Appendices

Appendix 1. Text of Proposed Advisory Material

U.S. Department
of Transportation
Federal Aviation Administration

Advisory Circular

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1. PURPOSE

This AC/AMC describes guidance for showing compliance with § 25.1302 and several other rules in § 25 that relate to the installed equipment used by the flight crew in the operation of the aircraft. In particular, this AC/AMC addresses the design and approval of installed equipment intended for the flight crewmembers' use from their normally seated positions on the flight deck. This guidance is not mandatory and does not constitute a regulation. This AC/AMC describes acceptable approaches to compliance. This AC/AMC also provides recommendations for the design and evaluation of controls, displays, system behavior, and system integration, as well as design guidance for error management.

2. BACKGROUND

Flight crews make a positive contribution to the safety of the air transportation system because of their ability to assess continuously changing conditions and situations, analyze potential actions, and make reasoned decisions. However, even well trained, qualified, healthy, alert flight crewmembers commit errors. Some of these errors may be influenced by the design of the systems and their associated flight crew interfaces even with systems and associated interfaces that are carefully designed. Although most of these errors have no significant safety consequences, or are detected and/or mitigated in the normal course of events, accident analyses show that flight crew performance and error have been identified as significant factors in a majority of accidents involving transport category airplanes. Accidents most often occur as a result of a sequence or combination of errors and safety related events (e.g., equipment failure, weather conditions). These analyses also show that the design of the aircraft flight deck and other systems can influence the performance of flight crew tasks and the occurrence and effects of some flight crew errors.

A number of regulatory requirements are in place that are intended to improve aviation safety by requiring that the flight deck and its equipment be designed to have certain capabilities and characteristics. The approval of flight deck systems with respect to design-related flight crew error has typically been addressed by invoking rules that are system specific or rules with general applicability, such as 25.1301(a), 25.771(a), and 25.1523. However, little or no guidance has been available to show how the applicant may address potential crew limitations and errors. As a result, regulation §25.1302 and this advisory material have been developed.

In many cases, showing compliance with regulatory requirements related to designing for compatibility with human capabilities and limitations is subject to a great deal of interpretation and may vary depending upon the novelty, complexity, or other factors related to system design. It is considered beneficial to provide guidance describing a structured approach for selecting and developing acceptable means of compliance to aid in standardizing certification practices.

3. SCOPE AND ASSUMPTIONS

This AC/AMC describes guidance for showing compliance with § 25.1302 and guidance related to several other rules associated with installed equipment used by the flight crew in operation including 14 CFR/CS §§ 25.771(a), 25.771(c), 25.773, 25.777(a-c), 25.1301(a), 25.1303 (CS), 25.1309(a), 25.1321, 25.1322, 25.1329, 25.1523, 25.1543(b), and 25.1555(a), and Appendix D. It should be noted that, although some guidance is provided related to these other regulations, this document does not comprehensively address means of compliance for any regulation other than 25.1302.

This document also provides recommendations for the design and evaluation of controls, displays, system behavior, and system integration as well as design guidance for error management. This material applies to flight crew interfaces and system behavior for installed systems and equipment used by the flight crew on the flight deck in the operation of the aircraft in normal and non-normal conditions. It applies to those airplane and equipment design considerations within the scope of §14 CFR/CS 25 for type certificate, amended type certificate, supplemental type certificate (STC) projects, and amended supplemental type certificate projects. It does not apply to flight crew training, qualification, or licensing requirements. Similarly, it does not apply to flight crew procedures, except as required within §14 CFR/CS 25.

This AC/AMC is not intended to provide a full roadmap for consideration of equipment design used by the flight crew related to human performance. Other requirements are already in place for specific equipment used by the flight crew related to human performance, including other paragraphs of 14 CFR Part 25, Part 121, JAR OPS 1, and other parts of the regulations associated with training and qualification of flight crew. Where guidance in other AC/AMCs is provided for specific systems, the specific guidance is assumed to have precedence if a conflict exists with guidance provided herein. References to other relevant AC/AMCs are shown in section 4. Guidance contained in section 6 details a structured approach to develop compliance with those rules relating to design compliance objectives in section 7. Section 8 describes general Means of Compliance and their applicability.

In showing compliance to the rules referenced by this AC/AMC, the applicant may assume a qualified flight crew trained in the use of the installed equipment. This means a flight crew that is allowed to fly the airplane by meeting the requirements in the operating rules for the relevant authority (in the US, the FAA). The applicant is not required to consider acts of violence, willful negligence, or non-compliance with established or published procedures, disregard of alerts or displayed information, or errors in judgment or airmanship that are not contributed to by the design. Additionally, the applicant is not required to consider skill errors associated with manual control of the airplane.

4. RELATED DOCUMENTS

The following is a list of regulations, advisory circulars, and other documents that are relevant to flight deck design and flight crew interfaces and which may be useful when reviewing this document.

4.1 Federal Aviation Regulations and Joint Aviation Regulations

The following is a list of regulations related to flight deck design and flight crew interfaces for which this document provides guidance. However, it should be noted that this document does not provide a comprehensive means of compliance for any of the regulations beyond 25.1302.

Table 4.1 Regulations for which this AC/AMC provides guidance and where guidance can be found in this document.

Rule	*General topic*	*Where guidance can be found in this AC/AMC*
§ 25.771(a)	Unreasonable concentration or fatigue	Error, 7.6. Integration, 7.7. Controls, 7.3 System Behavior, 7.5.
§ 25.771(c)	Controllable from either pilot seat	Controls, 7.3 Integration, 7.7.
§ 25.773	Pilot compartment view	Integration, 7.7.
§ 25.777(a)	Location of cockpit controls.	Controls, 7.3. Integration, 7.7.
§ 25.777(b)	Direction of movement of cockpit controls	Controls, 7.3. Integration, 7.7.
§ 25.777(c) *	Full and unrestricted movement of controls	Controls, 7.3. Integration, 7.7.

Rule	***General topic***	***Where guidance can be found in this AC/AMC***
§ 25.1301(a)	Intended function of installed systems	Error, 7.6. Integration, 7.7. Controls, 7.3. Presentation of Info., 7.4, System Behavior, 7.5.
§ 25.1302 DRAFT	Flight crew error	Error, 7.6. Integration, 7.7. Controls, 7.3. Presentation of Info., 7.4. System Behavior, 7.5.
JAR 25.1303	Flight and navigation instruments	Integration, 7.7.
§ 25.1309(a)	Intended function of required equipment under all operating conditions	Controls, 7.3. Integration, 7.7.
§ 25.1321 *	Visibility of instruments	Integration, 7.7.
§ 25.1322	Warning caution and advisory lights	Integration, 7.7.
§ 25.1329 (EASA: new FAA: draft))	Autopilot, flight director and autothrust	System Behavior, 7.5.
§ 25.1523	Minimum flight crew	Controls, 7.3. Integration, 7.7.
§ 25.1543(b)	Visibility of instrument markings	Presentation of Info., 7.4.
§ 25.1555 (a)	Control markings	Controls, 7.3.
§ 25 Appendix D	Criteria for determining minimum flight crew	Integration, 7.7.

* EASA differences (valid as of 1 October 2000 – CS 25 change 15) CS paragraph text differs from the 14 CFR paragraph.

Table 4.2 List of AC/AMCs referenced in this document:

The following is a list of advisory circulars which are referenced in this document.

AC/AMC related rule	***General topic***	***Associated Advisory Circulars***
§ 25.1309(c)	Minimizing flight crew errors that could create additional hazards.	AC 25.1309-1B (in work)
§ 25.1523	Minimum flight crew and workload.	AC 25.1523-1
§ 25.1322	Colors for warning, caution, or advisory lights.	AC 25.1322-1 (in work)
§ 25.1329 (new)	Autopilot, Flight Director, Autothrust	AC 25.1329 (new)
	Electronic Displays	AC 25-11

Note: Not all regulations associated with flight deck design and human performance are listed in the tables above. This document does not provide guidance for regulations that already have specific design requirements, such as 25.777(e) “Wing flap controls and other auxiliary lift device controls must be located on top of the pedestal, aft of the throttles, centrally or to the right of the pedestal centerline, and not less than 10 inches aft of the landing gear control.”

4.2 Related EASA CS-25 Book 2: Advisory Means of Compliance (Decision No. 2003/2/RM of the Executive Director of the Agency of 17 October 2003)

- AMC 25.11
- ACJ 25.785 (g)
- AMC 25.1309
- ACJ 25.1321 (a)
- AMC 25.1329
- ACJ 25.1543

4.3 FAA and JAA Orders and Policy

- Policy Memo ANM-99-2, Guidance for Reviewing Certification Plans to Address Human Factors for Certification of Transport Airplane Flight Decks.
- Policy Memo ANM-0103, Factors to Consider When Reviewing an Applicant’s Proposed Human Factors Methods of Compliance for Flight Deck Certification.
- FAA Notice 8110.98, Addressing human factors/pilot interface issues of complex, integrated avionics as part of the Technical Standard Order (TSO) process

4.4 Other documents

The following is a list of other documents that are relevant to flight deck design and flight crew interfaces and which may be useful when reviewing this document. However, some contain special constraints and limitations particularly those that are not aviation specific. For example, International Standard ISO 9241-4 has considerable useful guidance that is not aviation specific. Therefore, when using this document, applicants should take into account environmental factors such as the intended operational environment, turbulence, and lighting as well as cross-side reach.

- SAE ARP 4033 (Pilot-System Integration), August 1995
- SAE ARP5289, Electronic Aeronautical Symbols
- SAE ARP-4102/7, Electronic Displays
- FAA Human Factors Team report on: The Interfaces Between Flight crews and Modern Flight Deck Systems, 1996
- DOT/FAA/RD –93/5: Human Factors for Flight Deck Certification Personnel
- ICAO 8400/5. Procedures for Air Navigation Services ICAO Abbreviations and Codes. Fifth Edition, 1999
- ICAO Human Factors Training Manual: DOC 9683 – AN/950
- International Standards ISO 9241-4, Ergonomic requirements for office work with visual display terminals (VDTs)

5. DEFINITIONS AND ACRONYMS.

The following is a list of terms, abbreviations, and acronyms used throughout this advisory material and in part 25.

5.1 Abbreviations and acronyms

AC – Advisory Circular

AMC – Acceptable Means of Compliance (EASA term)

CS – Certification Specifications (EASA term)

DOT – Department of Transportation

EASA – European Aviation Safety Agency

FAA – Federal Aviation Administration

FAR – Federal Aviation Regulations

ICAO – International Civil Aviation Organization

ISO – International Standards Organization

JAA – Joint Aviation Authorities

JAR – Joint Aviation Requirements

JAR OPS – Joint Aviation Regulations (Operations)

MOC – Means of Compliance

RTCA – Radio Technical Committee for Aeronautics

SAE – Society of Automotive Engineers

STC – Supplemental Type Certificate

TAWS – Terrain Awareness Warning System

TC – Type Certificate

TCAS – Traffic Collision Avoidance System

TSO – Technical Standards Order

V/S – Vertical Speed

V1 – Speed designating go/no-go decision point on take off

VNAV – Vertical Navigation

VOR – VHF Omni Range

5.2 Definitions

The following is a list of terms and definitions used in this document.

Alert – A generic term used to describe a flight deck indication meant to attract the attention of, and identify to, the flight crew a non-normal operational or airplane system condition. Warnings, Cautions, and Advisories are considered to be alerts. (Reference definition in AC/AMC 25.1322)

Automation – The autonomous execution of a task (or tasks) by the aircraft systems initiated by a high level control action of the flight crew.

Conformity – The official verification that the flight deck/system/product is of the actual hardware/software and complies and conforms with the design documentation. Conformity of the facility is one parameter that distinguishes one means of compliance from another.

Control Device (Flight Deck Control) – Device utilized by the flight crew to transmit their desired intention(s) to the aircraft systems.

Cursor Control Device – Control device, typically used in conjunction with a graphical user interface on an electro-optical display, for interacting with virtual controls.

