Federal Aviation Administration

DOT/FAA/AM-13/21
Office of Aerospace Medicine
Washington, DC 20591

Multi-Function Displays: A Guide for Human Factors Evaluation

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November 2013

Final Report

Report Documentation Page

1. Report No. DOT/FAA/AM-13/21[†]	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Multi-Function Displays: A Guide for Human Factors Evaluation [†](reprint from DOT/FAA/OAM-TM-03-01)		5. Report Date November 2013
		6. Performing Organization Code
7. Author(s) Chamberlain RM, Heers ST, Mejdal S, Delnegro RA, Beringer DB*		8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency name and Address FAA Aircraft Certification Service 800 Independence Ave., S.W. Washington, DC 20591		13. Type of Report and Period Covered
		14. Sponsoring Agency Code AIR-130

15. Supplemental Notes

Compiled under contract DTFA-02-01-14446 in conjunction with the FAA Civil Aerospace Medical Institute (CAMI). All authors are from Monterey Technologies, Inc., except one designated by (*), who is from CAMI.

16. Abstract

This guide is designed to assist aircraft certification personnel and avionics manufacturers in evaluating the human factors aspects of Multi-function Displays (MFDs) for FAA certification. The guide focuses specifically on human factors and does not address issues concerning the functional performance or operational accuracy of the display units. The guide is expected to be used as an assistive tool, and is organized as a checklist to provide structure for MFD evaluations. The guide summarizes human factors standards, guidelines, and research on MFDs, and evaluation criteria are grouped in sections of related areas ordered to facilitate the evaluation process. Regulatory documents, advisory information, and recommended practices relevant to the specific topics are cited with each section.

17. Key Words Multi-Function Displays, Display Design, Avionics, Human Factors Criteria, Aircraft Certification, Controls, Human Factors Guidelines	18. Distribution Statement Document is available to the public through the Internet: www.faa.gov/go/oamtechreports

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 101	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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INTRODUCTION

This guide has been designed to assist aircraft certification personnel and avionics manufacturers in evaluating the human factors aspects of Multi-Function Displays (MFDs) for FAA certification. The guide focuses specifically on human factors and does *not* address issues concerning the functional performance or operational accuracy of the display units.

This document can be thought of as an assistive tool, organized in the form of a checklist to add more structure in the evaluation process by pointing out some important attributes of design that research has shown can significantly lower the demands on the user. With the wide range of functional requirements put on different MFDs, there is a correspondingly wide range of questions and design issues. Therefore, human factors guidelines are provided as a reminder to aircraft certification personnel as to what to consider, along with research supporting "best practices" in the design of an MFD.

The procedures and guidance presented are intended to provide a standardized approach for evaluating the human factors aspects relevant to MFD design. The directions described are not meant to unnecessarily restrict trained inspectors, and it is expected that their judgments and expertise will be applied to determine when the application of individual considerations or criteria are inappropriate or too restrictive.

The guide summarizes a variety of human factors standards, guidelines, and research on MFDs. The topics representing the human factors evaluation criteria are grouped into sections of related areas and are ordered to facilitate the evaluation procedures. Each evaluation topic is presented in two facing pages. The left page provides the evaluation procedures and considerations, while the right page presents additional information on the considerations and guidelines.

The evaluation procedures on the left page provide a short description of each topic, followed by instructions on what activities to perform to assess the issues relevant to the topic. This is followed by a checklist of several items which should be considered in evaluating whether or not the displays meet the human factors standards in that topic area.

The right page presents applicable regulatory documents, along with supporting advisory information and recommended practices relevant to the topic on the opposite page. This information is provided to expand on the human factors issues relevant to the topic area. Limited details of experimental studies are described, and some technical details and example information are provided. The complete references to documents containing more detailed and specific information are available in the section at the end of this guide.

The information used to generate this guide was extracted from the Literature Review and Annotated Bibliography and from the Human Factors Design Guidelines for Multifunction Displays produced by Monterey Technologies, Inc. under FAA Contract Order No. DTFA-02-98P80590. Additional current and contemporary sources were also used.

HOW TO USE THIS GUIDE

There are 19 human factors evaluation criteria presented in the guide. For organizational purposes, these 19 topics have been grouped into five categories in a bench test section and four categories in a flight test section. Bench test items make up the first half of the guide, and criteria that need a flight test environment for a complete evaluation are found in the second half.

Each evaluation topic is presented as a pair of facing pages, as is depicted following. The left page presents the table that is used during the evaluation procedure. This table lists the topic name, description, and an evaluation procedure that describes the activities performed to assess how well the target system meets evaluation criteria.

The next section of the table presents a checklist of items that are considered when evaluating the unit with respect to the evaluation topic. Each evaluation consideration is stated as a simple yes or no question, although answers to individual items may not be absolute. A N/A column is also provided for situations where the evaluation item is not relevant to the current display. Individual judgments and expertise should be employed in determining how to apply a given item to the current evaluation and when the individual considerations or criteria are inappropriate or too restrictive.

Examination of some criteria in the bench test group may require the unit to be installed on a flight deck or for the unit to be operated in a range of conditions that are likely to occur during actual flight. Asterisks are used to identify these items and call attention to the fact that a complete evaluation may not be possible until a flight test is performed. Similarly, in the flight test section, asterisks denote those items that are also evaluated using a bench test.

Following an area where additional notes can be made regarding the evalution of the topic, the table concludes with the summary evaluation for the evaluation criteria. This overall assessment should reflect the scores given for each of the criteria in that section and the inspector’s judgement of any special circumstances or contributing factors that were noted.

Further information relevant to the evaluation topic is presented on the opposing right-hand page. The top section of this page lists the applicable regulatory references. The reference that appears in bold is the primary regulatory requirement for evaluation of the current characteristic.

Below the applicable regulatory documents is a section that provides additional descriptive information regarding the evaluation topic. This information elaborates on the consideration items that are listed in the table, providing extended definitions, explanations, examples, and accepted practices. The inspector may consult this information as necessary during the evaluation process to aid in assessing the compliance of the unit to the standards and guidelines.

The sources of the information described are cited at the bottom of the section. If the inspector wishes to research the topic area for more detailed information, the full references for all citations in the guide may be found at the end of this document.

An evaluation summary table follows the individual checklist sections. This table lists all evaluation criteria topics in the preceding section. The page numbers cross reference the individual criteria with the corresponding checklist in the guide. The evaluation score for each of the topic areas may be listed in this summary table to easily depict the overall apriasal of the unit. The final overall rating of the unit may be made at the bottom of the table. A comments area is provided on the right-hand page for the inspector to summarize any remarks pertainaint to the overall evaluation.

This guide is organized with tabs indicating major sections, colored pages that are intended as permanent pages in the guide, and white pages that are provided for the evaluators to record information on MFD's. The white pages are intended to be removed upon completion of an evaluation and maintained in the permanent record. New pages should be printed from the accompanying CD and inserted into the guide for the next MFD evaluation.

Example of Evaluation Pages

2.3.1. MFD Information Grouping

Description:
Information may be grouped in a variety of ways in an MFD. The information can be combined and layered or can be segregated by windows. Within a single display, various elements may be added or removed in order to aid the pilot's comprehension of the situation.

Evaluation Procedure:
Select various individual displays, overlay related displays, pull-up windows, and note how the design of the display combines and separates the information. Also note the methods available to add/remove information.

Evaluation Considerations:	Yes	No	N/A
1) Does the pilot have the ability to remove non-essential information that may cause clutter? * For example, a map display may be simplified by temporarily removing irrelevant symbols.			
2) When the crew can select multiple sources of data or multiple modes of operation, are the sources and modes clearly identified? *			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

* A bench test may also be performed to evaluate this item.

2.3.1. MFD Information Grouping

Applicable Regulatory Documents:

CFR: 23.771, 23.1309, 23.1301, 23.1311, **23.1523**

AC: 23.1311-1A

Other Guidance: ARP 4102

Advisory Information and Accepted Practice:
One of the more popular methods of grouping information is the layering of one function over another. Two or more functions are combined to present one information display. One of the major pitfalls of overlaying is the potential for cluttering. Information may become so densely packed that the MFD ceases to be an effective display. Dense displays are well known for increasing mental workload and head-down time. One technique of reducing display clutter is to remove or minimize non-essential display elements. For example, in some types of cockpit displays of traffic information (CDTI), only aircraft within a certain range of distance are presented at full brightness, whereas other aircraft are dimmed. Another clutter management feature in CDTIs is the option to bring-up, only when desired, aircraft ID blocks that contain speed and ID information for each aircraft. The removal or minimization of unnecessary clutter eases interpretation and minimizes head-down time.

Another issue in overlaying concerns the degree to which the displays are functionally related. For example, terrain, weather, and traffic functions are highly related. Each of these three functions is concerned with possible external obstacles and barriers in flight. These functions may be, and sometimes are, successfully overlaid in an MFD. Conceptually, overlaying their related functions make sense. However, if two functions are not related, yet displayed concurrently, they should be clearly segregated. Unrelated functions may be displayed in separate windows or separated by borders of some kind. This minimizes confusion and helps provide some structure and organization to the MFD.

Because pilots almost certainly have some differences in interaction style, they should be provided with at least some options to reconfigure the MFD to suit individual tastes and preferences. Display configurations may also change based on experience level and flight objectives. Another important aspect of information grouping is the information options available. Information sources and modes must be clearly presented on the display so that the most effective and appropriate grouping can be made by the pilot.

Additional References:

Dillard, A. (1999)
RTCA (1999)
Stokes, A. & Wickens, C. (1988)

1.1 MFD Controls

1.1.1. MFD Control Placement

Description:
MFD controls should be readily accessible and appropriately placed to allow for easy operation. Controls should be spatially separated and controls that have to be operated in flight must be visible at all times during all lighting conditions.

Evaluation Procedure:
Note the location, placement, visibility, and accessibility of MFD control devices.

Evaluation Considerations:	Yes	No	N/A
1) Are the controls located such that they provide convenient operation?			
2) Are MFD controls physically separated enough to prevent inadvertent activation? *			
3) Are the controls located so that the pilot has full and unrestricted movement of each control without interference from either his clothing or the cockpit structure when seated?*			
4) Are the actual, physical MFD controls (e.g., buttons and keys) clearly backlit? *			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Fail
Summary Evaluation:				

* May require a flight deck environment for full assessment.

1.1.1. MFD Control Placement

Applicable Regulatory Documents:

CFR: **23.777**, 23.1367, 23.1381, 23.1523,

AC: 23.1311-1A

Other Guidance: ARP 4102

Advisory Information and Accepted Practice:

Current cockpit designs require that the pilot remain head-down in order to enter control inputs. Because of the difficulty in dividing attention between control inputs and other tasks, one of the goals of MFD interface design is to reduce attentional demands of control inputs. The appropriate control placement and configuration has been found to significantly reduce head-down time and improve pilot-MFD interaction. Past research has shown that inappropriate placing leads to confusion, increased head-down time, and selection errors whereas proper control placement and configuration increases head-up time, response speed, and selection accuracy.

MFD system design must ensure that controls are located to provide convenient operation. All available controls should be located within the full range of motion when the pilot is seated, without interference by nearby objects such as structures or clothing. Pilots must be able to operate controls without exaggerated movements of the body.

