CDI	Course Deviation Indicator
CRT	Cathode Ray Tube
DOT	Department of Transportation
EADI	Electronic Attitude Director Indicator
EFIS	Electronic Flight Instrument System
EHSI	Electronic Horizontal Situation Indicator
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
HSI	Horizontal Situation Indicator
ILS	Instrument Landing System
INS	Inertial Navigation System
MEL	Minimum Equipment List
PFD	Primary Flight Display
RNAV	Area Navigation
ROM	Read Only Memory
RTCA	Radio Technical Commission for Aeronautics
RTO	Rejected Takeoff
SAE	Society of Automotive Engineers
STC	Supplemental Type Certificate
TSO	Tec nical Standard Order
VOR	Very High Frequency Omnirange Station

3. RELATED REGULATIONS AND DOCUMENTS.

a. Regulations. Compliance with many sections of Part 25 of the FAR may be related to, or dependent on, cockpit displays, even though the regulations may not explicitly state display requirements. Some applicable Sections of Part 25, as amended through Amendment 25-54, are listed below. The particular compliance method chosen for other regulations not listed here may also require their inclusion if CRT displays are used in the flight deck.

§ 25.207	Stall warning.
§ 25.672	Stability augmentation and automatic and power-operated systems.
§ 25.677	Trim systems.
§ 25.699	Lift and drag device indicator.
§ 25.703	Takeoff warning system.
§ 25.729	Retracting mechanism.
§ 25.771	Pilot compartment.
§ 25.777	Cockpit controls.
§ 25.783	Doors.
§ 25.812	Emergency lighting.
§ 25.841	Pressurized cabins.
§ 25.857	Cargo compartment classification.
§ 25.858	Cargo compartment fire detection systems.
§ 25.859	Combustion heater fire protection.
§ 25.863	Flammable fluid fire protecton.
§ 25.901	Powerplant installation.
§ 25.903	Engines.
§ 25.1019	Oil strainer or filter.
§ 25.1141	Powerplant controls: general.
§ 25.1165	Engine ignition systems.
§ 25.1199	Extinguishing agent containers.
§ 25.1203	Fire detector systems.
§ 25.1301	Equipment: Function and installation.
§ 25.1303	Flight and navigation instruments.
§ 25.1305	Powerplant instruments.
§ 25.1309	Equipment, systems, and installations.
§ 25.1321	Arrangement and visibility.
§ 25.1322	Warning, caution, and advisory lights.
§ 25.1323	Airspeed indicating system.
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§ 25.1329	Automatic pilot system.
§ 25.1331	Instruments using a power supply.
§ 25.1333	Instrument systems.
§ 25.1335	Flight director systems.
§ 25.1337	Powerplant instruments.
§ 25.1351	Electrical systems and equipment: general.
§ 25.1353	Electrical equipment and installations.
§ 25.1355	Distribution system.
§ 25.1381	Instrument lights.
§ 25.1383	Landing lights.
§ 25.1431	Electronic equipment.
§ 25.1435	Hydraulic systems.

§ 25.1441	Oxygen equipment and supply.
§ 25.1457	Cockpit voice recorders.
§ 25.1459	Flight recorders.
§ 25.1501	Operating limitations and information: general.
§ 25.1523	Minimum flightcrew.
§ 25.1541	Markings and placards: general.
§ 25.1543	Instrument markings: general.
§ 25.1545	Airspeed limitation information.
§ 25.1549	Powerplant and auxiliary power unit instruments.
§ 25.1551	Oil quantity indicator.
§ 25.1553	Fuel quantity indicator.
§ 25.1555	Control markings.
§ 25.1581	Airplane flight manual: general.
§ 91.33	Instrument and equipment requirements.
§ 91.51	Altitude alerting system or device; turbojet powered civil airplanes.
§ 121.305	Flight and navigational equipment.
§ 121.360	Ground proximity warning--glide slope deviation alerting system.

b. Advisory Circulars.

AC 20-88A	Guidelines on the Marking of Aircraft Powerplant Instruments (Displays).
AC 25.1309-1	System Design Analysis.
AC 25.1329-1A	Automatic Pilot Systems Approval.
AC 90-45A	Approval of Area Navigation Systems for Use in the U.S. National Airspace System
AC 120-28C	Criteria for Approval of Category III Landing Weather Minima.
AC 120-29	Criteria for Approving Category I and Category II Landing Minima for FAR 121 Operators.

c. Technical Standard Orders.

TSO-C113	Airborne Multipurpose Electronic Displays.

d. Industry Documents.

(1) The following documents are available from the Radio Technical Commission for Aeronautics (RTCA), One McPherson Square, Suite 500, 1425 K Street NW, Washington, D.C. 20005:

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

(2) The following documents are available from the Society of Automotive Engineers, Inc. (SAE), 400 Commonwealth Drive, Warrendale, PA 15096:

ARP 268F	Location and Actuation of Flight Deck Controls for Transport Aircraft.
AS 425B	Nomenclature and Abbreviations, Flight Deck Area.
ARP 450D	Flight Deck Visual, Audible and Tactile Signals.
ARP 926A	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 1834	Fault/Failure Analysis for Digital Systems and Equipment.
ARP 1874	Design Objectives for CRT Displays for Part 25 (Transport) Aircraft.
AS 8034	Minimum Performance Standards for Airborne Multipurpose Electronic Displays.

(3) The following documents are presently in draft form:

ARP 1782	Photometric and Colormetric Measurement Procedures for Direct View CRT Display Systems.
ARP 4032	Human Integration Color Criteria and Standards.

NOTE: In the event of conflicting information, this advisory circular takes precedence as guidance for certification of transport category airplane installations.

e. Research Reports. The following documents are available through the National Technical Information Service, Springfield, Virginia 22161:

DOT/FAA/RD-81/38, II	Aircraft Alerting Systems Standardization Study Volume II Aircraft Alerting Systems Design Guidelines.
DOT/FAA/PM-85-19	The Development and Evaluation of Color Systems for Airborne Applications.

4. GENERAL CERTIFICATION CONSIDERATIONS.

a. Display Function Criticality. The use of electronic displays allows designers to integrate systems to a much higher degree than was practical with previous airplane flight deck components. With this integration can come much greater simplicity of operation of the airplane through automation of navigation, thrust, airplane control, and the related display systems. Although normal operation of the airplane may become easier, failure state evaluation and the determination of criticality of display functions may become more complex. This determination should refer to the display function and include all causes that could affect the display of that function, not only the display equipment. "Loss of display," for example, means "loss of capability to display."

(1) Criticality of flight and navigation data displayed should be evaluated in accordance with the requirements in §§ 25.1309 and 25.1333 of the FAR. Advisory Circular 25.1309-1 clarifies the meaning of these requirements and the types of analyses that are appropriate to show that systems meet them. Advisory Circular 25.1309-1 also provides criteria to correlate the depth of analysis required with the type of function the system performs (nonessential, essential, or critical); however, a system may normally be performing nonessential or essential functions from the standpoint of required availability and have potential failure modes that could be more critical. In this case, a higher level of criticality applies. Pilot evaluation may be a necessary input in making the determination of criticality for electronic displays. Advisory Circular 25.1309-1 recommends that the flight test pilot: (1) determine the detectability of a failure condition, (2) determine the required subsequent pilot actions, and (3) determine if the necessary actions can be satisfactorily accomplished in a timely manner without exceptional pilot skill or strength.

(2) Software based systems should have the computer software verified and validated in an acceptable manner. One acceptable means of compliance for the verification and validation of computer software is outlined in RTCA Document DO-178A. Software documentation appropriate to the level to which the verification and validation of the computer software has been accomplished should be provided as noted in DO-178A.

