RECOMMENDED PRACTICES AND GUIDELINES FOR PART 23 COCKPIT/FLIGHT DECK DESIGN

GAMA PUBLICATION NO. 10
Version 1.0 - Original Release

General Aviation Manufacturers Association

GAMA

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1.0 PURPOSE

The purpose of this document is to provide manufacturers of small aircraft and systems with human factors (HF) recommendations for the design of cockpits/flight decks and their associated equipment to enhance overall aircraft safety. This document should be useful to manufacturers as they proceed through the design, development and evaluation efforts. The guidelines in the document address issues relevant to new generation products, as well as to existing products and their use in new and existing cockpits/flight decks. This document will be helpful to manufacturers seeking certification of their products because it is consistent with the newly developed Federal Aviation Administration (FAA) and Industry Guide to Product Certification published in January 1999.

2.0 SCOPE

Industry has historically given serious consideration to human factors in the design of aviation products. This document endeavors to provide a systematic approach in this area for present and future designs. The scope of this document is limited to a compilation of human factors best-practices criteria that if applied will lead to a more effective human-machine interface and consistent design and evaluation of aircraft systems. The document is focused on human-system interface design issues related to the development, installation and evaluation of highly integrated, software-intensive avionics in small airplanes. References to existing human factors standards are made when they are available.

This document will be most useful to those individuals who have a basic understanding of HF design, certification and evaluation processes. Basic understanding of HF principles and practices may be acquired through formal study or by consulting knowledgeable persons (e.g. FAA Specialists, DERs, airframe & avionics companies). Additional information on HF topics are referenced in Appendix A.

The primary intent of this document is to provide HF guidelines to enhance overall aircraft safety. As a consequence, when the cockpits of in-service aircraft are upgraded or modified, the proposed changes should consider using the HF practices defined in this document.

The contents of the document are specifically aimed at providing manufacturers with a standard process for integrating human factors criteria into their designs. The design recommendations are always accompanied by an evaluation method and lessons-learned information.

Training recommendations are not specifically addressed in this document, however, training issues need to be considered early in the design process. Human factors assessments recommended in this document should be helpful in developing training objectives and determining the level of training required for proficiency.

3.0 BACKGROUND

The General Aviation Manufacturers Association (GAMA) sponsored the effort to develop a single document containing best HF practices and guidance for Part 23 cockpits/flight decks. This document is a follow-on of that work completed on revision of AC 23.1309-1C and AC 23.1311-1A and supports a systematic consideration of HF aspects in aviation design.

Systems continue to increase in complexity. This has resulted in a need for improved pilot-machine interfaces to reduce the degree to which incorrect pilot actions contribute to accidents. This document is intended to facilitate optimization of designs to give these systems enhanced HF interfaces. Utilization of the guidelines in this document should result in improved safety and resolution of human factors issues early in the design process.

This document has potential benefit to the small aircraft manufacturing community in that it provides:

1. Information developed from several companies who have many years of experience in developing and applying human factors design to their aviation products. Users of the best practices that are described in this document will benefit from previous design efforts and lessons learned in applying those practices.

2. Utilization of the human factors guidance and evaluation methodology described in this publication will aid in development of a standardized approach for all industry developers and evaluators.

3. Utilization of the best practices described in this document will lead to safer error-tolerant designs. This should result in a reduction of aircraft accidents and incidents.

This is a living document and it may require future revisions to stay abreast of new approaches and techniques that could be used in designs and as a result of field experience gained from use of the document. A form is included at the end of this publication in Appendix G that may be used to submit comments to GAMA.

The contributors to this document are listed in Appendix F. They include representatives from industry and the FAA.

4.0 DEFINITIONS

The following definitions are derived either from specific sources or from the accepted understanding of a meaning due to common usage. When a recognized source for a specific definition is available, it will be indicated at the end of the definition. More information pertaining to HF subjects as discussed in this document may be obtained from a list of “Reference and Related Documents” contained in Appendix A. Appendix C contains a list of acronyms that are used in this document.

Backup Display or Data Source is the display of a parameter or selection of a different data source when the pilot elects to use it in lieu of the primary display or data source of that parameter. (Source: committee consensus)

Basic-T is the standard arrangement of flight instruments displaying attitude, altitude, airspeed and heading information. (Source: 14 CFR PART 23.1321.)

Design Eye Box is a three-dimensional volume of space surrounding the Design Eye Reference Point that designers and evaluators use to determine the acceptability of display and control locations. The design-eye-box is defined as a 2-½ inch sphere centered on the Design Eye Reference Point that encompasses the eyes of a pilot from the expected user population when properly seated at the pilot's station. (Source: Committee consensus)

Design Eye Reference Point is a single reference point in space selected by the designer where the midpoint between the pilot's eyes is assumed to be located for design purposes when the pilot is properly seated at the pilot's station. The reference point is the center of the design-eye-box. (Related terms include 'operational eye position' and 'flight eye position'). (Source: AC 25.773-1)

Expected User Population refers to the physical characteristics and operational experience of a cross section of the user population that will be expected to pilot an aircraft. The population definition should account for critical dimensions that are pertinent to the operation of the system under consideration. (Source: committee consensus)

Function (as used in systems design) is a characteristic action required to be performed or to be accomplished by one or more of a system's elements: human, hardware or software. A function may be defined at *any level* of a system. It may be further decomposed to *any number of lower levels* of functionality (e.g. sub-function, sub-sub-function, etc.) relative to the originally defined system requirements. Functions are then allocated, based on the system design, to be performed by the human, hardware, or software component.
(Source: DSMC Systems Engineering Management Guide)

NASA TLX Evaluation is a multi-dimensional subjective workload rating technique. This method requires the evaluator to perform two types of evaluations to obtain a measure of workload. The first method requires the evaluator to select from a series of paired words or phases to determine which one of the two best describes the impression of workload for the task. The second part requires the evaluator to rate each of those same word phrases using a scale to indicate their singular contribution to workload.

Primary Display is the display of a safety of flight parameter that is located in front of the pilot. A Primary Flight Display (PFD) is an example of a primary display.
(Source: committee consensus)

Primary Field-of-View is based upon the optimum vertical and horizontal visual fields from the design eye reference point that can be accommodated with eye rotation only. With the normal line-of-sight established at 15 degrees below the horizontal plane, the values for the vertical (relative to normal line-of-sight forward of the aircraft) are +/-15 degrees optimum, with +40 degrees up and -20 degrees down maximum. For the horizontal visual field (relative to normal line-of-sight forward of the aircraft), the values are +/-15 degrees optimum, and +/-35 degrees maximum. These values are illustrated in Figure 3.1. (Source: FAA Human Factors Design Guide. DOT/FAA/CT-96/1)

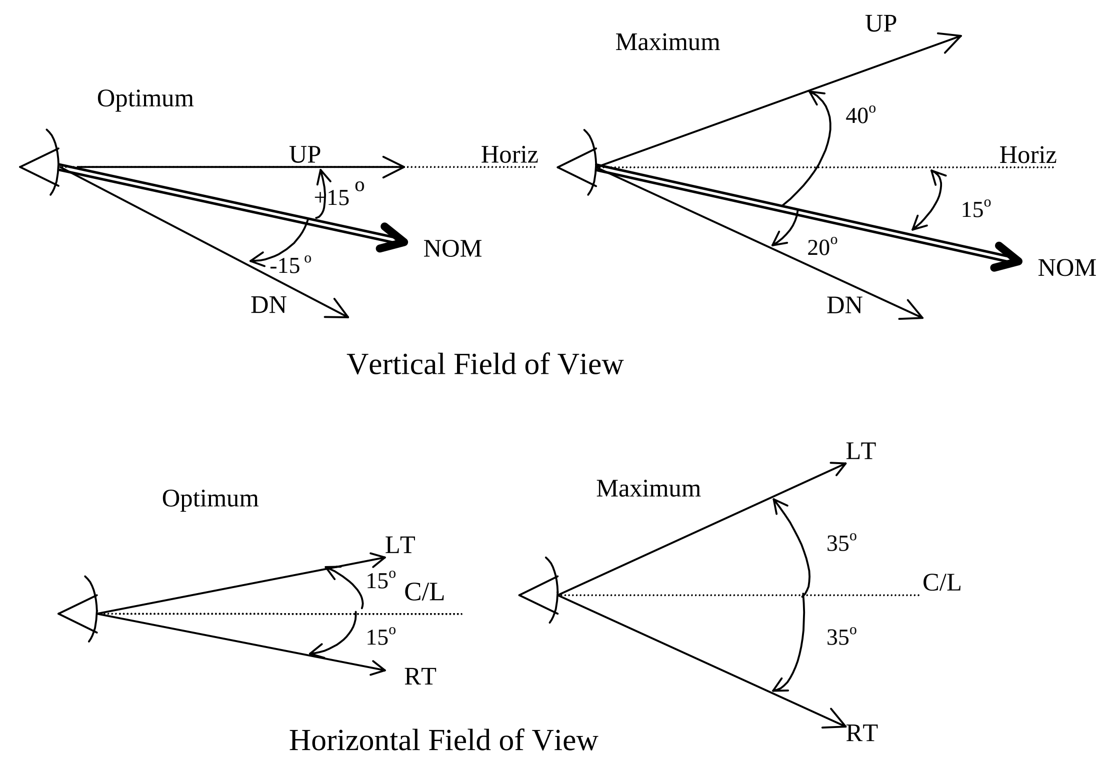

Figure 3-1
Primary Field of View

<u>Reversionary Display</u> is an additional display that can serve as a secondary means of providing primary flight parameter(s). (Source: AC 23.13ll)

<u>Secondary Display</u> is the display of a parameter that the pilot looks at that is used to view information needed for system or aircraft control, but not the information needed immediately for safety of flight. (Source: committee consensus)

<u>Secondary Field-of-View</u> is based upon the optimum horizontal and vertical visual fields from the design eye reference point that can be accommodated with head rotation. These values are +/- 60 degrees horizontal and + 65 and - 35 degrees vertical. These values are established from the normal line of sight and illustrated in Figure 3.2. The Secondary Field-of-View range defines the ability of the pilot to observe the operation and to use the critical parameters of a system without inducing disorientation or undue body movement.
(Source: FAA Human Factors Design Guide DOT/FAA/CT-96/1)

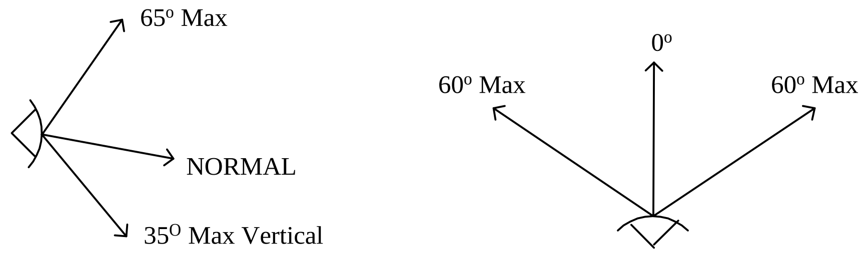

Figure 3-2
Secondary Field of View

Situational Awareness is the development of a mental picture by the pilot resulting from the continuous use of the flight related information. Integration of this information with previous knowledge is used to direct pilot behavior, define further information gathering needs and anticipate future events. (Source: committee consensus)

Structured Survey is a method, usually of the paper-and-pencil variety, but sometimes administered via a computer, used to collect the responses from a group of the user population. This survey may use rating scales, rank-ordering methods, or multiple-choice questions to sample opinions, attitudes, and historical factual data.
(Source: committee consensus)

Subjective Survey is a data collection technique that asks respondents to give their personal opinions on a subject or issue. Responses are collected using interviews, open ended questions, ranking or rating scales. (Source: committee consensus)

Systems Advisory is the presentation of specific data, through audio or visual annunciation, about the operational status of a system. (Source: committee consensus)

Visibility, External is the amount of external environment visible from the design eye reference point and/or box including obstructions fixed to the aircraft, e.g., canopy/windshield structure, wings, tail, etc. (Source: MIL-STD-1776A, AC-25.773-1)

Visibility, Internal is the amount of the internal cockpit environment visible from the design eye position and/or box including obstructions fixed to the aircraft or fixed in the cockpit, e.g., flight displays, control wheel/stick, throttle, glare shield, control panels, seats, restraining devices, knees, arms, etc. (Source: 14 CFR PART 23.1321, MIL-STD-1776, ARP-4102)

Warning/Caution/Alerting/Messaging is the presentation to the aircrew of a system condition that needs evaluation for possible action by the aircrew.
(Source: committee consensus)

Workload is a multidimensional construct with three different components: sensory, cognitive, and psychomotor. The sensory component refers to the complexity of the visual, auditory, or kinesthetic stimuli to which the pilot must attend; the cognitive component refers to the level of information processing required from the pilot; the psychomotor component refers to the complexity of the pilot's behavioral responses. [An example of a situation where the pilot workload becomes high is when the aircraft is on a final instrument approach in IFR conditions, loses an engine and must both fly the aircraft and attend to the engine problem].
(Source: committee consensus)

5.0 HUMAN-CENTERED DESIGN CONSIDERATIONS

5.1 Innovative Design Leading to Improved Safety

This document provides HF guidance that will enhance the ability of manufacturers to use the advances made through new technology to economically produce and certify innovative designs improving operational safety. It is necessary to note that innovative designs, in and of themselves, do not ensure improved safety. However, appropriate implementation of new designs using new technologies will produce the desired safety improvements.

5.2 Human Centered Design Process

Certification programs can derive benefits from the application of a human centered design process. The designer should develop a process to ensure that HF is considered throughout the design, development and evaluation stages of the program. One such approach is described in ARP-4033. The HF design process should be an internal company activity that is in place prior to the design being started. These HF design criteria need to be addressed during the conceptual phase of the design to produce timely certification approvals.

Overall, the Human Centered Design (HCD) goal is **to optimize the composite system design as installed in an aircraft; not just the design of an individual product or subsystem**. A consistent human-system interface for the pilot should result from the process of developing a systems solution.

(See Appendix B for a short review of general philosophies and principles of good human-centered design interface considerations.)

6.0 HUMAN FACTORS IN PRODUCT DEVELOPMENT & EVALUATION

The designer's task is to address HF issues and considerations, both with respect to the specific system being developed, and to the operational use of the aircraft and its systems. A goal of the design team is to ensure that the aircraft and its systems are safe, easy to learn and intuitive to operate. Good HF designs facilitate efficient and consistent task performance. The level of involvement of human factors expertise in the test and evaluation of the system is one of the most important determinants of a successful product development effort.