In addition to ensuring control accessibility, designers must also spatially separate controls from each other so that erroneous activation of one control during the use of another is prevented. Another reason to allow for adequate spacing of controls is so that controls and displays are not obscured by each other. Location may also be used to aid in identification and prevent confusion between controls.

In order to maintain ready access to controls, controls must remain visible and discriminable under all ambient light conditions. Each control device should be clearly backlit. Because of their small size, backlighting control panels and keypads is especially important.

Additional References:

Dillard, A. (1999)
OAM Tech. Report DOT/FAA/AM-01/17 (2001)
DOD-HDBK-743A (1991)
MIL-HDBK-759C (1995)
MIL-STD-1472F (1999)
STANAG 3705 (1992) (NATO)
DO-238A (1999) (RTCA)
Sirevaag, E. et al. (1993)
Smith, S. & Mosier, J. (1984) TR ESD-TR-84-190

1.1.2. MFD Control Labels

Description:
Labels are typically assigned to MFD controls to clearly indicate their functions. Labels may be physical or software-generated. Soft labels usually appear as legends on the MFD monitor and correspond to the surrounding bezel push-buttons.

Evaluation Procedure:
Note the size, location, and assignment of labels to MFD controls.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Is each MFD control labeled to identify its function?			
2) Have standardized or commonly employed terms, abbreviations or icons been used for labeling?			
3) Does the label accurately & intuitively denote/imply the associated function?			
4) Are the menu option labels and their associated bezel buttons clearly co-located?			
5) Are the labels legible when seated at a minimum viewing distance of 30 inches?			
6) Are the labels readable under the full range of normally accepted ambient light conditions? *			
7) Are soft-control labels consistently located on all MFD screens?			
8) If the labels appear on the display, are they placed in such an area that important information is not covered?			
9) Are functions that are available across multiple screens consistently mapped to the same controls, to the extent possible? For example, a button used to accept input parameters on one screen should be the same button on all other screens that involve accepting input parameters.			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

***** May require a flight test environment for full assessment.

1.1.2. MFD Control Labels

Applicable Regulatory Documents:

CFR: 23.771(a), 23.1301, 23.1311, 23.1367, 23.1523(a), **23.1555(a)**

AC: 23.1311-1A

Other Guidance: DO-229, ARP 4102, ARP 4105

Advisory Information and Accepted Practice:

Each MFD control should have some type of label to identify its function. A control may be dedicated, meaning that it always performs the same function, regardless of the state of the MFD, or flexible, meaning that its function changes as the MFD changes in mode or function. Because of space limitations, most MFD functions share the same controls. Dedicated MFD controls are reserved only for the most safety-critical and frequently used functions. Dedicated controls typically have hard labels permanently affixed on or near them, whereas flexible controls have software-generated labels that change as the display changes. Clearly and consistently labeled controls reduce reliance on memory and facilitate learning. Given that there are usually 26 bezel push-button controls surrounding the MFD monitor, clear control labeling is necessary.

In the design of control labels, one must also consider the environmental conditions that influence legibility. Labels should be in a font that is appropriate for the normal viewing angle and distance. At a minimum, the labels should be readable from a distance of 30 inches. Ideally, labels should also remain legible during aircraft vibrations. Labels should be legible under all possible lighting conditions, including full sunlight.

To minimize head-down time, each label should be positioned so that it unambiguously refers to the appropriate control. Software-generated labels or legends should be carefully aligned with the corresponding bezel buttons to prevent erroneous selections. These labels should be consistently located across screens to prevent confusion. The same design concerns also apply to physical labels: they should be clearly and consistently associated with the appropriate controls.

If a control function is available across multiple screens, then that function label should be consistently mapped to the same push-button control, to the extent possible. For example, if the function to adjust a radio frequency was consistently available across several sequential screens, then that function should always be mapped to the same push-button. If it is not possible to assign that function to the same exact button, then it should at least be programmed to an adjacent button.

Additional References:

Calhoun, G. (1978)
Francis, G. (1998)
Parush, A. (1987)
Reising, J. & Curry, D. (1987)

1.1.3. MFD Data Entry

Description:
MFD controls support data entry and other kinds of pilot input. The MFD system should be responsive and facilitate data entry. It should also allow for more than one way to input the data and should be designed to help prevent serious data entry errors.

Evaluation Procedure:
Note the responsiveness of the system to pilot input, cursor positioning, and the use of controls. If in a flight test environment, note control responsiveness under conditions of turbulence.

Evaluation Consideration:	Yes	No	N/A
1) Does the MFD system respond or give feedback to pilot input within a half second after input?			
2) Is there more than one way to input the data (e.g., touchpad, keyboard, control panel, etc.)?			
3) When a page that requires data entry is displayed, is the cursor set to an appropriate position? For example, is the cursor automatically positioned at the first blank parameter box that needs to be filled?			
4) Is the pilot required to confirm important or consequential entries before they are executed?			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

1.1.3. MFD Data Entry

Applicable Regulatory Documents:

CFR: 23.671, 23.771, 23.777, 23.1301, **23.1523**

AC: 23.1311-1A

Other Guidance: ARP 4102

Advisory Information and Accepted Practice:

Data entry using the MFD control input methods provided should be easy and effective. To minimize confusion, the MFD system should be responsive to any data entry or other control inputs. Inputs should be processed quickly and feedback should be displayed on the MFD screen within 500 ms. If there is a delay in processing, then that information should be made available to the pilot. Feedback is also important so that the pilot is given an opportunity to review the control inputs made and correct any erroneous inputs.

To facilitate data entry, it is also recommended that cursors be properly positioned on the screens that require data entry. For example, if the pilot must input a value for meters on a page, then the cursor should automatically appear at that data field for meters when the page is selected. Automatic cursor placement is very valuable in minimizing tedious control input actions and reducing head-down time.

Another aspect of data entry is the control input methods available. In the event of a control failure and to accommodate differing pilot preferences, a variety of redundant control input devices should be provided. Control design must also consider the fact that pilots also differ in terms of hand strength, handedness, and dexterity. Some of the more popular MFD control devices include joysticks, touchpads, trackballs, and control panels. Voice recognition systems are also being extensively investigated as a new control device. The potential for system or device failures further necessitates the need for multiple means to accomplish the same control input. Redundant control methods are necessary for flight safety and optimal pilot performance.

Although errors in data entry are likely, effective error management techniques seriously reduce their impact. One technique used to minimize serious input errors is to require pilot confirmation of especially important or consequential entries. In this way, irrecoverable errors are prevented.

Additional References:

DOT/FAA CT-96-1
MIL-STD 1472
British Defense Standard 0025, Part 1
GAMA Publication 10, 7.2.1
Nielson (1993); (Usability Engineering)
Card, S., English, W., & Burr, B. (1978)
Karat, J., McDonald, J., Anderson, M. (1984)
Reising, J. & Curry, D. (1987)
Sirevaag, E. et al. (1993)

1.1.4. MFD Display Manipulation Controls

Description:
The ability to move among multiple screens, pages, and windows is an important interface consideration. In order to reduce navigational distance, defined as the number of steps required to arrive at a destination screen from any other screen, dedicated controls or short-cuts for manipulating display elements are often implemented.

Evaluation Procedure:
View several display functions, including multi-page functions and windows, noting the options available for moving between screens, pages, windows and other displays. Note any controls or short cuts dedicated to navigating between these elements.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Is there a dedicated button so that only one action is required to return to the default display mode? Note: This button is often labeled “Main,” “Home,” or “RTN.”			
2) Is there a dedicated button so that only one action is required to back-up, undo, or return to the previous display? Note: This button may be labeled as “PREV,” “Undo,” “Return,” or “Back.”			
3) When data are displayed across multiple pages, are there direct controls to move back and forth over the pages of displayed material (e.g., by scrolling or paging)?			
4) If several windows are displayed at once, does the pilot have a means to shift among them to select which window will be active (e.g., through the use of arrow keys or cursor selection)?			
5) Are sequential selections mapped to the same soft-key button, to the extent possible? For example, if radio is the most commonly selected subsystem under communications, then the radio function should be mapped to the same button as communications.			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

1.1.4. MFD Display Manipulation Controls

Applicable Regulatory Documents:

CFR: 23.671, 23.771, 23.777, 23.1301, **23.1523**

AC: 23.1311-1A

Other Guidance: ARP 4102, ARP 4155, ARP 5364

Advisory Information and Accepted Practice:

The functions assigned to controls have a tremendous impact on navigation efficiency, defined as the number of steps required to arrive at a destination screen from any other screen. Currently, the primary MFD controls are hard-key and soft-key bezel push buttons. Hard-key buttons have a dedicated function, regardless of the display or operation mode selected. Soft-key buttons have software-generated functions and labels that are dependent upon the current display and operation mode. In a study conducted by Seidler and Wickens (1992), it was found that providing a dedicated button to return to the top-level of a hierarchically-organized MFD menu helped users navigate throughout the entire system. A dedicated button to return to the MFD default display is also useful to recover from error. If the wrong sequence of selections is made, the pilot has a ready means to return to the beginning. A dedicated button to return to the default MFD display may be labeled as “Main” or “Home”.

Along with a dedicated button to return to the default display, the provision of a dedicated back-step or return button is recommended. If the wrong display or menu option is selected, a dedicated back-up button would allow the pilot to return to the previous display where the incorrect selection was made and also review the series of selections that were made up to a certain point. Dedicated return buttons may be labeled, among others, “Back”, “Return”, or Undo”.

In an MFD, there are some functions or displays that exceed the capacity of single page. Multi-page functions or displays usually include checklists and other synoptic information. To effectively view these pages, a means to move back and forth across the pages is suggested. Scrolling may be accomplished via navigation buttons or keyboard function keys. Similarly, when multiple windows are presented simultaneously on the MFD, the pilot should be able to select which window to activate.

Another important consideration for control layout is the mapping of sequential functions to the same or adjacent buttons. For example, a common control sequence may be to select a radio to adjust the frequency. The same button that was used to select the radio may also be mapped to adjust the frequency of that radio. This organization of control functions reduces head-down time and allows for speedy navigation.

Additional References:

GAMA Publication #10, section 7.2.1
Calhoun, G. (1978)
Parush, A. (1987); Seidler, K. and Wickens, C. (1992)

1.1.5. MFD Immediate Access

Description:
By definition multi-function displays provide a display and control interface for a number of different functions. Because the display is shared between different features or functions, it is important that the user be able to quickly and easily switch between the major functions of the display provided by the system.

Evaluation Procedure:
Select each of the primary available display modes and note the following.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Is mode/function access consistent? For example, access via dedicated buttons.			
2) Is there a direct means (e.g., dedicated buttons, voice commands, or keyword entry) to access frequently used operation modes or functions?			
3) Is there a direct means (e.g., dedicated buttons, voice commands, or keyword entry) for the flight crew to select higher priority information?			
4) Do important and frequently used functions/modes have dedicated bezel push-buttons and/or menu short-cuts?			
5) Is there another way to get to the desired screen directly; f or instance, a keyword/shortcut entry or voice command?			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

1.1.5. MFD Immediate Access

Applicable Regulatory Documents:

CFR: 23.671, 23.771, 23,777, 23.1301, **23.1523**

AC: 23.1311-1A

Other Guidance: ARP 4102, ARP 5364

Advisory Information and Accepted Practice:
For immediate access to specific MFD functions and operation modes, the methods by which operation modes or functions are accessed should be clear and effective. Direct control methods should also be consistent across all of the functions supported by the MFD system. Required actions should conform to recognized behavioral stereotypes for data entry and information access devices. Failure to observe this standard can result in increased training time, increased data entry and information access times, and potential confusion when transitioning between function/modes during high-workload situations.

