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Human Factor Considerations in the Design of Multifunction Display Systems for Civil Aircraft

RATIONALE

The G-10 committee has agreed to stabilize this document as the content has been determined to be basic and stable information not dynamic in nature.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE G-10, Aerospace Behavioral Engineering Technology Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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FOREWORD

This Aerospace Recommended Practices (ARP) document contains information developed by the SAE G-10 Multifunction Display (MFD) Subcommittee that is intended to be used for guidance in the design of multifunction display systems to be installed in a civil aircraft flight deck.

Modern technology has made it possible to install electronic flight instruments, either head-down or head-up, that are capable of providing flight information previously displayed on electro-mechanical instruments. In addition, systems can be designed to provide a flight crew selectable display of information from several systems on the same unit, either individually, or in combinations of two or more sets of information. The integration of new systems, such as traffic information, navigation, terrain guidance, geographical mapping functions, data link and weather, among others, into the flight deck, where space is at a premium, has created the need to integrate these functions into multifunction flight deck display systems.

The additional information provided by the new systems is extremely valuable in improving flight crew situational awareness (to include single pilot operation), communications, and efficiency, and overall safety of modern flight. However, there is a danger of overloading flight crews and not gaining full benefit from the systems. To avoid this, it is important that guidelines and standards for the design and integration of MFDs be developed, particularly in areas related to human performance and limitations, perception, ergonomics, cognitive abilities, automation and information processing. These data should be applied in conjunction with a complete task analysis to ensure that system performance requirements are well defined prior to the actual integration and implementation of the functioning MFD system. The overall goal is to minimize flight crew task loading and enhance human performance consistent with the overall required performance and safety goals of the aircraft system.

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1. SCOPE:

The function of a multifunctional display (MFD) system is to provide the crew access to a variety of data, or combinations of data, used to fly the aircraft, to navigate, to communicate, and to manage aircraft systems. MFDs may also display primary flight information (PFI) as needed to insure continuity of operations. This document sets forth design and operational recommendations concerning the human factors considerations for MFD systems.

The MFD system may contain one or more electronic display devices capable of presenting data in several possible formats. MFDs are designed to depict PFI, navigation, communication, aircraft state, aircraft system management, weather, traffic, and/or other information used by the flight crew for command and control of the aircraft. The information displayed may be combined to make an integrated display or one set of data may simply replace another.

The information contained in this document can be applied to the design of all MFDs, including electronic flight bags (EFB), regardless of aircraft type. This document makes extensive use of “lessons learned” and information developed and currently in use by systems and airframe manufacturers through the evolutionary development of today’s advanced systems.

Some assumptions used in developing this document include:

- MFDs will incorporate a human-centered design using knowledge gained from previous work and research.
- This document is intended to apply to new systems or modifications to existing systems.
- Each function of a MFD is capable of providing accurate and timely information appropriate to the tasks of the flight crew for certain aircraft operations throughout all phases of flight.
- MFD systems will be based on the aeronautical English language, but other languages may have to be considered.
- MFD systems will meet international harmonized certification requirements.
- Use of the information in this document is subject to the certification requirements for a given airplane.
- The design process should include operator training considerations throughout its development.
- PFI will be available on the flight deck at all times.

1.1 Purpose:

This document is meant to serve as guidance material manufacturers, operators and certifying officials on the human-factors considerations that should be included in a MFD design and implementation. The use of multifunction displays is growing rapidly throughout the aviation industry and, as with most new technologies and systems, the functional design often outpaces the integration of proper human-factors considerations. Baseline guidance is needed to achieve maximum benefit from the technology, and to allow continued growth in usage and functionality. Just because a particular application is not discussed does not preclude the use of MFDs for addition applications as technology and needs evolve.

1.1 (Continued):

The scope of this document and various reference materials are provided in Section 1 and Section 2. Section 3 describes the functionality that could be incorporated in MFD systems. Section 4 discusses the design objectives that should be considered in MFD design, regardless of application. Section 5 addresses implementation and integration and Section 6 discusses training. Appendices have been added to provide supporting information for the sections. Appendix A provides a matrix representation of possible combinations of displayed data. A bibliography of literature relevant to this document is presented in Appendix B.

2. REFERENCES:

The following publications form a part of this document to the extent specified herein. The latest issue of Society of Aerospace Engineers (SAE) publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001. Only latest version of the documents will appear in the reference list.

AS425C Nomenclature and Abbreviations for Use on the Flight Deck.
ARP571C Flight Deck Controls and Displays for Communication and Navigation Equipment for Transport Aircraft
ARP1068B Flight Deck Instrumentation, Display Criteria and Associated Controls for Transport Aircraft
ARP1093 Numeral, Letter & Symbol Dimensions for Aircraft Instrument Displays
ARP1874 Design Objectives for CRT Displays for Part 25 (Transport) Aircraft
ARP4032A Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays
ARP4033 Pilot-System Integration
ARP4101/2 Flight crew Visibility From The Flight Deck.
ARP4102 Flight Deck Panels, Controls and Displays.
ARP4102/1 On Board Weight and Balance System
ARP4102/2 Automatic Braking System (ABS)
ARP4102/3 Flight Deck Tire Pressure Monitoring System
ARP4102/4 Flight Deck Alerting Systems (FAS)
ARP4102/7 APPENDIX A, Electronic Display Symbology for EHSI/PFD
ARP4102/7 APPENDIX B, Electronic Display Symbology for EHSI/ND
ARP4102/7 APPENDIX C, Engine Displays
ARP4102/8A Flight Deck, Head-Up Displays
ARP4102/13 Data Link

2.1 (Continued):

ARP4102/15	Electronic Library System (ELS is a resource; it is in the process of being replaced by a broader scope supplement “Electronic Data Management System (EDMS)”)
ARP4105B	Abbreviations and Acronyms for Use on the Flight Deck
ARP4107	Aerospace Glossary for Human Factors Engineers
ARP4155A	Human Interface Design Methodology for Integrated Display Symbology
ARP4256	Design Objectives for Liquid Crystal Displays for Part 25(Transport) Aircraft
ARP4791A	Human Engineering Recommendations for Data Link Systems
ARP5108	Human Factors Criteria Design for Terrain Separation Assurance Display technology
ARP5287	Optical Measurement Procedures for Airborne Head-Up Display (HUD)
ARP5288	Transport Category Airplane Head-Up Display (HUD) Systems
ARP5289	Electronic Symbols for Charting
ARP5365	Human Interface Criteria for Cockpit Display of Traffic Information
AS8034	Minimum Performance Standards for Airborne Multipurpose Electronic Displays
AS8055	Minimum Performance Standard for Airborne Head-Up Display (HUD)
ARP50017	Aeronautical Charting
ARP50062	Human Factors Issues Associated with Terrain Separation Assurance Display Technology

2.2 U.S. Government Publications:

Available from Federal Aviation Administration (FAA), 800 Independence Ave, SW, Washington, DC 20591.

AC 20-EMP/	Airworthiness Approval of Aeronautical Telecommunications Network Compatible Airborne Data Link Systems
AC 20-DC	Guidelines for Design Approval of Aircraft Data Communication Systems
AC 23.18	Installation of Terrain Warning System
AC 23.1309-1C	Equipment, Systems, and Installations in Part 23 Airplanes
AC 23.1311-1A	Installation of Electronic Display Instrument Systems in Part 23 Airplanes
AC 25-11	Transport Category Airplane Electronic Display Systems
AC 25-23	Airworthiness Criteria for the Installation Approval of a Terrain Awareness and Warning System (TAWS) for Part 25 Airplanes
AC 25.1309-1A	System Design Analysis
DOT/FAA	The Interfaces between Flight Crews and Modern Flight Deck Systems. Human Factors Team (1996), Washington, DC
DOT/FAA/PS-89/1	Flight Status Monitor Design Guidelines (Anderson, et al 1989)
FAA-RD-81-3811	Aircraft Alerting System Standardization Study: Volume II. Aircraft Alerting System Design Guidelines (Berson, et al 1981)
FAR Part 23	Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
FAR Part 25	Airworthiness Standards: Transport Category Airplanes
FAR Part 27	Airworthiness Standards: Normal Category Rotorcraft
FAR Part 29	Airworthiness Standards: Transport Category Rotorcraft
JAR Part 25	Airworthiness Standards: Transport Category Airplanes

2.2 (Continued):

TSO-C92c	Airborne Ground Proximity Warning Equipment
TSO-C113	Airborne Multipurpose Electronic Displays

2.3 Other Publications:

ARINC 649	Electronic Library Systems
CS Report 9213	Guidelines For The Use of Color On Air Traffic Control Displays
ICAO, Annex 4	Aeronautical Charts
ICAO, Annex 14	Aerodrome Design and Operations
ICAO, Annex 15	Aeronautical Information Services, 10th Edition, Incorporating Amendments 1-29, July 1997
RTCA /DO-239	Minimal Operational Performance Standards for Traffic Information Service (TIS/TIS-B) Data Link Communication, WG3, April 1997
RTCA/DO-257	MOPs for the Depiction of Navigation Information on Electronic Maps
RTCA/DO-243	Cockpit Display of Traffic Information (CDTI)
RTCA/DO-200	Preparation, Verification and Distribution of User-Selectable Navigation Databases
RTCA/DO-200A	Standards for Processing Aeronautical Data
RTCA/DO-201	User Recommendations for Aeronautical Information Services
GAMMA	Publication 10

2.4 Definitions:

Definitions of words used in this document shall be as noted in the Glossary of Terms. The word "shall" is used to express an essential (mandatory) requirement, such as emergency or critical situations. Compliance requires that there be no deviation. The word "should" is used to express a recommendation. Deviation from the specified recommendation may require justification.