Design Philosophy – A high level description of human-centered design principles that guide the designer and aid in ensuring that a consistent, coherent user interface is presented to the flight crew.

Display – Device (typically visual but may be auditory or tactile) that transmits data or information from the aircraft to the flight crew.

Multifunction Control – A control device that can be used for many functions as apposed to a control device with a single dedicated function.

Task Analysis – A formal analytical method used to describe the nature and relationship of complex tasks involving a human operator.

6. METHODOLOGICAL APPROACH TO CERTIFICATION COMPLIANCE

This section describes applicant activities, communication between the applicant and the authority, and the documentation of these activities.

There are significant advantages for applicants to involve the regulatory authorities in the earliest possible phases of application and design and to reach timely agreements on potential design related human factors issues in order to reduce the risk during the certification process. The following activities typically take place during the development of a new type certification or a new flight deck system or function. These activities occur before official certification data is submitted to demonstrate compliance with the regulations. The applicant may choose to discuss or share these activities with the regulatory authorities on an information-only basis, and, where appropriate, the regulatory authorities may wish to participate in assessments that the applicant is performing with mockups, prototypes, and simulators.

A negotiation process may occur that will determine the level of involvement of the regulatory authorities in the compliance demonstrations. This is sometime called “certification credit”. Certification credit means that the authorities and the applicant have agreed, as part of the certification planning process, that a specific evaluation, analysis or assessment of a human factors issue will become part of the demonstration that the design is in compliance with the regulations. Refer to the relevant FAA documents.

Figure 1 illustrates the interaction between section 6.0, 7.0 and 8.0 of this document. These sections are used simultaneously during the certification process. Section 6.0 details the applicant activities and communication between the applicant and the authorities. Section 7 provides means of compliance on specific topics. Sections 7.2, 7.6 and 7.7 provide the applicant assistance in determining the inputs required for the scoping discussion outlines in section 6.1. Sections 7.3 through 7.5 provide the applicant assistance in determining the list of applicable regulations required for the discussions in section 6.2. Section 8 provides a list of acceptable general means of compliance used to guide the discussions for section 6.3. Section 6.4 lists the items that may be documented as a result of the above discussions.

Inputs:
- Systems, components and features
- Intended function and relation to flight crew tasks (guidance in **section 7.2**)
- Integration aspects (guidance in **section 7.7**)

Criteria: Levels of novelty, complexity, integration

Outputs:
- List of selected systems, components and features (including their intended functions and relevant flight crew tasks)

1[st] Step described in section 6.1:
Identify systems, components and features in terms of degree of novelty, complexity, and integration

Inputs:
- List of selected systems, components and features including their intended functions and relevant flight crew tasks)
- Section 7: Objectives and specific guidance for Error (7.2), Controls (7.3), Displays (7.4), System Behavior (7.5) and Integration (7.6)

Criteria: Applicability of objectives and requirements to the systems, components and features

Outputs:
- Objectives and requirements applicable to the list of selected systems, components and features
- Selected systems, components and features that require usual MoC and those that require more elaborated MoC because section 7 guidance material is not applicable

2[nd] Step described in section 6.2:
Identify how the regulations apply to the selected systems, components, and features and which aspects of the design require substantiation

Inputs:
- List of selected systems, components and design features requiring usual or more elaborated Mo
- Section 8 MoC (list, usage, limitations)

Criteria: Maturity, past certification experience, and novelty, complexity, integration

Outputs:
- List of MoC for selected design features documented in a certification plan

3[rd] Step described in section 6.3:
Select appropriate means of compliance

Section 6 - Fig. 1: Methodical approach to planning certification for design related human performance issues

6.1 Definition of scope

The following tasks will define the scope of the certification program.

In a process internal to the applicant, the flight deck controls, information and system behavior that involve flight crew interaction should be considered. The applicant should be able to explain the intended functions of the system(s), components and features. The objective is to improve understanding about how the flight crew tasks might be changed or modified as a result of the introduction of the proposed system(s), components and features. Guidance can be found in section 7.2, Intended Function and Associated Tasks.

The applicant should identify the level of integration of the new system or feature and its interaction with other flight deck systems. Specific information on integration aspects can be found in section 7.7.

The applicant should identify the safety implications of the flight deck system, new or additional controls, or information display. Section 7.6, Flight Crew Error Management, provides guidance on error detection, error recovery and error effects.

The applicant should identify the degree of design novelty. When determining degree of novelty associated with a design, the following factors should be considered:

a. Introducing new technologies that operate in new ways for either established or new flight deck designs.

b. Introducing unusual or additional operational procedures as a result of the introduction of new technologies.

c. Introducing a new way for the flight crew to interact with systems utilizing either conventional or innovative technology.

d. Introducing new uses for existing systems that change the flight crew's tasks or responsibilities.

The expected outcome is a listing of two types of features distinguished by their novelty. The first are the least novel systems, components and features that may <u>not</u> require extra scrutiny during the certification process. These features must still be shown to be compliant with the regulations, but will follow a typical certification process that may be less rigorous and may not follow the process described below. The second types of features are the more novel ones that <u>may</u> require extra scrutiny during the certification process. Demonstration of compliance for these features will follow the process documented in this section.

The applicant should discuss the two lists with the authorities and reach an agreement on the scope of flight deck controls, information and system behavior that will require extra scrutiny during the certification process.

The results of this section, the two lists, should be documented in accordance with section 6.4.

6.2 Applicable Regulations

The applicant should identify design approval objectives of the systems, components, and features for which means of demonstrating compliance must be selected. This can be accomplished in part by identifying design attributes that can adversely affect flight crew performance or pertain to avoidance and management of flight crew errors.

Specific design approval objectives for regulations involving human performance are discussed in Section 7. The applicability of each design approval objective in Section 7 will depend on the design features identified in section 6.1.

Since section 7 is a set of design objectives to comply with a subset of regulations. The applicant should also consider the applicability of the entire list of regulations provided in section 4.

The expected output is a list of regulations that will be complied with and for which design approval objectives will be scrutinized.

6.3 Select appropriate means of compliance.

After identifying what should be shown in order to demonstrate compliance, the applicant should review sections 7 and 8 for guidance on selecting the means, or multiple means, appropriate to the design.

Section 7 identifies specific means of compliance that can be used to demonstrate compliance to the regulations.

Section 8 identifies general means of compliance that have been used on many certification programs and discusses their selection, appropriate uses, and limitations. Other means may be proposed by the applicant, subject to approval by the authorities.

All of these factors should be considered together, so appropriate method(s) of compliance can be selected and agreed by the Authority.

Once the human performance issues have been identified and means of compliance have been selected and proposed to the regulatory authorities, a negotiation process can occur that will determine the level of involvement of the regulatory authorities in the compliance demonstrations. This is sometime called "certification credit". Certification credit means that the authorities and the applicant have agreed, as part of the certification planning process, that a specific evaluation, analysis or assessment of a human factors issue will become part of the demonstration that the design is in compliance with the regulations. Certification credit can be granted when data is transmitted to the authorities using standard certification processes. This data will be a part of the final record of how the applicant has complied with the rules.

The output of this step will consist of the means of compliance that will be used to show compliance to the regulations. The output will also list any certification credit efforts that will take place during the certification process.

6.4 Documentation

The applicant may document the certification process, outputs and agreements described in the previous paragraphs. The following is a summary of what may be contained in the document:

a. The new aircraft, system, control, information or feature(s)

b. The design feature(s) that is being evaluated and is the feature(s) new or novel

c. The level of integration of the new feature(s)

d. The safety implication of the new feature(s)

e. The flight crew tasks that are affected or any new tasks

f. Any new flight crew procedures

g. The specific regulations that must be complied with

h. The means of compliance (one or several) that will be used to show compliance

i. The method for transferring data to the authorities

7. DESIGN APPROVAL OBJECTIVES

After the identification of systems, components, and features of a new design that are potentially affected by the regulations, and once the degrees of novelty, complexity, and level of integration have been assessed using the initial process steps found in Section 6, the following contents of Section 7 will help identify what should be shown to demonstrate compliance.

To comply with the requirements of 14 FAR/CS 25, the design of the flight deck systems should appropriately address the foreseeable capabilities and limitations of the flight crew. To assist the applicant in complying with this overall objective, this section has been divided into subsections that provide guidance on meeting the applicable design approval objectives associated with the following topics:

a. Intended function and associated tasks

b. Controls

c. Presentation of information

d. Equipment behavior

e. Flight crew error management

f. Integration

Each sub-section covers the following two elements:

a. What the applicant should show to establish compliance with the applicable regulations. These statements express the airworthiness standard for use in complying with the applicable regulations. They are not what might otherwise be referred to as industry “best practices.” Obviously, not all criteria can or should be met by all systems. Because the nature of the guidance in this AC/AMC is broad and general, some of the guidance will conflict in certain instances. Therefore, the applicant and regulator must apply some judgment and experience in determining which guidance applies for what parts of the design and in what situations.

b. Applicable regulations, for which compliance is being shown.

As described in the Background and Scope sections of this document, flight crew error is a contributing factor in accidents. Regulation 25.1302 was developed to provide a regulatory basis, and this AC/AMC provides guidance to address design-related aspects of avoidance and management of flight crew error by taking the following approach:

a. First, by providing guidance about design characteristics that are known to reduce or avoid flight crew error and that address flight crew capabilities and limitations. Subparagraphs (a) through (c) of 25.1302 describe requirements that are intended to reduce the design contribution by assuring the provision of information and controls needed by the flight crew to perform the tasks associated with the intended function of the installed equipment, and by assuring that the controls and information are provided in a usable form. In addition, the system behavior that is operationally relevant must be understandable, predictable, and supportive of the flight crew tasks. The following discussions on intended function, controls, presentation of information, system behavior, and integration contain guidance that supports avoidance of design-induced flight crew error.

b. Second, subparagraph (d) of 14 CFR/JAR 25.1302 addresses the fact that since flight crew errors will occur, even with a well-trained and proficient flight crew operating well-designed systems, the design must support the management of those errors to avoid safety consequences. The section below on flight crew error management provides relevant guidance.

Sections 7.2 through 7.7 expand on this approach and, in combination with Sections 6 and 8, provide acceptable means of compliance to achieve these design approval objectives. Section 7.1 provides explanatory and applicability material extracted from the preamble of 25.1302 to assure that the methods of compliance match the intent of the rule.

7.1 Explanatory and Applicability Material about 25.1302

14 CFR/CS Part 25 contains regulations for the design of flight deck equipment that are system-specific (e.g., 25.777, 1321, 1329, 1543 etc.), generally applicable (e.g., 25.1301(a), 1309(c), 771(a)), and for establishing minimum flight crew in 25.1523 and Appendix D. Regulation 25.1302 augments the previously existing generally applicable rules by adding more explicit requirements for design attributes related to the avoidance and management of flight crew error. In addition, other ways to avoid and manage flight crew error are regulated through the rules (e.g., Parts 61, 91, 121, 135 etc. for FAA and JAR FCL and JAR Ops for EASA) that govern the licensing and qualification of pilots and aircraft operations. Taken together, these complementary approaches provide a high degree of safety.

This complementary approach is important, and is based upon the recognition that equipment design, training/licensing/qualification, and operations/procedures each provide a safety contribution to risk mitigation and that an appropriate balance is needed among them. In the past there have been cases where design characteristics known to contribute to flight crew error were accepted based upon the rationale that training or procedures would mitigate that risk. However, it is now known that this approach often can be inappropriate. Similarly, due to unintended consequences, it would not be appropriate to require the equipment design to provide total risk mitigation. For example, if a pilot misunderstands a controller's clearance, it does not follow that the authorities should mandate datalink or some other design solution as a Part 25 requirement. In the current regulations, some error mitigations are required of the equipment as part of the operating rule requirements (e.g., Terrain Awareness and Warning Systems), but not as part of the airworthiness requirements.

As stated, a proper balance is needed among design approval requirements in the minimum airworthiness standards embodied in Part 25 and the requirements for training/ licensing/ qualification and operations/procedures. The proposed regulation is written and scoped with the intention of achieving that appropriate balance.