Direct access should be made available to the most frequently used operation modes and functions. Direct access capability significantly reduces navigation times and minimizes mental workload and memory retrieval. The benefits of direct access are most obvious in the completion of time-critical tasks. It is much more cumbersome and laborious to navigate a hierarchical menu than to simply de-press a push-button to reach a particular function or mode. Ideally, there should be redundant forms of direct access to accommodate pilot preferences and as a back up in case of failures. Direct access may come in many forms. Some of the most common forms include bezel push buttons, direct access codes which must be entered via keyboard, menu short cuts, and voice activation.

The means by which a function or mode is accessed should remain consistent across displays. For example, if a traffic-related function is accessed via a menu short cut on a weather display, it should also be available from the same menu-short-cut on a terrain display. This consistency increases the predictability of the MFD, making it easier to learn and use. To maintain situational awareness, direct access to higher priority information is also recommended. Direct access to higher priority information may be provided through a bezel button or a keyboard function. To facilitate overall navigation, most MFD designs incorporate dedicated push buttons to the most frequently used functions and operation modes. The buttons are usually embedded in the bezel, surrounding the monitor.

One of the newer control techniques is the use of direct access codes. These codes allow pilots to move directly to particular screens without navigating menus and are typically used as a supplement to other navigation aids. If a voice recognition system is in place, then direct access codes may be verbalized by the pilot. However, because most voice recognition systems are still in the development phase, direct access keywords are usually entered via a keyboard.

Additional References:

Francis, G. (1998)
Paap, K. & Cooke, N. (1997)
Parush, A. (1987)

1.1.6. MFD Control Interfaces and Methods

Description:
Several means of interfacing with the MFD are available. For example, selection may occur either directly via buttons or a touch-screen or indirectly via a keyboard, joystick, or trackball. Regardless of the control-input methods provided, selections of options on the MFD displays must be made with stability and ease.

Evaluation Procedure:
Navigate through the MFD menus, noting the available menu option selection methods.

Evaluation Considerations:	Yes	No	
1) Do the control devices make consistent, accurate selections? For example, inputs are accurately processed, and uncommanded selections do not occur.			
2) Do the control methods provide tactile and/or visual feedback when operated?			
3) Is the control operating pressure light enough not to impede rapid sequential use? *			
4) Are controls operable with one hand?			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

***** May require a flight test environment for full assessment.

1.1.6. MFD Control Interfaces and Methods

Applicable Regulatory Documents:

CFR: 23.251, 23.671, 23.771, 23.777, 23.1301, **23.1523**

AC: 23.1311-1A

Other Guidance: ARP 4102, ARP 4155.

Advisory Information and Accepted Practice:

For effective interaction, MFD controls must conform to the basic operational requirements of cockpit environments. Most of the controls used in stationary, desktop settings cannot be used in aviation applications because vibration and jitter make them subject to inadvertent activation. Currently, there is debate concerning the proper control device(s) to be used in the cockpit. One of the newer control techniques that is being vigorously investigated is the use of voice recognition systems. One issue that is agreed upon is that whatever control method implemented, it must allow for stable, positive selections, even in conditions of high turbulence. Control input methods must also be reliable. For example, it is recommended that voice recognition systems must achieve at least a 95% accuracy rate in word recognition before being implemented at a primary control device.

The control device and display are often physically separated in MFD systems. For example, buttons are usually embedded in the bezel surrounding the MFD monitor and keyboards are usually displaced entirely from the monitor. In operating the displaced controls, the pilot is usually concentrated not on the control itself, but on the resulting change displayed on the monitor. For this reason, it is important to provide feedback to the pilot regarding the control-input actions. One form of feedback is tactile, in that, the pilot senses, with their hand, that a control action has been executed. Feedback may also be given visually in the form of a display change. Redundant forms of feedback are recommended.

Another issue in the operation of MFD controls is repetitive hand movements. MFD control devices should not require exaggerated or elaborate movements of the hands to be activated. In fact, the pressure required to operate the control should be light enough so that the pilot is able to make repetitive selections over a short period of time using the same control device. Control devices should also be operable with one hand. For example, pilots should not have to depress two buttons at once in order to activate a particular function or operation mode. Currently, some of the more commonly used MFD control devices, each with its own advantages and disadvantages, are joysticks, touchpads, trackballs, button panels, and joysticks.

Additional References:

GAMA Pub. #10 - 7.2.1, 7.2.5.2
MIL-STD-1472l; ARP 4104 (SAE)
Faerber, R. et al. (1999)
Francis, G. & Reardon, M. (1997)
Johnson, W., Battiste, V., & Bochow, S. (1999)
Reising, J. & Curry, D. (1987)

1.2 MFD Menus

1.2.1. MFD Menu Organization

Description:
The MFD menu should be organized in such a way that it makes sense to the pilot. It is usually agreed that the optimal menu and display organization is based on functional categories, such as aircraft systems, weather, traffic, terrain, communications, etc. Once displays and menu options are categorized, they are typically arranged in frequency of use. An optimal organization allows predictability, allowing a significant reduction in workload and increased response times.

Evaluation Procedure:
Navigate through the MFD menus and note how the menu options have been categorized, ordered, and labeled.

Evaluation Considerations:	Yes	No	N/A
1) Are the menu options organized into functional categories? For example, functional categories may include weather, traffic, communication, and systems information.			
2) Are options arranged in the MFD menu so that the most frequently used functions are listed above less frequently used functions? For example, the frequently used weather functions should be higher in the list than the less-frequently-used systems functions.			
3) Are catch-all categories, such as "miscellaneous" or "other," avoided as menu options?			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

1.2.1. MFD Menu Organization

Applicable Regulatory Documents:

CFR: 23,1309, 23.1311, **23.1523**

AC: 23.1311-1A

Other Guidance: ARP 4102, ARP 4155

Advisory Information and Accepted Practice:

The pilot's mental model, or internal conception of the MFD system and its processes, is heavily influenced by the manner in which the MFD menu is organized. MFD menus are typically arranged hierarchically, meaning that options become more specific as sub-menus are added. Past research has shown that poor hierarchical menu design results in reduced user satisfaction and performance. One of the biggest dilemmas in hierarchical menu design is whether to increase breadth, the number of items in a given menu list, or depth, the number of sub-menus. Combining related menu options into groups is one solution that usually results in less breadth and more depth. Research has demonstrated that appropriate grouping can be very effective in improving performance. As a form of chunking, grouping related menu options facilitates learning and memory retrieval.

In an MFD, menu options are typically grouped into functional categories, such as weather, traffic, communications, and systems. This organization facilitates MFD navigation and also allows the optimal menu breadth to be increased from 4 to 13 menu items per list to 16 to 36 menu items per list. In addition to categorization of menu options, a menu's organization may be improved by listing menu items in order of frequency of use. Those functions or functional categories that are most frequently selected should be at a higher menu level than less frequently access functions or operation modes. For example, weather-related functions are accessed much more frequently than systems-related functions and should, therefore, be available as a menu option prior to systems-related functions. Organizing the menu so that the most frequently used options are readily available significantly reduced workload and head-down times.

One of the more commonly misused menu organizational techniques is to provide a catchall category, such as "miscellaneous" or "other". Research has shown that including such a category as a menu choice results in confusion and menu navigation errors. Efforts must be made to ensure that all available functions and operation modes are organized into logical categories.

Additional References:

Fisher, D., Yungkurth, E., & Moss, S. (1990)
Francis, G. (1998)
Norman, K. (1991)
Paap, K. & Cooke, N. (1997)
Paap, K. & Roske-Hofstrand, R. (1986)
Snowberry, K., Parkinson, S., & Sisson, N. (1985)
AHCI Style Guide, V. 2.2 (1998) Rpt. # 64201-97U/61223

1.2.2. MFD Menu Options

Description:
MFD functions are generally organized in a hierarchical menu tree, requiring the user to navigate through the hierarchy in order to find the display of choice. The terminology used to describe menu options must be clear to the pilots so that navigation errors are prevented.

Evaluation Procedure:
Navigate through the MFD menus and note the labels of each of the menu items. Note whether the categorical menu options have expanded descriptors if the category name is so ambiguous that a further description or preview is needed.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) If menu options correspond to general categories (e.g., traffic or weather), are there text descriptors which further explain what is contained in the category. Note: Descriptors may consist of 2-5 keywords, depending on how abstract the category to be described is.			
2) Do the more vague or ambiguous menu options have longer or more detailed descriptors?			
3) Do the descriptors for each menu option consist of a preview of the options found at the next lower level in the hierarchy?			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

1.2.2. MFD Menu Options

Applicable Regulatory Documents:

CFR: 23.671, 23.1301, 23.1523, **23.1555**

AC: 23.1311-1A

Other Guidance: DO-229, DO-257, ARP 4102, ARP 4155

Advisory Information and Accepted Practice:

Because MFD options are most often partitioned across multiple menu panels, pilots are typically required to navigate through the menu hierarchy in order to find the display of choice. The majority of errors in these menu-driven systems occur because the meanings of menu options are unclear to the pilot. A navigation error results when a particular menu selection leads to an unintended path and the user is forced to retreat and start over. One method of increasing clarity is to append descriptors to each menu option.

Research on menu terminology suggests that adding descriptors to menu options can be very effective when users have had limited experience with a menu panel that consists of options corresponding to fairly general or abstract categories. Under these conditions, menu options with descriptors are preferred over those without and result in fewer navigation errors.

For categories that are more abstract and difficult, descriptors consisting of only a few examples are less valuable. It is suggested that increasingly more descriptors are needed, as categories become more abstract, so that the user is provided with an understanding of the range of items contained within those categories. It has also been found that knowledge of upcoming options is more useful in making choices at higher levels compared to lower levels in the menu hierarchy.

Research has found that including a miscellaneous category as a menu choice results in a great deal of confusion and encourages erroneous navigation. This finding illustrates the influence of context on the selection process; that is, the meaningfulness of a menu option name is heavily determined by the other names on the menu panel. Again, the importance of carefully choosing and organizing the elements of a hierarchical menu is seen.

Additional References:

Dumais, S. & Landauer, T. (1983)
Lee, E., Whalen, T., McEwen, S., & Latremouille, S. (1984)
Paap, K. & Cooke, N. (1997)
Snowberry, K., Parkinson, S., & Sisson, N. (1985)

1.2.3. MFD Menu Depth and Breadth

Description:
MFD functions are generally organized into a hierarchical menu tree. Menu organization influences the ease and speed with which pilots are able to access needed functions. The depth of the tree refers to the number of levels in the hierarchy. The breadth of the tree refers to the number of items or choices within each level.

Evaluation Procedure:
Go through the MFD menus and note the number of items in each menu list (breadth). Also, note the number of levels in each menu branch (i.e., the number of times you can select menu options until there are no more options left).