2.5 Abbreviations and Acronyms:

AC	Advisory Circular
ACARS	Aircraft Communications, Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ADC	Air Data Computer
ADF	Automatic Directional Finder
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
AIP	Aviation Information Publications
AOCDL	Aeronautical Operational Control Data Link
APU	Auxiliary Power Unit
ARINC	Aeronautical Radio Inc.
ARD	Aerospace Resource Document
ARP	Aerospace Recommended Practice
AS	Aerospace Standard

2.5 (Continued):

ATC	Air Traffic Control
ATIS	Airport Terminal Information System
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Services
CAA	Civil Aviation Authority
CAS	Crew Alerting System
CAT	Clear Air Turbulence
CBI	Computer Based Instruction
CDI	Course Deviation Indicator
CDTI	Cockpit Display of Traffic Information
CPDLC	Controller to Pilot Data Link Communications
CNS	Communication, Navigation and Surveillance
CRC	Cycle Redundancy Check
DFIS	Digital Flight Information System
DME	Distance Measuring Equipment
DOT	Department of Transportation
DP	Datum Point
EDMS	Electronic Data Management System
EFB	Electronic Flight Bag
EFIS	Electronic Flight Instruments System
EGT	Exhaust Gas Temperature
EICAS	Engine Indication and Crew Alerting System
EMD	Electronic Map Display
EPR	Exhaust Pressure Ratio
ETA	Estimated Time of Arrival
ETE	Estimated Time Enroute
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FIS	Flight Information Systems
FLIR	Forward Looking Infrared
FMS	Flight Management System
FOQA	Flight Operations Quality Assurance
GLS	GPS Landing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HDD	Head-Down Display
HUD	Head-Up Display
Hz	Hertz
ICAO	International Civil Aeronautical Organization
IMC	Instrument Meteorological Conditions
IFR	Instrument Flight Rules
IR	Infrared

2.5 (Continued):

ILS	Instrument Landing System
INS	Inertial Navigation System
LAAS	Local Area Augmentation System
LLTV	Low Light Level Television
LOFT	Line Orientated Flight Training
LORAN	Long Range Navigation System
MCDU	Multifunction Control Display Unit
MEL	Minimum Equipment List
METAR	Meteorological Aviation Report
MFD	Multifunction Display
MLS	Microwave Landing System
MMWR	Millimeter Wave Radar
NAS	National Airspace System
NDB	Non-Directional Beacon
ND	Navigation Display
NOTAM	Notice To Airmen
NIS	NAS-wide Information System
OEM	Original Equipment Manufactured
PFD	Primary Flight Display
PFI	Primary Flight Information
PFR	Primary Flight Reference
PWS	Predictive Windshear System
RNP	Required Navigation Performance
RWS	Reactive Windshear System
SA	Situational Awareness
SAE	Society of Aerospace Engineers
SMGCS	Surface Movement Guidance and Control System
TACAN	Tactical Air Navigation
TAF	Terminal Area Forecasts
TAWS	Terrain Awareness Warning System
TCAS	Traffic Alert and Collision Avoidance System
TIS/TIS-B	Traffic Information Service/Traffic Information Service Broadcast
UAT	Universal Access Transceiver
UV	Ultra Violet
VDL	VHF Data Link
VFR	Visual Flight Rules
VHF	Very High Frequency
VOR	VHF Omni-Range
VORTAC	VHF Omni Range and Tactical Navids
WAAS	Wide Area Augmentation System

3. SYSTEMS FUNCTION:

The MFD, as a single display or in combination with one or more other displays, may be used to depict weather, moving maps, traffic and other information. These displays should provide accurate and timely information to the flight crew for aircraft operation and navigation throughout all phases of flight and under all normally expected conditions.

Various technologies are moving very quickly so therefore not all technologies are depicted in this document.

3.1 Primary Flight Information:

Primary Flight Information (PFI) is the essential information that the flight crew must have to safely maneuver and control the aircraft throughout all phases of flight. This information must always be present as a continuous, full-time display of attitude, altitude, airspeed, track or heading, and vertical velocity for each required crewmember.

PFI may be displayed on multiple instruments or on a single display. In either case, PFI must be located within the primary field of view for each pilot in a manner consistent with the format specified in FAR 25.132. This information, known as the basic "T", must be provided in the

primary field of view whether presented on a head-down display (HDD), or head-up display (HUD). There should be adequate visual separation from other instruments and indicators to allow easy visual acquisition and tracking. Primary flight information also provides the flight crew with the information necessary to perform instrument maneuvers during any phase of flight. This includes a prominent attitude display that permits the pilot to readily recover from unusual attitudes. A failure indication of any required data shall be provided as part of the PFI. Any additional information provided in the display shall not interfere with PFI data.

3.2 Primary Flight Display:

The Primary Flight Display (PFD) is the common name given to the MFD that contains the PFI considered essential to the safe operation of an aircraft. This information is provided to the flight crews on displays (head-up or head-down) located directly in front of the pilot. A failure of any PFI sensor input to the PFD must be suitably annunciated on the PFD. A failure of any source of display data for the PFD shall provide automatic switching, or reversion, to another suitable source with flight crew alerting. In addition, if there is a failure of the entire PFD display unit, automatic reversion of PFD information to another suitable display is required.

The PFD should include the means to present the angle of attack margin from stick shaker, and flight path vector and longitudinal acceleration. The PFD should also include the Flight Director function and the mode annunciation function of the Flight Guidance System. This includes the engagement status of the Autopilot, Flight Director and Autothrust System.

3.2 (Continued):

The PFD should also include the tactical navigation function. This is considered navigation information necessary for the tactical control of the flight path by the pilot. This will require a path deviation indication scaled appropriately for the Required Navigation performance (RNP). A moving map format may also be presented. Time critical alerts and any other information considered necessary for the current phase of flight should also be displayed in each PFD.

The PFD may be used to provide information that will assist in airborne self-separation. This may include target speeds, vertical speeds, flight path angles and headings.

3.3 Primary Engine Information:

Primary engine information includes the engine parameters considered essential to setting the appropriate engine thrust for each phase of flight and important supplemental information necessary to monitor or confirm proper engine operation. The primary thrust setting information is generally exhaust pressure ratio (EPR), torque and/or N1 for turbine engines. Supplemental information typically including exhaust gas temperature (EGT), N2 and Fuel Flow may be displayed as primary or secondary information. Primary engine information must be continuously displayed to each pilot. In the event the MFD that displays the primary engine information fails, another MFD must be available to present the primary engine information. Primary engine information is typically displayed as a single display near the centerline of the flight deck. It may be displayed on separate MFDs closer to the design eye position for each pilot.

3.4 Secondary Engine Information:

Secondary engine information includes the engine parameters considered supplemental in nature. This information typically includes oil pressure, oil temperature, engine vibration, and fuel used. Secondary information does not need to be presented on a continuous basis. However, if caution and warning limit conditions occur for any of the secondary engine parameters, an automatic means to display the parameter with the exceedance shall be provided.

3.5 Visual Crew Alerting System (CAS) Information:

Crew alerting should include a master caution and warning aural and visual alerting system that serves as an attention getting mechanism to direct the pilot's attention to a centralized crew alerting display. Crew alerting information is characterized as a centralized visual display of warning, caution, and advisory information that is continuously available and readily visible to each pilot. In the event of a failure of the MFD that displays this information, another suitable MFD must be used to present this information. It may also be displayed on separate MFDs closer to design eye position for each pilot. Crew alerting information is supplemented by attention-getting aural and visual alerts for cautions and warnings that then direct the pilot's attention to the crew alerting display. This display is intended to be specific so as to direct the pilot to the appropriate checklist procedure to remedy or address the problem.