This section provides guidance related to conducting human factors assessments. Test and evaluation methods may be used for entire cockpits, integration of new system components into existing cockpits, or single individual components without reference to a specific cockpit. Specific guidance is provided for tailoring the HF evaluation effort in paragraph 6.1.7. A suggested content and structure for the Human Factors Evaluation Plan is included in Appendix D.

6.1 Purpose of a Human Factors Evaluation

The purpose of conducting a HF evaluation is to ensure that the HF criteria are correctly addressed. This is accomplished by data collection and testing regarding the adequacy of the system design and operational characteristics in the performance of tasks and functions associated with the system/component. For a system that provides an interface for human interaction, such as a control panel or display screen, human performance becomes an essential part of overall system performance. It is therefore essential that human factors designers conduct early evaluations of the capability of the human and system to perform the intended functions.

6.2 Design & Evaluation Teams

As systems continue to become more complex and integrated, the need for HF considerations becomes even more critical to ensure safe aircraft operation. History has substantiated the benefit of developing teams comprised of different disciplines when designing, developing and evaluating complex systems. Essential to an effective and well-balanced design team is adequate representation of human factors expertise with adequate authority to ensure HF principles are considered in the design. Such a team should be composed of display designers, control designers, human factors specialists, flight test pilots, customer pilot population; and flight operations, manufacturing/quality, training and certification personnel.

6.3 Human Factors Coordinator

It is desirable that a single individual or one office in a particular organization, with adequate organizational authority to ensure HF considerations are addressed, be identified and held responsible for the direction and coordination of human factors activities and participation in design reviews. These individuals should have some formal training in human factors principles and several years of experience, particularly in the application of human engineering principles and practices in the design, development and evaluation of aircraft systems/products.

6.4 Benefits

An evaluation plan can provide many benefits to a design and development organization including:

- Serving as a checklist to assure proper project planning has been performed with regard to the evaluation of the functions involved, the product and sequences of events,

- Assuring that a thorough review of applicable user, operational and environmental requirements and related design guidance have been accomplished,

- Providing a "road map" for project progression from beginning to end,

- Assisting in efficient project management,

- Aiding in the early identification and resolution of HF-related issues,

- Reducing misunderstandings and last-minute difficulties both inside and outside the design organization, and

- Reducing program costs and schedule impacts.

6.5 Design Goals and Activities

A HF evaluation plan should be developed early in the design program to ensure that human factors expertise is available and functioning during the conceptual development phase and throughout the life cycle of the system. The plan should address the processes and methods that will be employed to verify the design concept. Some of the specific goals and activities that need to be addressed in the human factors plan relative to the evaluation of a system (including the human pilot) are listed below.

Goals:

- The pilot is capable of operating the provided functions without exceptional skill or ability and without excessive effort, either physical or mental (requirements fall with normal range of human capabilities).

- The design is suitable for the intended use by the pilot (human operator).

- The design is intuitive to the point that no training is required to use it.

Activities:

- Define a process to identify the HF issues and deficiencies of the defined system and operation throughout the design phase.

– As the HF evaluation is being completed, evaluate alternative designs and operational solutions to provide improved HF interfaces.

– Verify that no unsafe operational condition or situation exists when the pilot uses the system. Include the evaluation of error recognition and recovery from mistakes.

– Verify that the design is consistent with the intended operational use and environment.

– Determine that training materials are appropriate and consistent with the intended operation of the system.

6.6 Early Analysis

Prior to development of the plan, human factors experts and representative users should be involved in analysis of system operational, conceptual and design requirements. The type of analyses that may be conducted include: high-level cognitive/behavioral task-analysis procedural evaluations (complexity, number of steps, nomenclature, etc), reach analysis via computer modeling, time-line analysis for assessing task demands and workload, or other methods depending upon the issue being considered. The goal of this effort is to identify key HF issues and areas that need to be addressed in the HF evaluation plan. The evaluation plan should focus on those areas and issues that appear to be the most problematic. Usually, these areas are comprised of complex and/or frequently performed tasks subject to error, which could have detrimental operational consequences if performed incorrectly.

6.7 Tailoring the Plan

Installation of a new or modified system or device that results in a different human-vehicle interface or human tasking will need to be assessed for its human-performance implications. The level of assessment will vary proportional to the degree of change of the physical characteristics and operational procedures for a given control/display interface device. The primary concern should be what effect the new operation will have on human tasking and overall system performance.

All assessments should begin with some type of high-level analyses to identify changes in pilot tasking with the new system. For systems that have very little effect on the human-vehicle interface, for example replacing a standard analog fuel indicator (needle) with a digital readout of fuel remaining, the level of analysis may be quite limited. In some cases, a simple description of the change, rationale for the modification and any underlying human tasking/performance assumptions would suffice. Modifications that significantly change the human-vehicle interface will require a more thorough analysis to ensure that all of the key human factors issues have been identified.

There are certain attributes and characteristics of a component that should be considered when deciding which level of evaluation to use and how representative it is of the test article and test setup (fidelity). The list that follows is by no means comprehensive, but includes some of the more important issues that need to be considered.

6.7.1. Independence & Interaction

An independent, stand-alone system that does not interact with other aspects of the pilot interface in the cockpit would most likely require little analysis or evaluation. However, for components that are more integrated with other systems in cockpit and/or with higher levels of interaction and that perform functions critical to safe flight, more in-depth evaluations with greater fidelity will need to be conducted.

6.7.2. Novelty

Technology that is more mature and in wide use with a proven track record would most likely require minimal analysis and/or evaluation. However, new or novel applications of existing technology also should be subject to more rigorous test and evaluation methods.

6.7.3. Complexity/Automation

Complex manual and automated systems impose demands on the pilot that are difficult to envision and understand. Consequently, more sophisticated and realistic testing must be employed to understand and identify human-system interface and performance issues. Tests should be performed using the system's normal and backup or reversionary modes of operation.

6.7.4. Criticality

Highly critical systems that could affect the safety of the flight if misinterpreted or operated incorrectly should be tested in realistic environments (high-quality simulation or flight-testing).

6.7.5. Dynamics

Highly dynamic control or display features need to be evaluated under conditions that replicate the expected dynamic flight environment.

6.7.6. Training Requirements

Products that are relatively simple to learn and operate in the cockpit would most likely require little analysis or evaluation. A goal is to make the system as simple to use as possible such that little or no training is required. Training should not be used to compensate for design shortcomings. However, some products will likely require a significant amount of training to operate and the interfaces will probably need to be evaluated in an environment that replicates the full spectrum of activities in which the pilot may be involved.

6.7.7. Subjective Criteria

Requirements that have specific, objectively measurable criteria can often employ less sophisticated and involved test and evaluation methods. As more subjective criteria are used to qualify the system interface and performance, more integrated and representative testing will need to be conducted to compensate for the greater uncertainties associated with subjective evaluations.

The design team should refer to the above list when developing the HF test and evaluation plan. Once the system function under examination has been categorized in these areas, tests should be selected that are commensurate with the level identified in the above areas. The information presented in Table 6.1 provides a high-level summary to define the level of effort and test fidelity required to evaluate an HF design based on the categorization of the attributes and characteristics.

Level of Interaction, Novelty, Complexity/Automation, Criticality, Dynamics, Training Requirements and/or Subjective Criteria		
Low	**Moderate**	**High**
- System Description & Drawing Review, - Visual/Manual Access Study, - Procedure Evaluation, - Task Analysis, and/or - Bench and/or Flight Tests	- System Description & Drawing Review, - Visual/Manual Access Study, - Procedure Evaluation, - Task Analysis, and/or - Bench Tests -Part-task - Demonstrations using: -Electronic Models, -Mockups, -Simulators, and/or -Actual Aircraft on the Ground	- System Description & Drawing Review, - Visual/Manual Access Study, - Procedure Evaluation, - Task Analysis, and/or - Bench Tests - Demonstrations using: -Electronic Models, -Mockups, -Simulators, and/or -Actual Aircraft on the Ground - Comprehensive, Full-task, Integrated Evaluations conducted in: - High Fidelity Simulators, and/or in - Actual Aircraft and Flight Environment

Table 6.1- Guidance for Defining the Level of Human Factors Test & Evaluation Required

6.7.8. Human Factors Evaluation Plan

A well-written evaluation plan provides a structured, consistent approach that documents the assessment, identification and resolution of HF issues. The plan describes the evaluation objectives, the evaluation approach, test equipment, data collection and analysis techniques to be used.

The purpose of a human factors evaluation plan is to define an evaluation approach for determining the acceptability of a specific aircraft or subsystem function. The evaluation plan defines how human factors testing and evaluation will be conducted. This evaluation should be conducted from a human-machine interface perspective of the operational functions of a system as the development of the products occurs. HF issues need to be considered in periodic design reviews of the products. Methods to take early corrective action for revisions to the product requirements and the design data need to be in place as HF issues are addressed and solutions resolved. This plan should consider appropriate operational issues and scenarios. This will include such items as defined mission of the aircraft, operational environment, expected weather during operation, etc. If it is planned to install the system in various aircraft categories and sizes, there also needs to be an evaluation to determine if versions of configurations need to be addressed. The plan needs to cover the design from conception throughout the life cycle of the system. A key aspect of this process is to identify design and/or operational deficiencies that may degrade human-system performance.

The use of testing to discover design and operation deficiencies can provide valuable information about the impact these deficiencies will have on pilot-system performance and aircraft safety. Based on the results of these evaluations, decision-makers can better determine whether the system is acceptable as is, or if modifications are necessary. Further tests and evaluations may be required to determine the adequacy of alternative configurations or of modifications incorporated to address specific design and operation deficiencies. To guide this process a structured, comprehensive test and evaluation plan should be developed.

The plan should include methods to take early corrective action for resolution of issues identified during the evaluation. This may include deficiencies to the product and any design modification. At the end of a development program, a report(s) should be completed documenting the history of the HF evaluation. A summary of the results, conclusions and recommendations should be generated. The report should be clearly and succinctly written in terms appropriate for upper-level management to enable them to determine that HF criteria have been met.

Although an HF program plan may vary in form and content, there are certain elements that should be included and addressed in any plan. This plan should be at an overview level supplemented by detailed documents, test methods, checklists, etc. as necessary for a particular program. Appendix D contains a suggested structure that may be used for developing a HF evaluation plan.

7.0 HUMAN FACTORS DESIGN AND EVALUATION GUIDELINES

The human factors evaluation should concentrate on the cockpit/flight deck as a whole. This may mean that evaluations include individual components, as well as an evaluation of the integrated system. When considering HF evaluation, the appropriate operational requirements need to be considered in addition to the specific evaluation at the cockpit/flight deck level. The design and evaluation best practices guidelines provided in this section have been divided into the following two sub-sections:

– Systems and Equipment Design Guidelines.

– Functional Integration Guidelines.

The Systems and Equipment Design Guidelines sub-section focuses on specific and individually defined topics. These items may be assessed by inspection or measurement of physical characteristics such as size, shape, position, brightness, etc. of the displays and controls in an aircraft that provide the human interface to the cockpit. However, they may require the use of the following types of assessment tools.

1. Workload analysis and task performance analyses can take on several formats with several different techniques. They can focus on a subsystem (e.g. hydraulic system control); on a collection of subsystems (e.g. avionics suite); or on the entire cockpit. These evaluations are recommended for new installations or as appropriate for retrofit installations into existing cockpits. Because the human-machine interface usually involves consideration of several factors, these analyses will usually include a number of variables for computing the results.

2. The results of tests conducted on a sample of the user population and characteristics may be necessary. If it is possible, it is preferred that human performance be objectively measured. Measured performance data may be used to document the human performance of the tasks that the subsystem or system requires. The data for any of these approaches may be taken in part-task simulators, full-motion simulators, or on actual aircraft as defined in the HF evaluation approach to be used.

The approaches that are expected to be used may be documented in a Program HF Evaluation Plan. Such a plan may be used as a communication vehicle during the program and when regulatory approval is requested. (See Section 6 and Appendix D for a description of the contents of such a plan.)

The Functional Integration Guidelines sub-section focuses on topics that are the result of placing sub-systems or systems in the same cockpit. They are often the result of introducing new levels of integration of previously separate display or control functions. In any case, most of the issues related to integration will require the use of the assessment tools and sample population methods noted above. In some instances redundant information may be presented in more than one section. This has been done intentionally to reflect important aspects of one particular criterion to one or more other criteria.

These best practices guidelines are shown in a table format. Each element is defined providing the following information in each block in the table:

7.0 Section Title **(Short description)**	
	Performance Based Guideline: (Minimum acceptable performance) This guideline block defines the intended outcome or capability that the specific design is to provide to the pilot. This guideline is not intended to define a specific design.
	References: (Criteria that supports Performance Based Guideline) The reference block contains 14 CFR PARTs and industry documents that provide a basis for the criteria and/or contain additional relevant information or guidance on the subject area.
	Critical Design Activities: (Necessary steps to include in the design) The critical design activity block indicates the design approach that needs to be taken to ensure that HF criteria are addressed. This block may show some examples of how the performance defined for this type of design has been evaluated in the past.
	Performance Rationale & Background: (Why guideline is needed) The performance rationale & background block provides reasons for the performance guidelines being used, e.g. for the specific element in question, what value does the defined performance criteria bring to the pilot.
	Evaluation Procedure: (Methods for completing an evaluation) An evaluation procedure is shown to provide an acceptable method to evaluate and test that a function or feature meets the Performance Base Guideline. This may not be the only method to make such an evaluation. More than one procedure may be shown here. This procedure(s) is based on previous experience and rationale for current technology and may be applicable to new technology approaches.
	Evaluation Rationale & Background: (Why an evaluation is needed) The rationale and precedence for use of the evaluation method is provided to indicate the rationale that has been used in the past for evaluation of this item as well as experience and possibly results of studies and more formal documented activities that have occurred.

7.1 Systems and Equipment Design Guidelines

The Systems and Equipment Design Guidelines for the cockpit define allocated functions, cockpit arrangement, physical characteristics of the user, seat locations, and other physical characteristics of the cockpit and its systems.