(3) Past certification programs have resulted in the following determinations of display criticality. Unconventional airplane and display design may change these assessments. In the failure cases discussed below, hazardously misleading failures are, by definition, not associated with a suitable warning.

(i) Attitude. Display of attitude in the cockpit is a critical function. Loss of all attitude display, including standby attitude, is a critical failure and must be extremely improbable. Loss of primary attitude display for both pilots must be improbable. Display of hazardously misleading roll or pitch attitude simultaneously on the primary attitude displays for both pilots must be extremely improbable. Display of hazardously misleading roll or pitch attitude on any single primary attitude display must be improbable.

(ii) Airspeed. Display of airspeed in the cockpit is a critical function. Loss of all airspeed display, including standby, must be extremely improbable. Loss of primary airspeed display for both pilots must be improbable. Displaying hazardously misleading airspeed simultaneously on both pilots' displays, coupled with the loss of stall warning or overspeed warning functions, must be extremely improbable.

(iii) Barometric Altitude. Display of altitude in the cockpit is a critical function. Loss of all altitude display, including standby, must be extremely improbable. Loss of primary altitude display for both pilots must be improbable. Displaying hazardously misleading altitude simultaneously on both pilots' displays must be extremely improbable.

(iv) Vertical Speed. Display of vertical speed in the cockpit is an essential function. Loss of vertical speed display to both pilots must be improbable.

(v) Rate-of-Turn Indication. The rate-of-turn indication is a nonessential function and is not required if the requirements of paragraph 4a(3)(i) are met.

NOTE: Operational rules may require the installation of a rate-of-turn indicator.

(vi) Slip/Skid Indication. The slip/skid or side slip indication is an essential function. Loss of this function to both pilots must be improbable. Simultaneously misleading slip/skid or side slip information to both pilots must be improbable.

(vii) Heading. Display of stabilized heading in the cockpit is an essential function. Displaying hazardously misleading heading information on both pilots' primary displays must be improbable. Loss of stabilized heading in the cockpit must be improbable. Loss of all heading information in the cockpit must be extremely improbable.

(viii) Navigation. Display of navigation information (excluding heading, airspeed, and clock data) in the cockpit is an essential function. Loss of all navigation information must be improbable. Displaying hazardously misleading navigational or positional information simultaneously on both pilots' displays must be improbable.

NOTE: Because of a relationship between navigation capability and communicated navigation information, the following related requirements are included. Nonrestorable loss of all navigation and communication functions must be extremely improbable. Loss of all communication functions must be improbable.

(ix) Propulsion System Parameter Displays.

(A) The required powerplant instrument displays must be arranged and isolated from each other so that the failure or malfunction of any system or component that affects the display or accuracy of any propulsion system parameter for one engine will not cause the permanent loss of display or adversely affect the accuracy of any parameter for the remaining engines.

(B) No single fault, failure, or malfunction, or probable combinations of failures, shall result in the permanent loss of display, or in the misleading display, of more than one propulsion unit parameter for a single engine.

(C) Combinations of failures which would result in the permanent loss of required powerplant instrument displays for more than one engine must be improbable.

(D) Combinations of failures which would result in the hazardously misleading display of any parameter for more than one engine must be extremely improbable.

(E) No single fault, failure, or malfunction, or combinations of failures not shown to be extremely improbable, shall result in the loss of all propulsion system displays.

(F) Required powerplant instruments that are not displayed continuously must be automatically displayed when any inhibited parameter exceeds an operating limit or threshold, including fuel tank low fuel advisory or maximum imbalance limit, unless concurrent failure conditions are identified where crew attention to other system displays takes priority over the powerplant instruments for continued safe operation of the airplane. In each case, it must be established that failure to concurrently display the powerplant instruments does not jeopardize the safe operation of the airplane.

(G) Propulsion system parameters essential for determining the health and operational status of the engines and for taking appropriate corrective action, including engine restart, must be automatically displayed after the loss of normal electrical power.

(H) Individual fuel tank quantity information must be displayed whenever the fuel system is not in the normal configuration for flight.

(x) Crew Alerting Displays. Crew alerting of selected parameters may be an essential function. Loss of crew alerting for essential functions must be improbable. Display of hazardously misleading crew alerting messages must be improbable.

(xi) Flightcrew Procedures. The display of hazardously misleading flightcrew procedures caused by display system failure, malfunction, or misdesign must be improbable.

(xii) Weather Radar. Display of weather radar in the cockpit is a nonessential function; however, presentation of hazardously misleading information must be improbable.

NOTE: Operational rules may require the installation and functioning of weather radar.

b. Compliance Considerations.

(1) Human Factors. Humans are very adaptable, but unfortunately for the display evaluation process, they adapt at varying rates with varying degrees of effectiveness and mental processing compensation. Thus, what some pilots might find acceptable and approvable, others would reject as being unusable and unsafe. Airplane displays must be effective when used by pilots who cover the entire spectrum of variability. Relying on a requirement of "train to proficiency" may be unenforceable, economically impractical, or unachievable by some pilots without excessive mental workload as compensation.

(i) The test program should include sufficient flight and simulation time, using a representative population of pilots, to substantiate:

(A) Reasonable training times and learning curves;

(B) Usability in an operational environment;

(C) Acceptable interpretation error rates equivalent to or less than conventional displays;

(D) Proper integration with other equipment that uses electronic display functions;

(E) Acceptability of all failure modes not shown to be extremely improbable; and

(F) Compatibility with other displays and controls.

The manufacturers should provide human factors support for their decisions regarding new or unique features in a display. Evaluation pilots should verify that the data supports a conclusion that any new or unique features have no human factors traps or pitfalls, such as display perceptual or interpretive problems, for a representative pilot population.

(ii) It is desirable to have display evaluations conducted by more than one pilot, even for the certification of displays that do not incorporate significant new features. At least one member of the team should have previous experience with the display principles contained in this document. For display designs that incorporate unproven features, evaluation by a greater number of pilots should be considered. To help the FAA certification team gain assurance of a sufficiently broad exposure base, the electronic display manufacturer or installer should develop a test program with the certificating office that gathers data from FAA test pilots, company test pilots, and customer pilots who will use the display. A reasonable amount of time for the pilot to adapt to a display feature can be allowed, but long adaptation times must receive careful consideration. Any attitude display format presented for FAA approval should be sufficiently natural in its design so that no training is required for basic manual airplane control.

(iii) For those electronic display systems that have been previously approved (including display formats) and are to be installed in airplanes in which these systems have not been previously approved, a routine FAA certification should be conducted. This program should emphasize the systems' integration in the airplane and may require further detailed systems failure analysis (where "system" means the display, driving electronics, sensors and sources of information).

(iv) Simulation is an invaluable tool for display evaluation. Acceptable simulation ranges from a rudimentary bench test set up, where the display elements are viewed statically, to full flight training simulation with motion, external visual scene, and entire airplane systems representation. For minor or simple changes to previously approved displays, one of these levels of simulation may be deemed adequate for display evaluation. For evaluation of display elements that relate directly to airplane control (i.e., air data, attitude, thrust set parameters, etc.), simulation should not be relied upon entirely. The dynamics of airplane motion, coupled with the many added distractions and sensory demands made upon the pilot that are attendant to actual airplane flight, have a profound effect on the pilot's perception and usability of displays. Display designers, as well as FAA test pilots, should be aware that display formats previously approved in simulation may well (and frequently do) turn out to be unacceptable in actual flight.

(2) Hardware Installation.