The following material is extracted from the preamble of 25.1302:

Introduction. The introductory sentence of this rule states the requirement that the provisions of this paragraph apply to each item of installed equipment that is intended for the flight crew's use in operation of the aircraft from their normally seated positions on the flight deck.

"Intended for the flight crewmember's use in the operation of the aircraft from their normally seated position," means that the intended function of the installed equipment includes use by the flight crew in the operation of the aircraft; e.g., a display that provides information to enable the flight crew to navigate. The phrase "flight crewmembers" is intended to include any or all individuals comprising the minimum flight crew as determined for compliance with §25.1523. The phrase "from their normally seated position" means the flight crewmembers are seated at their normal duty stations for operating the aircraft. It is intended to limit the scope of this requirement so that it does not address systems or equipment that are not used while performing their duties in normal and non-normal conditions in the operation of the aircraft. For example, this paragraph is not intended to apply to items such as certain circuit breakers or maintenance controls intended for use by the maintenance crew (or by the flight crew when they are not operating the aircraft).

The phrase "it must be shown" means that the applicant is required to provide sufficient evidence to support compliance determinations for each of the requirements in the proposed rule. This language "must be shown" is not intended to require a showing of compliance beyond what would be required according to §21.21(b). Accordingly, the extent of demonstrations, tests or data needed to show compliance with the proposed rule is not expected to entail more extensive or onerous efforts for items that are simple or similar to previously approved equipment and installations.

The phrase "individually and in combination with other such equipment" means that the requirements of this paragraph must be met when the equipment is installed on the flight deck with other equipment and that it must not cause other equipment to be unable to comply with these requirements. For example, a display must not be designed such that it provides inconsistent or conflicting information relative to other installed equipment.

In addition, the provisions of this paragraph presume a qualified flight crew trained in the use of the installed equipment. This means that the design must meet these requirements for flight crewmembers who are allowed to fly the airplane by meeting the qualification requirements in the operating rules for the relevant authority (in the US, the FAA). If type design or supplemental type design approval is sought before a training program is accepted, the applicant should document any novel, complex, or highly integrated design features and assumptions made during design that have the potential to affect training time or flight crew procedures. The rule and associated material are written assuming that either these design features and assumptions, or knowledge of a training program (proposed or in the process of being developed) will be coordinated with the appropriate operational approval authorities when judging the adequacy of the design.

The phrase that states "the equipment be designed so that the flight crew can safely perform the tasks associated with the intended function of the equipment" applies in both normal and non-normal conditions. Tasks intended for performance under non-normal conditions are generally those prescribed by non-normal (including emergency) flight crew procedures. The phrase "safely perform the tasks" is intended to describe the safety objective that the equipment design enables the flight crew to perform the tasks with sufficient accuracy and in a timely manner, and without unduly interfering with other required tasks. The phrase "tasks associated with the intended function" is intended to characterize either tasks required to operate the equipment or tasks for which the equipment's intended function provides support.

<u>25.1302 (a)</u> This sentence requires that, for any flight deck equipment identified in the lead sentences of the proposed rule, appropriate controls must be installed and the necessary information must be provided. In addition, the controls and information displays must be sufficient to accomplish the tasks of the flight crew. This was included because a review of the existing deficiencies in the regulations revealed that it was necessary to explicitly describe that the control and information requirements of the flight crew must be met. Although this may seem obvious, it is important to be explicit, since it is not reflected in other parts of the rules.

<u>25.1302 (b)</u> This subparagraph addresses the requirements of the flight deck controls and information that are necessary and appropriate to accomplish the flight crew tasks, as determined through (a) above. The intent is to assure that the design of the control and information devices make them usable by the flight crew. In particular, this subparagraph seeks to reduce the occurrence of design-induced flight crew errors by imposing design requirements on flight deck information presentation and controls. Subparagraphs (1) through (3) specify these design requirements for different aspects of that usability.

Design requirements about information and controls are necessary to:

- Properly support the flight crew in planning their tasks,
- Make available to the flight crew appropriate, effective means to carry-out planned actions, and
- Enable the flight crew to have appropriate feedback information about the effects of their actions on the aircraft.

<u>Subparagraph (1)</u> specifically requires that the controls and information must be provided in a clear and unambiguous form, at a resolution and precision appropriate to the task. For information, "clear and unambiguous" means that it can be perceived correctly (e.g., is legible), that the information can be comprehended in the context of the flight crew task, and that it supports the flight crew's ability to carry out the action intended to support the tasks. For controls, the requirement for "clear and unambiguous" presentation means that the crew must be able to use them appropriately to achieve the intended function of the equipment without contributing to crew confusion or errors that could degrade safe operation.

The general intent is to foster the design of equipment controls whose operation is intuitive, consistent with the effects on the parameters or states they affect, and compatible with the operation of other controls on the flight deck. "Resolution and precision appropriate to the task" means that the control or information must be provided, or must operate, at a level of detail and accuracy appropriate to the accuracy required for accomplishing the task expected of the flight crew. Insufficient resolution or accuracy would mean that the flight crew could not perform the task adequately. Conversely, excessive resolution has the potential to make a task too difficult due to poor readability or the implication that a task must be accomplished more accurately than it needs to be.

<u>Subparagraph (2)</u> requires that the controls and information be accessible and usable by the flight crew in a manner consistent with the urgency, frequency, and duration of their tasks. This means, for example, that controls used more frequently or urgently must be readily accessed (e.g., take fewer steps or actions to perform the control function). Less accessible controls may be acceptable if they are needed less frequently or urgently. It also means that controls used less frequently or urgently should not interfere with controls that are used more urgently or frequently.

<u>Subparagraph (3)</u> requires that the equipment presents information so that the flight crew can be aware of the effects on the aircraft or systems that result from flight crew actions, if that awareness is required for safe operation. The intent of this requirement is to assure that flight deck equipment provides feedback to the flight crew about system or aircraft states that result from flight crew actions, so that the flight crew can detect their own errors.

This subparagraph was included to provide a regulatory basis that recognizes that new technology enables new kinds of flight crew interfaces that previous rules don't address. Specific deficiencies of existing rules are described below:

- 25.771 (a) addresses this topic for controls, but does not include criteria for information presentation.

- 25.777 (a) addresses controls, but only its location.
- 25.777(b) and 25.779 address direction of motion and actuation but do not encompass new types of controls such as cursor control devices. These rules also do not encompass the types of control interfaces that can be incorporated into displays via menus, for example, thus affecting their accessibility.
- 25.1523 and Appendix D have a different context and purpose (i.e., determining minimum crew), so they do not address these requirements in a sufficiently general way.

<u>**25.1302 (c)**</u> states that the installed equipment must be designed so that the behavior of the equipment that is operationally relevant to the flight crew's tasks is: (1) predictable and unambiguous, and (2) designed to enable the flight crew to intervene in a manner appropriate to the task (and intended function).

This rule paragraph was included because those improved flight deck technologies, involving integrated and complex information and control systems, which have increased safety and performance, have also introduced the need to ensure proper cooperation between the flight crew and those systems. Service experience has shown that flight crew confusion can result from equipment behavior (especially from automated systems) that is excessively complex or dependent upon logical states or mode transitions that are not well understood or expected by the flight crew. Such design characteristics have been determined to contribute to incidents and accidents.

The phrase "operationally-relevant behavior" is intended to convey the net effect of the equipment's system logic, controls, and displayed information upon the flight crew's awareness or perception of the system's operation that is necessary for planning actions or operating the system. This is intended to distinguish such system behavior from the functional logic within the system design, much of which the flight crew does not know or need to know and which should be transparent to them.

<u>Subparagraph (1)</u> is intended to describe that the system behavior needs to be such that a qualified flight crew can know what the system is doing and why. "Predictable and unambiguous" means that a crew can retain enough information about what the system will do under foreseeable circumstances as a result of crew action or a changing situation so that they can operate the system safely. It is necessary for this behavior to be unambiguous because crew actions may have different effects on the airplane depending on the current state of the airplane or its operational circumstances.

<u>Subparagraph (2)</u> requires that the design must be such that the flight crew will be able to take some action, or change or alter an input to the system in a manner appropriate to the task.

<u>**Subparagraph 25.1302 (d)**</u> addresses the reality that even well-trained, proficient flight crews using well-designed systems will make errors, so the equipment must be designed to enable the flight crew to manage errors that result from their interaction with the installed equipment. Errors "resulting from flight crew interaction with the equipment" means those errors in some way attributable to, or related to, the design of the controls, information, or equipment behavior (e.g., indications and controls that are complex and inconsistent with each other or other systems on the flight deck, or a procedure that is inconsistent with the design of the equipment) are considered to be within the scope of this regulatory and advisory material.

"Managing errors" means that the design of the equipment must:

a. Enable the flight crew to detect and/or recover from the errors resulting from their interaction with the equipment, or

b. Ensure that effects of such flight crew errors on the airplane functions or capabilities are evident to the flight crew and continued safe flight and landing is possible, or

c. Discourage such flight crew errors by using switch guards, interlocks, confirmation actions, or other effective means, or

d. Preclude the effects of errors through system logic, redundant, robust, or fault tolerant system design.

The requirement to manage errors applies to those errors that can be reasonably expected in service from qualified and trained flight crews. The term “reasonably expected in service” means those errors that have been seen in service with similar or comparable equipment or which can be projected to occur based upon general experience and knowledge of human performance capabilities and limitations related to the use of controls, information, or system logic of the type being assessed.

The statement “This subparagraph does not apply to skill-related errors associated with manual control of the airplane” is intended to exclude errors resulting from flight crew proficiency in control of flight path and attitude with the primary roll, pitch, yaw and thrust controls, and which are related to the design of the flight control systems. These issues are considered to be adequately addressed by existing rules such as 14 CFR 25 Sub-part B and §25.671(a).

It is not intended that the design be required to compensate for deficiencies in flight crew training or currency/recency of experience, assuming at least the minimum requirements for flight crew certification for the intended operation based on certification of flight crewmembers (per 14 CFR or JAR Ops or JAR FCL, for the US and Europe, respectively) as discussed above.

This requirement is intended to exclude management of errors as a result of decisions, acts, or omissions by the flight crew that are not in good faith. This exclusion is intended to avoid imposing requirements on the design to accommodate errors that are committed with malicious or purely contrary intent. The proposed rule is not intended to require the applicant to consider errors that are a result of acts of violence or threats of violence.

This “good faith” exclusion is also intended to avoid imposing requirements on the design to accommodate errors that are due to obvious disregard for safety by a flight crewmember. However, it is recognized that errors committed intentionally may still be in good faith and could be contributed to by design characteristics under certain circumstances; for example, a poorly designed procedure that is not compatible with the controls or information provided to the flight crew.

Requiring that errors be manageable only “to the extent practicable” is intended to address both economic and operational practicability. The intent is to avoid imposing requirements without considering the economic feasibility and commensurate safety benefit. In addition, it is intended to address operational practicability, i.e., to avoid introducing error management features into the design that would inappropriately impede flight crew actions or decisions in normal or non-normal conditions. For example, it is not intended to require so many guards or interlocks on the means to shut down an engine that the flight crew would not be able to do this reliably within the time available. Similarly, it is not intended to reduce the authority or means for the flight crew to intervene or carry out an action when it is their responsibility to do so using their best judgment in good faith.

This subparagraph was included because managing the errors that do occur as a result of flight crew interaction with the equipment (that can be reasonably expected in service) is an important safety objective. Even though the scope of applicability of this material is limited to errors for which there is a contribution from, or relationship to, design, this rule subparagraph is expected to result in design changes that will contribute to safety (such as "undo" functions in certain designs, among others).