3.6 Navigation Information:

Vertical and lateral navigational information is that information required by the flight crew to establish a flight path and monitor the aircraft's progress along that flight path. Navigational information is available to the flight crew from a number of sources. Sources for navigation data may be derived from external systems such as VHF Omni-Range/Distance Measuring Equipment (VOR/DME), Long Range Navigation System (LORAN), or Global Positioning System/ Wide Area Augmentation System (GPS/WAAS), or may be internal, as provided by a flight management system (FMS) using an Inertial Navigation System (INS), Global Positioning System (GPS), or VOR/DME with an updateable and loadable navigation database. The navigation information computed and/or displayed may include: latitude/longitude, estimated time of arrival (ETA), estimated time enroute (ETE), bearing to waypoint, distance to waypoint, aircraft heading, navigation waypoint(s), airports, airspace use symbology, actual track, desired track, track angle error, vertical path error, ground speed, and flight plan waypoints. It may also include approach charts, Visual Flight Rules / Instrument Flight Rules (VFR/IFR) enroute charts, terrain and obstacle data, taxi charts, taxi guidance and ground facilities data.

3.7 Weather Information:

Weather information, including weather radar, icing, lightning, windshear, meteorological aviation reports (METARs), terminal area forecasts (TAFs), airport terminal information system (ATIS), or environmental hazards can be provided from a combination of on-board sensors and data link information. Display elements of various weather and hazard information should be consistent within itself and with other MFD display elements.

An expanding suite of on-board systems is available to assist the crew in understanding the weather. The capability of these systems is varied. Weather radar, providing data to display several levels of precipitation by use of color, is common. Some weather radar systems provide added features including profile view, ground clutter reduction mode, turbulence detection, and automatic and manual levels of basic radar management. To this can be added a lightning detector system. Windshear and icing detection systems can provide information to better cope with these phenomena.

Data link weather systems can also provide a wide array of weather information. This information can be the result of individual sensors or can be a composite of several sensors. It can also include additional environmental information on such hazards as volcanic ash or atmospheric ozone conditions. One implementation of data link weather information is through the use of a flight information system (FIS).

A means to integrate weather information with other display elements, such as navigation data, should be provided in a manner to best support the mission. This integration may include the ability to selectively layer the information displayed and should include the availability status of the sources of environmental data. The controls to manage these various sources should present the crew with logical combinations for the selection of features.

3.7.1 Weather Radar: The weather radar is the principle on-board means of detecting hazardous weather. When displayed on an MFD in combination with other data that could be critical to safe flight, the weather radar display shall not obscure the critical data. Colors used to depict weather severity on the radar shall not conflict with colors used to display other critical information such as conflicting air traffic, threatening terrain, or more imminent weather threats.

3.7.2 Icing Information and Alerts: An ice detection feature may be provided via an onboard sensor. The detection information should be integrated into the crew alerting system so that the flight crew will be alerted immediately to any significant icing on the aircraft surfaces. A synoptic page may be provided on the MFD that will allow the crew to evaluate the situation in more detail.

3.7.3 Lightning Information and Alerts: Atmospheric lightning activity may be displayed by itself or layered with the weather radar and/or navigation information. It is possible to provide lightning strike data to the flight deck as an aid in determining the severity and location of severe thunderstorms via data linked weather information and/or onboard sensors. If this information is provided it should be available for crew access on the MFD, but shall not obscure or conflict with other higher priority weather data.

3.7.4 Windshear Information and Alerts: Windshear systems can provide both predictive and reactive alerts. Alerting and guidance shall be provided immediately on the PFD in the presence of windshear. The MFD may provide more detailed information.

3.7.5 Wake Vortex/Clear Air Turbulence Information and Alerts: Wake Vortex and/or Clear Air Turbulence (CAT) systems can provide both predictive and reactive alerts. Suitable alerting shall be provided when wake vortex or CAT conditions are detected.

3.8 Terrain and Obstacles:

Current technologies employed to provide terrain awareness include basic ground proximity warning systems (GPWS) using a radar altimeter and barometric altimeter input and terrain awareness warning systems (TAWS) utilizing digital terrain and airport databases. In addition to terrain or obstacle alerting, TAWS will provide a terrain display that may be integrated into an MFD and the crew alerting information display.

3.9 Airport Mapping:

Airport surface maps with a variety of attributes and alerting algorithms are being developed to prevent potential hazardous surface movements while allowing for more efficient surface operations. Accuracy, resolution and integrity of the various functional attributes will vary, dependent upon the specific needs of each operational application. Airport map depictions can be used as either stand-alone charts displayed on MFD's or can be used with the following additional overlay functions, capabilities and features:

- Airport moving map with geo-referenced "own-ship" position overlays
- Automatic Dependent Surveillance-Broadcast (ADS-B) and Traffic Information Service (TIS-B) traffic information overlays, including surface vehicle depictions
- Controller to Pilot Data Link Communication (CPDLC) / taxi guidance overlays (e.g., clearances and instructions)
- Graphical airport-specific Notice To Airmen (NOTAM) overlays
- Aircraft landing gear position predicator displays
- Over steer taxi director displays.
- Runway Incursion Alerting and Ground Traffic

The above functional capabilities are intended to address the runway incursion safety issue, collisions at non-towered airports, runway excursion incidents, and Surface Movement Guidance and Control System (SMGCS) applications.

3.10 Traffic Information:

A cockpit display of traffic information (CDTI) system performs the function of presenting surveillance information about the surrounding air traffic to the flight crew. The information presented may include the relative position of other aircraft in the vicinity with respect to own aircraft, flight identification, target selection and highlighting, selectable display ranges, range references, closure rate, ground speed, ground track and other pertinent information. The type of information displayed will vary, depending on the application or the intended operational use of the information. Traffic information for the CDTI may be obtained from one or more on-board sources or data link, including, but not limited to, ADS-B, TIS/TIS-B, and Traffic Alert and Collision Avoidance System (TCAS).

A graphical presentation of traffic on a HDD, accompanied by an aural alert, is the most common method of providing traffic alerts, but other types of presentation, such as graphical head-up, are also possible. Regardless of the method of implementation, the traffic display on an MFD shall provide a positionally accurate depiction of other traffic to enable the flight crew to maintain situational awareness of other aircraft.

3.11 Aircraft Systems Functions:

The MFD may be capable of displaying that information required to operate the on-board systems. If this capability is provided, there should be a means to monitor individual systems functions and status.

3.11.1 System Status Information: System status information provides relevant data on typical performance parameters of systems such as the electrical system (volts, amperage, percentage load, etc.) the fuel system (each fuel tank quantity, total fuel tank quantity, fuel temperature, fuel pump pressure, cross feed valve position, etc.) the hydraulic system (pressure, quantity, temperature), the environmental system (cockpit temperature, cabin temperature, cargo temperature, engine and Auxiliary Power Unit (APU) bleed air pressure etc.), anti-ice systems (valve position, tail temperature, wing temperature, nacelle temperature, etc.), oxygen systems (pressure, quantity, temperature, etc.). These data need not be displayed full time but must be accessible to the flight crew with minimal effort when needed. Data should present with sufficient resolution for the pilot to determine non-normal system performance before alert conditions are reached. Presentations should include the primary indices and the normal/acceptable ranges of values that each parameter may take in accordance with current regulations.

3.11.2 System Synoptic Displays: Synoptic displays provide a condensed representation of the functionality of aircraft systems to the flight crew. Current system designs provide status information, such as pressures, temperatures, quantities, generator frequency, voltage and may also allow for direct system control. Malfunction or other abnormal operating conditions should be presented to the flight crew and maintenance personnel through synoptic pages on the MFD. A means to provide monitoring of aircraft systems to alert the flight crew upon approaching or exceeding an out-of- tolerance situation or an abnormal trend condition is recommended. The synoptic display should provide the flight crew and maintenance personnel with ready access to emergency procedures, consequences of system failure, suggested corrective actions, checklists, or recommended maintenance procedures.

3.11.3 Aircraft Configuration: This information is used to indicate the status and settings of specific subsystems on the aircraft. This category includes displays indicating the deployment of devices such as landing gear, flaps, slats, ground and flight spoilers, lateral/longitudinal/directional trim position, auxiliary power-generating devices (ram-air turbine), cabin access systems (doors, etc.) and similar systems. This information must be available and readily accessible, to the flight crew at all times. Means must be provided to indicate malfunctions, cautionary indications or failures to the flight crew.