(i) It is assumed that all display equipment has met the requirements set forth in SAE Document AS 8034 or guidance provided in TSO C113. Therefore, the purpose of the following guidance is to ensure compatibility of the flight qualified equipment with the airplane environment. It is recognized that the validation of acceptable equipment installations considers the individual and combined effects of the following: temperature, altitude, electromagnetic interference, radiomagnetic interference, vibration, and other environmental influences. The installation requirements of Part 25 of the FAR are applicable to critical, essential, and nonessential systems, and should be determined on a case-by-case basis by the aircraft certification office based on the specific circumstances.

(A) Analysis and testing shall be conducted to ensure proper operation of the display at the maximum unpressurized altitude for which the equipment is likely to be exposed.

(B) Electromagnetic interference analysis and testing shall be conducted to show:

(1) That the installed system is not susceptible to interference from other airplane systems, considering both interference of signal and power systems; and

(2) That the installed equipment does not affect other airplane systems.

(C) If improper operation of the display system can result from failures of the cooling function, then the cooling function must be addressed by analysis and test/demonstration.

(ii) Pilot-initiated preflight tests may be used to reduce failure exposure times associated with the safety analysis required under § 25.1309(d) of the FAR. However, expecting an equipment preflight test to be conducted prior to each flight may not be conservative. If the flightcrew is required to test a system prior to each flight, it should be assumed, for the safety analysis, that the flightcrew will actually accomplish this test once per day, providing the preflight test is conveniently and acceptably implemented. An autotest feature designed to preclude the need for pilot initiated preflight tests may receive credit in the safety analysis.

5. INFORMATION SEPARATION.

a. Color Standardization.

(1) Although color standardization is desirable, during the initial certification of electronic displays color standards for symbology were not imposed (except for cautions and warnings per § 25.1322). At that time the expertise did not exist within industry or the FAA, nor did sufficient service experience exist, to rationally establish a suitable color standard.

(2) In spite of the permissive CRT color atmosphere that existed at the time of initial EFIS certification programs, an analysis of the major certifications to date reveals many areas of common color design philosophy; however, if left unrestricted, in several years there will be few remaining common areas of color selection. If that is the case, information transfer problems may begin to occur that have significant safety implications. To preclude this, the following colors are being recommended based on current day common usage. Deviations may be approved with acceptable justification.

(3) The following depicts acceptable display colors related to their functional meaning recommended for electronic display systems.

(i) 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

(ii) Specified display features should be allocated 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 intended to be associated with those analog parameters that constitute "fly to" or "keep centered" type information.

(iii) Precipitation and turbulence areas should be coded as follows:

Precipitation 0 - 1 mm/hr	Black
1 - 4 "	Green
4 - 12 "	Amber/Yellow
12 - 50 "	Red
Above 50 "	Magenta
Turbulence	White or Magenta

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

(4) When deviating from any of the above symbol color assignments, the manufacturer should ensure that the chosen color set is not susceptible to confusion or color meaning transference problems due to dissimilarities with this standard. The FAA test pilot should be familiar with other systems in use and evaluate the system specifically for confusion in color meanings.

(5) The FAA does not intend to limit electronic displays to the above colors, although they have been shown to work well. The colors available from a symbol generator/display unit combination should be carefully selected on the basis of their chrominance separation. Research studies indicate that regions of relatively high color confusion exist between red and magenta, magenta and purple, cyan and green, and yellow and orange (amber). Colors should track with brightness so that chrominance and relative chrominance separation are maintained as much as possible over day-night operation. Requiring the flightcrew to discriminate between shades of the same color for symbol meaning in one display is not recommended.

(6) Chrominance uniformity should be in accordance with the guidance provided in SAE Document ARP 1874. As designs are finalized, the manufacturer should review his color selections to ensure the presence of color works to the advantage of separating logical electronic display functions or separation of types of displayed data. Color meanings should

be consistent throughout all color CRT displays in the cockpit. In the past, no criteria existed requiring similar color schemes for left and right side installations using electromechanical instruments.

b. Color Perception vs. Workload.

(1) When color displays are used, colors should be selected to minimize display interpretation workload. Symbol coloring should be related to the task or crew operation function. Improper color coding increases response times for display item recognition and selection, and increases the likelihood of errors in situations where response rate demands exceed response accuracy demands. Color assignments that differ from other displays in use, either electromechanical or electronic, or that differ from common usage (such as red, yellow, and green for stoplights), can potentially lead to confusion and information transferal problems.

(2) When symbology is configured such that symbol characterization is not based on color contrast alone, but on shape as well, then the color information is seen to add a desirable degree of redundancy to the displayed information. There are conditions in which pilots whose vision is color deficient can obtain waivers for medical qualifications under Part 61 of the FAR. In addition, normal aging of the eye can reduce the ability to sharply focus on red objects, or discriminate blue/green. For pilots with such deficiency, display interpretation workload may be unacceptably increased unless symbology is coded in more dimensions than color alone. Each symbol that needs separation because of the criticality of its information content should be identified by at least two distinctive coding parameters (size, shape, color, location, etc.).

(3) Color diversity should be limited to as few colors as practical, to ensure adequate color contrast between symbols. Color grouping of symbols, annunciations, and flags should follow a logical scheme. The contribution of color to information density should not make the display interpretation times so long that the pilot perceives a cluttered display.

c. Standard Symbology. Many elements of electronic display formats lend themselves to standardization of symbology, which would shorten training and transition times when pilots change airplane types. At least one industry group (SAE) is working toward identifying these elements and proposing suitable standards. Future revisions of this advisory circular may incorporate the results of such industry efforts.

d. Symbol Position.

(1) The position of a message or symbol within a display conveys meaning to the pilot. Without the consistent or repeatable location of a symbol in a specific area of the electronic display, interpretation errors and response times may increase. The following symbols and parameters should be position consistent:

(i) Autopilot and flight director modes of operation.

(ii) All warning/caution/advisory annunciation locations.

(iii) All sensor data: altitude, airspeed, glideslope, etc.

(iv) All sensor failure flags. (Where appropriate, flags should appear in the area where the data is normally placed.)

(v) Either the pointer or scale for analog quantities should be fixed. (Moving scale indicators that have a fixed present value may have variable limit markings.)

(2) An evaluation of the positions of the different types of alerting messages and annunciations available within the electronic display should be conducted, with particular attention given to differentiation of normal and abnormal indications. There should be no tendency to misinterpret or fail to discern a symbol, alert, or annunciation, due to an abnormal indication being displayed in the position of a normal indication, and having similar shape, size, or color.

(3) Pilot and copilot displays may have minor differences in format, but all such differences should be evaluated specifically to ensure that no potential for interpretation error exists when pilots make cross-side display comparisons.