7.1.1. Anthropometric Considerations

7.1.1.1. Anthropometric assessment (The physical characteristics of the human associated with the cockpit arrangement.)	
	Performance Based Guideline: The controls and displays are to be arranged and located within the cockpit/flight deck in such a manner that the pilot can adequately see, reach and manipulate those controls and displays needed to operate the aircraft systems. All equipment should be operable from the normal pilot's station without removal of the safety belt or other equipment.
	References: 14 CFR PART 23.773; 14 CFR PART 23.1321,British Defence Standard 00-25 Part 2, Feb 1997
	Critical Design Activities: Application of anthropometric guidelines (e.g., arrangement and location of controls and displays) has the intended purpose of placing the pilot within the aircraft system such that the following activities are adequately supported for the majority of the intended population: – Visual surveillance external to the cockpit -Detection of airborne traffic -Viewing for landing -Viewing for obstruction avoidance – Visually accessing internal displays and controls such that a clear and unobstructed view, free from glare and reflections, can be obtained such that external visual surveillance is minimally disrupted. – Manually accessing and manipulating controls with minimal potential for improper or accidental activation. HF considerations for Anthropometric Design Parameters. – Define a Design-Eye-Reference-Point (See note in Rationale block.) – Define User Population. – The cockpit should be designed to accommodate the widest possible range of user population physical characteristics as practical. – Define Critical Dimensions. – Establish Test Considerations mockups, computer models, etc. This could be accomplished by defining cockpit visual and manual access areas. – Consider seat restraints when locating controls and displays. – Evaluate emergency evacuation considerations. – Displays and controls should be visually accessible without obstruction. (Consider visual sight limitations of user population.) – Controls should be accessible and able to be manipulated with minimal potential for inadvertent activation

7.1.1.1. Anthropometric assessment

(The physical characteristics of the human associated with the cockpit arrangement.)

Performance Rationale & Background:

It is essential to accommodate the Anthropometric characteristics of the user during the development of the cockpit including its systems and equipment. Inability to provide adequate outside-the-cockpit viewing and inability to see and reach critical controls and displays compromises safety and has contributed to accidents and incidents.

GENERAL NOTE WHEN APPLYING HF GUIDELINES:

The manufacturer should always establish a design-eye-reference-point for the aircraft being developed. The pilot design-eye-reference-point whether operationally used or not is essential in defining the physical arrangement of a cockpit in a consistent manner based on good HF principles. This reference point should be determined by considering the seat location, seat adjustment capability, pilots sizes and the resulting position of the pilot's head when the pilot is seated in a position to operate the aircraft. The reference point will establish the center of the design-eye-box. The design-eye-box allows a movement of the pilot's head 2½ inches in each direction from the center of the box. The design-eye-box allows this minimum of head movement that is still considered to be within the eye reference position.

Evaluation Procedure:

Determine user population physical characteristics, including all critical physical dimensions (e.g. sitting eye height, arm reach, leg length, stature, etc.). Then evaluate how well the cockpit design accommodates the intended user. Evaluations are typically performed using the following three methods:

1) Place mannequins, representative of the population at various points on the normal curve, on paper drawings to get an idea of accessibility of cockpit features.

2) Ensure that a cross section of the user population is used when evaluating a system or parameter utilizing a cockpit mockup or development fixture to determine the accessibility of cockpit features.

3) Create a three dimensional model of the design in a computer-aided drawing environment and insert human models representative of different physical dimensions (or worst case) selected from the normal curve of the chosen population to determine the accessibility of cockpit features.

Visual accessibility can be addressed in each case through superimposing the visual field angles from design-eye-point over the engineering drawings of main instrument panels, or confirm compliance in mockup evaluations. The cockpit should be designed for the widest range of user population physical characteristics.

Evaluation Rationale & Background:

Anthropometric testing is needed to establish design compatibility with the intended user population. Inability to provide visible and functional accommodations may compromise safety. Inadequate accommodation has been shown to contribute to pilot error and aircraft accidents and incidents.

7.1.2. Controls

7.1.2.1. Direction of control motion

(How controls should move in relationship to pilot input and expected response.)

Performance Based Guideline:

Controls must produce system responses that are directionally compatible with the control movements.

References:

14 CFR PARTS 23.671 (b); 23.779; 23.1301 (b); 25.777 (b); 25.779

Critical Design Activities:

Verify that aircraft or function response to each control is in the same relative direction as the control is moved.

Cockpit design philosophy should provide a consistent relationship between control motion and the resulting response. User expectations and societal conventions need to be considered in the design process. For example, when the power levers or throttles are moved forward, one expects the aircraft to increase in speed due to an increase in thrust. Some examples of expectations are:

- Knobs used for heading, course, path commands, guidance, etc. should turn clockwise for right turns or commands to the right, and counterclockwise for left turns or commands to the left.

- Alternate-action buttons that latch should be "on" when indented or latched. Momentary buttons need annunciation unless response is evident, e.g. engine start will cause an engine response immediately.

- Switches in the side consoles, instrument and bulkhead panels, overhead or on pedestal have been arranged as per the following:

  Option 1;
  Horizontally oriented side consoles, overhead and pedestal = forward for on, rearward for off.
  Forward instrument panel, vertically oriented side consoles, and bulkhead panels = up for on and down for off.

  Option 2;
  Horizontally oriented side consoles and pedestal = forward for on, rearward for off.
  Overhead panels = forward for off, rearward for on.
  Forward instrument panel, vertically oriented side consoles, and bulkhead panels = up for on and down for off.

  Options 1 and 2 should not be mixed. Also, when the same systems are used in more than one airframe, the concept for each of these configurations needs to be addressed at the outset of the design.

Performance Rationale & Background:

The movement of all cockpit controls must be natural and consistent to avoid incorrect pilot response.

Evaluation Procedure:

Determine that the controls motion is consistent with the expected aircraft or system response. The analysis that supported the design approach used needs to be validated with procedural evaluations utilizing representative users. The results of these evaluations should be documented.

Evaluation Rationale & Background:

Ideally, all aircraft regardless of type should have a standard philosophy for control direction movement. The basic concern is to evaluate whether the function being controlled by a specific control motion responds as expected to avoid human error and to enhance safety. It is critical to flight safety that all controls operate the systems consistent with the pilots' expectations.

7.1.2.2. Identification of controls

(The ability to select the correct control for the desired function.)

Performance Based Guideline:

Pilot input controls should be readily identifiable as to the function they control. The control must be identifiable from the pilot's normal operating position in all ambient light conditions.

References:

14 CFR PARTS 23.671 (b); 23.677; 23.777(a)

Critical Design Activities:

Perform early analysis to determine that each control meets one or more of the following criteria.

- The function of the control is intuitive.
- The shape of the control is unique and, where possible, meaningful so it can be identified directly with the function.
- The control is associated with a related function such that the control function is understood by its physical location.
- Each control is labeled for direction of movement, function being controlled, or with the units of the function as applicable.
- Multi-function controls need not be labeled providing that their functions are obvious by either configuration or location.

An alternate approach may be accepted when rationale is provided that validates the control meets the intent of this requirement. Also see the section on Data Interface Designs and Functions.

Performance Rationale & Background:

The pilot must be able to find specific controls in the cockpit and the control must be identifiable in some manner under all environmental and lighting conditions.

Past implementations have used a variety of approaches to provide this capability. These include unique control shapes (throttle lever, mixture control, flap handle), engraving on the control (HDG or a heading icon on the heading knob, CRS or a course icon on the course knob), and identifiable because of location (line select key next to a display menu). These methods have been successful to varying degrees. Every attempt should be made to use common and intuitive nomenclature and abbreviations.

Evaluation Procedure:

The process should begin with the review of control design documents and drawings. Ensure that all controls are identifiable such that their function is either obvious, due to one or more design characteristics, or that the control is properly labeled as to its intended function. Once the control hardware is available, evaluate it in the areas discussed previously. For some controls it may be necessary to indicate its direction of operation (movement). As soon as possible, evaluate the controls installed in their designated locations in a geometrically accurate mockup or the actual aircraft. Be especially attentive to the capability to locate, identify and operate the control from all potential seating positions. If the aircraft has a design eye locator, conduct the evaluation from that position. During reviews and evaluations, ensure that:

- recognized industry standards have been used as much as possible for the design of the physical characteristics (size and shape) of the control and its labeling,
- labels identify the function of the control and are applied consistently across the cockpit,
- the symbol or number/word/abbreviation to identify the control is marked on the control or immediately adjacent to the control,
- multi-function controls are located immediately adjacent to the display function, annunciation or menu label and clearly associated with it by placement or pictorial indication.

Evaluation Rationale & Background:

Evaluation testing needs to ensure that a control can be unambiguously identified by the pilot and moved in a manner to achieve the desired result from the system.

7.1.2.3. Tactile feedback

(The physical feel and feedback of the control back to the user when it is operated.)

Performance Based Guideline:

Controls should have a friction device, tactile feel or other method to allow the pilot to receive feedback that pilot response has been received by the system.

References:

14 CFR PARTS 23.1301(d); 23.1309(b)(1); MIL-STD-1472F

Critical Design Activities:

Determine that each control device has been evaluated to meet accuracy and feel requirements of the installation where it is being used.

Iterative testing will likely be necessary to complete the design activities to determine the level of tactile feel needed for a particular device.

– Touch screen sensitivity should be such that the pilot physically touches the screen before an input to the system is completed. Annunciation should change when an icon or screen location is touched. Contamination on the screen must not create unusable selection of functions.

– Touch pad sensitivity should be such that the pilot physically touches the pad before an input to the system is completed. For functions where space is available on the touch pad to allow the pilot to unambiguously make a selection by touching the pad in a unique area, absolute locations on the pad may be used. Relative movement of the finger on the pad, like a computer mouse, may also be used. In either case, intuitive knowledge, cues, annunciation, locator marks, etc. should be provided so the pilot understands the means of system operation.

– Keyboard keys need to have adequate positive depression force to ensure that the parameter selected is obvious to the pilot. Annunciation is needed when a selection is made. There is a need to show that the keyboard is usable under various environments, e.g. vibration, turbulence, etc.

– Joy Sticks and track balls need adequate friction or pushback force to ensure the user exerts a positive force to change the position of the device. There is a need to demonstrate that environmental conditions do not affect operation during different phases of flight and that response is such that movement of the control results in the expected response of aircraft or display relative to the direction of movement of the control.

– For other types of control devices refer to referenced design guidance documents in Appendix A.

Performance Rationale & Background:

The movement or resistance pressure of a knob or switch device needs to be adequate so that the pilot realizes that the desired selection has been completed. On the other end of the spectrum, the device should not move inadvertently or have such little movement or resistance pressure that the pilot can not sense when the selection is complete.

The various knobs, buttons, switches, etc. allowing pilot inputs must have adequate feedback to the pilot to provide tactile feel to positively allow adjustment of the control to the resolution needed by the system. This feel can be implemented in a number of ways, e.g. wafer springs, detents, locks, pressure, over center clicks, etc. Additionally, these tactile feel approaches will ensure that the control will not move or the output drift when environmental conditions are present, e.g. vibration, changing temperature, shock, turbulence, moisture, etc. Some input devices need to have additional appropriate feedback or annunciation to the pilot.

7.1.2.3. Tactile feedback (The physical feel and feedback of the control back to the user when it is operated.)	
	Evaluation Procedure: Activate all controls, buttons, and switches to ensure that they have physical (tactile) feedback to the pilot to indicate that a selection has been made. Review evaluation processes and reports that indicate that an acceptable level of evaluation of tactile feedback of the various input devices has been made for the system. Operate the input devices noting that physical resistance to movement is present. The resistance should be high enough that a selection can be accomplished without an incorrect or double selection of a function occurring. The resistance must be low enough to make the selection correctly and repeatedly. For controls that have been previously approved, little evaluation is necessary.
	Evaluation Rationale & Background: Each input device should have some resistance to movement so that it will stay in the last position selected under conditions of vibration, inadvertent hitting of the device, etc., but adequate feedback so the completion of an operation is obvious.

7.1.2.4. Lighting of controls (The flood or integral cockpit lighting provided to the pilot to locate and legibly read cockpit controls.)	
	Performance Based Guideline: All controls should be easy to locate and read under all ambient lighting conditions. Control lighting should not interfere with visibility internal to the cockpit or viewing tasks to the external environment of the aircraft.
	References: 14 CFR PARTS 23.1311(a)(2); 23.1381 and AS-4103
	Critical Design Activities: Design individual cockpit components to have lighting characteristics and controls that meet consistent criteria so the pilot can see, find and read each display or control in all ambient lighting conditions (direct sunlight to total darkness). Designs should provide uniformity in lighting and consistent maximum and minimum brightness levels across the controls.
	Performance Rationale & Background: It is necessary to ensure that the pilots can find each control under all anticipated lighting conditions to make the correct input for each parameter required for safe flight. For example, dark cockpits that have highly integrated systems may provide relief to the pilots causing them to make fewer errors. With a dark cockpit/flight deck configuration, little spill lighting is present to illuminate peripheral controls and input devices. The solution for these systems is to properly light, label and annunciate functions integral with the control in an appropriate manner as the device is needed throughout various phases of flight. However, the lighting of one control should not interfere with the viewing and identifying of adjacent controls. Light leaks should be minimized to reduce unwanted light from entering the cockpit.
	Evaluation Procedure: The intent of this evaluation is to ensure that the pilot can find and select the correct input device or display located throughout the cockpit for normal operating positions and conditions. Sitting in the pilot position in the cockpit/flight deck, determine that each control and device needed by the pilots to perform their duties can be found in all ambient lighting conditions (direct sunlight to total darkness). The evaluation should address the criticality of data being used in the cockpit. For those data that are essential to safe flight, the controls should be identifiable without undue movement of the pilot's head or body. Additionally, care should be taken during the evaluation to ensure that another cockpit control or display does not hide the identifying label or symbol.
	Evaluation Rationale & Background: The evaluator should consider the effects of both aircraft lighting (cockpit and external) and natural illumination across the expected range of operation. Dimming ranges for control lighting should be good enough to obtain adequate readability throughout the expected ambient lighting environment.

7.1.2.5. Location and arrangement

(The development of logical locations for cockpit controls.)

Performance Based Guideline:

Hardware input controls should be placed in the cockpit and arranged in a consistent manner to allow ease of use by the pilot. The criticality of the function being controlled must also be considered in determining the position of the control in the cockpit/flight deck.

References:

14 CFR PART 23.777(b); ARP-4102; MIL-STD-1472F; Aviation Human-Computer Interface (AHCI) Style Guide.

Critical Design Activities:

The criticality of each function in the cockpit/flight deck must first be established. A particular control would then occupy a position in the cockpit consistent with the criticality of the function it is controlling.

Other principals to consider when designing for control location include:

- functional arrangements (controls with related functions are placed together)
- arrangements according to importance (controls with the most important functions are given prime locations)
- optimal location arrangements (controls are arranged so that optimal manipulation of the total ensemble is achieved)
- reviewing above references of industry best practices for standardized instrument panel layout

In addition to functional criticality, determine which controls are used most frequently and in what sequence. Design the cockpit/flight deck system so that the controls used most frequently are placed in preferred locations and in relatively close proximity to each other. When considering sequence of use, it is recommended that the controls be placed in a proximal or spatial sequence that corresponds to the order in which they are to be used. An example of applying both principles is the fuel shut off control that is in proximal location to the throttles, which are used sequentially and frequently together.