7.2 Intended Function and Associated Tasks

To demonstrate compliance with §25.1301(a) and §25.1302, an applicant must show that the design is appropriate for its intended function. Additionally the applicant should explain the intended functions of the systems, components and features. This includes ensuring that the equipment is designed such that the flight crew can safely perform their tasks associated with the intended function, individually and in combination with other such equipment, in normal and non-normal conditions. Additionally it is important to understand how flight crew tasks might be changed or modified as a result of the introduction of the proposed systems, components and features. The applicant’s statement of intended function must be sufficiently specific and detailed for the Authority to be able to evaluate if the system is appropriate for the intended function(s) and the associated pilot tasks. This is particularly important for systems with a flight crew interface, as the Authority must evaluate the intended function from the pilot’s perspective as well as from a systems perspective. For example, a statement that a new display system is intended to “enhance situation awareness” must be further substantiated, as a wide variety of different displays (e.g., terrain awareness, vertical profile, and even the primary flight displays) enhance situation awareness in different ways. Thus, it is necessary to provide a greater level of detail to identify the specific aspect(s) of situation awareness that are to be enhanced and show how the design supports those aspects.

It is recommended that intended function(s) and associated task(s) be described for the system, as well as for individual features or functions of that system. It is acceptable for a system to have multiple intended functions, provided each is documented and that all information depicted or indicated to the flight crew support one or more of the documented intended functions.

The questions below are intended to provide guidance in determining compliance with 25.1301 and 25.1302 with respect to the applicant's statement of intended function. As with determining compliance with any regulation, the Authority will make the determination of whether the statement of intended function is sufficiently specific and detailed to be able to evaluate compliance. A formal task analysis is not required. Additionally, it should be noted that new and novel features may require a greater level of detail, while previously approved systems and features typically require less.

The following questions may be used to evaluate whether the statement of intended function(s) and associated task(s) are sufficiently specific and detailed:

a. Does each feature and function have a stated intended function? Are there one or more tasks associated with this feature/function? Is this task (or tasks) described?

b. What assessments, decisions, or actions are the flight crew members intended to make based on the system?

c. What other information is assumed to be used in combination with the system?

d. What is the assumed operational environment in which the equipment will be used (e.g., the pilots tasks and operations within the flight deck, phase of flight and flight procedures)?

e. If the flight deck or system is designed with a subset of pilots in mind, what are the assumptions made about those pilots (e.g., special consideration to accommodate pilot heights beyond those required by 25.777(c), unique cultural experiences, language, training, etc.)?

f. What impact will the design or use of this system have on other flight deck systems?

The method(s) of compliance must be adequate to enable the Authority to determine the following:

a. Are the controls and information adequate to support the intended functions and associated tasks?

b. Is the statement of intended function detailed enough to enable an evaluation of compliance with §25.1301?

c. Are the precision, resolution, integrity, reliability, timeliness, and update rate of the information matched appropriately to the task(s) associated with the intended function?

d. Does the system provide awareness to the flight crew, if required for safe operation, of the effects resulting from flight crew actions on the aircraft or systems?

e. Does the use of the system impair the flight crew's ability to use other systems? Does the system design or use impair the intended function of other systems or equipment?

7.2.1 Example of Intended Function Considerations for Controls

The following is an example of items to be considered when demonstrating compliance to §25.1301 and §25.1302 for controls. As discussed above, the intended function or purpose and individual features of each control should be identified, defined, and related to flight crew tasks so that functionality can be evaluated.

Intended function of a control should be defined and documented as part of a system functional description at the following levels, as applicable:

a. System response to control input (e.g., direction, length and restrictions of travel, sensitivity)

b. Control method (graphical display of controls and selections, pop-up elements, conditional function requiring separate arming action)

c. Control hierarchy (when several control methods are available or when manual and automatic features are available)

d. Integration with displays and other controls

e. Normal control modes (auto, manual, standby, etc.)

f. Reversion, degraded, and failure modes

7.3 Controls

7.3.1 Introduction

To comply with 25.1302, the design of flight deck controls must adequately address the following aspects: clear and unambiguous presentation of control related information, accessibility, usability, the adequacy of feedback (including clear and unambiguous indication when crew input is not accepted or followed by the system), and design of controls for error management. This sub-section provides design approval objectives for requirements found in 25.771(a), 25.777(a), 25.777(b), 25.1301(a), 25.1301(b), 25.1302, 25.1543(b), 25.1555(a).

For the purposes of this AC/AMC, controls are defined as devices which the flight crew manipulates in order to operate, configure, and manage the airplane and its flight controls, systems, and other equipment. This may include equipment in the flight deck such as control panels, cursor control devices, and keypads but also includes graphical user interfaces for control such as pop-up windows and pull-down menus that provide control functions.

Controls can take the form of (for example):

a. Handles

b. Buttons

c. Switches/knobs

d. Alphanumeric keyboards

e. Cursor control devices

f. Touch screens

g. Voice controls

7.3.2 Clear and Unambiguous Presentation of Control Related Information

7.3.2.1 Distinguishable and Predictable Controls [§25.1301(a), § 25.1302]

Each flight crew member should be able to identify and select the current function of the control with speed and accuracy appropriate for the task. The function of a control should be readily apparent such that little or no familiarization is required. The consequences of control activation should be evaluated to be predictable and obvious to each flight crewmember. This includes the control of multiple displays with a single device and shared display areas that the flight crewmembers access with individual controls. Some ways in which controls can be made distinguishable or predictable are via differences in form, color, location, and/or labeling. Color coding is usually not sufficient as a sole distinguishing feature. This applies to physical controls as well as controls that are part of a graphical user interface.

7.3.2.2 Labeling [§25.1301(b), § 25.1543(b), §25.1555(a)]

For general marking of controls see §25.1555(a). Labels should be readable from the crewmember’s normally seated position in all lighting and environmental conditions. If a control performs more than one function, labeling should include all intended functions unless the function of the control is obvious. Labels of graphical controls accessed via a cursor control device such as a trackball should be included on the graphical display. In the case of menus that lead to additional choices, the menu label should be meaningful given the choices to which it will give access.

Labeling can be accomplished by means of text or icons. Text and icons should be shown to be distinct and meaningful for the function that they label. Standard and/or non-ambiguous abbreviations, nomenclature, or icons consistent within a function and across the flight deck should be used. For example, ICAO 8400 provides standard abbreviations and is one possible standard that could be applied to the flight deck.

Hidden functions (such as clicking on empty space on a display to make something happen) may be acceptable if alternate means are available for accessing the function. However, the design should still be evaluated for ease of use and crew understanding.

When using icons instead of text labeling, it should be shown that only brief exposure to the icon is required in order for the flight crew to determine the function and method of operation of a control. Based on design experience, the following guidelines for icons have been shown to lead to designs that are usable:

a. Icons should be analogous to the object it represents, or

b. Icons should be in general use in aviation and well known to flight crews, or

c. Icons should be based on established standards, when they exist, and conventional meanings.

In all cases, use of icons in lieu of text should be shown to be at least equivalent in terms of speed and error rate to text labels or it should be shown that the increased error rate or task times have no significant implications for safety, flight crewmember confusion, or flight crew workload.

7.3.2.3 Interaction of Multiple Controls [§25.1302]

If multiple controls for the flight crew are provided for a function, it should be shown that there is sufficient information to provide the flight crew awareness of which control is currently functioning (e.g., which flight crewmember's input has priority when two cursor control devices can access the same display). Caution should be used when dual controls can affect the same parameter simultaneously.

7.3.3 Accessibility of controls [§25.777(a), §25.1302]

It should be shown that each flight crewmember in the minimum flight crew, as defined by 25.1523, has access to and can operate all necessary controls. Accessibility is one factor in determining whether controls support the intended function of the equipment used by the flight crew. Any control required for flight crewmember operation in the event of incapacitation of other flight crewmembers (in both normal and non-normal conditions) should be shown to be viewable, reachable, and operable by flight crewmembers with the stature as specified in 25.777(c), from the seated position with shoulder restraints on (if shoulder restraints are lockable, this may be shown with shoulder restraints unlocked).

Each flight deck control should provide for full and unrestricted movement without interference from other controls, equipment, or structure in the flight deck.

The layering of information, such as by the use of menus or multiple displays, should not hinder the flight crew in identifying the location of the desired control. Accessibility should be shown in conditions of system failures (including crew incapacitation) and Minimum Equipment List dispatch.

Control position and direction of motion should be oriented from the vantage point of the flight crewmember, and control/display compatibility should be maintained from that regard. For example, a control on an overhead panel requires movement of the flight crewmember's head backwards and orientation of the control movement should take this into consideration.

7.3.4 Usability

7.3.4.1 Environmental issues with controls [§ 25.1301(a), § 25.1302]

Turbulence or vibrations and extremes in lighting levels should not prevent the crew from performing all the tasks at an acceptable level of performance and workload. If the use of gloves is anticipated for cold weather operations, the design should account for the effect of their use on the precision and size of the controls. The sensitivity of controls should be such as to afford precision sufficient to perform the tasks even in adverse environments as defined for the aircraft's operational envelope. Analysis of environmental issues as a means of compliance (see 8.3.3) is necessary but not sufficient for new control types or technologies or for novel use of controls that are themselves not new or novel.

Controls required to regain aircraft or system control and controls required to continue to operate the airplane in a safe manner should be shown to be usable in conditions such as dense smoke in the flight deck or severe vibrations (fan blade loss; see AC 25-24 for definition of sustained engine imbalance).

7.3.4.2 Control-display compatibility [§ 25.777(b)]

The relationship and interaction between a control and its display must be readily apparent, understandable, and logical. In many instances a control input is required in response to information on a display or is needed to change a parameter setting on a display. For example, when using a rotary knob that has no obvious "increase" or "decrease" function, the control motion should be assessed with regards to flight crew expectations and its consistency with other controls in the flight deck. A thorough evaluation of the implementation regarding its susceptibility to entry errors at the appropriate level of simulation may be necessary. SAE ARP 4102, section 5.3, is an acceptable means of compliance for controls utilized in flight deck equipment.

When a control is used to move an actuator through its range of travel, feedback of the actuator's position within its range should be provided within the time required for the relevant task (e.g., trim system positions, autothrottle target speed, and various systems valves).

Dedicated display controls should be mounted as close as possible to the display or function being controlled. It is generally preferable to locate controls immediately below a display because in many cases mounting controls immediately above a display will cause the flight crewmember's hand to obscure viewing of the display when operating controls. However, controls on the bezel of multifunction displays have been found to be acceptable.

Spatial separation between a control and its display may be necessary, as is the case with a system's control located with others for that same system, or as one of several controls on a panel dedicated to controls for that multifunction display. Because large spatial separation between a control and the display can result in usability problems, particularly if a control is widely separated from the display, it should be shown that the control is usable (e.g., error rate and access time) for the task.

In general, blocking visibility of information with controls should be avoided. If range of control movement temporarily blocks visibility of information, it should be shown that this information is either not necessary at that time or is available elsewhere.

Annunciations/labels on electronic displays should be identical to labels on the related switches and buttons located elsewhere in the flight deck. If display labels are not identical to related controls, then it must be shown that flight crew members can quickly, easily, and accurately identify associated controls.

7.3.5 Adequacy of Feedback [§25.771(a), § 25.1301(a), § 25.1302)]

In order to provide awareness to the flight crew of the effects of their actions, feedback for control inputs is necessary. Each control should provide feedback to the crewmember for menu selections, data entries, control actions, or other inputs. This feedback might be visual, audible, or tactile. Feedback, of whatever form, should be provided to inform the crew that a control has been activated (commanded state/value), that the function is in process (given an extended processing time), and/or that the action associated with the control has been initiated (actual state/value if different from the commanded state). The type, length of display, and appropriateness of feedback will depend upon the crew's task and the specific information required for successful operation. For example, switch position alone is insufficient if feedback of actual system response or the state of the system as a result of an action is required.

Tactile feedback is valuable for controls that may be used while looking outside or at unrelated displays. Keypads should provide tactile feedback for any key depression. In cases when this is omitted, it should be replaced with appropriate visual or other feedback to show that the system has received the inputs and is responding as expected.