Evaluation Considerations:	Yes	No	N/A
1) Is there a consistency in depth and breadth across menus? For instance, there should not be one menu list with two items and other menu lists with eleven or twelve items.			
Is the breadth of the menu selections (i.e. the number of options in a list) appropriate?			
2) Is the depth of the menu selections appropriate?			
3) Are the highly important functions available at a relatively high level in the hierarchy as opposed to being buried down within the hierarchy?			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

1.2.3. MFD Menu Depth and Breadth

Applicable Regulatory Documents:

CFR: 23.671, 23.771, 23.1301, **23.1523**

AC: 23.1311-1A

Other Guidance: ARP 4102

Advisory Information and Accepted Practice:

Menu depth refers to the number of levels in a hierarchical menu, whereas menu breadth refers to the number of items in a given menu list. Research on hierarchical menu design has evaluated search times for finding a specific menu option with menus of varied depth and breadth. Lee and MacGregor proposed a quantitative model to provide the optimal menu breadth, using human processing, human response, and computer response times. Depending on the values for these times, the optimal breadth is typically in the range of 4 to 13 items per panel. The longer it takes to comprehend each menu option, the lower the optimal breadth will be (i.e., the shorter the optimal menu list).

Length of menus (menu breadth). Ideally, the number of options in the list should be more toward the middle of the 4 to 13 range. Other considerations may include the number of options that can be viewed on one screen For example, if 8 options can be displayed on one screen, it is probably ideal to display a maximum of 8 options. Whereas, if the screen can display only 6 options, you could expect two pages of options (no more than 12). Furthermore, Paap and Roske-Hofstrand found that, if meaningful groups of options (categories) can be presented for each menu, then the optimal breadth can increase from 4 to 8 to 16-36 menu options per list.

Depth of menus. Generally, hierarchical menus for each separate feature or function in an MFD should not be more than 2 or 3 levels deep. In an MFD, a single menu level is automatically added because of the access to multiple functions. Key features and functions should be maintained at the highest levels of the menus. For example, while it may be adequate to require pilots to navigate two or three menus through the system for pre-flight data, strategic data such as traffic and weather should be available at the highest levels of the menu hierarchy.

Additional References:

Francis, G. & Reardon, M. (1999)
Lee, E. & MacGregor, J. (1985)
Paap, K. & Roske-Hofstrand, R. (1986)
Snowberry, K., Parkinson, S. & Sisson, N. (1983)

1.3. MFD Displays

1.3.1. MFD Display Content and Organization

Description:
To avoid confusion and conflict among various sources of information, MFD displays should remain as consistent as possible across all functions and modes.

Evaluation Procedure:
View individual and overlaid displays. Note the consistency of display features, such as organization, color, and symbology, across different functions.

Evaluation Considerations:	Yes	No	N/A
1) Does each screen/page have a title located in a consistent place to indicate its purpose?			
2) Is the current operational mode of each displayed subsystem clearly indicated?			
3) Do functional areas remain in the same relative location across all screens, to the extent possible? For example, if input fields are located to the left on one screen, they should also be located to the left on other screens.			
4) When multiple functions are overlaid, is scaling automatically adjusted so all overlays conform to the same scale?			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

1.3.1. MFD Display Content and Organization

Applicable Regulatory Documents:

CFR: 23.671, 23.771, 23.777, 23.1301, **23.1523**

AC: 23.1311-1A

Other Guidance: ARP 4102

Advisory Information and Accepted Practice:

MFD systems are designed to integrate multiple functions and operational modes in a single electronic display. Integration occurs via functional overlays and windowing. To facilitate integration, it is important that functions and modes share some display consistency. Conflicting display elements across functions result in increased mental workload. Guidelines for electronic displays have recommended that display fields should be standardized across screens (Boff & Lincoln, 1988). Common display sections that appear across multiple screens should always appear in the same relative locations. For example, aircraft status information that appears on several related pages or screens should consistently appear in a single display location (e.g., lower left). This screen design technique allows users to develop spatial expectancies, thereby reducing workload and visual search times.

Another display feature that promotes consistency is the presentation of a screen title. Screen titles are useful to indicate the source or purpose of particular screens. This becomes especially important when dealing with multiple information sources as in an MFD system. Software-generated screen titles should be consistently located across display screens. In overlaying multiple functions, it may be necessary to dim or minimize screen titles in order to reduce clutter. Similarly, MFD operational modes must be indicated in a consistent manner. Modes are usually indicated by highlighting or color-coding the active mode to distinguish it from other available modes. Modes may also be incorporated into screen titles.

Consistent look and feel across functions and modes of operation is extremely important in MFD overlays. To achieve optimal response speeds and improve accuracy, it must be ensured that display elements are not only compatible within a single display, but also across multiple displays. The distance scaling of a display overlay should be automatically adjusted to match the scaling of the original display. Color and symbology should also remain clear, distinct, and semantically consistent in overlapping displays.

Additional References:

GAMA Pub. #10
Boff, K. & Lincoln, J. (1988)
Campbell, J., Hanowsik, R., Hooey, B., Gore, B. & Kantowitz, B. (1997)
Calhoun, G. (1978)
Parush, A. (1987)

1.3.2 MFD Display Color Usage

Description:
To maintain effectiveness, color usage should be consistent throughout the MFD and the entire flight deck. Otherwise, confusion and misinterpretation are likely to happen as the flight crew attempts to integrate information across multiple sources both within and outside of the MFD. Colors can be very effective in facilitating information grouping and processing in electronic displays. For color usage to be effective in an MFD, colors must be distinct and meaningful.

Evaluation Procedure:
Observe the use of color in individual and overlaid displays and note the following:

Evaluation Considerations:	Yes	No	N/A
1) Is the number of colors used for coding on a single display limited to seven or less (excluding red for warnings and yellow for cautions)?			
2) Is the use of color consistent in display overlays and across MFD functions and modes? For example, the earth's surface is consistently indicated by the same color in both traffic and weather displays.			
3) Are bright, highly saturated colors only used for flight critical data?*			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

***** May require a flight deck environment for full assessment.

1.3.2. MFD Display Color Usage

Applicable Regulatory Documents:

CFR: 23.1311, **23.1322**, 23.1321(e), 23.1311 (a)(2)

AC: 23.1311

Other Guidance: ARP 4032, ARP 4102/7/8

Advisory Information and Accepted Practice:

In aviation contexts, color-coding has been very effective in enhancing the representation and organization of data. However, as more colors are used to transmit information, density is increased and the benefits of color-coding are lost. The number and extent of colors should be minimized so that they remain effective. Although recommendations vary, most guidelines suggest the use of between six and nine colors in electronic displays. For color-coding to be functionally effective, MFD color assignments must be both internally consistent and in agreement with existing flight-deck standards. Color consistency eases display interpretation and increases system predictability.

On any given MFD display, colors should be easily identifiable and distinguishable from each other in order to prevent confusion and errors of interpretation. Special care must be made to ensure that colors remain distinct when displays are overlaid. It is also recommended that colors be used redundantly with other information encoding techniques, such as size, shape, and brightness. In other words, the information available through color should also be available via other means. To minimize display clutter, it is recommended that the use of bright, highly saturated colors be minimized. Bright colors should be reserved for warnings and other alerts which require immediate attention.

Much research suggests that the color red should only be used to indicate warnings and other safety-critical information and the color yellow should be assigned to only cautionary information. Once other colors are assigned specific meanings, these assignments should remain fixed across all MFD functions and modes, to the extent possible. The use of same or similar colors to convey different information should be avoided.

The SAE ARP 4032 recommends that display features be color-coded as follows:
Warnings (Red)
Flight envelope and critical parameter list (Red)
Cautions, abnormal sources (Amber/Yellow)
Earth (Brown)
Scales and associated figures (White)
Engaged modes (Green)
Sky (Cyan/Blue)
Instrument landing systems (ILS) deviation pointers (Magenta)
Flight director bars (Magenta or Green)

1.3.3. MFD Display Symbology

Description:
Symbols are used throughout MFD systems to represent objects and concepts. For symbols to be meaningful and effective, they must be clear, consistent, and distinct.

Evaluation Procedure:
Observe the MFD icons and symbology under various lighting conditions, paying special attention to the clarity and distinctiveness of each symbolic depiction.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Do symbols clearly depict the situations, concepts, or objects represented and are they consistent with industry standards?			
2) Are symbols/icons simple in appearance (e.g., basic shapes without fine details)?			
3) Are different symbols used for tasks that require different responses (i.e., each symbol should be used for a single purpose)?			
4) Is icon/symbol usage consistent across multiple pages of the MFD?			
5) Are the icons that are used to represent failure or emergency situations accompanied by textual displays?			
6) Are symbol attributes having strong attention-grabbing value (e.g., flashing color) used sparingly? *			
7) Are symbols/icons that are to be interpreted together presented in such a way as to facilitate the interpretation (i.e. close in proximity or design)?			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

* May require a flight test environment for full assessment.

1.3.3. MFD Display Symbology

Applicable Regulatory Documents:

CFR: 23.1309, **23.1311**

AC: 23.1311

Other Guidance: ARP 4102, ARP 4105, ARP 4155

Advisory Information and Accepted Practice:

A common method of encoding information in electronic displays is through the use of symbols and icons. In MFD displays, symbols are non-verbal, graphical representations of objects and/or concepts. Typically, a symbol is chosen because of a commonly understood relationship or association with the object or concept to be represented. In MFD displays, icons and symbols should unambiguously communicate the object or idea that they represent. Whether used alone or in combination, symbols are useful in communicating information rapidly and effectively.

The meaning of a symbol or icon should remain consistent across functions and screens in an MFD. A symbol should always have the same meaning regardless of its context. For example, an inverted chevron used to represent ownship in a weather display should also be used to represent ownship in a traffic display. To minimize pilot error, common symbology for tasks that require different responses should be avoided. To facilitate interpretation, symbols that are related to each other should be aligned or near each other on the display. Symbols should also be simple in appearance. Icons and symbols are most effective when they consist of basic shapes. Fine detail tends to result in symbol confusion and misinterpretation.

Symbols should be discriminable from an average viewing distance of 29 inches, a minimum viewing distance of 10 inches, and a maximum viewing distance of 40 inches under all lighting conditions. To increase discriminability, symbols may also be varied in size, shape, and pictorial realism. However, care must be taken to ensure that symbol attributes that have strong attention-grabbing value (e.g., flashing color) are used sparingly and only when justified by the relative priority of the top-level task in relation to the user's other tasks. Icons that represent failure or emergency situations should be accompanied by a textual display.

Additional References:

Dillard, A. (1999)
Campbell, J., Carney, C., & Kantowitz, B. (1997)
Pejtersen, A. & Rasmussen, J. (1997)
RTCA (1999) DO-238A
Rubin, J> (1994)
SAE (1988) ARP 4155
Stokes, A. & Wickens, C. (1988)

1.3.4. MFD Messages, Text, and Labels

Description:
Messages and data must be clear and useful to the flight crew. Data labels, message terminology, and abbreviations must follow existing aviation conventions. Labels are needed for both displayed data and blank, to-be-filled data fields.

Evaluation Procedure:
View various MFD displays, noting the terminology and abbreviations used in messages and data labels.

Evaluation Considerations:	Yes	No	N/A
1) Is message terminology consistent with existing aviation conventions?			
2) Are error messages clear and meaningful to the pilot? *			
3) Are abbreviations consistent with existing aviation conventions (e.g., ABS for absolute, ACFT for aircraft)?*			
4) Are data in a directly usable form that does not require any type of conversion?			
5) If needed, are data labeled with the appropriate units of measurement or symbology (e.g., km., ft., in., ˚)?			
6) Are labels located sufficiently close to their respective data fields but separated perceptually from the data field?			
7) Is the type and format of expected input data indicated (e.g., a to-be-filled blank parameter box is labeled min. to indicate that minutes are needed)?			
8) When multiple functions are overlaid, is text consistent across overlays?			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

* May require a flight test environment for full assessment.

