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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.

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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.

TABLE OF CONTENTS

1. SCOPE	5
1.1 Purpose	5
2. REFERENCES	6
2.1 SAE Publications.....	6
2.2 U.S. Government Publications	7
2.3 Other Publications	8
2.4 Definitions	8
2.5 Abbreviations and Acronyms	8
3. SYSTEMS FUNCTION	11
3.1 Primary Flight Information	11
3.2 Primary Flight Display	11
3.3 Primary Engine Information.....	12
3.4 Secondary Engine Information.....	12
3.5 Visual Crew Alerting System (CAS) Information	12
3.6 Navigation Information	13
3.7 Weather Information.....	13
3.7.1 Weather Radar	14
3.7.2 Icing Information and Alerts	14
3.7.3 Lightning Information and Alerts	14
3.7.4 Windshear Information and Alerts	14
3.7.5 Wake Vortex/Clear Air Turbulence Information and Alerts	14
3.8 Terrain and Obstacles	14
3.9 Airport Mapping	15
3.10 Traffic Information	15
3.11 Aircraft Systems Functions	15
3.11.1 System Status Information	16
3.11.2 System Synoptic Displays.....	16
3.11.3 Aircraft Configuration	16
3.11.4 Self-Diagnostics	16
3.12 Data Link Functions	17
3.12.1 Controller to Pilot Data Link Communications.....	17
3.12.2 Aeronautical Operational Control Data Link.....	18
3.13 The Radio Management System Function.....	18
3.14 Electronic Data Management System.....	19
3.15 Electronic Checklist.....	20
3.16 Imaging Systems.....	20

TABLE OF CONTENTS (Continued)

4. DESIGN OBJECTIVES.....	21
4.1 Crew Interface.....	21
4.1.1 Consistency of Design	21
4.1.2 Simplicity	21
4.1.3 Intuitiveness	22
4.1.4 Readability	22
4.1.5 Accessibility.....	22
4.2 Information Characteristics	22
4.2.1 System Response and Information Accuracy	22
4.2.2 Conflicting Information	23
4.3 Reliability.....	23
4.3.1 Maintain Situational Awareness	23
4.3.2 Error and Fault Detection and Verification	23
4.3.3 False Alarms	23
4.3.4 Failure Effects on Other Systems	23
4.4 Mode and Data Source Awareness	23
4.5 Display Design Considerations	24
4.5.1 Coding.....	24
4.5.2 Symbology	24
4.5.3 Color.....	24
4.5.4 Discrimination.....	25
4.5.5 Glare and Reflections.....	25
4.5.6 Ghost Images.....	25
4.5.7 Display Drift.....	25
4.5.8 Display Flicker and Jitter	25
4.5.9 Parallax Errors	26
5. IMPLEMENTATION AND INTEGRATION.....	26
5.1 User Input Controls	26
5.1.1 Direct Control	26
5.1.2 Indirect Control.....	27
5.2 Layering	27
5.3 Clutter Control	28
5.4 Automatic Switching and Pop-Ups.....	28
5.5 Visual Crew Alerting and Display Prioritization	29
5.6 Sensor and Information Fusion	29
5.7 Windowing and Data Block	30
5.8 Reconfiguration Modes	30
5.9 Synoptic, System Displays and Maintenance Pages	31
5.10 Data Link	31
5.11 Menu Structures and Architecture.....	31
5.12 Default Settings.....	32
5.12.1 Power-Up	32

TABLE OF CONTENTS (Continued)

5.12.2	Multiple Pages.....	32
5.12.3	Sub-Function Status.....	32
5.12.4	Default Parameter Insertion	32
5.12.5	Blank Parameter Boxes	32
5.12.6	Cursor Positioning.....	33
5.13	Overlays	33
5.14	Self-Test	33
5.15	Data Storage and Retrieval	33
5.15.1	Data Storage	33
5.15.2	Data Retrieval	33
5.16	Retrofit Integration.....	34
6.	TRAINING.....	34
7.	GLOSSARY	35
	APPENDIX A RELATED LITERATURE	39
	APPENDIX B EXAMPLES OF EXISTING DISPLAY COMBINATIONS OF MFD FUNCTIONS	51

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 additional 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	Numerical, 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 Symbolology
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.