Visual feedback of varying forms is useful not only for knob, switch, and pushbutton position, but also for graphical control methods such as pull-down menus and pop-up windows. When interacting with a graphical control, the user should be given positive indication that a hierarchical menu item has been selected, a graphical button has been activated, or other input has been accepted.

Feedback in all forms should be shown to be obvious and unambiguous to the flight crew in performance of the tasks associated with the intended function of the equipment.

7.3.6 Controls and Error Mitigation [§ 25.1302]

It should be shown that the controls enable the flight crew to meet performance requirements and manage errors. The following control features are acceptable means to enable the flight crew to manage errors:

a. Arrangement taking into consideration flight deck tasks and the sequence of controls required to perform that task in order to facilitate correct flight crew actions, for example, arranging controls used in pre-flight setup and non-normal procedures to result in a simplified checklist flow.

b. Protection against inadvertent operation, related to the criticality of the function, by the use of covers, barriers, or other physical impediments such as multiple sequential motion provisions (e.g., depress before rotating), or requiring depression of the selection/actuation button or touchscreen for a specific length of time.

c. Provision of interlocking controls by either software logic, or physical or electrical means to minimize erroneous activation for controls intended only for use during specific flight phases (e.g., thrust reversers or propeller pitch for ground use).

d. Employment of logic for error detection and recovery to prevent erroneous data entry whenever possible for data entry keyboards, touch screens, cursor controls and similar input devices.

e. Indications of control mode, including both control state (on/off, auto/manual) and progress (e.g., armed/capture/track or hold), and their locations for ease of interpretation and error avoidance in normal and non-normal situations.

f. Provision of easily invoked control input recovery, for example, an “undo” capability that erases changes just made by the flight crew member and restores the current display to its previous state (particularly for data entry or menu navigation).

The applicant should show how errors can be managed for controls that do not incorporate one or more of these features (see Section 7.6 Flight Crew Error Management).

7.4 Presentation of Information

7.4.1 Introduction.

Presentation of information to the flight crew can be visual (e.g., on an LCD) and auditory (e.g., a “talking” checklist). Information presentation on the integrated flight deck, regardless of the medium used, should adequately address clear and unambiguous presentation of information, accessibility of information, and usability. For visual displays, this AC/AMC addresses mainly display format issues and not display hardware characteristics. This sub-section provides design approval objectives for requirements found in 25.1301(a), 25.1301(b), 25.1302, and 25.1543(b). In the event of a conflict between this document and AC/AMC 25-11 regarding guidance on specific electronic visual display functions, AC/AMC 25-11 takes precedence.

7.4.2 Clear and Unambiguous Presentation of Information

7.4.2.1 Qualitative and quantitative display formats [§25.1301(a), §25.1302]

Display formats should be shown to include the type of information that the flight crew requires for the task (e.g., text message, numerical value, rate, and state information), specifically with regard to the speed and precision of reading required. Rate information gives the flight crew an indication of the rate of change in the value of a certain parameter. State information conveys information concerning specific values at a given point in time.

If the sole means of detecting non-normal values is by flight crew monitoring of the values presented on the display, qualitative display formats should be employed as they better convey rate and trend information. In cases where this is not practical, the applicant must show that the flight crew can perform the tasks for which the information is used. Quantitative presentation of information is better for tasks requiring precise values.

Digital readouts or present value indices incorporated into qualitative displays should not make the scale markings or graduations unusable as they pass the present value index.

7.4.2.2 Consistency [§25.1302]

Where similar information is presented in multiple locations or modes (e.g., visual, auditory), consistent presentation of information is desirable. Consistency within the system in information presentation tends to minimize flight crew error. If information presentation cannot be made consistent within the flight deck it should be shown that differences do not increase error rate or tasks times leading to significant safety, flight crewmember confusion, or flight crew workload implications.

7.4.2.3 Characters, fonts, lines and scale markings [§25.1301(b), § 25.1543(b)]

Display format features such as fonts, symbols, icons and markings should be visible and legible with normal head movement by the applicable crew members seated at their stations. In some cases, cross flight deck readability may be required such as in the cases of display failure or cross checking flight instruments. Readability must be maintained in sunlight viewing conditions (per 25.773(a)) and should also be maintained in other adverse conditions such as vibration (as defined in AC 25-24). Figures and letters should subtend not less than the vertical angles defined in SAE ARP 4102-7 at the design eye position of the flight crewmember who normally uses the information.

7.4.2.4 Color [§ 25.1302]

The use of many different colors to convey meaning on displays should be avoided; however the judicious use of color can be very effective in minimizing display interpretation workload and response time. Color can be used to group logical electronic display functions or data types. A common color philosophy across the flight deck is desirable, although deviations may be approved with acceptable justification. Applicants should show that the chosen color set is not susceptible to confusion or misinterpretation due to differences in color usage between displays. Improper color coding increases response times for display item recognition and selection, and increases the likelihood of errors in situations where response rate demands exceed response accuracy demands. The extensive use of the colors red and amber for other than alerting functions or potentially unsafe conditions is discouraged in order to prevent diminishing the attention-getting characteristics of true warnings and cautions.

The use of color as the sole means of presenting information is discouraged but may be acceptable given the criticality of the information in relation to the task. Color, when used for task essential information, should be redundant to other coding methods such as texture or luminance differences. AC/AMC 25-11 contains recommended color sets for specific display features.

It should be shown that layering information on a display does not add to confusion and clutter as a result of the color standards and symbols used. Reliance on a flight crewmember to manually de-clutter such displays should also be avoided.

7.4.2.5 Symbology, Text, and Auditory Messages [§25.1302]

Many elements of electronic display formats can be presented based on established standards and conventional meanings. For example, ICAO 8400 provides standard abbreviations and is one standard that could be applied to flight deck text. SAE ARP 4102-7, Appendix A-C and SAE ARP 5289 are acceptable standards for avionic display symbology.

The position of a message or symbol within a display also conveys meaning to the flight crewmember. Without the consistent or repeatable location of a symbol in a specific area of the electronic display, interpretation errors and response times may increase. Careful attention should be given to the symbol priority (priority of displaying one symbol overlaying another symbol by editing out the secondary symbol) to assure that higher priority symbols remain viewable.

New symbols (a new design or a new symbol for a function which historically had an associated symbol) should be tested for flight crew comprehension, distinguishability, and retention.

Display text and auditory messages should be shown to be distinct and meaningful for the information presented. Messages should be assessed for whether they convey the meaning intended. Standard and/or non-ambiguous abbreviations and nomenclature consistent within a function and across the flight deck should be used.

7.4.3 Accessibility and Usability of Information

7.4.3.1 Accessibility of information [§ 25.1302]

Some information may not be necessary during all phases of flight. It should be shown that all necessary information for the phase of flight is manageable (configurable and accessible) by the flight crew on the dedicated and multifunction displays. Any information that is required for continued safe flight and landing should be shown to be accessible in the relevant degraded display modes following failures as defined by 25.1309. An assessment should be made of what information is necessary in those conditions, and the ability to simultaneously display all necessary information should be shown. Additionally, it should be shown that supplemental information does not displace or otherwise interfere with required information.

Analysis as the sole means of compliance is not sufficient for new or novel display management schemes. Simulation of typical operational scenarios should be used to validate the ability of the flight crew to manage the available information.

7.4.3.2 Clutter [§ 25.1302]

Clutter is the presentation of information that is distracting from the flight crewmember's primary task. Visual or auditory clutter is undesirable. Information should be presented simply and in a well-ordered way in order to reduce interpretation time. It should be shown that an information presentation (whether visual or auditory) presents the information the flight crewmember actually requires in order to perform the task at hand. The amount of information that needs to be presented at any point in time can be limited at the discretion of the flight crew (e.g., the most important information can be displayed all the time, and less important information can be displayed upon a user’s request). When flight crew selection of additional information is allowed, the basic display modes should remain uncluttered.

Automatic de-selection of data to enhance the flight crewmember’s performance in certain emergency conditions should be shown to provide the information that the flight crewmember requires, because automatically de-cluttering display options can hide needed information from the flight crewmember. Use of part-time displays depends not only on information de-clutter goals but also on display availability and criticality. Therefore, when designing such features, AC/AMC25-11 should be followed.

Because of the transient nature of auditory information presentation, care should be taken to avoid the potential for competing auditory presentations that may conflict with each other and hinder interpretation. Prioritization and timing may be useful to avoid this potential problem.

Information should be prioritized in accordance with the criticality of task; lower priority information should not mask higher priority information and higher priority information should be available, easily discernable, and usable. This does not imply that the display format needs to change based on phase of flight.

7.4.3.3 System response to control input [§25.1302]

Long or variable response times between control input and system response can adversely affect usability of a system. Response to control input such as setting values, displaying parameters, or moving a cursor symbol on a graphical display should be shown to be fast enough to allow the flight crew to complete the task to an acceptable level of performance. For actions requiring noticeable system processing time, an indication should be provided that the system response is pending.

7.5 System Behavior

7.5.1 Introduction

This section addresses the system behavior of installed equipment that is used on the flight deck. For the purpose of this section, systems are defined as hardware or software that performs a function or set of functions that the flight crewmembers need or use to accomplish their assigned tasks. Flight crew task demands vary depending on the characteristics of the system design. Systems differ in their responses to relevant flight crew input. The response can be direct and unique as in mechanical systems. The response can also vary as a function of an intervening subsystem (such as hydraulics or electrics). Some systems even automatically vary their response to capture or maintain a desired aircraft or system state.

As described in Section 7.1, paragraph (c) of 14 CFR 25.1302 states that the installed equipment must be designed so that the behavior of the equipment that is operationally relevant to the flight crew's tasks is: (1) predictable and unambiguous, and (2) designed to enable the flight crew to intervene in a manner appropriate to the task (and intended function).

Subparagraph (1) is intended to describe that the system behavior needs to be such that a qualified flight crew can know what the system is doing and why. "Predictable and unambiguous" means that a crew can retain enough information about what the system will do under foreseeable circumstances as a result of crew action or a changing situation so that they can operate the system safely. This is intended to distinguish such system behavior from the functional logic within the system design, much of which the flight crew does not know or need to know.

Subparagraph (2) recognizes that if flight crew intervention is part of the intended function of the system the crewmember may need to take some action, or change an input to the system, and therefore the system must be designed accordingly.

Improved technologies, which have increased safety and performance, have also introduced the need to ensure proper cooperation between the flight crew and the integrated, complex information and control systems. If system behavior is not understood or expected by the flight crew, confusion may result. As system behavior depends on the functions allocated to it and the allocation of such functions also directly affects flight crew tasks, both should be considered in close combination.

Since a system can be automated, system behavior also includes automated system behavior. For the purposes of this section, 'automated systems' are defined as hardware or software that performs a function, or set of functions, that the flight crew could perform but that is performed by the automated system under control or supervision of the flight crew. Such systems still involve human tasks and require crew attention for effective and safe performance. Examples include the FMS, electrical system controllers, and fuel system controllers. Alternatively, systems that are designed to operate autonomously, in the sense that they require very limited or no human interactions, are referred to as 'automatic systems'. Such systems are switched 'on' or 'off 'or run automatically and are not covered in this section. Examples include Fly-By-Wire, FADEC, and Yaw Dampers. Detailed specific guidance for automatic systems can be found in relevant parts of 14 CFR/CS 25.

Service experience has shown that flight crew confusion can result from automated system behavior that is excessively complex or dependent on logical states, or mode transitions that are not understood or expected by the flight crew. Such design characteristics have been determined to contribute to incidents and accidents.

This sub-section provides guidance material for showing compliance with these design approval objectives for requirements found in 25.1302(c), rules 25.1301 (a), 25.1309 (c) or any other relevant parts of 14 CFR/CS 25.

7.5.2 System Function Allocation

As system behavior depends on the functions allocated to it and allocation of such functions also directly affects the flight crew tasks, both should be considered in close combination. The result of a system functional allocation is a description of system functions and flight crew tasks allocated to either the system, the human, or a combination thereof. It is recommended that functional allocation be documented as part of the design development activities, and that the allocation be applied in a manner that is consistent with the relevant flight deck design philosophy.