Performance Rationale & Background:

Controls and displays that need to be readily available to the pilots should be located in a more accessible position than those that are less critical. Additionally, sequentially and frequently used controls need to be addressed.

The cockpit has limited area to mount the controls and input devices.. This can lead to placing controls to close to one another and creating the potential for inadvertent activation. In situations where controls must be closely grouped consideration should be given to protecting critical controls from inadvertent operation by guarding them (put covers, shields, etc.) or increasing the amount of force necessary for operation.

The location of navigation controls becomes very important if the navigation systems are used during critical phases of flight. Some functions on a navigation control display unit (CDU) may be located on the rear center pedestal out of the pilot's primary field-of-view, while functions that need to be used in higher workload phases of flight, e.g. approach, need to be located in the primary FOV. As an example, if a mode selection is necessary on approach, then provisions should be provided to place this selector in a primary FOV location.

Evaluation Procedure:

Review the criticality of the data displayed in the cockpit displays and the input devices for those data. Those display and input devices needed to safely fly the aircraft in critical phases of flight should be located in the pilot's- primary FOV. Specific command and position data, e.g. navigation systems, including GPS, course deviation and steering data, should be in the primary FOV. Other displayed data and input devices for lower criticality functions may be in the secondary FOV.

Evaluation Rationale & Background:

Those data and input devices needed in real time to fly the aircraft need to be located in front of the pilot flying the aircraft. The design location philosophy should provide a basis for defining the evaluation procedure. These evaluations are to determine the effects of the location of the various controls and determine if they are consistent with expected pilot responses, in addition to avoiding negative transfer.

7.1.3. Display Characteristics

7.1.3.1. Contrast

(The ability to distinguish items on a display under various ambient lighting conditions.)

Performance Based Guideline:

The display should provide adequate contrast to be easily readable under all operational ambient lighting conditions that will be encountered during flight (direct sunlight to total darkness). Reflections and glare should not result in unreadable displays.

References:

14 CFR PART 23.1311; AC 23.1311; MIL-HDBK-87213; SAE ARP 4256; SAE ARP 1782

Critical Design Activities:

Complete an analysis to establish appropriate values of brightness and contrast needed to operate in the ambient light environment in the cockpit/flight deck. Establish a means to evaluate, measure and record lighting values of the display. Conduct a user test in the cockpit for both day and night environments.

Displays should be constructed, arranged, and mounted to minimize adverse levels of interference from reflections of illumination sources, windows, and other visual displays.

Performance Rationale & Background:

Because of differences in transparency, optical properties of glass, cockpit/flight deck arrangement and colors used, each airframe presents a unique problem to ensure that the pilot can read the displays from direct sunlight to total darkness.

Contrast is the measure of relative light and dark luminance on a display. This is a required element in the ability to discern a symbol or textual message against the background. Minimum contrast ratios should be specified for both bright and dark ambient light conditions.

Contrast is affected by unwanted reflections of light from another source back to the viewer. Both spectral and diffuse reflectance contributes to this and serves to reduce the effective contrast ratio for the display under conditions of external illumination. While these requirements may be specified individually, measuring display contrast under expected ambient conditions adequately covers the combined effect.

Typical brightness/contrast values used in the past are contained in MIL-HDBK-87213 and are as follows:

Day contrast (alphanumeric, graphics, pictorials and video) 3 or 4:1 contrast ratios for graphics provided the contrast is measured against spectral and diffuse backgrounds.

Night contrast. Dark contrast should be such that the display is readable under night conditions. Generally, dark contrast is easier to attain and will be considerably higher than that achievable under high ambient conditions.

Evaluation Procedure:

In the target cockpit or one that is similar in arrangement, materials and color, evaluate that the displays are readable in direct sunlight to total darkness. The lighting controls should provide adequate range to meet this guideline. The direct sunlight lighting conditions to be considered need to be agreed between the designer and the evaluator prior to the testing. To be readable, the primary critical data needs to be visible enough to read the data in a timely manner and without error.

7.1.3.1. Contrast
(The ability to distinguish items on a display under various ambient lighting conditions.)

Evaluation Rationale & Background:
The ability to read the primary data must be adequate to allow the pilot to safely fly the aircraft under adverse lighting conditions without significant added workload.

The dynamic range of electronic displays should be adequate to meet the requirements for operation at night and still bright enough under bright sunlight conditions. The intent of this guideline is to provide a readable display for the required operating environment without creating additional work for the pilot, e,g. having to shield the display to read it. It is not intended to require dynamic ranges far beyond what is actually needed to make the display usable. It is necessary to determine the lowest acceptable brightness lighting level under which this test should be conducted. One method is to adjust the dimming control to a value determined by laboratory or ground testing and then to evaluate the acceptability of the display brightness under direct sunlight conditions.

7.1.3.2. Luminance uniformity and balance

(The balance of the display parameters so that each is equally readable with each specific dimmer setting.)

	Performance Based Guideline: The symbols, graphics and alphanumeric parameters need to appear uniformly lit across the faces of the displays.
	References: 14 CFR PARTS 23.1311; 23.1301; 23.1321; and MIL-HDBK-87213; ARP 1782
	Critical Design Activities: Large area uniformity of +/- 20 percent within one-fourth of the display and +/- 40 percent overall has been required for displays. Tighter tolerances are usually not necessary since the eye is not very sensitive to brightness variations over large areas. Abrupt changes (discontinuities or edges) however, are objectionable. A much tighter requirement (+/- 10% within 10 mm has been used) is needed for small area uniformity, especially if the non-uniformity form patterns, such as rows or columns. Designs should provide uniformity in lighting and consistent maximum and minimum brightness levels across the displays.
	Performance Rationale & Background: Lack of uniform brightness and unbalanced display of characters can lead to the pilot missing critical data on a display. Care needs to be taken to have this uniformity and balance at all lighting conditions in the cockpit and throughout the dimming range of the displays.
	Evaluation Procedure: Evaluate that as the brightness is adjusted from full dim to full brightness that the characters appear to be uniform in appearance. Review any available design measurement data to verify that uniformity and balance have been maintained in the design.
	Evaluation Rationale & Background: Uniformity and balance of characters are dependent upon a variety of design parameters. The end result should be a display where all characters give the appearance that all the symbols and alphanumerics are equally readable. Each display as well as the full complement of displays in the cockpit should have uniform brightness and balance to be easily readable.

7.1.3.3. Luminance and dimming ranges

(The required minimum and maximum values and uniformity of lighting across the range of brightness for controls and displays with common dimming controls.)

	Performance Based Guideline: The dimming range and tracking of the dimming for displays and controls will be as consistent as possible for all displays on one dimming control. The dimming control may be a manual and/or automatic dimming device.
	References: 14 CFR PART 23.1311(a)(2)
	Critical Design Activities: All displays in a cockpit are used under varying ambient lighting conditions. This requires manual lighting controls for all LCD equipment. The range of the control shall permit the displays to be legible under all expected ambient luminance. The control should provide multiple steps or continuously variable illumination. If automatic dimming is implemented, the rate of change of dimming with changing light conditions needs to account for the characteristics of the human eye response. Avoid sudden or extreme changes of illumination levels.
	Performance Rationale & Background: The human eye does not perceive light linearly. To make adjustments to lighting very useable in a cockpit environment it is desirable to make the lighting track non-linearly and have the lighting range adequate to cover the full range of lighting conditions that will be encountered. The lighting on different displays need to be matched in a manner so that the eye perceives equal light levels on all the cockpit displays and controls as much as possible. One of the worst case scenarios exists in a bubble canopy designed to have readable displays in a 10,000 foot candle environment. This of course is not the case for other cockpit configurations such as those that are partially enclosed. The best way to determine the optimum display performance and tradeoffs is to conduct actual measurement of ambient light for the particular cockpit configuration. Once that is established display range design can be determined.
	Evaluation Procedure: By examination and/or analysis determine that the brightness of lighting tracks all the displays and controls on each manual or automatic dimming control from the brightness needed in direct sunlight to total darkness. The final evaluation test conditions should make use of natural lighting versus artificial lighting in a laboratory environment. During this test the color should remain constant across the displays and controls. Individual dimming controls may be installed at individual instruments to control the relative brightness between instruments.
	Evaluation Rationale & Background: The adjustment of dimming in the cockpit should track and be appropriate for the ambient lighting conditions to minimize pilot workload and to provide readability of all displays connected to a single control.

7.1.3.4. Flicker and update rates (Level of visible flashing of the display parameters when the display is in use.)	
	Performance Based Guideline: The display should not exhibit flicker, jitter, noise or display lags.
	References: 14 CFR PART 23.1311; AC 23.1311-1A; AS-8034; ARP-1068B; MIL-HDB-87213
	Critical Design Activities: To support a design, the display manufacturer needs to define update rates of data, screen refresh rates, etc. that provide acceptable display flicker levels when minimum update rates are used in the system.
	Performance Rationale & Background: Refresh rates of data on displays must be fast enough so that flicker or other perturbations in the display data are not noticeable to the human eye. Typically, the refresh rates causing flicker and noise on the display are a result of inadequate memory and/or speed of the processor being used in the design. With new technology, this is seldom a problem. A standard 30-Hz frame, 60-Hz or higher field raster video is widely used on CRTs. Stroke written graphics and computer-generated raster graphics with thin lines are written at 50 Hz (typically found to be acceptable for some applications) non-interlaced for PC monitors. LCDs generally must be driven with symmetric drive voltages; any asymmetry in this system results in flicker at one-half the frame rate. Update rates of data on displays must be fast enough so that required symbol motion is free from objectionable lag or stepping. Map displays may be judged as adequate with a much slower update rate (1 Hz) than critical data such as attitude, heading or air data symbology (>15 Hz).
	Evaluation Procedure: Put the system in a configuration where the maximum amount of data is being presented on all the displays in the cockpit with movement of data on the display. Note that flicker or update rates of data are not perceptible and the motion is smooth to the eye under these conditions.
	Evaluation Rationale & Background: Flicker and display noise can be controlled by the design of a product. A 50 or 60HZ refresh rate is typically adequate to remove traces of visible flicker on the display. If the designer of the hardware has shown that a minimum level of refresh rate is implemented in the design, little evaluation is necessary. This problem was initially a concern on the original digital systems where the quantity of data being presented was taking all the capability of the processor and memory to support the function being displayed. This is usually not a problem, but a check needs to be conducted to ensure that the minimum guidelines have been met.

7.1.3.5. Legibility and visibility (How readable a display is.)	
	Performance Based Guideline: Displays should be legible under all anticipated viewing conditions. Alphanumeric information displayed to the pilot should have adequate size to allow for easy viewing from the cockpit-design-eye considering the given viewing distance and viewing angle.
	References: 14 CFR PARTS 23.773 (2); 23.1321; 23.1311; and DOT/FAA/CT-96-1; MIL-HDBK-87213; British Defence Standard 00-25 (Part 7)
	Critical Design Activities: Typically a viewing distance of 16 to 28 inches should be provided. The vertical viewing angle for alphanumeric characters should be 16 minutes of arc for black and white displays and 21 minutes of arc for color displays. The preferred angles are 20 min and 30 min respectively. The following formula can be used to determine minimum sizes: Visual angle (min) = (57.3) (60)L/D Where L= size of the object and D= distance from the eye to the object. Note: sixty minutes of arc = one degree, 17.45 milli-radians (mr) = one degree, 3.44 minutes of arc = 1 mr. Size in degrees = arctan (symbol size/viewing distance). Recommendations for character height-to-width ratio, stroke width, spacing between characters, spacing between words, spacing between lines and viewing angle should also be considered Recommendations for these values are contained in Section 7 of DOT/FAA/CT-96-1.
	Performance Rationale & Background: Adherence to the recommended guidelines above help ensure readability of displays under all expected operating conditions. These values will also impact the amount of information that can be displayed without causing undue clutter. Unwanted glare and reflections in the cockpit can impair safety of flight by inhibiting proper view of the outside scene. It can also cause interference with the performance of normal tasks, cause operational mistakes and increase pilot workload. As a result, attention must be given early in the design process to develop a system that minimizes unwanted reflection and glare.
	Evaluation Procedure: Using the manufacturer's defined design-eye-position, record viewing distance and then measure character parameters using the above guidelines as a reference. In full sun on the ramp with various aircraft orientations, determine that reflections and glare do not create unreadable displays. Other techniques can also be used to perform the evaluation. They can include the use of cockpit mockups and other similar fixtures or the aircraft itself. Evaluation of engineering drawings may also be helpful.
	Evaluation Rationale & Background: Cockpit lighting evaluations are needed to determine the adequacy of display readability. The evaluations should include examination of any objectionable glare or reflections and how they can be eliminated. The evaluations should be conducted early in the program to avoid expensive redesign later in the program.

7.1.3.6. Resolution

(The physical quality of a display that translates into the subjective assessment of sharpness or crispness.)

Performance Based Guideline:
The resolution of the characters, symbols and data presented on the display shall be adequate to allow the pilot to unambiguously read the display.

References:
14 CFR PART 23.1311; AC 23.1311-1A; AS-8034; ARP-1068B; DOT/FAA/CT-96-1

Critical Design Activities:
Generally for the display of alphanumeric information on a CRTs the resolution should be at least 1.6 resolution elements per mm. (40 per inch). Alphanumeric characters should have at least 10 resolution elements per character height. If high reading speed is required, high-resolution monitors with at least 3.5 pixels per mm (90 pixels per inch) should be used. For displaying complex symbols and graphic detail the display should have at least 3.9 resolution elements per mm (100 per inch).

Performance Rationale & Background:
Resolution is very dependent upon many other display design parameters (brightness, contrast, viewing distance, location etc.). Resolution is also measured differently depending on the display medium (e.g. CRTs versus Flat Panel displays). As resolution increases, more detail can be distinguished or identified. On present day CRTs, resolution of values greater than 100 pixels per inch are easily obtained.

Resolution adequacy is always complicated and varies widely depending upon the user's perceptions and visual capabilities. Resolution represents the display's ability to present sharp edges and details in an image. The quality of the resolution of the display system significantly affects information extracted from electronic display images. The resolution must be sufficient to provide the user with appropriate levels of information so as not to create confusion, make errors, or require an unreasonable amount of time to extract the data. Resolution is measured differently for CRTs as opposed to Flat Panel Displays. Matrix addressed displays require smoothing of rotated symbols (anti-aliasing) to reduce distraction artifacts of motion.

Evaluation Procedure:
Set up the displays in a configuration with the smallest symbology set present and determine that the symbols can be differentiated under all orientations. Set up dynamic conditions and note that motion is acceptable and that symbols can be differentiated. Evaluate resolution in flight conditions where vibration and turbulence are present.