3.11.4 Self-Diagnostics: Components will have a built-in test, or self-diagnostic, function whereby the unit conducts a test of system functions, database and sensor integrity, and system sources resources available to ensure proper operation and to prevent erroneous data or guidance from being displayed. Failures will be detected and communicated to the flight crew.

3.12 Data Link Functions:

The concept of data link involves embedding encoded information into a defined packet, word or string of transmitted data in such a manner that the format is consistent and can be decoded for use at the receiving end. Some of the proposed applications, such as the use of data link to replace portions of the normal aircraft/air traffic control voice communications, may require flight deck interaction. Transfer of data from TCAS, CDTI, TIS/TIS-B, and ADS-B and other sources from outside the aircraft into aircraft systems for processing and implementation can be accomplished automatically. However, there may be safety related combinations, which may require the crew to be alerted to (or made aware of) the source of data being used, and whether the source has changed for any reason. All data received shall not degrade operation of on-board systems, and shall be not induce jitter, target positional errors, or inconsistencies.

3.12.1 Controller to Pilot Data Link Communications: The International Civil Aviation Organization (ICAO) has defined, through the Civil Aviation Authorities (CAA) and industry participation, an internationally coordinated standard for Controller to Pilot Data Link Communications (CPDLC) in an Aeronautical Telecommunication Network (ATN) environment. It is expected that the implementation of ATN, CPDLC will lead to significant user benefits including reduced delays, voice channel congestion, and workload.

CPDLC for Air Traffic Control (ATC) clearances and instructions in graphical, textual or numerical data format may be achieved through the selection from menus of one or more standardized messages into which the flight crew may have to insert various parameters. It remains necessary to provide the flight crew with a means to construct messages that explain situations or deal with circumstances that were not foreseen when the standard message sets were defined. Since CPDLC is bi-directional, it is necessary to allow both viewing of messages received in the flight deck from air traffic control, and the construction and transmission of messages from the aircraft to air traffic control.

CPDLC control and display have been implemented in a number of different ways, such as:

- A function of an MFD with interactive inputs being achieved through a combination of a cursor control device and separate keyboard.
- A stand-alone device with enough data link functionality to be considered an MFD. Here, inter-activity is achieved through integrated keys and through a separate keyboard.
- A separate function of a multifunction control display unit (MCDU).

The CPDLC function is normally selected to a specific MFD through selections made at a central control panel. Provisions should be made to allow selections using a cursor control device, or a MCDU keyboard, and special-purpose buttons should be used for highly repetitive functions. Single key selection of the basic menu should be possible when the flight crew has a message waiting that has not been acknowledged. Selections should be possible from the menu and sub-menus by selecting the required function on the MFD screen and entering any required values into the MCDU or other input device.

3.12.1 (Continued):

Data link messages used for communication generally come under seven acknowledged classes. These are:

Clearance:	An authorization for an aircraft to proceed under specified traffic conditions within controlled airspace.
Instruction:	ATC directive for specific actions.
Advisory:	Non-binding advice and information provided to assist in the safe conduct of a flight.
Report:	Response by a crewmember to inform ATC that a condition expressed in a clearance, instruction or request has been achieved.
Request:	Asking for something that may have an effect on the safe conduct of a flight. Emergency:Notification to ATC that a situation critical to continued safe flight has occurred.
Acknowledgment:	Response of the intent to comply with a clearance, instruction advisory information, request or emergency message.

3.12.2 Aeronautical Operational Control Data Link: Aeronautical Operational Control Data Link (AOCDL) data transfers occur from equipment to equipment automatically to send encoded data related to air traffic, weather and aircraft performance. A means should be provided for the flight crew to check the status of data transfers and a means to validate reception of specific data, such as the use of defined labels or function codes.

3.13 The Radio Management System Function:

The radio management system function generally includes a means for each pilot to preselect, select, and store radio frequencies (VHF 1,2,3, HF 1,2) tune navigation frequencies (VOR, ILS, MLS, GLS, ADF), and set Mode S transponder codes etc. These functions may be available in PFDs or other MFDs. Due to the criticality of the communication function, multiple location capability for this information should be provided.

3.14 Electronic Data Management System:

An electronic data management system (EDMS) is a library containing a variety of types of data, either stored in databases in the aircraft or accessible by data link. Information from EDMS may be displayed on aircraft MFDs or may be displayed on a separate flight crew access terminal. The system may have the capability of allowing crew members to complete any form or report that the operator uses by electronic data entry.

Data may be categorized as: permanent, valid for more than one flight; temporary, valid for a single flight; or transient, valid for less than a complete flight. Transient data is generally drawn from external sources. The types of data that are currently available include operating environment requirements and procedures, regulatory material, aircraft specific information, and company and crew specific information. A detailed list is provided below.

Operating environment information
Navigation information
Airport information
ATC requirements/procedures
Weather information/procedures
FIS
Terrain
Obstacles
Environmental Hazard Information
NOTAM updates
Regulatory and procedural material (e.g. FAR, AIM)
Aircraft, Company, and Crew specific information:
Limitations
Normal/Abnormal Emergency Procedures
MEL/CDL
Performance
Technical logbook
System schematics
Weight and balance
Company and crew specific information:
Company orders and procedures
Crew scheduling requirements and information
Security procedures
Passenger service procedures
Commercial information
Passenger lists
Airline operating timetables
Checklists
Company orders/NOTAMS

3.15 Electronic Checklist:

An electronic checklist presents the crew with a display of normal and/or abnormal procedures. This presentation may be static; for example, it may merely list the steps required by a checklist, thereby acting exactly like a paper checklist. In addition, electronic checklists may require entry by the crew of the completion of each step, and may highlight to the crew those steps that have been skipped or have not yet been completed. When aware of aircraft systems, the checklist may further automatically detect when steps have been completed or are unnecessary for the current aircraft configuration. Electronic checklists may be selected by the crew, or potentially may be selected automatically in response to embedded triggers (e.g. post-landing checklists being shown following landing) and/or in response to alerts generated by other cockpit systems (e.g. the automatic presentation of emergency procedures).

The checklists may be presented as a list of actions, using similar format to that used by paper checklists. Research suggests that the presentation of only one action at a time can lead to adverse checklist-following behavior (e.g., crew getting 'lost' in the procedure, or over-relying on the procedure). Other presentations of checklists may be possible, such as integration of checklist information into system status displays or system schematics. However, these presentations have not been widely tested and their impact on checklist-following behavior should be carefully examined during design; possible negative impact in terms of display concerns such as clutter should also be considered.

3.16 Imaging Systems:

Installation of cathode ray tube and liquid crystal displays in aircraft flight decks has provided a means for the presentation of electro-optical imagery. This technology allows the presentation of enhanced visual scenes after processing actual images.

Since the infrared system functions in a different part of the light spectrum, objects and terrain features concealed by darkness and certain types of visual obscurations may be visible. Enhanced visual systems include optical systems that employ visual light enhancing devices. The flight crew can then present this information on a display for reference.

In some applications, imagery may be presented on a HUD allowing overlaying of imagery and outside scenes. Adding imagery to conventional symbology results in the HUD becoming an MFD. Head-down displays can also be used for the display of imagery combined with conventional symbology. Sensor imagery has been used to improve aircraft landing capabilities and taxi operations in low visibility.

4. DESIGN OBJECTIVES:

The MFD should incorporate a human-centered design that enables the flight crew to gain the greatest level of safety, effectiveness, and efficiency. The following criteria should be incorporated into the design and integration.

4.1 Crew Interface:

The human centered design must provide the crew with simple operation, consistent performance and intuitive use, without negative transfer of information.

4.1.1 Consistency of Design: The overall operation of the MFD must be consistent between all modes of operation. The use of color, encoding and symbology should be consistent between the different display modes available to the MFD. Colors, symbology, and operation shall reflect the requirements of the existing regulatory guidance. If overlaying information, the scaling of the information must be consistent on the display. If multiple methods of performing the same operation are provided they should be implemented consistent with the overall cockpit design philosophy. The MFD should incorporate operational characteristics compatible with the existing flight deck design and configuration. The MFD should present symbology and colors that are consistent with other flight deck displays in order to avoid negative transfer. When an MFD is retrofitted into an existing cockpit, cockpit constancy should be evaluated and adjustments made, if necessary, to maintain the integrity of the original cockpit design philosophy.