(4) If the display incorporates slow rate "dithering" to reduce phosphor burn from stationary symbology, the entire display should be moved at a slow rate in order to not change the spatial relationships of the symbology collection as a whole.

e. Clutter. A cluttered display is one which uses an excessive number and/or variety of symbols, colors, or small spatial relationships. This causes increased processing time for display interpretation. One of the goals of display format design is to convey information in a simple fashion in order to reduce display interpretation time. A related issue is the amount of information presented to the pilot. As this increases, tasks become more difficult as secondary information may detract from the interpretation of information necessary for the primary task. A second goal of display format design is to determine what information the pilot actually requires in order to perform the task at hand. This will serve to limit the amount of information that needs to be presented at any point in time. Addition of information by pilot selection may be desirable, particularly in the case of navigational displays, as long as the basic display modes remain uncluttered after pilot deselection of secondary data. Automatic deselection of data has been allowed in the past to enhance the pilot's performance in certain emergency conditions (deselection of AFCS engaged mode annunciation and flight director in extreme attitudes).

f. Interpretation of Two-Dimensional Displays. Modern electromechanical attitude indicators are three-dimensional devices. Pointers overlay scales; the fixed airplane symbol overlays the flight director single cue bars which, in turn, overlay a moving background. The three-dimensional aspect of a display plays an important role in interpretation of instruments. Electronic flight instrument system displays represent an attempt to copy many aspects of conventional electromechanical displays, but in only two dimensions. This can present a serious problem in quick-glance interpretation, especially for attitude. For displays using conventional, discrete symbology, the horizon line, single cue flight director symbol, and fixed airplane reference should have sufficient conspicuity such that the quick-glance interpretation should never be misleading for basic attitude. This conspicuity can be gained by ensuring that the outline of the fixed airplane symbol(s) always retains its distinctive shape, regardless of the background or position of the horizon line or pitch ladder. Color contrast is helpful in defining distinctive display elements but is insufficient by itself because of the reduction of chrominance difference in high ambient light levels. The characteristics of the flight director symbol should not detract from the spatial relationship of the fixed airplane symbol(s) with the horizon. Careful attention should be given to the symbol priority (priority of displaying one symbol overlaying another symbol by editing out the secondary symbol) to assure the conspicuity and ease of interpretation similar to that available in three-dimensional electromechanical displays.

NOTE: Horizon lines and pitch scales which overwrite the fixed airplane symbol or roll pointer have been found unacceptable in the past.

g. Attention-Getting Requirements.

(1) Some electronic display functions are intended to alert the pilot to changes: navigation sensor status changes (VOR flag), computed data status changes (flight director flag or command cue removal), and flight control system normal mode changes (annunciator changes from armed to engaged) are a few examples. For the displayed information to be effective as an attention-getter, some easily noticeable change must be evident. A legend change by itself is inadequate to annunciate automatic or uncommanded mode changes. Color changes may seem adequate in low light levels or during laboratory demonstrations but become much less effective at high ambient light levels. Motion is an excellent attention-getting device. Symbol shape changes are also effective, such as placing a box around freshly changed information. Short-term flashing symbols (approximately 10 seconds or flash until acknowledge) are effective attention-getters. A permanent or long-term flashing symbol that is noncancellable should not be used.

(2) In some operations, continued operation with inoperative equipment is allowed (under provisions of an MEL). The display designer should consider the applicant's MEL desires, because in some cases a continuous strong alert may be too distracting for continued dispatch.

h. Color Drive Failure. Following a single color drive failure, the remaining symbology should not present misleading information, although the display does not have to be usable. If the failure is obvious, it may be assumed that the pilot will not be susceptible to misleading information due to partial loss of symbology. To make this assumption valid, special cautions may have to be included in the AFM procedures that point out to the pilot that important information formed from a single primary color may be lost, such as red flags.

6. DISPLAY VISUAL CHARACTERISTICS.

a. Visual Display Characteristics. The visual display characteristics of electronic displays should be in accordance with SAE Documents AS 8034, ARP 1874, and ARP 1068B. The manufacturer should notify the certification engineer of those characteristics that do not meet the guidelines contained in the referenced documents.

b. Chromaticity and Luminance.

(1) Readability of the displays should be satisfactory in all operating and environmental lighting conditions expected in service. Four lighting conditions known to be critical for testing are:

(i) Direct sunlight on the display through a side cockpit window (usually short term with conventional window arrangements).

(ii) Sunlight through a front window illuminating white shirts which are reflected in the CRT (a function of the CRT front plate filter).

(iii) Sun above the forward horizon and above a cloud deck in the pilot's eyes (usually a prolonged situation and the most critical of these four).

(iv) Night and/or dark environment. Brightness should be controllable to a dim enough setting such that outside vision is not impaired while maintaining an acceptable presentation.

(2) When displays are evaluated in these critical lighting situations, the display should be adjusted to a brightness level representative of that expected at the end of the CRT's normal useful life (5,000 to 20,000 hours), or adjusted to a brightness level selected by the manufacturer as the minimum acceptable output and measurable by some readily accomplished maintenance tests. If the former method is used, adequate evaluations should be performed to ensure that the expected end of life brightness levels are met. Some manufacturers have found, and the FAA has accepted, that 50 percent of original brightness level is a realistic end of life value. If the latter method is used, procedures should be established to require periodic inspections, and these limits should then become part of the service life limits of the airplane system.

(3) Large fields used in color displays as background (e.g., blue sky and brown earth for attitude) for primary flight control symbols need not be easily discriminated in these high ambient light levels, provided the proper sense of the flight control information is conveyed with a quick glance.

(4) Electronic display systems should meet the luminance (photometric brightness) levels of SAE Document ARP 1874. A system designed to meet these standards should be readily visible in all the lighting conditions listed in paragraphs 6b(1) and 6b(2), and should not require specific flight testing for luminance if the system has been previously installed in another airplane with similar cockpit window arrangements. If the display evaluation team feels that some attributes are marginal under extreme lighting conditions, the following guidelines may be used:

(i) The symbols that convey quick-glance attitude and flight path control information (e.g., horizon line, pitch scale, fixed airplane symbol and/or flight path symbol, sky pointer and bank indices, flight director bars) should each have adequate brightness contrast with its respective background to allow it to be easily and clearly discernible.

(ii) The combination of color and brightness of any subset of these symbols which may, due to relative motion of a dynamic display, move adjacent to each other and use color as an aid for symbol separation (e.g., flight director bars and fixed airplane symbol), should render each symbol distinctly identifiable in the worst case juxtaposition.

(iii) Flags and annunciations that may relate to events of a time critical nature (including warnings and cautions defined in paragraph 10 of this AC, as well as flight control system annunciations of mode reversions) should have a sufficient contrast with their background and immediate environment to achieve an adequate level of attensity (attention getting properties). Color discrimination in high brightness ambient levels may not be necessary if the symbol remains unambiguous and clearly distinct from adjacent normal state or alphanumeric characters.

(iv) Analog scale displays (heading, air data, engine data, CDIs, or course lines) should each have adequate brightness with its respective background to allow it to be easily and clearly discernible. Colored warning and caution markings on scales should retain color discrimination. Symbols used as targets and present value pointers in juxtaposition to a scale should remain distinct. If color is required to convey the meaning of similar shaped targets or indices, the color should remain easily discernible.

(v) Flags and annunciations should still be visible at low display brightness when the display is adjusted to the lowest usable level for flight with normal symbology (day or night).

(vi) Raster fields conveying information such as weather radar displays should allow the raster to be independently adjustable in luminance from overlaid stroke symbology. The range of luminance control should allow detection of color difference between adjacent small raster areas no larger than 5 milliradians in principal dimension; while at this setting, overlying map symbology, if present, should be discernible.