Evaluation Rationale & Background:
Static resolution and dynamic resolution should be evaluated with the prime objective to ensure that the data and symbols can be differentiated. Under dynamic conditions, symbol motion should appear smooth when the intended function is to be continuous. Low resolution displays should be evaluated for filling in of hollow symbols and with respect to aliasing effects when dynamic motion is present.

7.1.4. Display Content and Symbology

7.1.4.1. Placement and content of symbology

(The placement of information and symbology on displays in the cockpit/flight deck with respect to the pilot's ability to read that data.)

Performance Based Guideline:

The data content and symbology on displays and instruments shall be located such that primary, secondary, and lower levels of information are viewable by the pilot.

References:

14 CFR PART 23.1311; AC 23.1311-1A; AS-8034; ARP-1068B; NAWCADPAX-96-268-TM; DOT/FAA/CT-96-1

Critical Design Activities:

Displays provide the visual communication to the crew of the primary, secondary, and lower levels of information criticality to allow the performance of the required tasks. The data presented on the displays should contain the data that most efficiently provides the information needed by the pilot to safely control the aircraft.

Displays can take on many physical shapes. Discrete electromechanical instruments; individual electronic displays; a single large electronic display; and all combinations in between. Those combinations will have to satisfy the application's availability and reliability criteria. The display's physical size must allow data to be presented to satisfy the visual accessibility requirements that each level of data criticality requires.

There are several techniques that can be used to determine what level of data should be presented to the pilot under specific operating conditions and where it should be located based on the level of criticality for each type of information in the cockpit. One such tool is a functional allocation matrix. The tool chosen should relate the following types of considerations:

- Cockpit functions being supported.
- Accessibility under normal and abnormal conditions.
- Criticality to the operation considerations.
- Type of display information being provided (alerting, information).

Based on the evaluation of each display element, it can be determined what level of criticality it provides. It is beneficial to conduct an early analysis of display layout. Utilize models and mockups to conduct evaluations of proposed display configurations.

Performance Rationale & Background:

Whenever a pilot is faced with a large amount of data on a display, including the display controls, the presentation content and the symbology become a prime factor in display design. Search times to locate specific information on a display are decreased along with errors by consistent placement of information. Location of recurring functional groups and individual items should be similar from panel to panel and display to display.

Evaluation Procedure:

A small team of evaluators representative of the expected user population is an example of an effective evaluation scheme. This team should include, but not be limited to, test pilots and operational evaluators. A survey questionnaire that focuses the evaluator's attention with a structured set of questions, with some type of rating scheme, and asks for areas of acceptability and areas for recommendations and improvements of the content and arrangement of symbology has been shown to be effective.

Evaluation Rationale & Background:

Expect to conduct the evaluation in an iterative fashion. Iterative evaluations, conducted early in the design process, help minimize changes at the end. Iterative evaluations during development further help refine the display arrangement. Structured survey devices provide the evaluators a means to focus their response on specific aspects of the display designs. It also allows the results of the evaluation to be quantified.

7.1.4.2. Data density and clutter

(The amount of data presented in an area of the display.)

Performance Based Guideline:

Displayed information shall be presented to the user in a manner that allows for rapid recognition and understanding. Display integration should enhance status interpretation, decision making and situational awareness.

References:

14 CFR PART 23.1311; AC 23.1311-1A; AS-8034; ARP-1068B; NAWCADPAX-96-268-TM

Critical Design Activities:

Once the collection of data to be presented on a single display has been determined, the iterative design process should focus on ensuring that data is grouped with some or all of the following in mind:

- The amount of data presented should be easily interpretable by the user.
- Recognizing the subjectivity of the topic, consider designing different levels of display data density that can then be decluttered.
- Provide a default condition containing only the data required for a particular phase of flight.
- Provide decluttering by selectivity.
- Provide decluttering by hierarchy of information level.
- Provide ease of restoring decluttered data.
- Using an industry de facto standard grouping.
- Provide information that is related because of its common subject.
- Provide information that is required to perform a task.

Symbology color selection can have a significant role in the perception of data clutter. Considerable effort should be given to the selection of a color philosophy for a given display, a set of displays, and the full cockpit collection.

Display information design should be as uncluttered as possible. Display presentations should be perceived as uncluttered. Provide only information essential to making a decision or performing an action. Any additional information should be easily selectable/retrievable by the pilot.

Search times increase with the amount of irrelevant information on the display. The display should use the simplest, most natural and intuitive display concepts commensurate with the information transfer needs of the pilot. Consideration should be given for locating all information related to a particular task on the same display.

7.1.4.2. Data density and clutter

(The amount of data presented in an area of the display.)

Performance Rationale & Background:

Displays easily become visually overwhelming, cluttered and confusing when they present too much information. Human visual performance deteriorates with high-density levels of graphic information. Performance deterioration may be evidenced by increased user response time and/or lowered accuracy of visual perception. The provisions of options for reducing the density levels of graphic information are becoming increasingly critical in user interface design. Displayed information shall be presented to the user in a manner that allows for rapid recognition and understanding. Display integration should enhance status interpretation, decision making and situational awareness. Simply adding information elements to a single display may cause significant loss of situational awareness if the display is cluttered.

Determination of data clutter and density is a very subjective evaluation. However, a display should provide a reasonable combination of natural data separation and data separation with the appropriate display design structures. The crew that uses the display needs to be able to find and understand the information being presented with a reasonable effort under normal and abnormal conditions. Considerable use of existing discrete and multi-functional display formats can be made to serve as examples for what has proven to be acceptable in the past.

Existing displays, that have successfully presented similar combinations of data to the new design being addressed, can serve as a starting point for a new design. However, design goals that include a reduction in cockpit displays, a combination of previously separate cockpit displays, or the development of new combinations of displays, will need to address the design of the data layouts from the beginning. They will have to address the separation of data. An iterative design process is one method that has proven most useful.

Evaluation Procedure:

Develop evaluation criteria based upon applicable guidelines and evaluate system design. Compare design with functional requirements.

Evaluate the visual displays under typical cockpit environmental and operational conditions with representative users.

A small team of evaluators representative of the expected user population is an example of an effective evaluation scheme. This team should include test pilots and novices to take advantage of both extremes of opinions. A survey questionnaire that focuses the evaluator's attention with a structured set of questions, with some type of rating scheme, asks for recommendations and improvements of the display layout and arrangement has been shown to be effective. Performance measures could take the form of timing how long subjects take to locate/identify critical information within a display window, with the caveat that a certain amount of learning would need to be factored in or out depending on the design goals.

Evaluation Rationale & Background:

Expect to conduct the evaluation in an iterative fashion. Iterative evaluations, conducted early in the design process, help minimize changes at the end. Iterative evaluations during development further help refine the display arrangement. Structured survey devices provide the evaluator a means to focus their response on specific aspects of the display designs. It also allows the results of the evaluation to be quantified using the rating scale as a measurement tool.

7.1.4.3. Formatting

(The location and characteristics of individual alphanumeric and other symbols in a display area.)

Performance Based Guideline:

The pilot that uses the display needs to be able to find and understand the information being presented with a **reasonable** effort under normal and abnormal conditions.

References:

14 CFR PARTS 23.1311; 23.1301 through 23. 1337; AC 23.1311-1A; AS-8034; ARP-1068B

Critical Design Activities:

Adopt a consistent organization for the location of various display features from one display to another:

- Commands should be entered and displayed in a standard location on the display.
- System messages should appear in standard location. Messages may be provided in window overlays.
- Information displayed to provide context for the pilot entries should be distinctive in location and format and consistently displayed from one transaction to the next.
- Menus should be displayed in consistent screen locations for all modes, transactions and sequences.

Once the collection of data to be presented on a single display has been determined, the iterative design process should focus on ensuring that data is grouped with some or all of the following in mind:

- Consider selection of either company or industry standard formatting.
- Maintain adherence to the selected formatting standards.
- Consideration for formatting that highlights the common types of information.
- Consideration for formatting that highlights information that is required to perform a task.

Symbology color selection can have a significant role in the perception of the data formats. Considerable effort should be given to the selection of a color philosophy for a given display, a set of displays, and the full cockpit collection of various displays. A consistent format for similar data display is a desired design goal. Usability under all normal and abnormal conditions is essential.

Performance Rationale & Background:

New or combined formats need to provide a means for the expected pilot population to interpret and understand the data in order to carry out the necessary tasks. Acceptable formatting involves a mixture of disciplines. Some of those disciplines will be subjective. Data with considerable prior display history already provides well-defined examples of what is acceptable.

Existing displays including annunciated switches, that have successfully presented similar combinations of data to the new design being addressed, can serve as a starting point for a new design. However, design goals that include a reduction in cockpit displays, a combination of previously separate cockpit displays, or the development of new combinations of displays, will need to address the design of the data layouts from the beginning. They will have to address the separation of data that formatting can provide. An iterative design process is one method that has proven most useful.

Evaluation Procedure:

A small team of evaluators representative of the expected user population is an example of an effective evaluation scheme. This team should include test pilots and novices to take advantage of both extremes of opinions. A survey questionnaire that focuses the evaluator’s attention with a structured set of questions, with some type of rating scheme, and asks for areas for recommendations and improvements of the display layout and arrangement has been shown to be effective.

Evaluation Rationale & Background:

Expect to conduct the evaluation in an iterative fashion. Iterative evaluations, conducted early in the design process, help minimize changes at the end. Iterative evaluations during development further help refine the display arrangement. Structured survey devices provide the evaluator a means to focus their response on specific aspects of the display designs. They also allow the results of the evaluation to be quantified using the rating scale as a measurement tool.

Documentation of results of various formats evaluated and the “paper trail” to a final configuration provides a basis for rationale when the final configuration is established for approval.

7.1.4.4. Symbology (The specific attributes of symbols used in a display.)	
	Performance Based Guideline: To the extent possible, a symbol should be: an analog of the object it represents, in general use and well known to the users or based upon established standards or conventional meanings.
	References: 14 CFR PART 23.1311; AC 23.1311-1A; AS-8034; ARP-1068B; NAWCADPAX-96-268-TM; DOT/FAA/CT-96-1; SAE-ARP 4102/7 Appendices A,B,C,D
	Critical Design Activities: Use visual coding to facilitate: – Discrimination among individual symbols. – Identification of functionally related symbols. – Indication of relationships among symbols. – Identification of critical information within a display. Symbols can be coded by color, size, location, shape, or flash coding as applicable. Coding shall be consistent within a system or unit of equipment and between similar units of equipment.
	Performance Rationale & Background: A consistent philosophy for the symbology should be defined. This philosophy should be used throughout all the displays in the cockpit/flight deck. Exceptions to this philosophy need to be considered carefully with respect to their uniqueness in the operation of the systems involved.
	Evaluation Procedure: Develop a checklist based on applicable guidelines and evaluate the system design. Compare the design with functional requirements. Evaluate location-coding methods under typical cockpit environmental and operational conditions with a representative pilot population. Previous approvals and results of formal evaluations may be used to validate the rationale for a particular symbology approach. Introduction of new symbology should have an operational evaluation to ensure pilot performance is not degraded when compared against an existing configuration.
	Evaluation Rationale & Background: Where guidance is provided in advisory material, it may be used as a reference to determine that the symbology is acceptable. Rationale may be used that shows consistency with this material and its intent to address variations in specific systems. New symbology may introduce negative transfer, the requirement for specialized training or other adverse effects.

7.1.4.5. Display cues and prompts (The advance information presented to an event occurring.)	
	Performance Based Guideline: Adequate indication (cues) should be provided to the pilot(s) to ensure safe operation within the normal flight envelope.
	References: 14 CFR PART 23. 1309
	Critical Design Activities: The presentation of all required flight information must be done in a manner that the pilot can readily understand in order to maintain the airplane within its normal flight envelope. Transient /dynamic conditions that would cause the airplane to exceed its normal flight envelope should be annunciated promptly so that pilot intervention will prevent a hazardous flight condition. This applies to excessive pitch, roll and yaw attitudes as well as high and low speed awareness. In addition, engine parameter monitoring should be accomplished to ensure the safest possible engine operation. These conditions need to be sensed and specific cueing should be developed and integrated in the system design.
	Performance Rationale & Background: Under dynamic flight conditions an aircraft may transition rapidly from normal to an overspeed, stall or unstable flight condition with little pilot awareness. With adequate display cues, the pilots will know before this condition occurs and be able to intervene so as to prevent the hazardous flight condition from occurring.
	Evaluation Procedure: Determine the critical flight conditions of the aircraft. Determine that under transition flight conditions, adequate cues are presented to the pilots before warnings occur when the conditions are present. Particularly approaches to stall and overspeed conditions and unusual attitudes should be evaluated. Failure conditions should be considered. Under these conditions either symbols on the displays or other equivalent cues need to be actuated as the aircraft approaches the transition condition.
	Evaluation Rationale & Background: The intent of cues is to have advanced indication of the impending occurrence of an undesirable condition. The cues need to be obvious to the pilot using changes in colors, flashing symbols, etc. that instill quick pilot response before a stall warning, overspeed warning or similar condition occurs.

7.1.4.6. Guidance commands and navigation position

(The steering and position information being used to actively guide the aircraft.)

Performance Based Guideline:

Guidance and navigation displays that provide steering commands and indicator deviation from the desired flight path must be located so that the pilot can safely fly the aircraft during all phases of flight while seated at the primary flight controls with minimum head, eye, or hand movement.

References:

14 CFR PART 23.1321(a)

Critical Design Activities:

By examination or analysis, determine that navigation system inputs and navigation display parameters of commands and path deviation are located in the primary field-of-view. Other non-flight critical navigation information may be displayed in secondary-field-of-view. For example, a CDU that is not the sole or primary device being used to display dynamic position data used directly to fly the aircraft to maintain a navigation path may be in the secondary field-of-view, pedestal or side console areas and may display such data itself.

Performance Rationale & Background:

The information that the pilot needs to actively fly the navigation commands, e.g. deviation from GPS navigation path, needs to be in a location where the pilot can include the data in the primary instrument scan. This is real time data being used by the pilot to control the aircraft flight path. Much of the navigation information and control interface with the pilot is used as a crosscheck, as planning data or for intermittent use by the pilot. This data may be displayed in the secondary field-of-view of the pilot(s), in the pedestal or side console areas because it is required to be used by the pilot(s) to ensure the aircraft's navigation path is being flown.