If a MFD is used to display primary flight information on a head-up display system, the provisions of ARP 5288 will apply. The head down display of the primary flight information should emulate the head-up display and should be within the primary field of view. The use of color and symbology should be consistent between the different display modes available to the MFD. Colors, symbology and operation will reflect the requirements of the existing regulatory guidance, and will not lead to confusion or conflict with other flight deck instruments. If overlaying information, automatic adjustment of scaling should occur before information is presented. The design shall follow existing conventions for other flight deck displays when installed as a retrofit in order to avoid negative transfer.

4.1.2 Simplicity: The MFD system should represent the simplest design consistent with functional requirements and expected environmental operating conditions. The design of the MFD system should minimize the number of operator actions required to accomplish a task. Clear feedback should be provided to the operator to indicate that the control is properly actuated, that the desired response is achieved, and when the response is complete.

4.1.3 Intuitiveness: Control and use of the MFD should follow established conventions for control labeling, color usage and overall design.

The relationship of a control to its associated display should be immediately apparent and unambiguous to the operator. This relationship can be established through proximity, coding, labeling, etc. The response of a display to control movement should be consistent, predictable, and should conform to the operator's expectations.

Additionally, all controls necessary to operate the MFD should be readily available within normal field of reach for the flight crew, and should be labeled and backlit in a legible manner to allow easy identification and access.

MFD menu structure should follow a top-down architecture to allow a flight crew to sequentially step through the available pages in a logical way. The number of hierarchical levels used to control a process should be minimized. The system should at all times indicate the current position within the menu structure and must always allow an immediate return to the main menu. User memorization shall be minimized. See 5.11 "Menu Structures and Architecture" for further guidance.

4.1.4 Readability: The displays should be readable from the design eye position and from all positions normally expected to use the displays. Both static and dynamic text and graphics should be readable in all lighting conditions, including full sunlight. The internal lighting should allow adjustment across a range of brightness levels within established guidelines for electronic display systems. Any text displayed should be presented top up. In addition to English, critical text information displayed may be in the pilots' primary language.

4.1.5 Accessibility: Location of flight crew controls for the MFD should be located within the normal range of motion when seated at the flight crew's positions. Knobs, buttons and other controls should have adequate separation to allow the flight crew to make adjustments without inadvertently making false entries.

4.2 Information Characteristics:

4.2.1 System Response and Information Accuracy: Reliability and accuracy requirements should be consistent with regulatory requirement guidelines where specified. All displayed information should be required to have the necessary degree of fidelity and integrity to meet relevant operational requirements.

4.2.2 Conflicting Information: The MFD should detect sensor/data fusion errors when integrating data from different sources. The MFD design should not display conflicting information when this information is derived from multiple sources that are not in agreement. An exception to this case occurs when such data is provided to the operator in order to compare data sensors and/or sources. Inconsistencies shall be obvious or annunciated and not contribute to errors in information interpretation.

Sensor/data fusion is the integration or merger of data from multiple sensors to enhance system performance. Inconsistencies in aircraft position solutions from different data sources shall be identified and a means of removing selected navigation sources from the solutions shall be provided to the pilot. RTCA DO-187 provides guidance for the use of multiple position sensors.

4.3 Reliability:

Information must be timely and accurately displayed in such a way that it does not interfere with aircraft operations while providing immediate alerting to failures and emergencies. Since the MFD may be providing display of PFI, it must be able to operate in degraded modes with switching available to all displays that are still functional. The system design and installation must feature ease of operation, with readily accessible controls.

4.3.1 Maintain Situational Awareness: The MFD should present information necessary in a form that assists the flight crew in achieving a level of situational awareness commensurate with safe operation

4.3.2 Error and Fault Detection and Verification: When used as a flight warning system, the MFD should provide timely alerts to the flight crew and not interfere with priority functions. The annunciation should fall within the flight crew's normal eye scan, and should clearly identify the failure. MFD pages should be provided to allow the flight crew to diagnose and track the problem. Appropriate instructions should be available to mitigate or resolve the problem.

4.3.3 False Alarms: When conditions to display an alarm or a flag are not met, the MFD should not unduly display such warnings and alarms. The MFD logic should be designed to prevent false alarms.

4.3.4 Failure Effects on Other Systems: Failures within the MFD shall not degrade or impair the operation of other aircraft systems with which they are integrated. Failures should be annunciated for crew assessment, but other systems should continue to function as designed.

4.4 Mode and Data Source Awareness:

The pilot shall be made aware of the current active and armed mode of each function displayed on the MFD. In addition automatic mode switching shall be annunciated. When the crew can select multiple sources of data, the sources shall be clearly identifiable. Switch position alone is not considered an adequate annunciation of source or mode.

4.5 Display Design Considerations:

The requirements in these paragraphs apply to the MFD in its installed position and as viewed under all flight deck lighting and operating conditions. Display design should minimize usability errors across the display field of view consistent with the intended function of the MFD. Examples of errors include parallax, mis-registration, and poor lighting control. The manufacturer should specify the maximum allowable installation error. The use of encoding information through the use of color, shape, size, luminance, symbology, alphanumeric, location, and flash rate may aid the flight crew with the detection and interpretation of large amounts of information.

4.5.1 Coding: When information is encoded, it should not cause excessive distraction, disruption or interference with the interpretation of other flight deck information being presented. The encoding should follow existing conventions for display characteristics, and when layered with other MFD information should not interfere with the interpretation of the existing display.

4.5.2 Symbology: One of the more common methods of coding information is to convert it into a symbol. A symbol is a non-verbal depiction of a concept, object or set of interrelated concepts or objects. Typically symbols are selected based on their relationship and association to that which is to be represented. Symbols should clearly depict the situation, concept or object represented, or action to be taken. Symbols that are interpreted relative to each other should be aligned to preclude erroneous interpretation of information. Lines, symbols and characters should have no extraneous lines, markings, or gaps which could lead to erroneous interpretation of displayed data. Symbology design should take into account established symbology conventions and the use of symbology elsewhere on the flight deck.

4.5.3 Color: Color has traditionally been used in cockpit display systems to improve the flight crew's ability to recognize and respond to attitude, warnings and alerts, indicator status and other essential information, and to group information from the same source. There is a limit to the amount of information that can be conveyed by color alone. Studies indicate that the number of different colors that can be discriminated on a single display is generally limited to seven (7) to nine (9) colors. The reason for the limited number of colors is related to the human ability to discern color difference when the colors are too close together on the color spectrum. In some current displays, shading of colors can also indicate intensity, or some other gradation, such as in weather and terrain displays. The colors selected must demonstrate the ability to be distinguished easily and accurately under typical viewing conditions, especially during heavy workloads or stress.

4.5.3 (Continued):

Technology has now made it possible to generate a limitless number of colors, but the human ability to discern, or visually separate colors, remains unchanged. Existing guidance and convention have tried to apply order to color applications without being overly restrictive. Any use of color on a MFD display system should be clear and simple, conform to the requirements of FAA AC 25-11, and be applied consistently within the display and across the cockpit. Color differences between symbols of similar colors located at any position within the total display area should be sufficient to allow correct identification of an assigned color and prevent ambiguous interpretation of data. There are well-established conventions on some color applications. These include the use of red and amber for warnings and cautions, shades of blue to indicate the sky, and brown to indicate the earth's surface. In some applications, such as color radar, shades of green, yellow and red indicate rainfall intensity. In the latter example, the colors tallow/amber and red have their traditional cautionary and warning meaning and indicate levels of increasing probability of hazardous situations.

When color is used on a MFD to convey meaning, the colors should be explicitly defined and applied such as with the color red. The application of color-coding to a MFD should emphasize the functional context of the information the color is conveying and consider aesthetics only after functional requirements have been met. Because of variation in color perception among pilots and reduction in color discrimination with glare and high ambient illumination, color differences should be as large as possible. In cockpit display applications, color-coding is secondary to position and shape coding, such as symbology or text. A typical basic color schema includes red, amber, yellow, magenta, cyan, green, white, blue and black, where each color is assigned specific meaning.

When layering two or more functions, the use of the same or similar color to convey different information is not recommended. If the usage of the same or similar colors is required, then the meaning of the different information must be retained. This may be done by the use of patterning, bordering or blanking to clearly depict the different sets of data.

4.5.4 Discrimination: Displayed information should have sufficient luminance and/or color contrast to discriminate between symbols, characters and/or lines and overlaid background, between individual symbols, characters and lines when they overlay generated and ambient background and between backgrounds of various colors.

4.5.5 Glare and Reflections: The MFD installation and screen design should not allow reflections or glare from internal or external sources that could cause erroneous or ambiguous interpretations.

4.5.6 Ghost Images: Ghost images should not interfere with the interpretation of displayed information.

4.5.7 Display Drift: Dimensional and positional stability of the MFD presentations should be sufficient to ensure accurate interpretation of the information.