(5) Automatic brightness adjustment systems can be employed to decrease pilot workload and increase tube lifetime. Operation of these systems should be satisfactory over a wide range of ambient light conditions including the extreme cases of a forward low sun and a quartering rearward sun shining directly on the display. A measure of manual adjustment should be retained to provide for normal and abnormal operating differences. In the past it has been found that sensor location and field of view may be as significant as the tube brightness dynamics. Glareshield geometry and window location should be considered in the evaluation.

c. Other Characteristics. The displays should provide characteristics which comply with the symbol alignment, linearity, jitter, convergence, focus, line width, symbol and character size, chrominance uniformity, and reflection criteria of SAE Documents ARP 1874 and AS 8034. The manufacturer should identify any features which do not comply with these documents. The FAA test team should evaluate these characteristics during the initial certification of the displays as installed in the airplane with special attention to those display details which do not comply with the criteria of ARP 1874 and AS 8034. The test team will provide the determination of whether these characteristics of the display are satisfactory.

d. Flicker. Flicker is an undesired rapid temporal variation in display luminance of a symbol, group of symbols, or a luminous field. Flicker can cause mild fatigue and reduced crew efficiency. Since it is a subjective phenomena, the criteria cannot be "no flicker"; but because of the potential deleterious effects, the presence of flicker should not be perceptible day or night considering foveal and full peripheral vision and a format most susceptible to producing flicker. Refresh rate is a major determinant of flicker; related parameters are phosphor persistence and the method of generating mixed colors. Some systems will also slow down the screen refresh rate when the data content is increased (as in a map display with selectable data content). Frequencies above 55 hz for stroke symbology or non-interlaced raster and 30/60 hz for interlaced raster are generally satisfactory.

e. Dynamics. For those elements of the display that are normally in motion, any jitter, jerkiness, or ratcheting effect should neither be distracting nor objectionable. Screen data update rates for analog symbols used in direct airplane or powerplant manual control tasks (such as attitude, engine parameters, etc.) should be equal to or greater than 15 hz. Any lag introduced by the display system should be consistent with the airplane control task associated with that parameter. In particular, display system lag (including the sensor) for attitude should not exceed a first order equivalent time constant of 100 milliseconds for airplanes with conventional control system response. Evaluation should be conducted in worst case aerodynamic conditions with appropriate stability augmentation systems off in order to determine the acceptability of display lag.

7. INFORMATION DISPLAY. Display elements and symbology used in real-time "tactical" airplane control should be natural, intuitive, and not dependent on training or adaptation for correct interpretation.

a. Basic T. The established basic T relationships of § 25.1321 of the FAR should be retained. Deviations from this rule, as by equivalent safety findings, cannot be granted without human factors substantiation based on well-founded research or extensive service experience from military, foreign, or other sources.

(1) Deviations from the basic T that have been substantiated by satisfactory service experience and research are as follows:

(i) Airspeed and altitude instruments external to the attitude display drooped up to 15 degrees and elevated up to 10 degrees (when measured from the center of the attitude fixed airplane reference to the center of the air data instrument).

(ii) Vertical scale type radio altimeter indication between the attitude and altitude displays.

(iii) Vertical scale display of vertical speed between attitude and altitude displays.

(2) Airspeed and altitude within the electronic display should be arranged so that the present value of the displayed parameter is located as close as possible to a horizontal line extending from the center of the attitude indicator. The present value of heading should be vertically underneath the center of the attitude indicator; this does not preclude an additional heading display located horizontally from the attitude display.

(i) Moving scale air data displays should have their present value aligned with the center of the attitude display fixed airplane reference.

(ii) A single fixed airspeed scale with a moving pointer would optimally have certain critical ranges where the present value (or pointer position) for those ranges is within 15 degrees of a horizontal line from the attitude display fixed airplane reference; e.g., takeoff speeds (highly dynamic) and cruise speeds (long exposure). For airplanes with a large speed differential between takeoff and cruise, the linear tradeoff with speed resolution may preclude meeting this objective. In these cases, the manufacturer should prove that instrument scan, crosscheck, and readability are acceptable for all expected normal and abnormal maneuvers and applicable failure states of the airplane, including variability of the user pilot population.

(iii) Multiple range, fixed airspeed scales with moving pointers should be designed so that takeoff, cruise, and approach speed values are located within 15 degrees of a horizontal line through the attitude display fixed airplane reference symbol. The range switching point and hysteresis should be logically selected so that switching is unobtrusive and not detrimental to current speed tracking tasks or dynamic interpretation. Attributes of the individual scales must be such that there is no tendency for the pilot to lose the sense of context of speed range or misinterpret the displayed speed scale.

(3) In cases of adjacent air data instruments, such as a vertical scale airspeed inside an EADI and a conventional airspeed outside the EADI, the display closest to the primary attitude display will be considered the primary display, except in the case of supplementary displays where adequate human factors analysis and testing have been conducted to establish that the supplementary display does not decrease the level of safety from that provided by the primary display by itself (Example: fast/slow indicators).

(4) For retrofit of electronic displays into airplanes that previously exhibited variance from a basic T configuration, the electronic display installation should not increase this variance when considering the angle from the center of the attitude reference to the center of the airspeed and altimeter.

(5) Display switching to enable a so-called "cruise" display mode with the EHSI on top of the EADI has not been found acceptable.

(6) Instrument landing system glideslope raw data display has been allowed on either side of the electronic display. If glideslope raw data is presented on both the EHSI and EADI, they should be on the same side. The FAA recommends a standard location of glideslope scales on the right side as specified in SAE Document ARP 1068B. If the scale or its location is multifunctional, then it should be labeled and contain some unambiguous symbolic attribute related to the indicator's function.

(7) Compliance with § 25.1333 normally requires separate displays of standby attitude, air data, and heading. Since these displays are only used after a failure related to the primary instruments, the basic T arrangement requirements do not apply. However, all the standby instruments should be arranged to be easily usable by one of the pilots.

b. Compacted Formats.

(1) The term "compacted format," as used in this AC, refers to a reversionary display mode where selected display components of a two-tube CRT display, such as EADI and EHSI, are combined in a single CRT to provide somewhat better capability in case of a single tube failure. The concepts and requirements of § 25.1321, as discussed in paragraph 7a, still apply; however, it has been found acceptable to allow a compacted mode on either the EADI or EHSI after failure of one CRT.

(2) The compacted display, out of necessity, will be quite different from the primary format. Flags, mode annunciations, scales, and pointers may have different locations and perhaps different logic governing when they appear. The flight test evaluation should ensure the proper operation of all the electronic display functions in the compacted format,

including annunciation of navigation and guidance modes if present. All the normal EFIS functions do not have to be present in the compacted mode; those that are present should operate properly. Flags and mode annunciations should, wherever possible, be displayed in a location common with the normal format. In all cases the attitude display should meet the characteristics of paragraph 7e.

(3) If the remaining elements of the compacted upper display meet the characteristics of this document and the FAR governing required instrumentation, then a note in the AFM stating that the compacted display is an airworthy mode would be acceptable in order to allow dispatch with a failed lower tube configuration.

c. 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. This function should be included even if the system failure analysis is not dependent on such a mode, or if display test is also a maintenance function. The test mode (or a submode) should display warning flags in their proper locations. Alerting and annunciation functions should be exercised, but it normally would not be necessary for the test to cycle through all possible annunciation states, or to display all flags and alerts. It has been found acceptable to incorporate the display test with a centralized cockpit light test switch, and to have the display test function disabled while airborne. The test mode provides a convenient means to display the software configuration.

d. Primary Flight Displays.

(1) A side-by-side or over-under arrangement of large primary displays may integrate many air data, attitude, navigation, alerting, and annunciation functions, while removing their discrete instrument counterparts. For the initial approval of a new set of displays incorporating this arrangement, many of the evaluation concepts covered elsewhere in this AC must be adhered to, particularly those relating to the use of color and symbology for information separation (paragraph 5). The raw data airplane parameters necessary for manual control (attitude, airspeed, altitude, and heading) must still reside in a conventional basic T arrangement conducive to effective instrument crosscheck. This means that heading and attitude must be presented on the same display for a side-by-side CRT arrangement.

(2) Scale Markings.