Examples of Navigation Data:

Navigation	Map displays may include
-Deviation from path displays	-Planning
-Map displays	-Track Up
-Radar	-Terrain
-GPS CDU	-Present Position
-INS CDU	+North up
-FMS DU	+Track up or heading up
-ILS controls	+Aircraft symbol location
-VOR controls	-Hazards and means to alleviate them
-DME controls	+TAWS
-Topographic displays	+Weather Radar
	+TCAS
	-Operational considerations
	+RNP, VNAV, Wind inputs, etc.

Evaluation Procedure:

Determine all devices that will contribute to the required pilot(s) maintaining navigational awareness or that will provide the required pilot(s) information with respect to a flight or navigation system. Verify through analysis that these systems are located in the appropriate field-of-view (primary or secondary depending upon data criticality). These may include locations in the pedestal or side console areas. Suggestions for procedures used to verify these locations are as follows:

1) Analysis or examination of engineering drawings
2) Reach analysis of an electronic mockup or human modeling tool
3) Examination/evaluation of subjects in a physical mockup or aircraft

7.1.4.6. Guidance commands and navigation position (The steering and position information being used to actively guide the aircraft.)	
	Evaluation Rationale & Background: The purpose of evaluating the placement of aircraft navigation information in the required pilot(s)' primary field-of-view is to maximize the ability of the pilot(s) to concentrate attention forward of the aircraft and to minimize pilot fatigue in attaining essential aircraft control information. This is especially important during takeoff, initial climb, final approach, and landing phases of flight The pilot(s) should be able to monitor all systems contributing to the navigation or guidance of the aircraft, especially during critical phases of flight, with a minimum of head, eye, and hand movement. Placement of equipment in the primary field-of-view of the pilot(s) ideally facilitates this requirement. Placing non-critical navigation information in the secondary locations such as the pedestal or console areas can ease confusion and reduce clutter in primary viewing areas.

7.1.4.7. Critical functions, normal operation (The functions needed to safely control the aircraft under usual flight situations.)	
	Performance Based Guideline: Critical functions will be in the pilot's primary field-of-view with longitudinal awareness, lateral/vertical awareness and height awareness display symbols on horizontal line in front of the pilot using the information.
	References: 14 CFR PART 23.1321(d)
	Critical Design Activities: By examination or analysis determine that critical display functions are in the pilot's primary field-of-view from that pilot position.
	Performance Rationale & Background: Functions to maintain safe flight and landing need to be readily available to the pilot located in the pilot operating position. Those functions needed to maintain safe flight tend to be ones that have fast response times with respect to aircraft position and movement. The aircraft attitude is a fast responding loop. The pilots must take immediate action to preclude getting into an unusual attitude condition. On the other hand, the outer navigation and heading control loops are slower than attitude. Pilot action can be delayed a short period of time and still be able to maintain adequate track or path control of the aircraft. This implies that the display of Airspeed, Attitude and Altitude information must be located in a prescribed manner, like the Basic-T. However, more latitude maybe taken with the navigation display locations. Other display formats may be considered.
	Evaluation Procedure: Validate that attitude, altitude, airspeed and basic level of navigation (including heading) is within the pilot's primary field-of-view (FOV) as determined through visual field modeling in a three-dimensional electronic cockpit mockup, measurement in a development fixture or other mockup, or measurement on engineering drawings. Regardless of the specific implementation or parameter used, critical data and information should be displayed in the primary FOV.
	Evaluation Rationale & Background: Those parameters that are needed on a real time basis to navigate the aircraft from point A to point B need to be in front of the pilot flying the aircraft. The critical functions are typically defined as attitude, altitude, airspeed and some form of navigation, or their equivalent. Navigation includes the combined result of heading and a navigation path.

7.1.4.8. Critical functions, abnormal operation

(The functions needed to safely control the aircraft under failure or unusual flight situations.)

	Performance Based Guideline: Under failure conditions reversionary data in the Basic-T may be in the pilot's secondary field-of-view.
	References: 14 CFR PARTs 23.1311(b); 23.1321(d)
	Critical Design Activities: By examination or analysis determine that critical reversionary display functions are in the pilot's primary or secondary field-of-view from that pilot position.
	Performance Rationale & Background: Pilots have been found to be able to transition and safely fly the reversionary critical displayed functions in the pilot's secondary field-of-view when operating with specific failures. The data on these displays should be displayed consistently with the other cockpit displays.
	Evaluation Procedure: Determine that the display of reversionary functions is useable from the pilot's position. The displays may be located in the secondary FOV as determined through visual field modeling in a three-dimensional electronic cockpit mockup, measurement in a development fixture or other mockup, or measurement on engineering drawings.
	Evaluation Rationale & Background: Display of reversionary data needs to be in a location so that the pilot(s) can transition to it when the source of critical display data fails. The reversionary critical data, typically including attitude, altitude and airspeed, or their equivalent, need to be arranged and located in the cockpit to make the transition to these displays as simple as possible. The display hardware does not need to be in the primary FOV of the pilot flying, but they need to be located in a place in the cockpit that allows the pilot(s) to adequately read the data being presented. Examples have used the center instrument panel where both pilots can easily read the displays or in single pilot aircraft at the copilot's position when the distance across the cockpit is small enough to allow the reading of the displays from the pilot's operating position.

7.1.4.9. Information Fusion - Layering and Prioritization

(Using a single control or display device to utilize multiple systems or information sources.)

Performance Based Guideline:

Information fusion is the combination of data from multiple systems in such a way that the combined data may not be recognizable as coming from one source or another and how the end user will operate the systems. This type of data fusion is acceptable provided the source of the information is not relevant, such as the merging of some weather products. In other cases, such as vertical speed and vertical navigation, retaining source identity may be required. Depending upon the number and complexity of the systems or functions being utilized by the common control or display device, layering and prioritization of information should be implemented to decrease confusion due to clutter.

References:

14 CFR PARTS 23.1309; 23.1311; 91; 121 and 135

Critical Design Activities:

Determine what systems or functions will be controlled by, or displayed on the common device. Determine the extent to which layering, i.e. menu driven or hierarchical information presentation will be used. Determine the priority of each piece of information, groups of information, or information source. Design consideration should be given to maintaining a consistent control or display philosophy in order to maximize the pilot(s)' ability to effectively utilize the system. Color and shape coding are effective techniques for differentiating information sources.

A flight management system is an example of an information fusion system that both controls and displays information from various navigational and flight systems and presents an interface to the pilot(s) that is typically layered via a menu system.

Prioritization is often demonstrated on Electronic Flight Instrument Displays where multiple annunciations share a common field and are assigned relative display priorities or in audio systems having priorities assigned to multiple input sources to prevent more than one aural warning being given at one time.

Performance Rationale & Background:

Increases in typical aircraft system complexity coupled with limited placement area in the cockpit have perpetuated the need for information fusion in the form of controllers and displays. Implementation of system combinations in a consistent, logical manner has led to a decrease in pilot workload and an increase in cockpit resource management, contributing to an overall increase in safety of flight.

Evaluation Procedure:

Evaluate the information fusion system to determine that information is presented in a logical, user friendly manner such that the required learning curve is minimized. A cross section of experienced and inexperienced users should evaluate the usability of the system, the prioritization scheme, and the level of effort required to consistently recognize annunciations, critical, and nonessential information. Determine that the layering scheme and sharing of aural or visual fields will not lead to masking of critical information by other outputs.

Evaluation Rationale & Background:

The layering of information in an hierarchical structure can be inherently subjective and can potentially lead to confusion in a group of system users. In order to maximize the usability of a system design, evaluation should be conducted which takes into account input from a representative group of experienced and inexperienced users.

7.1.5. Warnings Cautions and Advisories

7.1.5.1. Alarms (Warnings)

(The information presented to the pilot of a failure or unacceptable operating condition.)

Performance Based Guideline:

Visual and auditory alarming systems must provide signals that can be detected, easily understood and interpreted for appropriate action by the pilots under all ambient lighting and noise environments encountered during all phases of operation. The warning system must also be designed to minimize crew errors that create additional hazards.

References:

14 CFR PARTS 23.1309; 23.1323; 23.1311; 91; 121; 135; and AC 23.1309-1C; NAWCADPAX-96-268-TM; MIL-STD-411; British Defence Standard 00-25 Part 7; MIL-STD-1472F

Critical Design Activities:

Analysis of the visual and auditory alarm system should be performed prior to implementing detail design efforts. These analyses should address operation, prioritization and categorization of system alerts. The analyses also need to consider the ambient lighting and noise environment in which the system has to perform. The analysis should consider the user's capabilities and limitations; for example, some older pilots have substantial hearing loss and vision impairments, which should be given consideration. The design should include iterative testing via simulation or other methods with representative users to assess integration compatibility.

Performance Rationale & Background:

Visual:

Every attempt should be made to eliminate possible confusion of alarms with any other displayed information. High priority alarms should be placed in the pilot's primary field-of-view. If all critical alerts cannot be placed within 15 degrees, a master warning display is also appropriate. Visual alarms should be presented until the pilot has responded or until the alarm condition no longer exists. Auditory or voice alerts should accompany high priority alarms.

A system test function should be included that illuminates all alarms available and verifies that all the alarms are functional. This test should be made possible through a single action. Larger text and higher luminance may be appropriate for alerting signals. The use of flash coding should be kept to a minimum. If flashing is used, the background should be free from other flashing signals; the flash rate should be between 3-5Hz with a duty cycle of 50%. Flashing presentations that could be simultaneously active should be synchronized. Auditory alarms should direct attention, but not cause interference to required tasks. Nuisance alarms should be addressed.

Master caution, master warning, master advisory, and summation lights or indicators used to indicate the condition of an entire subsystem should be set apart from lights or indicators that show status of the subsystem components. Indicators or lights used solely for maintenance and adjustment should be extinguished, covered or non-visible during normal equipment operation. Discrete lights and other such indicators should be used sparingly and should display only that information necessary for effective system operation.

Error and status messages should be located consistently at the pilot's station and on the same dedicated area with their respective displays. These messages may be emphasized by using a contrasting display feature (e.g. reverse video, highlighting, icons, etc.)

Colors should be consistent with the colors paragraph of this section.

7.1.5.1. Alarms (Warnings)

(The information presented to the pilot of a failure or unacceptable operating condition.)

Performance Rationale & Background: (cont.)

Auditory:

Auditory signals provide rapid alerting irrespective of head or eye position. If applied wisely auditory alarms can enhance safety of operation and improve crew response to emergency situations. Judicious use of these alarms must be addressed to preclude nuisance warnings in the cockpit. The number of auditory alarms should be kept to the minimum necessary to provide the desired result. Spoken alerts have advantages over other forms of auditory warnings as they can convey an explicit piece of information without having to interpret the tone or go to the visual display to determine the failure.

Effective auditory alarm systems will typically have the following characteristics:

- False alarms should be precluded to the extent possible.
- Auditory alerts should be easily recognized and understood in order to minimize the time required for the user to detect, assess and react to the problem and to initiate appropriate corrective actions.
- Audible alarms should be detectable and understood quickly and easily under all expected operating conditions including ambient noise, radio traffic, and crew voice communications.
- Audible alarms should be standardized.
- Audible alarms should be used in conjunction with visual alerts as appropriate.
- All audible alarms must be easily recognizable from one another. Each audio signal should have only one meaning.
- If headsets are worn, the alerting system should be usable through the headset unless external alerts are demonstrated to be discernable using noise canceling headsets.
- The audible alert signal should have a duration no less than 0.5 seconds and no longer than 3.0 seconds.

Evaluation Procedure:

Develop a checklist based on applicable guidelines and evaluate system design. Compare design with functional requirements. Evaluate the visual and audio displays under varying cockpit environmental and operational conditions with representative user population.

Specifically for audio alarms:

- Test for false alarms.
- Check for background noises that may mask the alert.
- Ensure the intended meaning of the signal is clear, unambiguous and immediately understood.
- Ensure that unique audio signals are used. Measure with instrumentation as appropriate and also obtain subjective assessments during program development.
- Ensure that a single tone is not used for more than one visual display in critical warning situations.

Evaluation Rationale & Background:

Evaluations are needed to insure that appropriate and easily understood warnings are provided to the pilot(s) under anticipated operating conditions.

7.1.5.2. Annunciation

(The aural and visual indications of the status of a function of a system.)

Performance Based Guideline:

Annunciations need to provide an unmistakable message to the pilot as to the condition of active functions. Their location needs to insure that they are available and understandable to the crew in accordance with their levels of criticality.

References:

14 CFR PART 23.1311; AC 23.1311-1A; AS-8034; ARP-1068B; DOT/FAA/CT-96/1

Critical Design Activities:

To ensure crew notification of the status of a function, and to ensure timely crew understanding of the importance of an annunciation, the following design points should be considered:

- Visual annunciations should be grouped to reflect the level of criticality, and functional relationships.
- Compliance with color conventions should be maintained.
- Visual annunciations should be consistent and their location may be centralized (for example, a CAS or master warning display), or may be located with the display of the related system information (for example navigation fail annunciation with the navigation display).
- Visual annunciations should take advantage of previous experience with similar annunciations in prior systems.
- The annunciation system design needs to reflect the overall system design. Systems with very few installed displays or controllers will tend to have discrete stand-alone annunciations. Highly integrated systems may time share portions of the displays. The design of the annunciation system needs to address the specific characteristics of a function.
- Retrofit applications impose significant challenges in complying with the points noted here. A good human interface solution needs to be pursued to the practical extent possible, although new annunciations should be added in a consistent manner with the existing installation.
- If an annunciation has an aural component, similar considerations as noted above should be made. In addition these considerations should include aural warning priorities; the total number of cockpit aural warnings; and the need or desire for volume control adjustment capability.

Performance Rationale & Background:

Annunciations provide the designer a means to notify the crew of the status of a function or the change of status of a function. The crew may have many other indications of the event or the annunciation may be the only indication.

The complexity of the system also has a significant role in determining the impact of a given annunciation. Discrete annunciations in simple systems must be made consistent with existing discrete annunciations to the extent possible. Annunciations provided on electronic displays may face a challenge in getting the pilot’s attention unless special care is taken. Highly integrated designs need to provide a level of pilot notification commensurate with the systems functional criticality.

Since vision is such a strong sensory input for humans, annunciations should typically include a visual component. These types of annunciations should consider shape and color. They may also have alphanumeric characters or a graphic icon, and may include aural warnings. They may be physically separate and discrete, or they may be displayed on a larger display along with many other types of information.

Evaluation Procedure:

The procedure will usually consist of an iterative series of evaluations. The evaluations should be conducted by a cross section of pilots that represent the expected operational community. A portion of their evaluation should take place in operational scenarios. Some portion can also occur in a part task simulator, or in fully functional simulators. Some type of survey documentation could be used to collect subjective evaluations of annunciation usability. Usability should consider the new system and the integration with other systems in the environment being considered.