4.5.8 Display Flicker and Jitter: The MFD display should not exhibit an unacceptable level of flicker or jitter under the full range of ambient operating conditions.

4.5.9 Parallax Errors: The MFD installation should be designed to minimize parallax errors that could cause misinterpretation when viewed from anywhere within the flight crew's normal head movement area. Examples of parallax include: the alignment of line select keys with the electronic display's text menu they are intended to select from on a multi-function control display unit (MCDU); MFD bezel select keys alignment with their displayed menu text or symbology; or multi-layered symbologies whose meanings can change depending on display viewing angles.

5. IMPLEMENTATION AND INTEGRATION:

Multifunction Display (MFD) systems are designed to integrate a number of separate flight deck displays and/or other data sources onto a single electronic display unit, with the flexibility to display single functions, or to integrate two or more types of information through overlays, fusion or windowing onto the MFD.

5.1 User Input Controls:

The flight crew shall be able to readily control all the information, features and functions available to the MFD with minimum control inputs or reliance on memory. The controls should be designed based on an analysis of the crew's requirement to access primary, secondary, and tertiary level functions.

Consideration should also be given to allowing access to the MFD through alternate controls. The reduction of the crew workload associated with the use of the MFD or the need for MFD control access redundancies are some factors influencing these considerations. Alternate controls may include indirect controls on the MCDU or a separate dedicated system. Any means of control, whether direct or indirect, should result in an acceptable crew workload.

5.1.1 Direct Control: Direct control refers to access to the display functions via dedicated function keys or direct touchscreen capability. The use of controls in the flight deck is an area of considerable study and warrants considerable attention for any application that is added to the flight deck. Therefore, a cursory discussion of major control issues is given here and it is recommended that readers reference other documents for more complete discussions of control design (e.g., MIL-STD 1472F).

The relationship of a control to its associated display and the display to the control shall be apparent and instantly recognizable to the operator. Direct controls should be coded or labeled to make sure that their identification is quick as well as accurate. One method of control recognition is shape coding. Shape coding allows the control knobs to be identified by simple touch.

Whenever possible, controls should be located as closely to the displays that they affect as is feasible. However, controls should be positioned so that neither the control nor the hand normally used for setting the control will obscure the display.

Additionally, the response of a display to actuation of the control should be consistent, predictable, and compatible with the operator's expectations. Response time for a display to present evidence of a control input should be minimized.

5.1.2 Indirect Control: Indirect control refers to access to the display functions via remote keyboards, mouse controls, track balls, joysticks, cursor control or other input devices. The input method should minimize the possibility of switching or data entry errors. Examples of such methods are: context checking, range checking, confirmation, and dissimilar serial actions.

If used, a menu structure should be designed to maximize operational suitability, minimize flight crew workload, minimize the possibility of human error, and offer immediate recovery from input errors.

The menu structure and architecture should directly and unambiguously support the users needs regarding task performance. The menu structure should be organized to minimize the number of steps, and the number of sub-menus should be designed to assure appropriate access to the desired information without over-reliance on memorization. When returning to higher priority information is desirable, this change should not be automatic, unless associated with time critical warnings such as TCAS, TAWS, or windshear alerts.

Any use of icons for short cuts to menus or sub-menus shall be consistent and a means for immediate return to a higher priority display shall be possible. If used, icons shall be clearly defined and identical icons will not be used for more than one function.

Designers and certifiers should be aware that humans sometimes mistake the location or focus of a cursor, and consider whether subsequent commands entered into the incorrect dialog box or window will have serious or benign consequences. User input control software functions should be designed to minimize the frequency and impact of cursor focus errors.

5.2 Layering:

Information may be presented as a single element of a display, or combined through the use of overlays or fusion, with other information on a display. The ability to perform layering is one of the greatest strengths of an MFD, but it also creates the potential to produce cluttered or misleading information. Therefore, the number of layers shall not cause the information displayed to become unusable through cluttering or obscuration. Combinations of multiple data presentations shall not cause conflicting interpretation of the symbology or icons. Conflicting range scaling shall not occur.

In most discussions concerning navigational displays for MFDs, we tend to think in terms of what we are accustomed to seeing on paper charts. Over an extended period of time, paper charts have evolved from relatively simple content to the present format that contains practically all information needed for a pilot to navigate the aircraft.

5.2 (Continued):

There are advantages and disadvantages to both the paper and electronic presentations. The paper charts can appear cluttered and difficult to read under some circumstances. However, they also permit manipulation by the pilot or other crewmember through folding, positioning, closer viewing and enhanced lighting to facilitate viewing. The electronic display can also appear cluttered, with the additional problem of color integration with any other information on the display and the pilot workload associated with manually manipulating and layering the display. The clear advantages of the electronic display are the abilities to select specific information to be viewed, eliminate unwanted detail, enable automatic display content, overlay weather, traffic, terrain and airport maps, although not all at the same time, and change scaling to enhance the presentation to fit mission needs. In addition, both pilots can see the same presentation, reducing the possibility of errors.

The automatic selection of displayed information can be based on range, phase-of-flight, and navigation or communications needs. Such automatic selections must be clearly indicated to the flight crew. When automatic display content is enabled, a means must be provided for the flight crew to select and deselect the information to be layered on the display. The system shall provide feedback on the identity and status of sources selected.

5.3 Clutter Control:

For a display to be usable, system designs should avoid presentation of excessive information, which can cause erroneous interpretation of the displays, increased workload and head-down time. In spite of this high level requirement, it still may be desirable to provide a means to declutter certain display formats. A means often used to declutter a moving map display is to select a lower range or to deselect the information that causes the display clutter such as airports, navigation aids, and intersections.

“Automatic” decluttering, deleting/relocating information without user input, should be avoided when important or critical information might be lost. Decluttering options should not lead to loss of information required for aircraft operation.

5.4 Automatic Switching and Pop-Ups:

The system may automatically switch between display modes, pages, or functions provided the new information, or mode of operation, is properly annunciated, will not cause crew confusion or remove essential information. The display change should not prevent the pilot from easily and quickly restoring the display to its previous state. Pop-ups may be in the form of an overlay, such as TCAS overlaying the moving map, or in a window format as a part of the total display. Window locations shall not obscure essential information.

5.5 Visual Crew Alerting and Display Prioritization:

Due to the ability to display information from a number of various sources on a MFD, it is necessary to develop a prioritization schema that ensures the continuous availability of essential information to the flight crew. Prioritization of time critical alerts such as: TAWS, PWS, TCAS and RWS have been established for transport category airplane applications. Crew alerting information systems require the prioritization of warning caution and advisory information be appropriately established. This prioritization includes both visual and aural alerts. The use of layering the new information over an existing moving map display or an existing weather display as a result of an automatic pop-up capability is a common technique. Annunciation of any system level warning, caution, and advisory alert should be compatible with the time critical alert schema. Systems information displayed on the MFD shall be prioritized in such a manner that it will allow ready access to critical information. Less critical information may be less accessible. A means will be provided for the flight crew to select higher priority information as needed with a single entry on the MFD control panel or keypad.

Visual alerts for time critical warnings that require immediate pilot action should be annunciated on the PFD. Terrain, traffic and weather are typically displayed in a layered format on the ND, although weather and terrain cannot be displayed at the same time in many current designs. Existence of a time critical threat should trigger an automatic pop-up and the appropriate display on the ND, as well as the appropriate aural alert. Subsequent time critical alerts of a higher priority may override the visual display, but must override the previous aural alert. Other MFD functions, such as checklists, synoptic and expanded systems information should only be shown when selected, as programmed by the crew or displayed by phase of flight.

5.6 Sensor and Information Fusion:

Data fusion is the combination of data from two or more systems in such a way that the combined data may not be recognizable as coming from one source or another. This type of data fusion is acceptable provided the source of the information is not relevant. Some examples include the merging of some weather products, certain RNP-based navigation functions, and terrain database information overlaid with ground mapping radar data. In other cases such as fusion of TCAS and ADS-B data, retaining source identity may be required. The flight crew should be able to easily determine the component sources of the fused data. A means should be provided to ensure that as different sources of information are merged, it is critical that the information is only fused when there is complete acceptable correlation between the two sources. The fused data presentation should cause no degradation of the display content.

5.7 Windowing and Data Block:

Information relevant to the aircraft and flight may be available to the flight crew through data messages provided in windows on the multifunction display. The data window or data block should initially be located in the same portion of the display, regardless of the function being displayed on the remainder of the display. The window location should be selected to provide the most operationally suitable information for the total display format without obscuring essential display information. Logic for positioning windows should provide an automatic and consistent means of displaying windows based on priority relative to the flight crew tasks and information requirements.