As a design approval objective the applicant should show that functions were allocated in such a way that:

a. The flight crew can be expected to complete their allocated tasks successfully in both normal and non-normal operational conditions, within the bounds of acceptable workload and without inducing undue concentration and fatigue (see FAR 25.1523 for workload evaluation);

b. Flight crew interaction with the system enables them to understand the situation as assumed per the design assumptions, and enables timely detection of failures and crew intervention if applicable;

c. Task sharing and the distribution of tasks between the flight crew members during normal and non-normal operations is considered.

7.5.3 System Functional Behavior

The functional logic of the system is manifested in its behavior as experienced by the flight crew. The system's behavior results from the interaction between the flight crew and the automated system and is determined by:

a. The system's functions and the logic that governs its operation; and

b. The user interface, which consists of the controls and information displays that communicate the flight crew's inputs to the system and provide feedback on system behavior to the crew.

This distinction is crucial for designing automated systems appropriately because designers may underestimate the undesirable impact on crew performance that can result from the functional logic governing system behavior. Examples of such difficulties for the flight crew are:

a. Complexity of the interface for both inputs (entering data) and outputs;

b. Understanding and anticipating mode selections and transitions; and

c. Understanding and anticipating system intentions and behaviors.

As a design approval objective the applicant should describe the relationship between operation of the system and how it is exhibited on the flight deck in relation to crew tasks. In addition the applicant should show that the system's functional behavior is designed so that:

a. It is predictable, unambiguous, and consistent from a flight crew perspective; and

b. It enables the flight crew to intervene in a manner appropriate to the task; and

c. The crew can maintain awareness and understanding of system behavior in a timely manner.

7.5.4 Controls for Automated Systems

Automated systems can perform various tasks as selected by the crew and performed under supervision of the crew. Controls should be provided for managing the functionalities of such a system or set of systems. The design of such ("automation specific") controls should enable the crew to:

a. Safely prepare the system for the task to be executed or the subsequent task to be executed. Preparation of a new task (e.g., new flight trajectory) should not interfere, or be confused with, the task being executed by the automated system.

b. Activate the appropriate system function without confusion about what is being controlled, in accordance with crew expectations (e.g., there should not be confusion when using a vertical speed selector which could set either vertical speed or flight path angle).

c. Manually intervene in any system function, as required by operational conditions, or to revert to manual control (e.g., loss of system functionality, system abnormalities, or failure conditions).

7.5.5 Displays for Automated Systems

Automated systems can perform various tasks with minimal crew interventions, but under the supervision of the flight crew. To ensure effective supervision and maintain crew awareness on system state and system "intention" (future states) the displays should provide salient feedback on:

a. Entries made by the crew into the system so that the crew can detect and correct errors.

b. Present state of the automated system or mode of operation. (What is it trying to do?)

c. Actions taken by the system to achieve or maintain a desired state. (What is it doing?)

d. Future states scheduled by the automation. (What is it doing next?)

e. Transitions between system states. (What is it going to do?)

The applicant should consider the following aspects of automated system design:

a. Indications of commanded and actual values enable the flight crew to determine whether the automated systems will perform in accordance with their expectations;

b. If the automated system nears its operational authority or is operating abnormally for the conditions, or is unable to perform at the selected level, it will inform the flight crew, as appropriate for the task;

c. Support of crew coordination and cooperation by ensuring shared awareness of system status and crew inputs to the system; and

d. Enabling the flight crew to review and confirm the accuracy of commands constructed before being activated. This is particularly important for automated systems as they can require complex input tasks.

7.6 Flight Crew Error Management

7.6.1 Showing Compliance with 25.1302(d)

It is important to recognize that flight crews will make errors, even when well trained, experienced and rested individuals are using well-designed systems. Therefore, §25.1302(d) requires that "To the extent practicable, the installed equipment must enable the flight crew to manage errors resulting from flight crew interaction with the equipment that can be reasonably expected in service, assuming flight crews acting in good faith. This subparagraph does not apply to skill-related errors associated with manual control of the airplane."

To comply with §25.1302(d) the design should:

a. Enable the flight crew to detect (see 7.6.2), and/or recover from the errors (see 7.6.3); or

b. Ensure that effects of flight crew errors on the airplane functions or capabilities are evident to the flight crew and continued safe flight and landing is possible (see 7.6.4); or

c. Discourage flight crew errors by using switch guards, interlocks, confirmation actions, or similar means, or preclude the effects of errors through system logic, redundant, robust, or fault tolerant system design (see 7.6.5).

These objectives:

a. Are, in a general sense, in a preferred order. However, any of the three are acceptable methods of compliance, subject to the further details in this section and the specific design characteristics.

b. Recognize and assume that flight crew errors cannot be entirely prevented, and that no validated methods exist to reliably predict either their probability or all the sequences of events with which they may be associated.

c. Call for means of compliance that are methodical and complementary to, and separate and distinct from, airplane system analysis methods such as system safety assessments.

Compliance with §25.1302(d) is not intended to require consideration of errors that are a result of acts of violence or threat of violence. Additionally, the rule is intended to require consideration of only those errors that are related to the design.

Errors that do have a design-related component (e.g., a procedure that is inconsistent with the design of the equipment, or indications and controls that are complex and inconsistent with each other or other systems on the flight deck) are considered to be within the scope of this regulatory and advisory material.

When demonstrating compliance, the applicant should evaluate flight crew tasks in both normal and non-normal conditions, considering that many of the same design characteristics are relevant in either case. For example, under non-normal conditions, the monitoring, communication, navigation, and flying tasks required for normal conditions are generally still present (although they may be more difficult in some non-normal conditions), so tasks associated with the non-normal conditions should be considered as additive. Therefore, the applicant should not expect the errors considered to be different than those in normal conditions, but any evaluation should account for the change in expected tasks.

To show compliance with 25.1302(d), an applicant may employ any of the general types of methods of compliance discussed in Section 8, singly or in combination, consistent with an approved certification plan as discussed in Section 6, and accounting for the objectives above and the considerations described below. When using some of these methods, it may be helpful for some applicants to refer to other references relating to understanding error occurrence. Here is a brief summary of those methods and how they can be applied to address flight crew error considerations:

> Statement of Similarity (section 8.3.1): A statement of similarity may be used to substantiate that the design has sufficient certification precedent to conclude that the ability of the flight crew to manage errors is not significantly changed. Data from service experience may also be used to identify errors known to commonly occur for similar crew interfaces or system behavior. As part of showing the applicant should identify steps taken in the new design to avoid or mitigate similar errors.
>
> Design Descriptions (section 8.3.2): Design descriptions and rationale may be structured to show how various types of errors are considered in the design, and addressed, mitigated or managed. A description of how the design adheres to an established and valid design philosophy can also be used as a means of substantiating that the design enables the flight crew to manage errors.
>
> Calculation and Engineering Analysis (section 8.3.3): As one possible means of showing compliance with 25.1302(d), an applicant may document means of error management through analysis of controls, indications, system behavior, and related flight crew tasks in conjunction with an understanding of potential error opportunities and the means available for the flight crew to manage the errors. Note that in most cases it is not considered to be feasible to predict the probability of flight crew errors with sufficient validity or precision. If an applicant chooses to use a quantitative approach, the validity of the approach should be established.
>
> Evaluations, Demonstrations, and Tests (section 8.3.4-6): For compliance purposes, evaluations are intended to identify error possibilities that may be considered in design or training for mitigation. In any case, the objectives and assumptions for the scenarios should be clearly stated before running the evaluations, demonstrations, or tests so that any discrepancy with those expectations can be discussed and explained in the analysis of the results.

As discussed further in Section 8, appropriate scenarios should be used in these evaluations, demonstrations, or tests that reflect the intended function and tasks, including use of the equipment in normal and non-normal conditions, and the scenarios should be designed to consider flight crew error. If inappropriate scenarios are used or important conditions are not considered, incorrect conclusions can result. For example, if no errors occur during an evaluation it may mean only that the scenarios are too simple. On the other hand, if some errors do occur, it may either mean that the design, procedures, or training should be modified, that the scenarios are unrealistically challenging, or that insufficient training occurred prior to the evaluation. In such evaluations it is not considered feasible to establish criteria for error frequency.

7.6.2 Error Detection

The equipment should be designed to provide information so that the flight crew can become aware of an error or a system/aircraft state that results from a system action. The applicant should show that this information is available to the flight crew, adequately detectable, and clearly related to the error in order to enable recovery in a timely manner.

Information for error detection may take three basic forms:

a. Indications provided to the flight crew during normal monitoring tasks (e.g., incorrect knob used, resulting in an unintended heading change that is detected through the display of target values; or presentation of a temporary flight plan for flight crew review before accepting it).

   Indications on instruments in the primary field of view that are used during normal operation may be adequate if the indications themselves contain information used on a regular basis and are provided in a readily accessible form. These may include mode annunciations and normal aircraft state information such as altitude or heading. Other locations for the information may be appropriate depending on the flight crew's tasks; e.g., on the Control-Display Unit when the task involves dealing with a flight plan. Section 7.4, Presentation of Information, contains additional guidance to determine whether the information is adequately detectable.

b. Crew indications that provide information of an error or a resulting airplane system condition (e.g., an alert to the flight crew about the system state that results from accidentally shutting down an hydraulic pump). Note that if the indication is an alert, it is related to the resulting system state, not necessarily directly to the error itself.

   The existence of a crew alert that occurs in response to a flight crew error may be sufficient to establish that information exists and is adequately detectable, if the alert directly and appropriately relates to the error. Definitions of alert levels in §25.1322 are sufficient to establish that the urgency of the alert is appropriate. The content of the indication providing information resulting from an error should directly relate to the error; indications for indirect effects of an error may lead the crew to believe there may be non-error causes for the annunciated condition.

c. "Global" alerts that cover a multitude of possible errors by annunciating external hazards or airplane envelope or operational conditions. Examples include monitoring systems such as TAWS and TCAS (e.g., a TAWS alert that results from turning the wrong direction in a holding pattern in mountainous terrain).

Consideration should be given to the following issues when establishing whether the degree or type of information is available to the flight crew, adequately detectable, and clearly related to the error:

a. The effects of some errors are easily and reliably determined by the system (e.g., by design), and some are not. In other cases, error detection can be facilitated through the design and arrangement of information that is monitored and scanned by flight crew, such as by aligning needles in the same direction during normal operation (e.g., engine speeds).

b. Airplane alerting and indication systems may not detect whether an action is erroneous because the systems cannot know pilot intent for many operational circumstances. In these cases, reliance is often placed on the flight crew's ability to scan and observe indications that will change as a result of an action (e.g., selecting a new altitude or heading, or making a change to a flight plan in a flight management system). For errors of this nature, detection is dependent on flight crew interpretation of information available. Training, crew resource management, and monitoring systems such as TAWS and TCAS are examples of ways to provide a redundant level of safety if a pilot, or all flight crewmembers, fail to detect certain errors.

c. From a design standpoint, some information, such as heading, altitude, and fuel state, should be provided as readily available indications rather than in the form of alerts when there is the potential for them to contribute to excessive nuisance alerts.

Establishing that the information is available and clearly related to the error may be done by design description when precedent exists or when a reasonable case may be made that the content of the information is clearly related to the error that caused it. In some cases, piloted evaluations (see 8.3.4) may be needed to assess whether the information provided is adequately available and detectable.

7.6.3 Error Recovery

Assuming that the flight crew detects errors or their effects, the next logical step is to assure that the error can be reversed, or the effect of the error can be mitigated in some way so that the airplane is returned to a safe state.

Acceptable means to establish that the error is recoverable is whether:

1. Controls and indications exist that can be used
   a. to reverse an erroneous action directly so that the airplane or system is returned to the original state, or
   b. to mitigate the effect so that the airplane or system is returned to a safe state, and
2. The flight crew can be expected to use those controls and indications to accomplish the corrective actions in a timely manner.