7.1.5.2. Annunciation (The aural and visual indications of the status of a function of a system.)	
	Evaluation Rationale & Background: Evaluations should insure that the operating condition of all systems appropriate to their criticality is annunciated to the pilot in an easily understood manner. Ideally, audible alarms shall exceed the prevailing ambient noise levels throughout the flight envelope. Signal characteristics should follow guidelines of DOT/FAA/CT-96/1.

7.1.6. Colors

7.1.6.1. Color selection

(The color assignment to various symbols and parameters.)

Performance Based Guideline:

Color may be used to enhance the readability of a display. The use of colors should be in accordance with a defined philosophy for the display parameters available.

References:

14 CFR PART 23.1311; AC 23.1311-1A; AS-8034; ARP-1068B; NAWCADPAX—96-268-TM; DOT/FAA/CT-96-1

Critical Design Activities:

Colors should be used in compliance with the 14 CFR PART definitions:

- RED should be used to indicate hazardous conditions that requires immediate pilot attention and may require immediate pilot action such as, error, failure, malfunction, danger, etc.
- FLASHING RED may be used to get quicker pilot recognition.
- YELLOW/AMBER should be used to indicate marginal conditions or to alert of situations where caution, recheck, or unexpected delay is necessary.
- GREEN should be used to indicate that monitored equipment/processes are within tolerance or a condition is satisfactory and that it is all right to proceed with an operation or transaction.
- WHITE should be used to indicate system conditions that do not have operability or safety implications, but indicate alternative functions.
- BLUE may be used as an advisory color. Preferential use of blue should be avoided.

Color may be used to identify information categories when it does not conflict with other color coding conventions and does not conflict with other color associations as noted above. Use of color should be secondary to shape or form for identifying icons or other symbols.

Coding only by color should be avoided as much as possible. Displayed information should be discernable even when viewed on a monochromatic display terminal or hard copy printout.

Consider the ambient light under which the display will be viewed when deciding the desired saturation of any given display color. Colors that appear highly saturated in a darkened environment will appear less saturated when viewed under high ambient illumination.

Colors should be easily distinguishable and color-coding should be used conservatively. Each color should represent only one category of displayed information.

Performance Rationale & Background:

Color-coding of displays can sometimes improve visual search and identification performance over monochrome formats. The impact of color-coding is highly situation specific and depends on factors such as pilot task, display format and density, and work environment. For highly dense displays with a visual search requirement, color-coding provides performance enhancement not available with other coding methods. However, irrelevant use of color, or using too many (7 or 8 is usually considered the maximum for uniquely discernable colors) colors in computer generated displays can cause performance decrements. There is also some evidence that color-coding may improve visual search and identification performance when task loading is high. Pilot preference strongly favors color displays.

Color is a good auxiliary code, where a multicolor display capability is available. A color code can be overlaid directly on alphanumerics and other symbols without significantly obscuring them, and color coding permits rapid scanning and perception of patterns and relationships among dispersed information items. Color enhances the ability of a pilot to detect and interpret particular commands, a portion of a screen, an error message, or any part of the interface requiring notice. How the color of a foreground object is perceived is directly related to its background color. Color should add substance to the interface, not dominate it.

7.1.6.1. Color selection (The color assignment to various symbols and parameters.)	
	Evaluation Procedure: Develop a checklist based on applicable guidelines and evaluate system design. Evaluate color-coding methods under typical cockpit environmental and operational conditions with a typical pilot population. Colors selected for coding should be tested with pilots to ensure that they are easily distinguishable. Testing should be conducted under realistic conditions, since such factors as display type and ambient lighting will affect color perception. Review the color philosophy and rationale for color assignments. Evaluate deviations from the color definitions typically used. Determine that the assignments are a consistent philosophy and that the color assignments generally protect those reserved for warnings and cautions, i.e. reds and yellows. Use of these colors may be permissible provided that cautions and warnings are clear. The use of these protected colors is only permitted when the basic color sets are depleted of colors that would provide adequate contrast for easy readability.
	Evaluation Rationale & Background: The usual method to evaluate color-coding methods is to set up typical cockpit environmental and operational conditions with a typical pilot population. Colors selected for coding should be tested with pilots to ensure that they are easily distinguishable. Testing should be conducted under realistic conditions, since such factors as display type and ambient lighting will affect color perception.

7.1.7. Cockpit Visibility

7.1.7.1. Internal vision (The view from the pilot's seated position, of the displays and controls necessary to operate the aircraft.)	
	Performance Based Guideline: All required displays and controls must be located so that the pilot, when seated in the normal pilot's position, can monitor and control the airplane's flight path and these displays. Displays and their associated controls shall be viewable with minimum head and eye movement.
	References: 14 CFR PART 23.1321; ARP 4101, Flight Deck Layout and Facilities; ARP 4102, Flight Deck Panels, Controls, and Displays
	Critical Design Activities: Displays and their associated controls are located so as to satisfy the criticality requirements determined in a functional allocation analysis. The most critical displays and their controls are located in the primary field-of-view. The next most critical displays and their controls are located in the secondary field-of-view.
	Performance Rationale & Background: Supporting rationale for this section can be found in: 7.1.2 – Controls – Inability to see critical displays and controls can compromise safety and has contributed to accidents and incidents. – It is necessary to insure that the pilot can find each display and control under all anticipated lighting conditions. – Displays and associated controls that need to be readily available to the pilot should be located in a more accessible position than those that are less critical. 7.1.4 – Display Content and Symbology 7.1.5 – Warnings, Cautions and Advisories Visual warnings must be placed in the primary field-of-view.
	Evaluation Procedure: Directly applicable procedures can be found, listed under ***Evaluation Procedure***, in: 7.1.1 – Anthropometric Considerations 7.1.1.1 – Anthropometry Assessment 7.1.2 - Controls 7.1.2.5 – Location and arrangement 7.1.4 – Display Content and Symbology 7.1.4.1 – Placement and content of symbology 7.1.4.7 – Critical functions, normal operation 7.1.4.8 – Critical functions, abnormal operation 7.1.5 – Warnings, Cautions and Advisories
	Evaluation Rationale & Background: Evaluations that gather feedback from a representative cross-functional team of users are necessary to insure that the complex cockpit vision issues are understood and properly addressed.

7.1.7.2. External vision, clear area of vision

(The pilot's view outside the cockpit/flight deck.)

Performance Based Guideline:

Sufficient external vision must be provided to enable the pilot to fly and control the aircraft safely. The pilot must have a clear and undistorted view to enable safe operations for taxi, takeoff, approach, landing, and the performance of any maneuvers that are within the operational limitations of the airplane.

Outside vision must be free from glare and reflections that could interfere with the pilot's vision for both day and night operations.

Moderate rain conditions must not unduly impair the pilot's view of the flight path in normal flight and while landing. Further, a means must be provided to maintain a free and unobstructed view of the outside world across all other meteorological conditions in which the airplane is certified to operate.

Each compartment must have a means to prevent formation of or remove fog or frost on the internal portions of the windshield unless it can be easily removed by the pilot without interruption of normal piloting duties.

References:

14 CFR PART 23.773(a); AC27-1A; AC 25.773.1; ARP 4101, Flight Deck Layout and Facilities; ARP 4102, Flight Deck Panels, Controls, and Displays; MILSTD 850; AMS-G-25871; MIL-P-25374

Critical Design Activities:

It is very difficult to discuss the critical design activities for external vision recommendations without also discussing anthropometry and geometry issues, as well as internal vision recommendations. They are all integrally linked. In addition, several other design disciplines are involved with this activity such as structural and performance engineering considerations. Therefore, concurrent engineering is a must. Concurrent engineering implies that no single discipline perform design work without coordination and concurrence from all of the involved disciplines including human factors.

Ideally cockpit vision considerations are developed from a point or locus of points, commonly referred to as the design eye reference point, that can be related back to the physical features of the aircraft in terms of waterline, buttline and station. From this position(s) determinations are made as to what outside parameters are most important and what visual angles of unobstructed vision are needed for the intended pilot user to safely fly and operate the aircraft. It is also from this position that attempts are made to optimize internal viewing. Several sources of current data exist from which to draw population dimensions that will suffice for GA needs. These sources are cited in the Anthropometry paragraphs herein. (See paragraph 7.1.1.1)

Clear vision areas for critical flight tasks should be determined by measurement of angles from the design eye position(s) using both eyes. Clear vision areas need to be established by the crew station design team. In the past, external vision criteria have been extracted from MILSTD 850, AC27-1A for rotorcraft and AC25.773-1 for transports. A visual protractor can be used to measure things like over the nose vision. It is also possible to use computer modeling to assess over the nose vision (typically CATIA models coupled with human performance models). All factors that impact safety and operation of the aircraft must be considered during the design process. The design must provide a level of safety that ensures adequate external vision to operate in the "see-and-avoid" environment. The reference documents provide design criteria that have been shown to provide adequate external vision.

Specific consideration should be given for:

- over the nose vision for landing,
- side vision and upward vision to see traffic,
- view of wingtips for taxiing,
- view of wing surfaces to detect icing and flight surfaces movement.

7.1.7.2. External vision, clear area of vision
(The pilot's view outside the cockpit/flight deck.)

Critical Design Activities: (cont.)

Consideration must also be given for the aerodynamics of the aircraft and landing approach speed. As an example, with a normal 3 degree ILS approach angle there should be adequate vision to see the runway for landing. The glareshield should not limit outside vision nor should it prevent the pilot from seeing information at the top of the instrument panel. Cockpit or cabin structure should not create obstructions in prime viewing areas. The pilot should be able to see around any obstructions. Any blockage should be small enough at the projected distance to be able to see that area with at least one eye at all times.

Evaluation of impediments to vision should include examining the condition of the windshield and any other cockpit transparency providing visibility to the outside. Luminance transmission should not be less than 70% (14 CFR PART 23.775). Military Standards AMS-G-25871 and MIL-P-25374 also contain information on construction, optical uniformity, physical properties, environmental exposure and luminance transmission that may be useful to consider during the design. The transparencies should be free from any optical distortions in primary viewing areas. Additional considerations may include end-of-life luminance transmission and the impact of anti-ice or de-ice systems. Glare and reflections should be minimized to prevent interference with external vision.

Performance Rationale & Background:

Clear vision is required for safe operation. Clear vision must also be attainable without compromising operation of flight controls or readability of other essential information in the cockpit. Utilization of criteria other than those provided by the reference documents will probably need added documentation and justification.

The cockpit/flight deck windshield must provide sufficient external vision to permit the pilot to safely perform any maneuver within the operating limits of the aircraft and, at the same time, afford an unobstructed view of the flight instruments and other critical components and displays from the same eye position. Aircraft designers and manufacturers should make every effort to build windshields that offer the pilot the maximum external vision possible given aircraft design constraints.

Precipitation clearing should be provided for the windshield panels directly forward of each pilot and should be effective at all thrust settings up to 1.6 Vs (clean) or 230 knots, whichever is less. The minimum area to be cleared should be 15 degrees left to 15 degrees right of the design eye position, upward to the horizon during the steepest approach path expected in operation. If windshield wipers are used, wiper speeds of approximately two sweeps per second have been found to be satisfactory in maintaining a clear area.

Flight test evaluations should be conducted during taxi, takeoff, approach and landing under actual rain conditions. Suitable documentation can be made in terms of photographs of windshield clearing performance, subjective pilot evaluations, plus rain intensity reports from local weather bureau measurements in the area of operation. Heavy rain is difficult to find, due to its low occurrence frequency. However, light and moderate rain is relatively easy to find. Test in light and moderate rain may be satisfactory if laboratory test data are available in light, moderate and heavy rain to form a basis for extrapolation of flight test results.

Flight test in rain simulated by an aerial tanker is an alternate method of flight evaluation. However, steady state conditions under such a test are very difficult to obtain.

If an icing approval is being requested, demonstrations must be made under applicable environmental conditions (14 CFR PART 25 Appendix C) to ensure that a sufficiently large viewing area is kept clear of ice, to permit safe operation.

7.1.7.2. External vision, clear area of vision

(The pilot's view outside the cockpit/flight deck.)

	Performance Rationale & Background: (cont.) Pilot compartment view criteria is adopted from the Society of Automotive Engineers Inc. (SAE) ARP 4101/2. The standard was based on a computerized study program that considered 10,000 hypothetical cases of pairs of airplanes on collision courses considering reasonable airplane mixes of type, speed, flight path angles, bank angles, etc. In addition, all known available data from actual midair collisions, reported near misses, and USAF Hazard Air Traffic Reports (HART) were used.
	Evaluation Procedure: Evaluations are best accomplished in an iterative fashion before design is frozen and changes become too costly to consider. Evaluations can be used with computer modeling, however, they should also be accomplished with real people and real hardware. It is appropriate to utilize computer modeling to evaluate external vision requirements but user testing in both mockups simulation and flight-testing should also accompany it.
	Evaluation Rationale & Background: It is extremely important to utilize real people and real hardware. Aircraft have been produced that strictly relied on computer modeling techniques with less than desirable results of the fielded product. Expensive redesign can be avoided and safer aircraft can be produced if sufficient steps are taken early in both the design and evaluation activities that support these aspects of development.

7.1.8. SPECIAL SUBSYSTEMS

The following unique items are specific areas of safety concern related to HF. They represent cases where accidents have occurred because of lack of pilot recognition of a problem or implementation, operational definition and failure conditions of the functions. These cases are included to provide some guidance for evaluation and criteria.

7.1.8.1. Checklists

7.1.8.1.1. Checklist content (The information contained within a checklist.)	
	Performance Based Guideline: Checklists should contain concise statements of actions necessary for the pilot to perform the required function. The checklist may be paper, electronic or both and should be easily accessible in flight and ensure that the pilot (crew) will properly configure the airplane for any given segment of flight.
	References: 14 CFR PARTS 23.1585; 135.83 and NASA Report 17764,- On the Design of Flight Deck Procedures; DOT/FAA/AM-91/7-The Use and Design of Flightcrew Checklists and Manuals
	Critical Design Activities: Before writing checklist details, identify and list all of the procedure objectives. It must first be determined exactly what the procedure is trying to establish. As with all other activities described in this document ensure the checklist design is acceptable for the typical General Aviation pilot. Checklists developed for two place air carrier operations with highly trained crews are far different than single pilot GA users with little experience or training. In the documentation that explains the procedure also include the reason the procedure is necessary. Consider standardization of procedures with other similar GA aircraft types where possible. Review checklists for having minimum steps to accomplish a task; good indices as to the content, logical sequence of steps; no tutorials (although references to added information may be given); checklists need to address all abnormal and emergency conditions; when the checklists are “expanded” to different levels each expansion should follow the same sequence.
	Performance Rationale & Background: Procedures are used to describe: – What the task is – When the task is to be performed – Who performs the task – How the task is done – What are the sequence of actions – What type of feedback is provided A function of a well designed checklist is to aid the pilot (crew) by outlining a progression of sub-tasks and actions to ensure that the primary task at hand will be carried out in a manner that is efficient, logical, and also resistant to error. Both paper and electronic checklists must consider the number of steps to get from the entry item to the action item. Since electronic checklists can provide considerably more information about the system, they must be implemented to lead the pilot rationally and rapidly between menus to a proper conclusion. The resultant system configuration, true specifically when abnormal operation is present, needs to be made clear to the pilot after the checklist is used.