(i) Air data displays have a requirement similar to attitude in that they must be able to convey to the pilot a quick-glance sense of the present speed or altitude. Conventional round-dial moving pointer displays inherently give some of this sense that may be difficult to duplicate on moving scales. Scale length is one attribute related to this quick-glance capability. The minimum visible airspeed scale length found acceptable for moving scales on jet transports has been 80 knots; since this minimum is dependent on other scale attributes and airplane operational speed range, variations from this should be verified for acceptability. Altimeters present special design problems in that: (1) the ratio of total usable range to required resolution is a factor of 10 greater than for airspeed or attitude, and (2) the consequences of losing sense of context of altitude can be catastrophic. The combination of altimeter scale length and markings, therefore, should be adequate to allow sufficient resolution for precise manual altitude tracking in level flight, as well as enough scale length and markings to reinforce the pilot's sense of altitude and to allow sufficient look-ahead room to adequately predict and accomplish level-off. Addition of radio altimeter information on the scale so that it is visually related to ground position may be helpful in giving low altitude awareness. Airspeed scale markings that remain relatively fixed (such as stall warning, V_{MO}/M_{MO}), or that are configuration dependent (such as flap limits), are desirable in that they offer the pilot a quick-glance sense of speed. The markings should be predominant enough to confer the quick-glance sense information, but not so predominant as to be distracting when operating normally near those speeds (e.g., stabilized approach operating between stall warning and flap limit speeds).

(ii) Airspeed reference marks (bugs) on conventional airspeed indicators perform a useful function, and the implementation of them on electronic airspeed displays is encouraged. Computed airspeed/angle-of-attack reference marks (bugs) such as V_{stall}, V_{stall} warning, V_1, V_R, V_2, flap limit speeds, etc., displayed on the airspeed scale will be evaluated for accuracy. Provision should be incorporated for a reference mark that will reflect the current target airspeed of the flight guidance system. This has been required in the past for some systems that have complex speed selection algorithms, in order to give the pilot adequate information required by § 25.1309(c) for system monitoring.

(iii) If any scale reference marks would not be available when equipment included on the MEL is inoperative, then the display should be evaluated for acceptability both with and without these reference marks.

(iv) Digital present value readouts or present value indices should not totally obscure the scale markings or graduations as they pass the present value index.

(v) Adjacent scale markings that have potential for interfering with each other (such as V_1, V_R, V_2 in close proximity) must be presented so that the intended reference values remain distinct and unambiguous.

(vi) At the present time, scale units marking for air data displays incorporated into PFDs are not required ("knots," "airspeed" for airspeed, "feet," "altitude" for altimeters) as long as the content of the readout remains unambiguous. For altimeters with the capability to display in both Metric and British units, the scale and primary present value readout should remain scaled in British units with no units marking required; the Metric display should consist of a separate present value readout that does include units marking.

(vii) Airspeed scale graduations found to be acceptable have been in 5-knot increments with graduations labeled at 20-knot intervals. If trend or acceleration cues are used, or a digital present value readout is incorporated, scale markings at 10-knot intervals have been found acceptable. Minimum altimeter graduations should be in 100-foot increments with a present value readout, or 50-foot increments with a present value index only. Due to operational requirements, it is expected that airplanes without either 20-foot scale graduations, or a readout of present value, will not be eligible for Category II low visibility operation with barometrically determined decision heights.

(3) Vertically oriented moving scale airspeed indication is acceptable with higher numbers at the top or bottom if no airspeed trend or acceleration cues are associated with the speed scale. Such cues should be oriented so that increasing energy or speed results in upward motion of the cue. To be consistent with this convention, airspeed scales with these cues should have the high speed numbers at the top. Speed, altitude, or vertical rate trend indicators should have appropriate hysteresis and damping to be useful and non-distracting. Evaluation should include turbulence expected in service.

(4) The integration of many parameters into one upper display makes necessary an evaluation of the effect of failure (either misleading or total loss) of a display at the most critical time for the pilot. The sudden loss of multiple parameters can greatly impact the ability of the pilot to cope with immediate airplane control tasks in certain flight regimes such as during takeoff rotation. If such failures are probable during the critical exposure time, the system must be evaluated for acceptability of data lost to the pilot. Automatic sensing and switching may have to be incorporated to preserve a display of attitude in one of the primary displays on the side with the failure.

e. Attitude.

(1) An accurate, easy, quick-glance interpretation of attitude should be possible for all expected unusual attitude situations and command guidance display configurations. The pitch attitude display scaling should be such that during normal maneuvers (such as takeoff at high thrust-to-weight ratios) the horizon remains visible in the display with at least 5 degrees pitch margin available. In addition, extreme attitude symbology and automatically decluttering the EADI at extreme attitudes has been found acceptable (extreme attitude symbology should not be visible during normal maneuvering). Surprise, unusual attitudes should be conducted in the airplane to confirm the quick-glance interpretation of attitude. The attitude display should be examined in 360 degrees of roll and ± 90 degrees of pitch. This can usually be accomplished by rotating the attitude source through the required gyrations with the airplane powered on the ground. When the airplane hardware does not allow this type of evaluation, accurate laboratory simulations must be used.

(2) Both fixed airplane reference and fixed earth reference bank pointers ("sky" pointers) have been approved. A mix of these types in the same cockpit should not be approved.

f. Digital, Analog, and Combinations. The FAA has a long standing policy of not accepting digital only displays of control parameters. The reason was the belief that only analog data in the form of a pointer/scale relationship provided necessary rate, trend, and displacement information to the pilot. However, the FAA will evaluate new electronic display formats which include digital-only or combinations of digital and analog displays of air data, engine instruments, or navigation data. Digital information displays will be evaluated on the basis that they can be used to provide the same or better level of performance and pilot workload as analog displays of the same parameters. Simulator studies can be valuable in providing experience with new display formats, but care must be taken to ensure that the simulator provides all the environmental cues germane to the parameter being evaluated.

g. Knob Tactile Requirements.

(1) Control knobs used to set digital data on a display that have inadequate friction or tactile detents can result in undue concentration being required for a simple act such as setting an out-of-view heading bug to a CRT displayed number. Controls for this purpose should have an appropriate amount of feel to minimize this problem, as well as minimizing the potential for inadvertent changes. The friction levels associated with standard resistive potentiometers have been shown in some cases to be inadequate.

(2) The display response to control input need not meet the dynamic requirements of paragraph 6e, but should be fast enough to prevent undue concentration being required in setting values or display parameters. The sense of motion of controls should comply with the requirements of § 25.777, where applicable.

h. Full-Time vs. Part-Time Displays. Some airplane parameters or status indications are required by the FAR to be displayed, yet they may only be necessary or required in certain phases of flight. If it is desired to inhibit some parameters from full-time display, an equivalent level of safety to full-time display must be demonstrated. Criteria to be considered include the following:

(1) Continuous display of the parameter is not required for safety of flight in all normal flight phases.

(2) The parameter is automatically displayed in flight phases where it is required.

(3) The inhibited parameter is automatically displayed when its value indicates an abnormal condition, or when the parameter reaches an abnormal value.

(4) Display of the inhibited parameter can be manually selected by the crew without interfering with the display of other required information.

(5) If the parameter fails to be displayed when required, the failure effect and compounding effects must meet the requirements of § 25.1309.

(6) The automatic, or requested, display of the inhibited parameter should not create unacceptable clutter on the display; simultaneous multiple "pop-ups" must be considered.

(7) If the presence of the new parameter is not sufficiently self-evident, suitable alerting must accompany the automatic presentation.

8. SWITCHING AND ANNUNCIATION. Switching and annunciation considerations made important by electronic displays are as follows:

a. Power Bus Transients.