1.3.4. MFD Messages, Text, and Labels

Applicable Regulatory Documents:

CFR: 23.1301, 23.1311, 23.1541, 23.1555

AC: 23.1311-1A

Other Guidance: ARP 4102, ARP 4105, ARP 4155

Advisory Information and Accepted Practice:

MFD messages are used to convey important flight and aircraft information to the pilot. Messages should be designed to communicate new information as concisely and effectively as possible. To further this goal, message terminology should be consistent with existing flight deck conventions. Consistent terminology reduces mental workload and head-down time. In particular, special attention should be given to error messages. Error messages should avoid reference to error codes unknown to the pilot.

Abbreviations used in menus, messages, or any other display feature should be consistent with aviation conventions. For example, some traditional aviation abbreviations include ALT for altitude, A/S for airspeed, and ACFT for aircraft. The Department of Defense Military Standard 783 D (1984) gives recommended abbreviations for a large collection of terms that may be used in an aircrew station.

The appropriate units of measurement should always accompany quantitative data. All blank and filled data fields should be labeled so that data may be correctly entered and interpreted. For example, a value for feet should have a label of “ft.”. A label should be clearly adjacent to its data field, but separated by a single space. For example, a blank data field may be labeled as __ ft. Blank data fields should clearly indicate the type and format of data required. In addition to abbreviations, commonly recognized symbols may also be used to label quantitative data to improve legibility. For example, the symbol for degrees (˚) can be used as a label.

Data must also be presented in a directly usable form. For example, if both feet and meters are necessary to the pilot, both values should be given by the MFD, eliminating the need to engage in a mental conversion. Another issue concerning data is overlaying functions. Alphanumeric data should be consistent in terms of font and size in functional overlays.

Additional References:

Calhoun, G. (1978)
Dillard, A. (1999)
Department of Defense (1984) MIL-STD-783D
Williges, R., Williges, B., & Fainter, R. (1988)

1.4. Information Accessibility

1.4.1. MFD Windows and Overlays

Description:
At the heart of MFD functionality is the ability to simultaneously present information from a variety of sources through the use of screen overlays and windows. Although extremely useful for integrating data from different sources, this feature also creates the potential for display clutter and mode confusion.

Evaluation Procedure:
Overlay various functions, noting the available selection options and the means used to identify each overlay. Also note window placement, control, and activation information.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) When various information overlays are selected for display, is the identity and status of each information overlay provided?			
2) When functions are overlaid on the display, is there a way for the pilot to select and deselect various overlays?			
3) Is the automatic deleting or relocating (without letting the pilot know) of various overlays avoided?			
4) When a window appears, is it consistently located in the same portion of the display, regardless of the function being displayed on the remainder of the display?			
5) When a window pops-up, is it located so that it does not obscure important information on the underlying display?			
6) When several windows are displayed concurrently, does the system indicate which window is active?			
7) Can a window be removed once a message has been acknowledged?			
8) Is there a way to automatically inhibit messages?			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

1.4.1. MFD Windows and Overlays

Applicable Regulatory Documents:

CFR: 23.1309, 23.1311, **23.1523**, 23.1555

AC: 23.1311

Other Guidance: ARP 4102

Advisory Information and Accepted Practice:

Of particular concern in MFD design is the organization and management of multiple overlaying displays. To reduce mental workload and reliance on memory, each overlay should be clearly identified with source and status information. Providing this information for each overlay also promotes consistency among displays, further reducing visual search times.

Another issue in overlaying functions is clutter. Clutter refers to an excessive amount of displayed information that compromises display effectiveness and usefulness. The pilot should have the ability to control the amount of information displayed, so that the display is always effective in presenting information. Providing a means for the pilot to select and de-select various overlays help achieve this goal. This technique also recognizes the individual differences in interaction styles, allowing the addition and removal of overlays according to subjective preferences. Similarly, overlays and/or windows should not be moved or removed through the use of automation, as this results in reduced situational awareness and, therefore, increased mental workload for the pilot.

The issue of display clutter arises again with windows. There are several design techniques used to reduce the impact of windows on information density. Windows should be consistently located on the display screen and positioned so that they do not cover important information. If windows are placed in a blank area or over less important information, then the pilot retains the ability to interpret the original display. When multiple windows are displayed, the MFD system should indicate which window is currently active. Otherwise, the pilot is forced to rely on short-term memory in order to recall the most recently displayed or activated window, thereby increasing mental workload and the chance of error.

Similarly, pilots should also have the means to remove a window once it has been read. The removal of non-essential windows is a simple yet effective de-cluttering technique. If a pilot does have this ability, providing a message log to minimize short-term memory demands is recommended. Finally, the pilot should have the ability to prevent non-critical messages from being displayed during situations of heavy workload. Pilots are typically given the option to automatically inhibit routine status messages so that the display remains clear for desired functions and alerts.

1.4.2. MFD Information Grouping

Description:
Information may be grouped in a variety of ways in an MFD. The information can be combined and layered or can be segregated by windows. Within a single display, various elements may be added or removed in order to aid the pilot's comprehension of the situation.

Evaluation Procedure:
Select various individual displays, overlay related displays, pull-up windows, and note how the design of the display combines and separates the information. Also note the methods available to add/remove information.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Can displays which support the same crew functions be displayed together? For example, terrain, traffic, and weather functions can be displayed together in some systems.			
2) If unrelated information is to be displayed concurrently, is the data clearly segregated via windowing or other techniques?			
3) Does the pilot have the ability to remove non-essential information that may cause clutter? * For example, a map display may be simplified by temporarily removing irrelevant symbols.			
4) Are pilots allowed to reconfigure certain characteristics of their display in order to satisfy their current task?			
5) When the crew can select multiple sources of data or multiple modes of operation, are the sources and modes clearly identified? *			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

* May require a flight test environment for full assessment.

1.4.2. MFD Information Grouping

Applicable Regulatory Documents:

CFR: 23.771, 23.1309, 23.1301, 23.1311, **23.1523**

AC: 23.1311-1A

Other Guidance: ARP 4102

Advisory Information and Accepted Practice:

One of the more popular methods of grouping information is the layering of one function over another. Two or more functions are combined to present one information display. One of the major pitfalls of overlaying is the potential for cluttering. Information may become so densely packed that the MFD ceases to be an effective display. Dense displays are well known for increasing mental workload and head-down time. One technique of reducing display clutter is to remove or minimize non-essential display elements. For example, in some types of cockpit displays of traffic information (CDTI), only aircraft within a certain range of distance are presented at full brightness, whereas other aircraft are dimmed. Another clutter management feature in CDTIs is the option to bring-up, only when desired, aircraft ID blocks that contain speed and ID information for each aircraft. The removal or minimization of unnecessary clutter eases interpretation and minimizes head-down time.

Another issue in overlaying concerns the degree to which the displays are functionally related. For example, terrain, weather, and traffic functions are highly related. Each of these three functions is concerned with possible external obstacles and barriers in flight. These functions may be, and sometimes are, successfully overlaid in an MFD. Conceptually, overlaying their related functions make sense. However, if two functions are not related, yet displayed concurrently, they should be clearly segregated. Unrelated functions may be displayed in separate windows or separated by borders of some kind. This minimizes confusion and helps provide some structure and organization to the MFD.

Because pilots almost certainly have some differences in interaction style, they should be provided with at least some options to reconfigure the MFD to suit individual tastes and preferences. Display configurations may also change based on experience level and flight objectives. Another important aspect of information grouping is the information options available. Information sources and modes must be clearly presented on the display so that the most effective and appropriate grouping can be made by the pilot.

Additional References:

Dillard, A. (1999)
RTCA (1999)
Stokes, A. & Wickens, C. (1988)

1.4.3. MFD Changing Between Functions

Description:
One aspect of MFD display sharing is changing between the functions to be displayed. Switching from one function to another may occur automatically or manually. To maintain situation awareness, this display change should be announced and the flight crew should be able to resume interrupted activities.

Evaluation Procedure:
Manually change functions and observe the changes. Note whether or not the changes are announced and the availability of controls to resume interrupted functions.

Evaluation Considerations:	Yes	No	N/A
1) When the system automatically switches between display modes, pages, or functions, is this change visually or aurally announced? *			
2) After an automatic change in the display, is the pilot able to easily and quickly restore the display to its previous state? (for example, via a dedicated "back" button) *			
3) If one function is suspended by switching to another function, is the pilot able to resume the suspended function and recover any associated data? *			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

* May require a flight test environment for full assessment.

1.4.3. MFD Changing between Functions

Applicable Regulatory Documents:

CFR: 23.1311, **23.1523**

AC: 23.1311

Other Guidance: ARP 4102, ARP 4033

Advisory Information and Accepted Practice:

Because each function shares the same display space, the MFD provides an efficient means of displaying multiple functions. One aspect of display sharing is changing between the functions to be displayed. Available both manually and automatically, the ability to change functions and modes is one of the greatest advantages of the MFD. Situational awareness becomes a special consideration in cases of automated display changes. An automatic change between functions or the automatic overlay of one function on another must be announced in some form so that the pilot remains aware of the current display state. If automatic display changes are not announced, then the pilot is likely to miss the significance of the display change altogether. The form of the announcement, whether visual, aural, or both, depends on how important the information change is. Function switches typically occur in cases where a rapid response is required.

Once a display change is acknowledged, the pilot should be able to return to the previous display easily and quickly. The ability to resume an interrupted function minimizes the amount of information that the pilot must maintain in short-term memory. The pilot is allowed to return to the interrupted function almost as soon as the change occurs. Ease of changing between displays also facilitates integration and comparison across displays, further reducing demands on short-term memory. Multi-function displays also should allow the recovery of any data associated with an interrupted function. Minimizing data loss is one of the easier methods of reducing pilot workload.

Additional References:

Dillard, A. (1999)
RTCA (1999)
Stokes, A., Wickens, C., & Kite, K. (1990)
Williges, R., Williges, B., & Fainter, R. (1988)

1.4.4. MFD Information Priorities

Description:
Because there is a limit to the amount of information that can be displayed at one time using an MFD, there must be a prioritization system in place so that information deemed more important to flight safety receives precedence over less important information. Prioritization is a method of ordering information in terms of importance and may be applied to the design of alerts, menu lists, and display pages.

Evaluation Procedure:
Note whether and in what way information is prioritized in alerts, menus, and multi-page functions.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Is there a prioritization schema for alerts, so that alerts are ordered according to some pre-defined priority system? * For example, a warning alert has a higher priority than, and therefore, precedes, a caution alert.			
2) Are alerts compatible with their assigned priorities? For example, in addition to getting precedence, a warning alert typically includes the color red and some kind of aural signal.			
3) Are menu items that are important to flight safety organized at a higher level than less important information?			
4) When a function is selected that requires multiple pages (e.g., checklists), is the page containing the most important information displayed first?			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

* May require a flight test environment for full assessment.