Message terminology should be consistent with existing aviation conventions and standards. Error messages should explicitly annunciate the source of the error. There should be the ability to remove a window after new messages have been acknowledged. However, a message log function is desirable to permit reviewing of old messages. Automatic means should be provided to inhibit non-critical messages that can become a nuisance or distraction during critical phases of flight. Message stacking logic should provide an automatic and consistent means of displaying messages ranked in order of priority relative to the flight crew tasks and information requirements.

Display of information such as NOTAMs and airport maps should be available for pilot selection and display as a window on the Navigation display or as information for display on the synoptic display. In no case should it be allowed to obscure or obstruct usage of primary navigation information.

5.8 Reconfiguration Modes:

Reconfiguration modes most commonly refer to the reconfiguration of the PFD information and the ND information as a result of the failure of the PFD display unit. This usually results in the replacement of the ND with the PFD or the combining of the essential information of each display into a compacted display format on the MFD. Another common reconfiguration mode is the one that combines the essential information provided on the primary engine display with the information provided on a secondary engine display. This reconfiguration mode may be automatic but a manual means to reconfigure is required. Reconfiguration mode selection can provide a substitute symbol generation unit, display unit or sensor unit. Reconfiguration for the loss of a symbol generation unit, which powers multiple display units, must be automatic provided a redundant symbol generation unit is part of the system design. Reconfiguration for the loss of the PFD display unit or the primary engine display unit must be automatic. If the sensor inputs to the system, such as air data computers, vertical gyros, directional gyros and inertial reference units are integrated, fused, or used in a Kalman filter format, automatic reconfiguration of the displayed sensor source information is permitted provided suitable integrity monitoring takes place. Prioritization and reversion of non-OEM inputs or data should be considered in the design.

5.9 Synoptic, System Displays and Maintenance Pages:

Messages on a graphical system displays shall be simple, spatially located on the outline of the aircraft corresponding to the location of the aircraft system and the messages should have proper color coding depending on the urgency. Messages on a textual display should be simple, identify the system and location, the level of urgency and a description of the problem.

A top down fault tree analysis should be used to identify the conditions, failures and events that would cause each failure. In order for the crew member to transition from the initial systems level display to the next display, it shall require no more that an acknowledgment by the operator. The means of acknowledging should be readily obvious to the user. Information presented should be structured as to what the operator needs to see at that particular time.

All messages should follow the general guidelines for MFD displays with respect to text size, ease of reading legible from the design eye position, colors and other established standards. The presentation of information should be designed to permit a presentation format that can be customized for current needs. The operator should have the option to eliminate clutter.

5.10 Data Link:

A means must be provided to insure that any information provided to the onboard aircraft systems, whether from ground facilities or other airborne systems, is received and transmitted accurately and in a timely manner.

Any time the flight crew receives a data link message in lieu of voice communications, the flight crew must receive an aural and visual alert that new data has been received. If data is used as part of the display for normal flight crew instrument displays, the data must be displayed only as an element of a flight crew selected display function, or mode, unless there is an emergency. In the case of an emergency, the flight crew will receive an auditory and visual alert to show the presence of new data and an indication of the nature of the emergency. Any auditory or visual alert will not degrade the information available on the PFD or interfere with critical crew functions.

5.11 Menu Structures and Architecture:

The menu structure should be designed to maximize operational suitability, minimize flight crew workload and minimize the possibility of human error. Design simplicity is integral to the usability of the system. The menu structure should be organized to minimize the number of button pushes or designations and the hierarchy should not exceed three levels. There should be an easy means to back out or “undo” an incorrect input or selection.

5.12 Default Settings:

A default is a predetermined setting, or value, which is utilized on power-up or on a change of major selection (e.g., a function change) to minimize set-up and search time by the crew. The most common forms of default are as follows:

- Selection of one of a menu of functions for display on an MFD when the aircraft is powered up.
- Selection of one of a number of pages related to a particular function for display on an MFD when the function is selected from the menu of functions or on power-up.
- Selection of function status (ON/ARMED/OFF), perhaps of a function which is an additional part of a display (e.g., weather radar), when a function is selected from a menu of functions or on power-up.
- Insertion of a value into a parameter box normally filled manually, on power-up or function selection
- Presentation of a blank parameter box or line demanding parameter insertion on power-up or function selection.
- Positioning of an electronic selection device, for example a cursor, to the selection box appropriate to the existing situation.

5.12.1 Power-Up: When electrical power is applied to the aircraft or restored following switching or fault in the avionics systems, the function most likely to be used first should be displayed on the multifunction display. The selection may be phase-of-flight sensitive or sensitive to aircraft, or aircraft system, status. In an aircraft with multiple MFDs, the suitability of the mix of functions should be considered when determining defaults.

5.12.2 Multiple Pages: When a function is selected requiring multiple pages, the page bearing the most critical information or the one most likely to be required for use first should be displayed. The selection may be phase-of-flight sensitive or sensitive to aircraft, aircraft system, or MFD function status.

5.12.3 Sub-Function Status: MFD display pages may be enhanced by the addition of optional display elements. On power-up, these additions should be off. When the basic function is subsequently selected, the sub-function should be in the last selected state. A possible exception is when the addition has a pop-up feature causing automatic display of the information in a time-critical situation; the addition should be displayed on selection of the function.

5.12.4 Default Parameter Insertion: Some MFD functions may be interactive, requiring flight crew input for one of a variety of functions. Where appropriate, a default value of the parameter may be automatically inserted into the entry box or line to reduce flight crew workload. This value may be pre-determined by the avionics manufacturer, may be specified by the airline as part of an airline policy file within the operational software, may vary with phase of flight or aircraft status, or may be a value which is varying dynamically with changes in aircraft state.

5.12.5 Blank Parameter Boxes: As an alternative to default values of parameters requiring insertion, blank parameter boxes or lines may be presented; these blanks can act as prompts to the flight crew.

5.12.6 Cursor Positioning: Interactive displays may utilize a cursor or similar electronic datum to allow the flight crew to designate a value or function for selection. By initializing the cursor to an appropriate default position on function selection or page change, flight crew workload and errors can be reduced. The position selected on a particular function display or page may vary with phase of flight or function status.

5.13 Overlays:

Overlaid information should not contain information portrayed in color that could be confused with color representations on the underlying image. Care must be taken to ensure that icon and symbol overlays are not ambiguous. Icons and symbols should be distinctive and readily discriminated from one another.

Alphanumeric overlays should be positioned so that they do not interfere with the utility of the underlying display. The font of the alphanumeric overlay should be simple and without extraneous details to facilitate readability. The color of the alphanumeric should be selected to have high contrast ratio against the underlying information. Ensure that overlay information is matched to the underlying display for scaling, color, and alphanumeric size. In certain cases alphanumeric attributes may have to be adjusted or eliminated to accommodate other displayed information.

5.14 Self-Test:

The MFD system shall be equipped with a means of automatically monitoring operations and shall alert the crew of any failure or errors. On power-up, the MFD will run a self-test that will identify internal failures and the presence of proper electrical power and continuity. Once in operation, the failure of any attached sensor will be alerted immediately, and errors between data from different sources supporting the same, or similar, functions shall be annunciated immediately. The status of any databases shall be available for crew review of currency and update. Time critical databases will be monitored and an immediate alert will be provided if outdated.

5.15 Data Storage and Retrieval:

5.15.1 Data Storage: An integrity protection scheme shall be incorporated in all data transfer operations. One example of such a scheme is Cycle Redundancy Check (CRC). Such a scheme insures that the transfer process completes error free thereby guaranteeing the data has been correctly transferred. RTCA/DO-200 (Standards for Processing Aeronautical Data) and RTCA/DO-201 (User Recommendations for Aeronautical Information Services) provide guidance in this area.

5.15.2 Data Retrieval: The method of data retrieval should take into account the purpose and use of the data. Time sensitive data used for navigation should be searched for and automatically loaded at start time or when new data media is detected. Mission data such as flight plans or user settings should only be loaded via a user initiated process.

Data for some uses has a defined period of validity. The data sub-systems shall inform the user when the current data is not current.

5.16 Retrofit Integration:

MFD equipment that is installed as a retrofit on older aircraft intended to function as new aircraft shall meet all the integration, reliability, and integrity requirements of this document. Every cockpit design reflects the set of design standards and state-of-the-art of equipment in place at the time of the original design. When a system is added to an existing design the system must integrate with the original display and controller design principles, and meet the required operational objectives. A MFD may need to occupy part of the primary or secondary fields of view and the controls will likely need special consideration. Poor integration of new displays or poor adaptation of the existing controls for use with new displays may increase the crew's workload.