To establish the adequacy of controls and indications that facilitate recovery from an error, a description of the system and crew interface may be sufficient. For simple or familiar system interface types, a description of the crew interfaces and procedures associated with indications will generally suffice. For systems and interfaces that are not novel, even if complex, appropriate precedence or service experience is an acceptable means of compliance.

To establish that the flight crew can be expected to use those controls and indications to accomplish the corrective actions in a timely manner, evaluation of flight crew procedures in a simulated flight deck environment can be a highly effective means. This should include examination of nomenclature used in alert messages, controls, and other indications, as well as the logical flow of procedural steps and the effects that executing the procedures have on other systems.

7.6.4 Error Effects

Another means of satisfying the objective of error mitigation is to assure that the effects of the error (e.g., relevant effects on aircraft state)

a. Are evident to the flight crew, and

b. Do not adversely impact safety (e.g., do not prevent continued safe flight and landing).

Piloted evaluations in the aircraft or in simulation may be relevant if pilot performance issues are in question for the purpose of determining if a state following an error permits continued safe flight and landing. Evaluations and/or analyses may be used to show that following an error, the flight crew has the information in an effective form and has the aircraft capability required to continue safe flight and landing.

7.6.5 Precluding Errors or Their Effects

For errors that are not reversible and which have potential safety implications, means to discourage the error are recommended. Acceptable ways to discourage errors include switch guards, interlocks or multiple confirmation actions. For example, generator drive controls on many airplanes have guards over the switches to discourage inadvertent actuation, because once disengaged, the drives cannot be re-engaged while in flight or with the engine running. An example of multiple confirmations would be presentation of a temporary flight plan for flight crew review before accepting it. Misleading display of information, which may include inaccurate information (e.g., sensor failures), may be addressed by removing the inaccurate information from the display, such as removing flight director bars or removing “own-ship” position from an airport surface map display when the data driving the symbol are incorrect..

The applicant should avoid applying an excessive number of protections for a given error. This could have unintended safety consequences if it hampers the pilot‘s ability to use judgment and take actions which are in the best interest of safety under circumstances and which have not been predicted by the applicant. Protections that become a nuisance in daily operation may be circumvented by flight crews using well-intended and inventive means which could have further effects not anticipated by the operator or the designer.

7.7 Integration

7.7.1 Introduction

This section addresses the installation and integration of a system into the flight deck, as well as the integration of a new or modified function into an existing system. Many systems, such as flight management systems, are integrated physically and functionally into the flight deck and may interact with other flight deck systems. Thus, it is important to consider the design not just in isolation, but also in the context of the overall flight deck. Integration issues include where a display or control is installed, how it interacts with other systems, internal consistency across functions within a multi-function display, as well as consistency with the rest of the flight deck's equipment.

This integration section provides general guidelines for the identification and resolution of integration issues, as well as guidance material for showing compliance with regulations related to integration. These regulations include 14 CFR/JAR §§ 25.771(a), 25.771(c), 25.773, 25.777(a-c), 25.1301(a), 25.1302, 25.1303 (JAR), 25.1309(a), 25.1321, 25.1322, 25.1523 and Appendix D. This applies to modifications and updates of existing flight decks with new installed equipment and new flight deck designs. The guidance is split into the following subsections:

a. Consistency (see 7.6.2)

b. Consistency trade-offs (see 7.6.3)

c. Environmental considerations (see 7.6.4)

d. Integration related workload and error (see 7.6.5)

7.7.2 Consistency

Consistency needs to be considered within a given system and across the flight deck. Inconsistencies may result in vulnerabilities, such as increased workload and errors, especially during stressful situations. For example, in some flight management systems the format for entering latitude and longitude differs across the display pages, which may induce pilot errors or at least increase pilot workload. Additionally, as errors may result if the latitude and longitude information is displayed in a format that differs from the way it is formatted on the most commonly used paper charts it is desirable to use formats that are consistent with other media whenever possible. While it is noted that trade-offs exist, as discussed in the next section, the following are areas to consider with respect to consistency within and across systems:

a. Symbology, data entry conventions, formatting, color philosophy, terminology, and labeling.

b. Function and logic, e.g., where two or more systems are active and performing the same function then they should operate consistently and use the same style interface.

c. Information presented with other information of the same type that is used in the flight deck, e.g., the navigation symbology used on other flight deck systems or on commonly used paper charts should be considered when developing the symbology to be used on electronic map displays.

d. The operational environment, e.g., where a flight management system is consistent with the operational environment so that the order of the steps required to enter a clearance into the system is consistent with the order in which they are given by air traffic management.

Adherence to a flight deck design philosophy is one means of achieving consistency within a given system as well as within the overall flight deck. Another means of achieving consistency is to standardize aspects of the design, such as by using accepted, published industry standards such as the labels and abbreviations recommended in ICAO Annex 8400/5. Standardizing the symbols used to depict navigation aids (e.g., VORs) might be done by following the conventions recommended in SAE ARP5289. However, inappropriate standardization, rigidly applied, can be a barrier to innovation and product improvement. Additionally, standardization may result in a standard to the lowest common denominator. Thus, guidance in this section is to promote consistency rather than rigid standardization.

7.7.3 Consistency Trade-Offs

It is recognized that it is neither always possible nor desirable to provide a consistent pilot interface. It is possible to negatively impact workload, despite conformance with the flight deck design philosophy, principles of consistency, etc. For example, all auditory alerts may adhere to the flight deck alerting philosophy, but the number of alerts may be unacceptable. Additionally, individual task requirements may necessitate the presentation of data in two significantly different formats. An example is where a display format for a weather radar display may show a sector of the environment, while a moving map display may show a 360 degree view. In such cases it should be demonstrated that the interface design is compatible with the requirements of the piloting task and that it can be used individually and in combination with other interfaces without interference to either system or function.

Additionally:

a. The applicant should provide an analysis which identifies each piece of information or data that is presented in multiple locations and show that the data is presented in a consistent manner or, where that is not true, justify why that is not appropriate.

b. Where information is inconsistent, the inconsistency should be obvious or annunciated, and should not contribute to errors in information interpretation.

c. There should be a rationale for instances where a system's design diverges from the flight deck design philosophy, and the impact on workload and errors should be considered.

d. The applicant should describe what conclusion the pilot is expected to draw and what action should be taken when the information on the display may conflict with other information in the flight deck (either with or without a failure).

7.7.4 Flight Deck Environment

It should also be recognized that the flight deck system is influenced by the physical characteristics of the aircraft into which a system is integrated, as well as the environmental characteristics. Thus, the system is subject to influences in and on the flight deck such as turbulence, noise, ambient light, smoke, and vibrations (such as those that may be due to ice or fan blade loss). Design of the system should recognize how such influences may affect usability, workload, and crew task performance. Turbulence and ambient light, for example, may affect the readability of a display. Flight deck noise may affect the audibility of auditory alerts. The impact of the flight deck environment must also be considered for non-normal situations, such as unusual attitude recovery or regaining control of the aircraft or system.

The flight deck environment also includes the layout, or physical arrangement, of the controls and information displays. The layout should take into account crew requirements in terms of:

a. Access and reach (to controls);

b. Visibility and readability of displays and labels; and

c. Task oriented location and grouping of human-machine interaction elements.

An example of poor physical integration would be a required traffic avoidance system obscured by thrust levers in the normal operating position.

7.7.5 Integration Related Workload and Error

When integrating functions and/or equipment, designers should be aware of the potential effects, both positive and negative, that integration can have on crew workload and its subsequent impact on error management. Systems must be designed and evaluated both in isolation and in combination with other flight deck systems to ensure that the flight crew is able to detect, reverse, or recover from errors. This may be more challenging when integrating systems that employ higher levels of automation or that have a high degree of interaction and dependency on other flight deck systems.

Applicants should show that the integrated design does not adversely impact workload or errors given the context of the entire flight regime (e.g., increased time to interpret a function, make a decision, and/or take appropriate actions). Controls, particularly multi-function controls and/or novel control types, may present the potential for misidentification and increased response times. Multi-function controls with hidden functions increase both crew workload and the potential for error, and therefore should generally be avoided.

Here are two examples of integrated design features that may or may not impact error and workload:

a. Presenting the same information in two different formats. This may increase workload, such as when altitude information is presented concurrently in tape and round-dial formats. Yet, different formats may be suitable depending on the design and the pilot task. For example, an analog display of engine revolutions-per-minute can facilitate a quick scan, whereas a digital numeric display can facilitate precise inputs. It is the applicant's responsibility to demonstrate compliance with 14 CFR 25.1523 and show that unacceptable levels of workload do not result from differences in the formats.

b. Presenting conflicting information. Increases in workload and error may result from two displays depicting conflicting altitude information on the flight deck concurrently, regardless of format. For instance, systems may exhibit minor differences between each pilot station, but all such differences should be evaluated specifically to ensure that the potential for interpretation error is minimized, or that a method exists for the flight crew to detect incorrect information, or that the effects of these errors can be precluded.

It should also be shown that the proposed function will not inappropriately draw attention away from other flight deck information and tasks so as to degrade pilot performance and thereby decrease the overall level of safety. Nevertheless, there are some cases where it may be acceptable for system design to increase workload. For example, adding a display into the flight deck may increase workload by virtue of the additional time pilots spend looking at it; however, this may be an acceptable trade-off given the safety benefit that the additional information provides.

Because each new system integrated into the flight deck may have a positive or negative effect on workload, it must be evaluated in isolation and combination with the other systems for compliance with 14 CFR 25.1523 to ensure that the overall workload is acceptable, i.e., that performance of flight tasks is not adversely impacted and that the crew's detection and interpretation of information does not lead to unacceptable response times. Special attention should be paid to 14 CFR Appendix D and specifically compliance issues with items listed as workload factors in that appendix such "accessibility, ease, and simplicity of operation of all necessary flight, power, and equipment controls."

8. MEANS OF COMPLIANCE

This section discusses considerations in the selection of the means of compliance. Six general means of compliance that have been found to be acceptable in demonstrating compliance to address human performance issues are provided. These means of compliance are generic and are used in all certification programs. The acceptable means of compliance to be used on any given project should be determined on a case-by-case basis, driven by the compliance issues. They should be developed and proposed by the applicant, and then agreed to by the certificating authority. The uses and limitations of each type of means of compliance are provided in section 8.3.

8.1 Selecting Means of Compliance

The means of compliance discussed in this section include: statements of similarity, design description reviews, calculations/analyses, evaluations, demonstrations, or tests. It should be recognized that there is no generic method to determine the appropriate means of compliance for a specific project. The choice of the appropriate means of compliance or a combination of several different means of compliance is dependent upon a number of factors specific to the project.

For some certification projects it may be necessary to employ more than one means of demonstrating compliance with a particular regulation (e.g., when flight testing in a conformed airplane is not possible, a combination of a design review and a part-task simulation evaluation may be proposed).

Once the design feature and/or tasks to be evaluated have been identified in Section 6 and the following questions have been answered as part of the process described in Section 6:

a. What safety implications are being evaluated?

b. What design features are being evaluated?

c. Are the features new or novel?

d. Are the design features parts of a highly complex system?

e. What specific flight crew task or tasks are being evaluated?

f. Is the task new or novel?

g. Are the procedures associated with the task new or novel?

h. What is the complexity of the task or tasks being evaluated?

i. What is the safety implication of not being able to correctly accomplish the task or tasks?

Then determine if an evaluation, demonstration or a test is needed to prove compliance.

a. What is the objective of the evaluation?

b. What data will need to be collected during the evaluation to meet the objective?

c. How will the data be collected and analyzed?

d. When appropriate, determine the pass/fail criteria for the evaluation?

Answering the following questions will aid in the selection of the means of compliance.

a. With which means of compliance will it possible to gather the required certification data?

b. Will a single means of compliance provide all of the data or will several means of compliance be used in series or in parallel?

c. What level of fidelity of the facility is required to collect the required data?

d. Who will be the participants?

e. What level of training is required prior to acting as a participant?

f. How will the data from an evaluation be presented to show compliance, since the Authority will not be present?

g. Will results of a demonstration be submitted for credit?

h. If a test is required, what conformed facility will be used?