1.4.4. MFD Information Priorities

Applicable Regulatory Documents:

CFR: **23.1322**, 23.1309

AC: 23.1309, 23.1311, 23-8

Other Guidance: ARP 4102/4

Advisory Information and Accepted Practice:

MFD information must be prioritized in terms of criticality to flight safety. For example, information that requires an immediate response from the flight crew must override any pre-existing display so that attention can be captured quickly and effectively. This override usually consists of a visual alert in the form of a display overlay or pop-up window and may be accompanied by some kind of aural alert. Alerts must be arranged in order of importance to flight safety, with alerts requiring immediate action taking precedence over other, less serious, alerts, so that flight crews do not become overwhelmed by multiple, simultaneous demands for attention.

Alerts typically fall into three general categories, in order of importance: 1) warnings that require immediate attention and immediate response, 2) cautions that require immediate attention and rapid response, and 3) advisories that require general awareness of borderline conditions. It is important that each alert is compatible with its assigned priority and carries information about how important it is. For example, warnings typically employ the color red, aural signals, and a textual message. Warnings should be used exclusively to indicate dangerous or hazardous conditions that require an immediate remedial response.

Information priority becomes an issue with menu design as well. Although aircraft systems information is not one of the most frequently accessed MFD functions, it is important the systems information most critical to flight safety is readily available. Specifically, in the menu for systems information, the most safety-critical options should be at a higher level in the hierarchy and at the top of lists. This systems menu organization allows easy access to aircraft synoptics in the event of a failure or other systems emergency, reducing response times and mental workload.

Functions or modes that contain multiple pages, such as checklists, should also reflect prioritization. That is, the most important or crucial page of the checklist should be the first page to be displayed, and the second most important page should be next, and so on. In general, prioritization is an effective method for ordering and assigning additional meaning to individual pieces of information.

Additional References:

Boff, K. & Lincoln, J. (1988)
DoD (1991) MIL-STD-411E
Dillard, A. (1999)
SAE (1997) ARP 5108
Stokes, A. & Wickens, C. (1988)

1.5. Warning Information

1.5.1. MFD Alert Information

Description:
MFD alerts are often used to quickly direct pilot attention. Alerting signals may be visual and/or aural and may vary in priority. Priority or urgency is coded by several means, such as color, signal intensity, and signal duration. For alerting signals to be effective, they must be immediately salient and meaningful to the pilot.

Evaluation Procedure:
Note the content, duration, intensity, and prioritization of MFD alerts.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Are high priority alerts signaled both visually and aurally? *			
2) Are inconsistencies among data sources announced via an alert of some kind? *			
3) Are alerts always sequenced so that only one situation is alerted at a time? * For example, 2 high-priority events should not be alerted at the same time; the less important event should be queued with notification given to the pilot.			
4) Are visual alerts significantly brighter than the other visual displays on the instrument panel? *			
5) Does the visual alert signal flash against a steady background? *			
6) Are visual alerting signals presented as within 15 degrees to the operator's line of sight? *			
7) Is the use of color redundant with other visual and auditory coding methods for alerts? *			
8) Is the auditory alerting signal varied so that it is intermittent or changes over time? *			
9) Upon user response, does the auditory signal shut-off?			
10) Are auditory signals capable of being turned off at the discretion of the user?			
11) If an alert does not receive a response within a fixed amount of time, are pilots reminded of the alert?			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

* May require a flight test environment for full assessment.

1.5.1. MFD Alert Information

Applicable Regulatory Documents:

CFR: 23.1301, **23.1309**, 23.1321, 23.1322, 23.1523

AC: 23.1311-1A

Other Guidance: ARP 4102, ARP 4102/4

Advisory Information and Accepted Practice:

Alerts are necessary to maintain situational awareness in an MFD. Alerts may serve as warnings, cautions, or advisories. Warnings require immediate pilot attention and may require an immediate response. Cautions require immediate attention and may require a rapid pilot response. Advisories require general awareness of a borderline condition. Alerts should be organized according to a prioritization schema so that the more important alerts precede, and are more salient than, the less important alerts. The highest priority alerts should be announced both visually and aurally to ensure that attention is captured.

Visual alerts may also be made more salient by having twice the brightness of the surrounding display or flashing against a steady background. They should be presented as close to the line-of-sight as possible. Aural alerts are reserved for the most important kinds of alerts, such as warnings and cautions. To counter the effects of frequency-specific hearing loss, an aural alert should consist of multiple frequencies. In addition, auditory signals should be intermittent or change over time in order to increase the chances of detection. Once an auditory signal is acknowledged and the pilot responds, the alert should turn off automatically. This feature minimizes distraction and sound clutter. Similar to non-critical pop-up windows, there should be a means to disable non-critical auditory signals.

Typically, inconsistencies or discrepancies among MFD functions are announced via an alert of some kind so that the pilot is notified of possible data errors. Significant discrepancies between similar MFD systems, such as attitude, navigation, and air data systems, and between sensor and display values may arise from equipment malfunctions or failures. In the event of a data conflict resulting from a malfunction, the pilot should be provided with the means to identify and remove the malfunctioning source from any future MFD data integration.

Alerts should be ordered so that more than one high priority event is not alerted at the same time. Alerting two or more high priority events simultaneously to the pilot reduces the effectiveness of either alert by itself and greatly increases the chances or confusion and misinterpretation. If two alerts need to be signaled, the more important alert should be presented first. However, the pilot should receive some notification that a second alert is in the queue. After there is a pilot response to the first alert, the second alert can then be announced. Prioritization ensures that each alert is presented consistently in order of importance to flight safety.

Additional References:

Boff & Lincoln (1988)
SAE ARP-5108
Stokes & Wickens (1988)

1.5.2. MFD Failures

Description:
Isolated failures both within and distinct from the MFD should be contained and their impact minimized. The MFD should be able to display primary flight information and operate in a partially functional mode. Non-MFD systems should not be influenced by MFD failures.

Evaluation Procedure:
Determine how the MFD display responds to emergency situations, function failures, and non-MFD system failures.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Is the MFD able to operate in degraded modes, and is the user able to change to any displays that are still functional? (i.e., if one feature quits, do the others still operate?) *			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

* May require a flight test environment for full assessment.

1.5.2. MFD Failures

Applicable Regulatory Documents:

CFR: **23.1309,** 23.1311

AC: 23.1311-1A

Other Guidance: ARP 4102

Advisory Information and Accepted Practice:

In addition to normal functioning, the MFD must also be properly designed for failure. In the event of isolated failures, MFD and cockpit design must ensure that any remaining functions and displays are operational, to the fullest extent possible. One failure should not snowball into a series of system failures. MFD systems are integrated with other aircraft systems. It is important that an MFD failure will not impair the performance of other, non-MFD systems. Non-MFD systems should continue to operate normally and specific MFD failures should be announced to the pilot for evaluation. Within the MFD system, failures of one or more functions should not degrade the performance of other, intact functions or operation modes. It should be possible to use a partially functioning or degraded MFD. The information essential to flight safety is available in the primary flight information (PFI), which is typically shown on the primary flight display (PFD). If there is a failure of the PFD, there should be a provision so that the PFI is automatically transferred to another MFD.

Additional References:

Dillard, A. (1999)

Stokes, A. & Wickens, C., & Kite, K. (1990)

1.6. Evaluation Summary

1.6. Evaluation Summary					
Category	**Page**	**Pass**	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Control Placement	2				
Control Labels	4				
Data Entry	6				
Display Manipulation Controls	8				
Immediate Access	10				
Control Interfaces and Methods	12				
Menu Organization	16				
Menu Options	18				
Menu Depth and Breadth	20				
Display Content and Organization	24				
Display Color Usage	26				
Display Symbology	28				
Message, Text, and Labels	30				
Windows and Overlays	34				
Information Grouping	36				
Changing between Functions	38				
Information Priorities	40				
Alert Information	44				
Failures	46				
OVERALL RATING					

Overall Observations and Comments

2. *Flight Test*

2.1. MFD Controls

2.1.1. MFD Control Placement

Description:
MFD controls should be readily accessible and appropriately placed to allow for easy activation. Controls should be spatially separated and visible at all times during all relevant lighting conditions.

Evaluation Procedure:
Note the location, placement, visibility, and accessibility of MFD control devices.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Are the flight crew controls for the MFD located within the normal range of eye-reference points when seated at the flight crew position?			
2) Are MFD controls physically separated enough to prevent inadvertent activation? *			
3) Are the controls themselves arranged so that they do not obscure other controls or displays when viewed from the normal range of viewing conditions?			
4) Are the actual, physical MFD controls (e.g., buttons and keys) clearly backlit? *			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Fail**
Summary Evaluation:				

***** A bench test may also be performed to evaluate this item.

2.1.1. MFD Control Placement

Applicable Regulatory Documents:

CFR: **23.777**, 23.1367, 23.1381, 23.1523,

AC: 23.1311-1A

Other Guidance: ARP 4102

Advisory Information and Accepted Practice:
Current cockpit designs require that the pilot remain head-down in order to enter control inputs. Because of the difficulty in dividing attention between control inputs and other tasks, one of the goals of MFD interface design is to reduce attentional demands of control inputs. The appropriate control placement and configuration has been found to significantly reduce head-down time and improve pilot-MFD interaction. Past research has shown that inappropriate placing leads to confusion, increased head-down time, and selection errors whereas proper control placement and configuration increases head-up time, response speed, and selection accuracy. MFD system design must ensure that all available controls are located within the full range of motion when the pilot is seated. Pilots must be able to operate controls without exaggerated movements of the body.

In addition to ensuring control accessibility, designers must also spatially separate controls from each other so that erroneous activation of one control during the use of another is prevented. Another reason to allow for adequate spacing of controls is so that controls and displays are not obscured by each other. In order to maintain ready access to controls, controls must remain visible and discriminable under all ambient light conditions. Each control device should be clearly backlit. Because of their small size, backlighting control panels and keypads is especially important.

Additional References:

Dillard, A. (1999)
OAM Tech. Report DOT/FAA/AM-01/17 (2001)
DOD-HDBK-743A (1991)
MIL-HDBK-759C (1995)
MIL-STD-1472F (1999)
STANAG 3705 (1992) (NATO)
DO-238A (1999) (RTCA)
Sirevaag, E. et al. (1993)
Smith, S. & Mosier, J. (1984) TR ESD-TR-84-190

2.1.2. MFD Control Labels

Description:
Labels are typically assigned to MFD controls to clearly indicate their functions. Labels may be physical or software-generated. Soft labels usually appear as legends on the MFD monitor and correspond to the surrounding bezel push-buttons.

Evaluation Procedure:
Note the size, location, and assignment of labels to MFD controls.

Evaluation Considerations:	Yes	No	N/A
1) Are the labels readable under the full range of normally accepted ambient light conditions? *			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

***** A bench test may also be performed to evaluate this item.

2.1.2. MFD Control Labels

Applicable Regulatory Documents:

CFR: 23.771(a), 23.1301, 23.1311, 23.1367, 23.1523(a), **23.1555(a)**

AC: 23.1311-1A

Other Guidance: DO-229, ARP 4102, ARP 4105

Advisory Information and Accepted Practice:

Each MFD control should have some type of label to identify its function. A control may be dedicated, meaning that it always performs the same function, regardless of the state of the MFD, or flexible, meaning that its function changes as the MFD changes in mode or function. Because of space limitations, most MFD functions share the same controls. Dedicated MFD controls are reserved only for the most safety-critical and frequently used functions. Dedicated controls typically have hard labels permanently affixed on or near them, whereas flexible controls have software-generated labels that change as the display changes. Clearly and consistently labeled controls reduce reliance on memory and facilitate learning. Given that there are usually 26 bezel push-button controls surrounding the MFD monitor, clear control labeling is necessary.