This integration effort, either at the cockpit level or within an existing MFD, requires many considerations. These may include the current operational implementation under both normal and abnormal conditions, the expected operational use of the added functionality, and the compatibility of these new features with the existing cockpit environment.

6. TRAINING:

The content, length and type of training program should be consistent with the design of the system(s), its capabilities, limitations, modes, operating principles, and installation in retrofit or new cockpits. Characteristics and system design principles should be explicitly conveyed to users through initial and recurrent training as well as appropriate operating manuals. The training program should assist the pilot in building a mental model of the entire system and provide support in understanding the complexity embedded in the architecture. Training programs, manuals, and computer-generated training aids should be available to users and instructors prior to the release date of the new equipment. Each functionality should be addressed independently, as a module, then as a cluster, and finally as an integrated system.

Clear, concise and easily understood documentation, operational guidelines, and limitations should be provided to all end-users. Training and operating manuals should provide appropriate guidance for an anticipated range of pilot (operator) experience. A variety of training techniques and tools should be considered. These may include, but are not limited to personal computer-based instruction (CBI), distance learning programs, or bulletins. State-of-the-art human-factors principles and methodologies should be applied and integrated with ground training, simulator, and realistic Line Oriented Flight Training (LOFT) scenarios to achieve a high level of proficiency.

7. GLOSSARY:

AIRSPACE: The atmosphere in which aircraft operate, extending upwards from the surface of the earth.

AIRWORTHY: In a condition suitable for safe flight

ALERT: A visual, auditory or tactile stimulus presented to attract the crew's attention and convey information concerning an event/situation.

AREA NAVIGATION (RNAV): {SC 181 DO-236}

AURAL ALERT: Discrete tone/sound used for attention getting.

BASIC "T": A term used to describe the location and orientation of primary flight information. The attitude information should be laterally centered in the front of the pilot, with airspeed/mach arranged to the left, barometric altitude information arranged to the right of the attitude indicator, heading information should be centered below the attitude information. The principles of instrument arrangement as specified in FAR 25.1321 should be applied as design guidance.

CAUTION: Non-normal operational or aircraft system conditions that require immediate crew awareness and subsequent corrective or compensatory crew action.

CONTROLLED FLIGHT INTO TERRAIN (CFIT): Accidents in which an aircraft, under control of a flight crew, is flown into terrain, obstacles, or water without prior awareness on the part of the flight crew in sufficient time to prevent the accident.

DIGITAL FLIGHT INFORMATION SERVICES (DFIS): Data linking support provided by private companies or government agencies that will make digital data linked products available to the aircraft. Products could include graphical weather, terrain, traffic, and other products provided on a pay-for-service basis.

ELECTRONIC FLIGHT BAG (EFB): A MFD in the form of a hard mounted, laptop or portable device that is used to provide supplemental information to the flight crew in lieu of paper or printed materials normally found in on-board flight manuals. The device may be carried onto the aircraft by the flight crew instead of, or in addition to, current supplemental materials, and does not replace the existing aircraft flight instruments and display systems. The EFB may also perform additional functions of completing flight plans, computing weight and balance values, or as an aide to aircraft loading inventories.

EXCURSION: Departing the intended surface of movement.

FALSE ALARM: An alert that occurs in a situation for which the system design should not have presented an alert.

7. (Continued):

FORWARD-LOOKING INFRARED (FLIR): Infrared imager used to provide a visual image in moderate visibility and at night.

FOVEA: The area in the back of the eye that has the greatest concentration of cones, resulting in the highest central visual acuity. Cone distribution gives the best vision within the central approximately 10 degrees of vision.

INCURSION: Crossing runway hold short line without the proper clearance.

INFRARED IMAGERS: Imagers that work on the same principle as solid-state visual spectrum devices but which detect emissions at wavelengths longer than those in the visible light spectrum (infrared spectrum).

INTEGRATED DISPLAY: A display where information from different sources is placed on a single display in such a way that it is graphically compatible with other data, and does not degrade, mask, corrupt, or render other information unusable. Note: integration can also be applied when discussing combining data and information.

LAYERING: Placing data from separate sources on a MFD one on top of the other where the information displayed retains it's source integrity and can be removed individually by deselecting the source.

LOW LIGHT TELEVISION (LLTV): A sensors operating in the visual spectrum that provides clear imagery at light levels in which the human eye would be ineffective. LLTV cameras are typically capable of providing images in bright starlight or quarter moon conditions, which expands their application in some low visibility and low light conditions.

MILLIMETER WAVE RADAR (MMWR): High frequency radar signals used to create visual images suitable for flight operations in low visibility. MMWR systems rely on the processing of range and bearing data using a horizontally scanning antenna to create visual images.

MULTIFUNCTION DISPLAY (MFD): A device or system capable of displaying a variety of data, either layered or windowed, on a single display unit.

MULTIFUNCTION CONTROL DISPLAY UNIT (MCDU): An input device that allows control of a multifunction display unit. Typically consists of a keypad, direct entry keys and a display.

NAVIGATION DISPLAY: A device capable of display of a variety of navigation and weather information, terrain and obstacle data, traffic information, or textual instructions and information. Information can be in graphical or textual format. Automated and operator control of the displayed data allows the operator to adequately layer the information to satisfy multiple situational requirements.

NON-DIRECTIONAL BEACON (NDB): A ground-based radio transmitter that emits an omni-directional radio signal. Aircraft equipped with Automatic Direction Finding (ADF) receivers can detect signals and indicate the bearing to the station.

7. (Continued):

NUISANCE ALERT: An alert that, while occurring as intended in the system design, is not appropriate to the specific situation in which it occurred.

PASSIVE MILLIMETER WAVE IMAGER: A high frequency detector for radiation over 1mm wavelength. This system relies on cosmic radiation as its illuminating source.

POP-UP MODE: The automatic presentation of information in response to a specified set of conditions.

PREDICTIVE WINDSHEAR SYSTEM (PWS): A system based upon the use of Doppler radar to look ahead of the airplane to detect and forewarn of severe windshear conditions.

PRIMARY FLIGHT DISPLAY (PFD): An electronic display that provides the flight crew continuous information critical to safely maneuver and control the aircraft through all phases of flight.

PRIMARY FLIGHT INFORMATION (PFI): Those data required by the flight crew to assure continued safe flight of the aircraft through all phases of flight.

PRIMARY FLIGHT REFERENCE (PFR): The source of information sufficient to maneuver the aircraft about all three axes and accomplish a phase of flight.

REACTIVE WINDSHEAR SYSTEM (RWS): The onboard system that detects a windshear condition based upon insitu information from airplane sensors and provides alerts and command guidance to escape the windshear event.

SYMBOLIC INFORMATION: Presentation of information by graphic representation.

TERRAIN DATABASE: Electronic storage of terrain data.

TERRAIN AWARENESS WARNING SYSTEM (TAWS): A system defined by TSO C-151 that uses terrain and airport databases, along with altitude and navigation information from an approved RNAV source to provide a forward looking terrain alert feature, protection from premature descents, certain basic ground proximity warning system features, a terrain display and certain voice alerts.

ULTRAVIOLET IMAGER: Imager that works in the ultraviolet (UV) spectrum around 0.25m that also features low atmospheric attenuation and scatter. The device extends visual capability in low visibility conditions by detecting UV emissions from the airport surface, obstacles and vehicle and aircraft anti-collision lights modified to allow UV radiation to pass through their lenses efficiently.

VISUAL ALERT: Discrete alphanumeric/light used for attention getting.

VISUAL DISPLAY: A cockpit presentation that provides an image of the outside world derived from MMWR, FLIR, video, or synthesizing source.

7. (Continued):

VISUAL SPECTRUM CAMERA: Video camera that can be positioned to represent the flight crew eye position, or mounted for viewing from any position on the aircraft.

VOICE ALERT: A spoken message that informs the flight crew of a situation that requires attention.

VOICE MESSAGE: A spoken message presented to the flight crew to give status or feedback on aircraft systems.

VHF OMNIDIRECTIONAL RANGING (VOR): A ground-based VHF radio transmitter that emits an omni-directional radio signal for aircraft navigation. The VOR may include distance-measuring equipment (DME) for determining distance from the station. The VOR may incorporate TACAN capabilities (VORTAC).

WARNING: An indication of an abnormal condition or failure of an aircraft system that requires immediate corrective or compensatory action by the crew.

WINDOWING: Segmenting a single display area into two or more independent display areas or inserting a new display area onto an existing display.

APPENDIX A
RELATED LITERATURE

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