8.2 Discussion and Agreement with the Authority on Compliance Demonstrations

The applicant's proposal for means of compliance must be coordinated with appropriate regulatory authorities or designated representatives to ensure that all aspects necessary for desired credit towards certification are achieved. These could include the planned scenarios, the necessary types of human performance issues to be explored, or the conditions under which the test will be conducted to provide a realistic environment for the evaluation.

8.3 Description of Means of Compliance

There are six general means of compliance found to be acceptable for use in demonstrating compliance related to flight deck design. They are:

a. Statement of Similarity (section 8.3.1),

b. Design Descriptions (section 8.3.2),

c. Calculation and Engineering Analysis (section 8.3.3),

d. Evaluations (section 8.3.4),

e. Demonstrations (section 8.3.5), and

f. Tests (section 8.3.6).

8.3.1 Statement of Similarity

Description

This is a description of the system to be approved and a description of a previously approved system, which details the physical, logical, and operational similarities, with respect to compliance with the regulations.
Deliverable
The statement of similarity could be part of the certification report with reference to existing certification data/documents.
Participants
Not applicable.
Conformity
Not applicable.
Uses
It may be possible to substantiate the adequacy of a design by comparison to previously certificated systems, which have shown that they are robust with respect to their lack of contribution to crew error and/or the ability for the flight crew to manage the situation should an error occur. This avoids repetition of unnecessary effort to justify the safety of such systems.
Limitations
This means of compliance must be used with care because the flight deck should be evaluated as a whole, rather than merely as set of individual functions or systems. For example, two functions that have been previously approved on two different programs may be incompatible when combined on a single flight deck. Also, changing one feature in a flight deck may necessitate corresponding changes in other features, in order to maintain consistency and prevent confusion.
Example
If the window design in a new aircraft is identical to that in an existing aircraft, a statement of similarity may be an acceptable means of compliance to meet FAR/CS 773.

8.3.2 Design Description

The applicant may elect to substantiate that the design meets the requirements of a regulation by describing the design. Drawings, Configuration Description and/or Design Philosophy have traditionally been used by applicants to show compliance with particular regulations. Selection of participants and conformity are not relevant to this group of means of compliance.

8.3.2.1 Drawings

Description
Layout drawings or engineering drawings, or both, which depict the geometric arrangement of hardware or display graphics.
Deliverable
The drawing which can be part of a certification report.
Uses
Drawings can be used for very simple certification programs when the change to the flight deck may be very simple and straight forward. Drawings can also be used to support the findings of compliance for more complex interfaces.
Limitations
The use of drawings is limited to physical arrangements and graphical concerns.

8.3.2.2 Configuration Description

Description
This is a description of the layout, general arrangement, direction of movement, etc., of the regulated item, or a reference to similar documentation. For example, such a description could be used to show the relative locations of flight instruments, groupings of control functions, allocation of color codes to displays and alerts, etc.
Deliverable
Explanation of functional aspects of crew interface to system: text description of certification item and/or functional aspects of the crew interface with the system (with visuals as appropriate).
Uses
Configuration descriptions are generally less formalized than engineering drawings, and are developed in order to point out the features of the design that are supportive of a finding of compliance. In some cases, such configuration descriptions may provide sufficient information for a finding of compliance with a specific requirement; however, more often, they provide important background information, while final confirmation of compliance is found via other means, such as demonstrations or tests. The background information provided by configuration descriptions may significantly reduce the complexity and/or risk associated with the demonstrations or tests because the applicant will have already communicated how a system works and any discussions or assumptions may have already been coordinated.
Limitations
Configuration descriptions may provide sufficient information for a finding of compliance with a specific requirement; however, more often, they provide important background information, while final confirmation of compliance is found via other means, such as demonstrations or tests. The background information provided by configuration descriptions may significantly reduce the complexity and/or risk associated with the demonstrations or tests.

8.3.2.3 Design philosophy

Description
This means of compliance can be used to demonstrate that the design philosophy found in the design documents' specifications for the product/system or flight deck have been used in the design process.
Deliverable
Text description of certification item and/or functional aspects of the crew interface with the system (with figures and drawings as appropriate) and relationship to overall design philosophy.
Uses
Documents the ability of a design to meet the requirements of the regulation while adhering to the flight deck philosophy.
Limitations
In most cases, this means of compliance will not be sufficient as the sole means to demonstrate compliance.
Example
Design philosophy may be used as a means of compliance when a new alert is added to the flight deck. The new alert may be consistent with the existing alerting philosophy.

8.3.3 Calculation/analysis

Description
Calculations or engineering analyses ("paper and pencil") assessments that do not require direct participant interaction with a physical representation of the equipment.
Deliverable
Report that details the type of analysis, its basis for decision making, components, and evaluation assumptions. Details the results and conclusions.
Participants
Conducted by the applicant.
Conformity
Not applicable.
Uses
Provides a systematic evaluation of specific or overall aspects of the human interface part of the product/system/flight deck. May be specified by regulatory guidance material.
Limitations
For analyses that are not based on advisory material or accepted industry standard methods, the validity of the assessment technique should be carefully considered. Furthermore, applicants may be asked to validate any computation tools used in such analyses. If analysis involves comparing measured characteristics to recommendations derived from pre-existing research (internal or public domain), the applicant may be asked to validate the use of the data derived from the research.
Example
A vision analysis may be conducted to demonstrate that the pilot has a clear and undistorted view out the windows. Similarly an analysis may be performed that demonstrates that flight, navigation and powerplant instruments are plainly visible from the pilot station. Conformation of the analysis may be necessary in a ground or flight test.

8.3.4 Evaluations

A wide variety of part-task to full-installation representations of the product/system or flight deck can be used for evaluations. These all have two characteristics in common: (1) the representation of the human interface and the system interface do not necessarily conform to the final documentation, and (2) the certification authorities are generally not present. The sections below address mock-ups, part-task simulation, full simulation, and in-flight evaluations that typically make up this group of means of compliance.

Description
Evaluations are assessments of the design that are conducted by the applicant who then provides a report of the results to the regulatory agency.
Deliverable
A report is delivered to the regulatory agency.
Participants
A participant may be anyone other than the regulator or a designee of the regulator.
Facilities

An evaluation can be conducted in a mock-up, bench or laboratory, simulator or an aircraft.
Conformity
Conformity is not required.
Mock-up evaluation
Mock-ups can be used as representations of the design, which allow participants to physically interact with the design. Three-dimensional representations of the design in a CAD system, in conjunction with three-dimensional models of the flight deck occupants, also have been used as "virtual" mock-ups for certain limited types of evaluations. For example, reach assessments using this technique can use either.
Example of a mock-up evaluation
An analysis to demonstrate that the controls are arranged so that pilots from 5'2" to 6'3" in height can reach all the controls. This analysis may use computer generated data based on engineering drawings. The applicant may demonstrate the results of the analysis in the actual aircraft.
Bench or laboratory evaluation
An evaluation can be conducted using devices that emulate the crew interfaces for a single system or a related group of systems, using flight hardware, simulated systems, or combinations of these.
Example of a bench or laboratory evaluation
A bench evaluation for an integrated system could be an avionics suite installed in a mock-up of a flight deck, with the main displays and autopilot controllers included. Such a tool may be valuable during development and for providing system familiarization to the authorities. However, in a highly integrated architecture, it may be difficult or impossible to assess how well the avionics system will fit into the overall flight deck without more complete simulation or use of the actual airplane.
Simulator evaluation
A simulator evaluation uses devices that present an integrated emulation (using flight hardware, simulated systems, or combinations of these) of the flight deck and the operational environment. They can also be "flown" with response characteristics that replicate, to some extent, the responses of the airplane. Fidelity requirements should be evaluated in view of the issue being evaluated.
Aircraft evaluation
This is an evaluation conducted in the actual aircraft.
Uses
Traditionally, these types of activities have been used as part of the design process without formal certification credit. However, these activities can result in better designs that are more likely to be compliant with applicable regulations.
Limitations
Evaluations are limited by the extent to which the facilities actually represent the flight deck configuration and realism of the flight crew tasks. As flight deck systems become more integrated, part-task evaluations may become less useful as a means of compliance, even though their utility as engineering tools may increase.

8.3.5 Demonstrations

Demonstrations are evaluations (as described above), but conducted by the applicant with participation by the regulatory authority and not requiring conformity. The applicant may provide a report or summary, requesting regulator concurrence on the findings. In each case, the applicant should note the limitations of the demonstration and how those limitations relate to the compliance issues being considered. The regulator should carefully consider which of its specialists will participate (for example, pilots, human factors specialists, or systems engineers), what data will be collected, and how the data will be collected. This is to ensure that the demonstration adequately addresses the compliance issues and that there is participation by the appropriate regulatory evaluators.

8.3.6 Test

Tests are means of compliance that are conducted in a manner very similar to evaluations which are described in above in section 8.3.4. There are a few significant differences: tests require a conformed product/system, and system interface; and the authorities or their designee must be present. A test can be conducted on a bench/laboratory, in a simulator, or on an aircraft.

Description
Tests are assessments of the design that are conducted with the regulatory authority present.
Deliverable
A report is delivered to the regulatory agency.
Participants
The regulatory authority must be present.
Facilities
A test can be conducted in a on a bench or in a laboratory, simulator or an aircraft.
Conformity
The facility must be conformed.
Bench or laboratory test
This type of testing is usually confined to showing that the components perform as designed. Bench tests are usually insufficient to stand alone as a means of showing compliance, but can provide useful supporting data in combination with other means.
Example of a bench or laboratory test
Visibility of a display under the brightest of the expected lighting conditions might be shown with a bench test, provided there is supporting analysis to define the expected lighting conditions. This might include a geometric analysis to show the potential directions from which the sun could shine on the display, along with calculations of expected viewing angles. These conditions might then be replicated in the laboratory.
Conformity related to a bench or laboratory test
The part or system would need to be conformed for it to show compliance.
Simulator test
A simulator test uses devices that present an integrated emulation (using flight hardware, simulated systems, or combinations of these) of the flight deck and the operational environment. They can also be "flown" with response characteristics that replicate the responses of the airplane. Fidelity requirements should be evaluated in view of the issue being evaluated.
Simulator test conformity and fidelity issues
If only parts of the flight deck are conformed then only those parts could be used. A flight crew training simulator can be used to validate most of the normal and emergency procedures for the design, and any workload effects of the equipment on the flight crew. If the flight deck is fully conformed and the avionics are driven by conformed hardware and software, then integrated avionics testing can be conducted and used for compliance. It should be noted that not all aspects of the simulation must have a high level of fidelity for any given compliance issue. Rather, fidelity requirements should be evaluated in view of the issue being

evaluated.
Aircraft test
The tests can be conducted either on the ground or in flight.
Example of an aircraft test
An example of a ground test is an evaluation for the potential of reflections on the displays. Such a test usually involves covering the flight deck windows to simulate darkness and setting the flight deck lighting to desired levels. This particular test may not be possible in a simulator, due to differences in the light sources, display hardware, and/or window construction. Flight testing during certification is the final demonstration of the design. Prior evaluations, tests and demonstrations are conducted in a variety of ways and at different levels of conformity. These are tests conducted in the actual airplane during flight. The airplane and its components (flight deck) are the most representative of the actual type design to be certified and will be the closest to real operations of the equipment. In-flight testing is the most realistic testing environment although this environment is limited to those evaluations that can safely be conducted. Flight testing can be the validation and verification of all the tests that have been conducted throughout the development and certification program. It is often best to use flight testing as a final confirmation of data collected using other means of compliance, including analyses and evaluations.
Limitations of flight tests
Flight tests may be limited by the extent to which the flight conditions of particular interest(e.g., weather, failure, unusual attitudes) can be located/generated and then safely evaluated in flight. It should also be noted that flight testing on the aircraft provides the least control over conditions of any of the means of compliance. The regulator and the applicant should discuss thoroughly how and when flight tests will be used to show compliance, as well as how flight test results will be used.