In the design of control labels, one must also consider the environmental conditions that influence legibility. Labels should be in a font that is appropriate for the normal viewing angle and distance. At a minimum, the labels should be readable from a distance of 30 inches. Ideally, labels should also remain legible during aircraft vibrations. Labels should be legible under all possible lighting conditions, including full sunlight.

To minimize head-down time, each label should be positioned so that it unambiguously refers to the appropriate control. Software-generated labels or legends should be carefully aligned with the corresponding bezel buttons to prevent erroneous selections. These labels should be consistently located across screens to prevent confusion. The same design concerns also apply to physical labels: they should be clearly and consistently associated with the appropriate controls.

If a control function is available across multiple screens, then that function label should be consistently mapped to the same push-button control, to the extent possible. For example, if the function to adjust a radio frequency was consistently available across several sequential screens, then that function should always be mapped to the same push-button. If it is not possible to assign that function to the same exact button, then it should at least be programmed to an adjacent button.

Additional References:

Calhoun, G. (1978)
Francis, G. (1998)
Parush, A. (1987)
Reising, J. & Curry, D. (1987)

2.1.3. MFD Control Interfaces and Methods

Description:
Several means of interfacing with the MFD are available. For example, selection may occur either directly via buttons or a touch-screen or indirectly via a keyboard, joystick, or trackball. Regardless of the control-input methods provided, selections of options on the MFD displays must be made with stability and ease.

Evaluation Procedure:
Navigate through the MFD menus, noting the available menu option selection methods.

Evaluation Considerations:	Yes	No	N/A
1) Are the control input methods usable in the full range of turbulence conditions?			
2) Is the control operating pressure light enough not to impede rapid sequential use? *			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

***** A bench test may also be performed to evaluate this item.

2.1.3. MFD Control Interfaces and Methods

Applicable Regulatory Documents:

CFR: 23.251, 23.671, 23.771, 23.777, 23.1301, **23.1523**

AC: 23.1311-1A

Other Guidance: ARP 4102, ARP 4155.

Advisory Information and Accepted Practice:

For effective interaction, MFD controls must conform to the basic operational requirements of cockpit environments. Most of the controls used in stationary, desktop settings cannot be used in aviation applications because vibration and jitter make them subject to inadvertent activation. Currently, there is debate concerning the proper control device(s) to be used in the cockpit. One of the newer control techniques that is being vigorously investigated is the use of voice recognition systems. One issue that is agreed upon is that whatever control method implemented, it must allow for stable, positive selections, even in conditions of high turbulence. Control input methods must also be reliable. For example, it is recommended that voice recognition systems must achieve at least a 95% accuracy rate in word recognition before being implemented at a primary control device.

The control device and display are often physically separated in MFD systems. For example, buttons are usually embedded in the bezel surrounding the MFD monitor and keyboards are usually displaced entirely from the monitor. In operating the displaced controls, the pilot is usually concentrated not on the control itself, but on the resulting change displayed on the monitor. For this reason, it is important to provide feedback to the pilot regarding the control-input actions. One form of feedback is tactile, in that, the pilot senses, with their hand, that a control action has been executed. Feedback may also be given visually in the form of a display change. Redundant forms of feedback are recommended.

Another issue in the operation of MFD controls is repetitive hand movements. MFD control devices should not require exaggerated or elaborate movements of the hands to be activated. In fact, the pressure required to operate the control should be light enough so that the pilot is able to make repetitive selections over a short period of time using the same control device. Control devices should also be operable with one hand. For example, pilots should not have to depress two buttons at once in order to activate a particular function or operation mode. Currently, some of the more commonly used MFD control devices, each with its own advantages and disadvantages, are joysticks, touchpads, trackballs, button panels, and joysticks.

Additional References:

GAMA Pub. #10 - 7.2.1, 7.2.5.2
MIL-STD-1472l; ARP 4104 (SAE)
Faerber, R. et al. (1999)
Francis, G. & Reardon, M. (1997)
Johnson, W., Battiste, V., & Bochow, S. (1999)
Reising, J. & Curry, D. (1987)

2.2. MFD Displays

2.2.1 MFD Display Color Usage

Description:
To maintain effectiveness, color usage should be consistent throughout the MFD and the entire flight deck. Otherwise, confusion and misinterpretation are likely to happen as the flight crew attempts to integrate information across multiple sources both within and outside of the MFD. Colors can be very effective in facilitating information grouping and processing in electronic displays. For color usage to be effective in an MFD, colors must be distinct and meaningful.

Evaluation Procedure:
Observe the use of color in individual and overlaid displays and note the following:

Evaluation Considerations:	Yes	No	N/A
1) Is color usage in the MFD display consistent with the use of color across the flight deck?			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

2.2.1. MFD Display Color Usage

Applicable Regulatory Documents:

CFR: 23.1311, **23.1322**, 23.1321(e), 23.1311 (a)(2)

AC: 23.1311

Other Guidance: ARP 4032, ARP 4102/7/8

Advisory Information and Accepted Practice:

In aviation contexts, color-coding has been very effective in enhancing the representation and organization of data. However, as more colors are used to transmit information, density is increased and the benefits of color-coding are lost. The number and extent of colors should be minimized so that they remain effective. Although recommendations vary, most guidelines suggest the use of between six and nine colors in electronic displays. For color-coding to be functionally effective, MFD color assignments must be both internally consistent and in agreement with existing flight-deck standards. Color consistency eases display interpretation and increases system predictability.

On any given MFD display, colors should be easily identifiable and distinguishable from each other in order to prevent confusion and errors of interpretation. Special care must be made to ensure that colors remain distinct when displays are overlaid. It is also recommended that colors be used redundantly with other information encoding techniques, such as size, shape, and brightness. In other words, the information available through color should also be available via other means. To minimize display clutter, it is recommended that the use of bright, highly saturated colors be minimized. Bright colors should be reserved for warnings and other alerts which require immediate attention.

Much research suggests that the color red should only be used to indicate warnings and other safety-critical information and the color yellow should be assigned to only cautionary information. Once other colors are assigned specific meanings, these assignments should remain fixed across all MFD functions and modes, to the extent possible. The use of same or similar colors to convey different information should be avoided.

The SAE ARP 4032 recommends that display features be color-coded as follows:
Warnings (Red)
Flight envelope and critical parameter list (Red)
Cautions, abnormal sources (Amber/Yellow)
Earth (Brown)
Scales and associated figures (White)
Engaged modes (Green)
Sky (Cyan/Blue)
Instrument landing systems (ILS) deviation pointers (Magenta)
Flight director bars (Magenta or Green)

2.2.2. MFD Display Symbology

Description:
Symbols are used throughout MFD systems to represent objects and concepts. For symbols to be meaningful and effective, they must be clear, consistent, and distinct.

Evaluation Procedure:
Observe the MFD icons and symbology under various lighting conditions, paying special attention to the clarity and distinctiveness of each symbolic depiction.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Are symbols discriminable at normal viewing distances under all flight deck lighting conditions?			
2) Is MFD symbology consistent with other symbology used on the flight deck?			
3) Are symbol attributes having strong attention-grabbing value (e.g., flashing color) used sparingly? *			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

***** A bench test may also be performed to evaluate this item.

2.2.2. MFD Display Symbology

Applicable Regulatory Documents:

CFR: 23.1309, **23.1311**

AC: 23.1311

Other Guidance: ARP 4102, ARP 4105, ARP 4155

Advisory Information and Accepted Practice:

A common method of encoding information in electronic displays is through the use of symbols and icons. In MFD displays, symbols are non-verbal, graphical representations of objects and/or concepts. Typically, a symbol is chosen because of a commonly understood relationship or association with the object or concept to be represented. In MFD displays, icons and symbols should unambiguously communicate the object or idea that they represent. Whether used alone or in combination, symbols are useful in communicating information rapidly and effectively.

The meaning of a symbol or icon should remain consistent across functions and screens in an MFD. A symbol should always have the same meaning regardless of its context. For example, an inverted chevron used to represent ownship in a weather display should also be used to represent ownship in a traffic display. To minimize pilot error, common symbology for tasks that require different responses should be avoided. To facilitate interpretation, symbols that are related to each other should be aligned or near each other on the display. Symbols should also be simple in appearance. Icons and symbols are most effective when they consist of basic shapes. Fine detail tends to result in symbol confusion and misinterpretation.

Symbols should be discriminable from an average viewing distance of 29 inches, a minimum viewing distance of 10 inches, and a maximum viewing distance of 40 inches under all lighting conditions. To increase discriminability, symbols may also be varied in size, shape, and pictorial realism. However, care must be taken to ensure that symbol attributes that have strong attention-grabbing value (e.g., flashing color) are used sparingly and only when justified by the relative priority of the top-level task in relation to the user's other tasks. Icons that represent failure or emergency situations should be accompanied by a textual display.

Additional References:

Dillard, A. (1999)
Campbell, J., Carney, C., & Kantowitz, B. (1997)
Pejtersen, A. & Rasmussen, J. (1997)
RTCA (1999) DO-238A
Rubin, J> (1994)
SAE (1988) ARP 4155
Stokes, A. & Wickens, C. (1988)

2.2.3. MFD Messages, Text, and Labels

Description:
Messages and data must be clear and useful to the flight crew. Data labels, message terminology, and abbreviations must follow existing aviation conventions. Labels are needed for both displayed data and blank, to-be-filled data fields.

Evaluation Procedure:
View various MFD displays, noting the terminology and abbreviations used in messages and data labels.

Evaluation Considerations:	Yes	No	N/A
1) Are error messages clear and meaningful to the pilot? *			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

***** A bench test may also be performed to evaluate this item.

2.2.3. MFD Messages, Text, and Labels

Applicable Regulatory Documents:

CFR: 23.1301, 23.1311, 23.1541, 23.1555

AC: 23.1311-1A

Other Guidance: ARP 4102, ARP 4105, ARP 4155

Advisory Information and Accepted Practice:

MFD messages are used to convey important flight and aircraft information to the pilot. Messages should be designed to communicate new information as concisely and effectively as possible. To further this goal, message terminology should be consistent with existing flight deck conventions. Consistent terminology reduces mental workload and head-down time. In particular, special attention should be given to error messages. Error messages should avoid reference to error codes unknown to the pilot.

Abbreviations used in menus, messages, or any other display feature should be consistent with aviation conventions. For example, some traditional aviation abbreviations include ALT for altitude, A/S for airspeed, and ACFT for aircraft. The Department of Defense Military Standard 783 D (1984) gives recommended abbreviations for a large collection of terms that may be used in an aircrew station.

The appropriate units of measurement should always accompany quantitative data. All blank and filled data fields should be labeled so that data may be correctly entered and interpreted. For example, a value for feet should have a label of “ft.”. A label should be clearly adjacent to its data field, but separated by a single space. For example, a blank data field may be labeled as __ ft. Blank data fields should clearly indicate the type and format of data required. In addition to abbreviations, commonly recognized symbols may also be used to label quantitative data to improve legibility. For example, the symbol for degrees, °, can be used as a label.