(1) The electronic attitude display should not be unusable or unstable for more than one second after the normally expected electrical bus transients due to engine failure, and should affect only displays on one side of the airplane. Recognizably valid pitch and roll data should be available within one second, and any effects lasting beyond one second should not interfere with the ability to obtain quick-glance attitude. For most airplanes an engine failure after takeoff will simultaneously create a roll rate acceleration, new pitch attitude requirements, and an electrical transient. Attitude information is paramount; transfer to standby attitude or transfer of control of the airplane to the other pilot cannot be reliably accomplished under these conditions in a timely enough manner to prevent an unsafe condition. In testing this failure mode, experience has shown that switching the generator off at the control panel may not result in the largest electrical transient. During an engine failure, as the engine speed decays, the generator output voltage and frequency each decay to a point where the bus control finally recognizes the failure. This can be a significantly larger disturbance resulting in a different effect on the using equipment. One practical way to simulate this failure is with a fuel cut. Other engine failure conditions may be more critical (such as sub-idle stalls) which cannot be reasonably evaluated in flight test. Analysis should identify these failure modes and show that the preceding criteria are met.

(2) The design objective should be displays that are insensitive to power transients; however, if the power transient is not related to a simultaneous airplane control problem, other failures which result in loss of displays on one side are not deemed as time critical, providing the switching concepts for multiple parameter displays are considered (paragraph 7d). Bus transients caused by normal load switching (hydraulic pump actuation, ovens, generator paralleling, etc.) should cause no visible effect on the display. Expected abnormal bus transients (i.e., generator

failure not caused by engine failure) should not initiate a power-up initialization or cold start process.

(3) The large electrical loads required to restart some engine types should not affect more than one pilot's display.

b. Reversionary Switching (Electronic Display Failure States).

(1) It has been found acceptable to have switching capability to allow the display of attitude on the lower display when the upper display unit has failed. It has not been acceptable to switch the EHSI or navigation display to the upper display unit (except compacted display). If a lower display unit should fail, the display of heading and navigation information has not been lost to the cockpit and very little credit could be given for such a switching function toward availability of navigation information. The primary reason for this restriction is because a "cruise" display mode, with the EADI and EHSI positions inverted, can potentially "untrain" an efficient instrument crosscheck. It is acceptable to switch the EHSI display to a centrally located auxiliary CRT (multifunction display).

(2) In case of a symbol generator failure, both the pilot's and the copilot's displays may be driven from a single remaining symbol generator. When this switching state is invoked, there should be clear, cautionary alerting to both pilots that the displayed information is from a single source.

c. Source Switching and Annunciation. When the type or source of information presented on the primary flight instruments can change meaning with manual or automatic mode or source selection, then this mode or source must be inherently unambiguous from the format of the display or from appropriate annunciation.

(1) Independent attitude, heading, and air data sources are required for the pilot and copilot primary displays. As long as independent sources are selected, there would ordinarily be no need for annunciation of these sources. If sources to the electronic displays can be switched in such a fashion that the flightcrew becomes vulnerable to hazardously misleading information on both sides of the cockpit as a result of a common failure, then this switching configuration should be accompanied by a cautionary alert in clear view of both pilots.

(2) If the source of navigation information is not ambiguous, such as a case when VOR/ILS is not switchable across the cockpit, then no source annunciation would be required. Likewise, if a single navigation computer could only be responsible for the HSI navigation data, then this source need not be annunciated.

(3) If a crewmember can select from multiple, similar, navigation sources, such as multiple VOR's or multiple, long-range navigation systems, then the display of the selected source data into a CDI type presentation should be annunciated (i.e., VOR 1, INS 2, etc.). The annunciation should

be implemented in such a fashion that a nonnormal source selection is immediately apparent. In addition, when both crewmembers have selected the same navigation source, this condition should be annunciated; for example, the copilot has off-side VOR selected, with VOR 1 annunciated in amber/yellow in the copilot's electronic display. Exceptions to this nonnormal annunciation requirement can be constructed. If the similar navigation sources are two navigation computers that ensure position and stored route identically through a cross-talk channel, electronic display of normal or nonnormal source annunciation would not be required provided a system disparity was annunciated.

(4) The increased flexibility offered by modern avionics systems may cause flightcrews to be more susceptible to selecting an inappropriate navigation source during certain phases of flight, such as approach. Since electronic displays may incorporate more complex switching, compensating means should be provided to ensure that the proper navigation source has been selected. In order to reduce the potential for the pilot selecting a nonapproach-qualified navigation source (such as INS) for an instrument approach, the FAA has approved the use of a discrete color, in addition to labeling, for data from nonapproach-qualified navigation sources when displayed on a CDI.

(5) If the primary heading display can be presented as true or grid heading or track:

(i) The electronic display should provide appropriate annunciation. Annunciation of magnetic heading is not normally required.

(ii) Either the display or heading source should provide a cautionary alert to the crew prior to entry into a terminal area with other than magnetic heading displayed. Examples of acceptable implementations include a simple alert when below 10,000 feet and in true heading mode, or a display alert generated by complex logic that detects the initiation of a descent from cruise altitude while still in true heading mode.

(6) There are situations where it may be desirable to have true heading displayed on the primary navigation display, and at the same time have VOR or ADF bearing pointers visible. All but a very small fraction of the VORs are referenced to Magnetic North; the electronic display should display the bearing pointer in such a fashion that it will point geometrically correct. If other display considerations permit, a separate readout of magnetic bearing to the VOR station would be desirable. If the electronic display cannot display this "corrected" geometric bearing, then some display attribute should make it clear to the flightcrew that the displayed geometry is not correct.

(7) Mode and source select annunciations on electronic displays should be compatible (this does not mean that the labels have to be identical, but that they are unambiguous in being able to identify them as the same function) with labels on source and mode select switches and buttons located elsewhere in the cockpit.

(8) If annunciation of automatic navigation system or flight control system mode switching is provided by the electronic display, selected modes should be clearly annunciated with some inherent attention-getting feature, such as a temporary box around the annunciation. Examples include vertical or lateral mode capture, release of capture, and autopilot or autothrottle mode change.

9. MAP MODE CONSIDERATIONS.

a. The map format should provide features recommended by SAE Document ARP 1068B. Evaluation of maps or navigation displays overlaid with raster radar returns should ensure that all map or navigation display symbology remains readable and easily discriminated from the radar data.

b. When a route or course line can be presented in a map format, it should be demonstrated that the route can be flown manually and with autopilot in heading hold or control wheel steering modes (if applicable) with course errors compatible with those course errors defined as allowable in the U.S. National Airspace System. Advisory Circular 90-45A discusses flight technical error and relates methods of accounting for piloting accuracy.

c. If instrument approaches are to be flown using a map format, previous certifications have included an AFM limitation requiring at least one pilot to monitor a raw data presentation. For ILS approaches, raw localizer and glide slope deviation presented in the ADI has been sufficient, and both navigation displays may remain in the map mode. For VOR approaches, a map course line may be used as the primary display for conducting the approach, providing the AFM limitations prescribe the allowable display mode configurations for proper raw data monitoring. Additional considerations include evaluation of crew time and task demands to configure the map/navigation computer for the approach. If it is desired to have both displays in the map mode for VOR approaches with no raw data monitoring, the accuracy and failure modes of the map display, navigation computer, and sensors must be shown to be compatible with the performance requirements and obstacle clearance zones associated with the type of approach being conducted.

d. When evaluating map failure modes, including failures induced by the symbol generator or the source navigation computer, consideration must be given to the compelling nature of a map display. It has been demonstrated that gross map position errors can go undetected or unbelieved because the flightcrew falsely relied on the map instead of correct raw data. This characteristic of crew interpretation reinforces the need to adhere to the criteria of paragraph 4a(3)(viii), (which defines navigation as an essential function) when considering equipment and navigation source requirements.