Data must also be presented in a directly usable form. For example, if both feet and meters are necessary to the pilot, both values should be given by the MFD, eliminating the need to engage in a mental conversion. Another issue concerning data is overlaying functions. Alphanumeric data should be consistent in terms of font and size in functional overlays.

Additional References:

Calhoun, G. (1978)
Dillard, A. (1999)
Department of Defense (1984) MIL-STD-783D
Williges, R., Williges, B., & Fainter, R. (1988)

2.3. Information Accessibility

2.3.1. MFD Information Grouping

Description:
Information may be grouped in a variety of ways in an MFD. The information can be combined and layered or can be segregated by windows. Within a single display, various elements may be added or removed in order to aid the pilot's comprehension of the situation.

Evaluation Procedure:
Select various individual displays, overlay related displays, pull-up windows, and note how the design of the display combines and separates the information. Also note the methods available to add/remove information.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Does the pilot have the ability to remove non-essential information that may cause clutter? * For example, a map display may be simplified by temporarily removing irrelevant symbols.			
2) When the crew can select multiple sources of data or multiple modes of operation, are the sources and modes clearly identified? *			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

***** A bench test may also be performed to evaluate this item.

2.3.1. MFD Information Grouping

Applicable Regulatory Documents:

CFR: 23.771, 23.1309, 23.1301, 23.1311, **23.1523**

AC: 23.1311-1A

Other Guidance: ARP 4102

Advisory Information and Accepted Practice:

One of the more popular methods of grouping information is the layering of one function over another. Two or more functions are combined to present one information display. One of the major pitfalls of overlaying is the potential for cluttering. Information may become so densely packed that the MFD ceases to be an effective display. Dense displays are well known for increasing mental workload and head-down time. One technique of reducing display clutter is to remove or minimize non-essential display elements. For example, in some types of cockpit displays of traffic information (CDTI), only aircraft within a certain range of distance are presented at full brightness, whereas other aircraft are dimmed. Another clutter management feature in CDTIs is the option to bring-up, only when desired, aircraft ID blocks that contain speed and ID information for each aircraft. The removal or minimization of unnecessary clutter eases interpretation and minimizes head-down time.

Another issue in overlaying concerns the degree to which the displays are functionally related. For example, terrain, weather, and traffic functions are highly related. Each of these three functions is concerned with possible external obstacles and barriers in flight. These functions may be, and sometimes are, successfully overlaid in an MFD. Conceptually, overlaying their related functions make sense. However, if two functions are not related, yet displayed concurrently, they should be clearly segregated. Unrelated functions may be displayed in separate windows or separated by borders of some kind. This minimizes confusion and helps provide some structure and organization to the MFD.

Because pilots almost certainly have some differences in interaction style, they should be provided with at least some options to reconfigure the MFD to suit individual tastes and preferences. Display configurations may also change based on experience level and flight objectives. Another important aspect of information grouping is the information options available. Information sources and modes must be clearly presented on the display so that the most effective and appropriate grouping can be made by the pilot.

Additional References:

Dillard, A. (1999)
RTCA (1999)
Stokes, A. & Wickens, C. (1988)

2.3.2. MDF Changing between Functions

Description:
One aspect of MFD display sharing is changing between the functions to be displayed. Switching from one function to another may occur automatically or manually. To maintain situation awareness, this display change should be announced and the flight crew should be able to resume interrupted activities.

Evaluation Procedure:
Manually change functions and observe the changes. Note whether or not the changes are announced and the availability of controls to resume interrupted functions.

Evaluation Considerations:	Yes	No	N/A
1) When the system automatically switches between display modes, pages, or functions, is this change visually or aurally announced? *			
2) After an automatic change in the display, is the pilot able to easily and quickly restore the display to its previous state? (for example, via a dedicated "back" button) *			
3) If one function is suspended by switching to another function, is the pilot able to resume the suspended function and recover any associated data? *			

Observations and Comments:

	Pass	Pass w/ Comment	Falls Short	FAR Failure
Summary Evaluation:				

***** A bench test may also be performed to evaluate this item.

2.3.2. MDF Changing between Functions

Applicable Regulatory Documents:

CFR: 23.1311, **23.1523**

AC: 23.1311

Other Guidance: ARP 4102, ARP 4033

Advisory Information and Accepted Practice:

Because each function shares the same display space, the MFD provides an efficient means of displaying multiple functions. One aspect of display sharing is changing between the functions to be displayed. Available both manually and automatically, the ability to change functions and modes is one of the greatest advantages of the MFD. Situational awareness becomes a special consideration in cases of automated display changes. An automatic change between functions or the automatic overlay of one function on another must be announced in some form so that the pilot remains aware of the current display state. If automatic display changes are not announced, then the pilot is likely to miss the significance of the display change altogether. The form of the announcement, whether visual, aural, or both, depends on how important the information change is. Function switches typically occur in cases where a rapid response is required.

Once a display change is acknowledged, the pilot should be able to return to the previous display easily and quickly. The ability to resume an interrupted function minimizes the amount of information that the pilot must maintain in short-term memory. The pilot is allowed to return to the interrupted function almost as soon as the change occurs. Ease of changing between displays also facilitates integration and comparison across displays, further reducing demands on short-term memory. Multi-function displays also should allow the recovery of any data associated with an interrupted function. Minimizing data loss is one of the easier methods of reducing pilot workload.

Additional References:

Dillard, A. (1999)
RTCA (1999)
Stokes, A., Wickens, C., & Kite, K. (1990)
Williges, R., Williges, B., & Fainter, R. (1988)

2.4. Warning Information

2.4.1. MFD Alert Information

Description:
MFD alerts are often used to quickly direct pilot attention. Alerting signals may be visual and/or aural and may vary in priority. Priority or urgency is coded by several means, such as color, signal intensity, and signal duration. For alerting signals to be effective, they must be immediately salient and meaningful to the pilot.

Evaluation Procedure:
Note the content, duration, intensity, and prioritization of MFD alerts.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Are high priority alerts signaled both visually and aurally? *			
2) Are inconsistencies among data sources announced via an alert of some kind? *			
3) Are alerts always sequenced so that only one situation is alerted at a time? * For example, 2 high-priority events should not be alerted at the same time; the less important event should be queued with notification given to the pilot.			
4) Are visual alerts significantly brighter than the other visual displays on the instrument panel? *			
5) Does the visual alert signal flash against a steady background? *			
6) Are visual alerting signals presented as within 15 degrees to the operator's line of sight? *			
7) Is the use of color redundant with other visual and auditory coding methods for alerts? *			
8) Is the auditory alerting signal varied so that it is intermittent or changes over time? *			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

***** A bench test may also be performed to evaluate this item.

2.4.1. MFD Alert Information

Applicable Regulatory Documents:

CFR: 23.1301, **23.1309**, 23.1321, 23.1322, 23.1523

AC: 23.1311-1A

Other Guidance: ARP 4102, ARP 4102/4

Advisory Information and Accepted Practice:

Alerts are necessary to maintain situational awareness in an MFD. Alerts may serve as warnings, cautions, or advisories. Warnings require immediate pilot attention and may require an immediate response. Cautions require immediate attention and may require a rapid pilot response. Advisories require general awareness of a borderline condition. Alerts should be organized according to a prioritization schema so that the more important alerts precede, and are more salient than, the less important alerts. The highest priority alerts should be announced both visually and aurally to ensure that attention is captured.

Visual alerts may also be made more salient by having twice the brightness of the surrounding display or flashing against a steady background. They should be presented as close to the line-of-sight as possible. Aural alerts are reserved for the most important kinds of alerts, such as warnings and cautions. To counter the effects of frequency-specific hearing loss, an aural alert should consist of multiple frequencies. In addition, auditory signals should be intermittent or change over time in order to increase the chances of detection. Once an auditory signal is acknowledged and the pilot responds, the alert should turn off automatically. This feature minimizes distraction and sound clutter. Similar to non-critical pop-up windows, there should be a means to disable non-critical auditory signals.

Typically, inconsistencies or discrepancies among MFD functions are announced via an alert of some kind so that the pilot is notified of possible data errors. Significant discrepancies between similar MFD systems, such as attitude, navigation, and air data systems, and between sensor and display values may arise from equipment malfunctions or failures. In the event of a data conflict resulting from a malfunction, the pilot should be provided with the means to identify and remove the malfunctioning source from any future MFD data integration.

Alerts should be ordered so that more than one high priority event is not alerted at the same time. Alerting two or more high priority events simultaneously to the pilot reduces the effectiveness of either alert by itself and greatly increases the chances or confusion and misinterpretation. If two alerts need to be signaled, the more important alert should be presented first. However, the pilot should receive some notification that a second alert is in the queue. After there is a pilot response to the first alert, the second alert can then be announced. Prioritization ensures that each alert is presented consistently in order of importance to flight safety.

Additional References:

Boff & Lincoln (1988)
SAE ARP-5108
Stokes & Wickens (1988)

2.4.2. MFD Failures

Description:
Isolated failures both within and distinct from the MFD should be contained and their impact minimized. The MFD should be able to display primary flight information and operate in a partially functional mode. Non-MFD systems should not be influenced by MFD failures.

Evaluation Procedure:
Determine how the MFD display responds to emergency situations, function failures, and non-MFD system failures.

Evaluation Considerations:	**Yes**	**No**	**N/A**
1) Is the MFD able to operate in degraded modes, and is the user able to change to any displays that are still functional? (i.e., if one feature quits, do the others still operate?) *			
2) Are non-MFD systems that are integrated with the MFD still able to function in the event of a failure within the MFD?			
3) Is there a provision for primary flight information to be automatically and manually transferred to another functional MFD system if the primary flight display (PFD) fails?			

Observations and Comments:

	Pass	**Pass w/ Comment**	**Falls Short**	**FAR Failure**
Summary Evaluation:				

***** A bench test may also be performed to evaluate this item.

2.4.2. MFD Failures

Applicable Regulatory Documents:

CFR: **23.1309,** 23.1311

AC: 23.1311-1A

Other Guidance: ARP 4102

Advisory Information and Accepted Practice:

In addition to normal functioning, the MFD must also be properly designed for failure. In the event of isolated failures, MFD and cockpit design must ensure that any remaining functions and displays are operational, to the fullest extent possible. One failure should not snowball into a series of system failures. MFD systems are integrated with other aircraft systems. It is important that an MFD failure will not impair the performance of other, non-MFD systems. Non-MFD systems should continue to operate normally and specific MFD failures should be announced to the pilot for evaluation. Within the MFD system, failures of one or more functions should not degrade the performance of other, intact functions or operation modes. It should be possible to use a partially functioning or degraded MFD. The information essential to flight safety is available in the primary flight information (PFI), which is typically shown on the primary flight display (PFD). If there is a failure of the PFD, there should be a provision so that the PFI is automatically transferred to another MFD.

Additional References:

Dillard, A. (1999)
Stokes, A. & Wickens, C., & Kite, K. (1990)

2.5. Evaluation Summary

2.5. Evaluation Summary

Category	Page	Pass	Pass w/ Comment	Falls Short	FAR Failure
Control Placement	56				
Control Labels	58				
Control Interfaces and Methods	60				
Display Color Usage	64				
Display Symbology	66				
Message, Text, and Labels	68				
Information Grouping	72				
Changing between Functions	74				
Alert Information	78				
Failures	80				
OVERALL RATING					

Overall Observations and Comments

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[This section provides the complete references corresponding to the citations that are contained within the Advisory Information and Accepted Practices sections.]

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