10. INTEGRATED WARNING, CAUTION AND ADVISORY DISPLAYS.

a. A "warning" should be generated when immediate recognition and corrective or compensatory action is required; the associated color is red.

A "caution" should be generated when immediate crew awareness is required and subsequent crew action will be required; the associated color is amber/yellow. An "advisory" should be generated when crew awareness is required and subsequent crew action may be required; the associated color should be unique, preferably not amber/yellow. Report No. DOT/FAA/RD-81/38, II, stresses the importance of preserving the integrity of caution and warning cues, including color. Although electronic displays, when used as primary flight displays, are not intended to be classified as integrated caution and warning systems, they do generate warnings, cautions, and advisories that fall within the above definitions. Use of red, amber, or yellow for symbols not related to caution and warning functions is not prohibited but should be minimized to prevent diminishing the attention-getting characteristics of true warnings and cautions.

b. Caution and warning displays are necessarily related to aural alerts and master caution and warning attention-getting devices. If the electronic display provides caution and warning displays, previously independent systems may be integrated into one system where single faults potentially may result in the loss of more than one crew alerting function. Integrated systems have been found to be satisfactory if the features outlined below are provided:

(1) Visual and aural master caution attention-getting devices are activated whenever a caution message is displayed. Different visual and aural master warning devices are provided which activate whenever a warning is displayed.

(2) An aural alert audible to all flight crewmembers under all expected operating conditions is sounded when any conditions exist that require crew recognition of a problem and either immediate or future action. If the aural alert occurs because of the landing gear configuration warning, overspeed warning, takeoff configuration warning, or ground proximity warning, the aural alert must sound continually while the conditions exist. The landing gear configuration warning may be automatically inhibited in those flight regimes where the warning is clearly unnecessary. Special means may be provided to cancel these aural warnings during selected nonnormal procedures. If any one warning is cancelled, the remaining warnings must still be available. Other aural alerts may be cancelled by the flightcrew. Certain alerts (either the aural portion or both aural and visual) may be inhibited in limited phases of flight, and enabled when that phase of flight is exited or terminated, provided the overall inhibition scheme increases safety. For example, systems have been approved that inhibit most alerts during (and immediately after) the takeoff. The safety objective is to reduce the incidence of unnecesary high-speed rejected takeoffs (RTO). Toward this end, the more effective type of system uses airspeed sensing to automatically begin the inhibit function. Systems requiring manual inhibition prior to initiation of takeoff have been approved, but have the undesirable effect of suppressing alerts that should properly instigate a low-speed RTO. Enabling of alerts should be automatic after an altitude gain appropriate to the type of airplane.

(3) A separate and distinct visual warning, caution, or advisory message is conspicuously displayed for each warning, caution, or advisory condition that the system is designed to recognize. The visual indication must be visible by all flight crewmembers under all expected lighting conditions. The colors of visual warning, caution, and advisory displays provided by this system must comply with § 25.1322.

(4) Malfunctions which would cause the loss of more than one of the aural or visual alerts are shown to be improbable. In meeting this requirement, considerations are given to the crew alerting features of the system in the event of the failure of the aural or visual alert and the phase of flight. The extent of credit for the alerting devices is to be determined by simulator and flight tests.

(5) Malfunctions which would cause the loss of both the crew alerting visual and aural devices are shown to be improbable.

(6) An analysis is conducted showing that the system design and installation meets the requirements of § 25.1309 of the FAR, Amdt. 25-41, or later. In showing compliance with § 25.1309(c), both the loss of annunciation and false annunciations are to be considered, and all annunciation requirements are to be assessed. If there are alerts generated by other airplane systems that are not incorporated in the centralized alerting system, then appropriate flight or simulator tests should be conducted to ascertain that these alerts retain the required degree of effectiveness and do not deteriorate the effectiveness of the integrated system. When determining the criticality due to loss of annunciation, the joint events of loss of annunciation and the probability of malfunction requiring annunciation are to be considered. The loss of annunciation by itself is not considered a critical event.

(7) The aural alerting is audible to the flightcrew under worst case ambient noise conditions, but not so loud and intrusive as to interfere with the crew taking the required action to ensure safe flight.

11. CHECKLISTS OR PROCEDURAL ADVISORY DISPLAYS.

a. For purposes of the following discussion, checklist displays are divided into three types: those modifiable by the flightcrew, those modifiable only on the ground by maintenance procedure, and those containing information "hardwired" into the system or in ROM (unchangeable read-only-memory).

(1) Data modifiable by the flightcrew. The responsibility for electronic checklist display contents rests with the flightcrew. For those operations where the airplane is commonly flown by the same flightcrew every day, this responsibility presents no burden on the pilots. At the other extreme, in an air carrier operation the pilots cannot be reasonably expected to review the contents of the checklist before their first flight of the day in that airplane. In order to implement this type of operation, the checklist format should allow for some means to easily determine the current status of the information; this means should be compatible with a

practically implemented procedure that operationally controls who makes changes, and when and how that change level is identified on the display.

(2) Data modifiable by maintenance procedure. The display system should lend itself to a means for the flightcrew to easily determine the change level of the checklist contents.

(3) Data prepared by the manufacturer and contained in ROM. It has been previously stated in the section on display criticality that the display of hazardously misleading flightcrew procedures must be improbable. This requirement applies not only to failure states of the display system, but to changes to the airplane after display certification. While it is the responsibility of the manufacturer and the FAA to provide acceptable procedures to the operator, it is the responsibility of the operator to identify any checklist changes that may be made necessary by airplane modification. The display manufacturer should design the system so that revision status is easily identifiable by, and such that required changes can be made available to, the operator. An airplane change that made the electronic checklist incompatible with the required crew procedures in a manner that could be hazardously misleading would require the corresponding change to be made to the checklist or the display to be disabled entirely.

b. The wide variety of configurations and corresponding AFM supplements within a single model may establish a unique set of checklist procedures for each individual airplane. Incorporation of STC's or other minor modifications could necessitate changes to the AFM, AFM supplements, or addition of new supplements. These changes would then require modifications to the electronically displayed checklists. At this stage of display development, it would seem advisable to limit displayed checklist information to that which can easily be changed or that which pertains only to the basic airplane. A hard copy of the AFM or approved operations manual and any checklists required by the operational rules must be available to the flightcrew at all times.

c. Because misleading information in an emergency procedure could be hazardous, those elements of the display system responsible for the content of such procedures are deemed to be essential, and the display of wrong or misleading information must be improbable. An analysis of the display system showing that such hazard is improbable should be accomplished, the major concern being that incorrect procedures may be presented which could result in confusion in the cockpit. This analysis does not have to include the probability of the flightcrew entering wrong information into a crew entry type of display.

d. Electronic checklists should be consistent in the level of detail among the various procedures. Checklist content that the crew may rely on for normal day-to-day procedures, but which is incomplete for abnormal or emergency procedures, may be unsatisfactory because of the extra time required for the crew to discover that the information required is missing and only obtainable from an alternate hardcopy checklist. Crew training, display response time, availability of display, and other cockpit cues are to be considered in evaluating the display system. If the system does not display all procedures required for safe operation of the airplane during normal and emergency conditions, testing is required to ensure that the proposed method for integrating an electronic checklist along with hard copy checklists does not decrease the level of safety in any foreseeable circumstance. If electronic checklists are installed, pilot workload should be no greater than that for using hard copy of the procedures.

12. SYSTEMS STATUS DISPLAYS. If airplane systems status displays are provided, based on flight phase and system failure conditions, the symbols representing the system components should be logical, easily understood, and consistent between display formats. The colors used should be compatible with the requirements of paragraphs 5a and 5b of this AC.