7.1.8.1.1. Checklist content
(The information contained within a checklist.)

Performance Rationale & Background: (cont.)

The intent of checklists is to provide the pilot with concise information based on the aircraft manufacturer's operational philosophy of the aircraft. This information needs to be easily found in the documentation on board the aircraft.

Checklists may be customized to specific operation of the aircraft. However, the operational procedures found in these checklists must be in accordance with the basic aircraft design. The user tends to make up the final aircraft checklist. Experience has found that checklists vary considerably between aircraft of a given type and the specific content and arrangement of each checklist. The problem occurs when the pilot needs to use a specific procedure with which he or she is not very familiar. This continues to result in failures with even seldom used normal operations causing problems.

Evaluation Procedure:

Testing checklists against the behavior of the typical user pilot should validate important cockpit procedures. The procedures should be examined for time to accomplish, completeness, correctness, subjective ratings, workload ratings, etc.

Review checklist content for the following:

- The checklists are sectionalized in accordance with the 14 CFR PART and/or GAMA Specification.
- A level of configuration control is in place to ensure that the procedures used in the aircraft are current.
- Determine that an individual of authority in the user's operation has approved the basic procedures and any revisions.
- In the aircraft, determine that the procedures convey the precise intent of the actions to be taken. This should include reviewing the wording to ensure it is in simple English and understandable.
- Determine that once a specific procedure is complete, that the checklist provides some indication of the status of the systems, particularly if a failure has occurred, and actions that may need to be taken to continue using the function(s).

Evaluation Rationale & Background:

The evaluation should concentrate on being able to find a particular procedure when it is needed and that the procedure is appropriate for the task to be performed.

There are several areas that cause the pilot to have problems accessing and using particular procedures when needed. The problems caused are a result of many factors including:

- The procedures provide too much information. When a procedure is needed, that is not the time to learn how to use the system or the philosophy behind its operation. Tutorials should be eliminated from the checklists.
- The access to a particular procedure needs to be easily accomplished. The pilot should not have to retrieve several sources for a related checklist. Checklist references to other checklists should be avoided. In automatic systems, a minimum of pilot actions should be necessary to acquire the precise procedure for a defined task. For procedures for critical situations, e.g. emergencies, the steps should be one or two and not a long continuing menu of selections to reach the desired procedure.
- After the checklist is completed, there needs to be some indication to the pilot of the system status. This includes what functions have been lost, alternatives left (particularly if another failure should occur), etc.

7.1.8.1.2. Actions required to get needed item
(The number of actions for the pilot to make a discrete selection.)

Performance Based Guideline:
Depending upon the priority of an action to make a selection, the number of pilot actions needed to reach the checklist item need to be minimized.

References:
14 CFR PARTS 23.1301; 23.1321

Critical Design Activities:
Evaluate the process that a pilot uses to get to a specific item in the checklist procedures. For those tasks that need immediate attention from the pilot, e.g. abnormal and emergency procedures, priority needs to be provided in the indexing scheme and for accessing the individual procedure dependent upon the criticality of the need for the procedure.

Performance Rationale & Background:
Ideally, every procedure needed by the pilot should be one step away whether with a manual checklist or one that is partially or fully automatically acquired. This is generally not practical with complex systems.

Checklists many times have been relegated to a secondary position to having the pilot “know” the aircraft and its systems very well. This has not lead to an efficient manner for the pilots to recover from a failure or problem condition. Even in normal operations, the accessibility of a specific procedure has been less than optimum.

Evaluation Procedure:
Determine that a specific procedure can be quickly found either through a simple manual index or automatic electronic search. Abnormal and Emergency procedures particularly need a minimum of steps to access a specific description of actions needed to be taken by the pilot.

For manual checklists:

- The book or device containing the checklist should be reachable by the pilot(s) from their normal seated position at their operating position.
- The needed book or device should be easily identified in the cockpit by feel, size, location or similar mechanism.
- Mechanical devices like large tabs, color and similar methods may be needed to allow the crew to immediately locate the correct procedure in the book.

For automatic checklists:

- The number of pilot actions should be limited to a minimum to get to a specific checklist (2 or 3 actions would typically be desired).
- The actions to get back to any other portion of the checklist should not be anymore difficult than to get to the first procedure. Care needs to be taken particularly for procedures that may occur in a sequence, e.g. an engine shut down followed by a fire warning.

Evaluation Rationale & Background:
A basic problem with manual checklists is that the book(s) may be in inaccessible locations in the cockpit or there may be so much material available that the specific book containing the desired procedure is difficult to find. On the other hand partially or fully automatic electronic checklists may require going through many menus to reach or change a checklist.

7.1.8.2. Control Systems

7.1.8.2.1. Manual or automatic electric surface trim

(The action to move the trim of the control surfaces either by pilot input or from an automatic system.)

Performance Based Guideline:

Manual or automatic electric surface trim must respond correctly in terms of direction and speed when commanded or overpowered by the pilot or when commands are supplied to the trim system by an automatic flight control system.

References:

14 CFR PARTS 23.161; 23.1309; 23.1329; AC 23.1309-1C; AC 23.1329-1C

Critical Design Activities:

The manual or automatic electric trim may be installed on any control axis of the aircraft. It should meet the following conditions;

Meet a safety analysis or show by testing that the trim system(s) will not cause a hazardous condition without a warning by showing:

- It will not run unless commanded by the manual or automatic input.
- It will run when commanded by manual or automatic input.
- It will run only in the direction it is commanded by manual or automatic input.
- It will run at the speed appropriate for an existing flight condition.
- It will produce a warning when excessive surface trim is present as a result of the pilot's or autoflight system's inputs.
- Current surface trim position indication may be displayed to the pilot in the secondary field-of-view.

Performance Rationale & Background

Failures in an electric system or pilot actions should not cause the trim to respond incorrectly without an appropriate warning.

The pilot realizes that he or she has responsibility of properly flying the aircraft. Failures or incorrect pilot action may cause the pilot to become confused about what the aircraft is doing. The natural response of the pilot is to "help" the aircraft. When this occurs with traditional electric trim systems, any pilot over riding actions of the system will cause the electric trim to run the wrong direction. This results in the aircraft getting into large out-of-trim conditions. A number of occurrences have happened when the pilot either inadvertently or knowingly took actions to cause the trim to run in the wrong direction. To design a system to accomplish this task may be expensive and complex in some aircraft.

Evaluation Procedure:

Review the safety analysis to determine if all the conditions are met or conduct tests on aircraft with each specific condition present and note that the system responds correctly.

Evaluation Rationale & Background:

The determination of the logic of a system with respect to the controlling trim parameters are limited in nature and usually are easily simulated. However, it has been found that a safety assessment is a very good indication as to the capability of a system to operate properly.

To implement some of the above logic to ensure the trim system will respond correctly under all the conditions in traditional aircraft with the primary control surfaces driven by a cable connection may take fairly sophisticated and expensive sensors in the primary control systems. The designer may elect to use this kind of implementation to ensure that adverse out-of-trim conditions do not occur. In lieu of such systems, the procedure provided in the aircraft flight manual needs to specify the required crew actions when an out-of-trim alert or warning occurs.

7.1.8.2.2. Overspeed warning and recovery (The information presented to the pilot of an overspeed condition and a capability for a commanded recovery.)	
	Performance Based Guideline: There should be a function that provides effective overspeed warning and a commanded recovery capability if the aircraft stability characteristics are such that it readily enters into an overspeed condition creating an unsafe condition.
	References: 14 CFR PARTS 23.1303 (e) (2); 23.1309
	Critical Design Activities: When an overspeed condition can occur without positive cues through the control system or by aircraft stability, an acceptable alert, such as an aural clacker or warning, must be provided to command the pilot's attention to the overspeed condition. If such a warning occurs, a recovery command either through the autoflight system or a manual command should be provided.
	Performance Rationale & Background If the aircraft aerodynamics do not provide inherent stability that controls an overspeed condition or the cues, e.g. wind noise, stick pressure, etc., to the pilot are not prominent when such a condition occurs, then adequate alerts to an overspeed condition need to be provided. Some kind of recovery command is necessary to allow the pilot to safely get the aircraft back to stable flight without overstressing the aircraft. There have been cases, particularly in high performance airplanes, where high-speed in-flight structural breakups have occurred. In many cases the aircraft were in flight conditions where very little operational margin was present. An example is high altitude, heavy gross weight flight where there is a small margin between realizable airspeed and stall. Depending upon the aerodynamic characteristics of the airframe, the recovery from a stall under these conditions can overstress the airframe beyond its design limits. In such cases, angle-of-attack floors or similar algorithms need to be in place in the system not only to warning the pilot of on-set of an overspeed condition, but also to provide a recovery command. An obvious flight condition related to a MACH pitch over has been addressed for many years. These systems ensure that the aircraft will not get into a configuration that would result in a "MACH tuck" condition. However, other aircraft with little drag can also inadvertently get into an overspeed condition. Usually this is not as critical as the MACH pitch over situation, but it can become a serious safety problem. Some small Part 23 airplanes are turbocharged and others are also pressurized, having high performance capabilities both in terms of altitude and airspeed. The present Part 23 regulations only require new turbine powered airplanes to incorporate aural overspeed warning devices. The accident record indicates that the high performance reciprocating airplanes are having high speed incidents and could benefit from this device. Therefore, the same type of aural overspeed warning devises also should be considered in the high performance reciprocating airplanes.
	Evaluation Procedure: Determine by reviewing test and evaluation data that the system does meet overspeed warning and recovery criteria or conduct a flight test to observe that overspeed warning is provided prior to the aircraft actually going into an overspeed condition. Evaluate overspeed recovery in each of the modes available for that system, e.g. manual commands or an automatic control, during the recovery process. Aircraft structural limits should not be reached during the recovery maneuver.
	Evaluation Rationale & Background: The system should provide the pilot with adequate information to understand that an overspeed condition is occurring and provide some way to realize a reasonable recovery. The evaluation needs to consider how stable the aircraft is as well as the quickness in which it enters an overspeed condition. For aircraft that may be certified for very high altitudes, pilot incapacitation may occur if there is a loss of pressurization. If this is the case, then the evaluation would reasonably expect some kind of automatic recovery system to be implemented.

7.1.8.3. Aircraft Systems

7.1.8.3.1. Fuel quantity and indication awareness (The presentation of the fuel quantity and the empty condition of the aircraft fuel tanks.)	
	Performance Based Guideline: There should be a fuel quantity measurement capability installed that provides accurate usable fuel quantity values through the range of the indicating system and provides an indication and an alert to a low fuel condition.
	References: 14 CFR PARTS 23.1337; 23.963(e); 23.1553
	Critical Design Activities: The fuel measuring system, whether a manual gauge or an electric system should have an accurate indication of a full tank quantity, an unusable quantity and intermediate markings providing an indication of fuel quantity throughout the range. In addition, a low fuel warning indication is needed. The warning should provide both a visual and an aural alert to the pilot(s).
	Performance Rationale & Background Many small aircraft accidents and fatalities are caused by fuel exhaustion and fuel starvation. This situation has been a result of the pilot not knowing how much fuel is remaining and trying to stretch the amount remaining to arrive at a destination. Reasonable accurate intermediate readings of fuel remaining and an alert when the fuel reaches an unacceptably low level need to be provided. The Small Airplane Directorate has initiated a new rule making an effort to assist in addressing this issue. There are a large number of accidents attributable to both fuel exhaustion and fuel starvation. The exhaustion incidents are caused by the pilot not knowing how much fuel he or she is actually starting with, not knowing the consumption rate, inaccurate gauges until empty, no warning of low fuel, and trying to stretch the distance flown. The fuel starvation incidents are primarily caused by mismanagement of the aircraft fuel system. Many fuel starvation accidents were caused by not switching tanks and allowing the tank being used to run dry.
	Evaluation Procedure: Determine by examination that markings are provided for full, empty and at least three intermediate markings of fuel quantity and that a low warning indication, either aural or markings on the fuel indicator, is present. Review test reports or if no such reports are provided, conduct tests to determine that in a level flight condition at least three intermediate markings are provided that indicate fuel quantity within $\pm$ 5% of actual fuel in the tank, that the empty mark shows 0 units of usable fuel when the tank reaches the unusable fuel level. The low fuel alert should be designed to warn the pilot(s) when a minimum of 45 minutes of fuel remains under level flight cruise conditions.
	Evaluation Rationale & Background: The intent is to ensure that under normal operating conditions, the pilot has a reasonably accurate indication of fuel remaining. Also, when the fuel reaches a minimum level that the pilot needs to refuel, adequate alerting of the pilot is needed to ensure that fuel exhaustion does not occur. The range of the aircraft and fuel consumption rate should be used by the manufacturer to determine what a reasonable reserve fuel level should be.

7.1.8.3.2. Electrical power control and switching

(The manner in which the aircraft primary electrical system is switched between power busses.)

Performance Based Guideline:

The power bus arrangement and switching needs to provide logical Master Switch operation and reversion appropriate to the complexity of the power system during normal and emergency operation.

References:

14 CFR PART 23.1361

Critical Design Activities:

A power system architecture should be defined that allows the pilot to protect the electrical equipment from undesirable electrical transients, to isolate failed systems logically and to maintain a maximum capability to continue safe flight with primary power outages.

Performance Rationale & Background:

Power switching is needed to control the application of power to the aircraft systems under normal, abnormal and emergency conditions.

Depending upon the expected operation of the aircraft, the availability of electrical power can have different levels of criticality. For VFR operations, only a master switch that controls all of the aircraft power may be required for small aircraft. For operation in weather, icing, etc. it is necessary to isolate primary or backup system power to ensure that adequate data is available to the pilot when system failures or primary power failures occur.

Evaluation Procedure:

Determine that power availability requirements have been addressed that are compatible with the requested operation for the aircraft.

A master switch needs to be available to remove all the power from the aircraft systems in-flight or on the ground. The safety assessment may be reviewed to determine that the designer has addressed and defined operation for loss of electrical power. System failures when the system is being certified to be used in icing or weather operation need to be considered.

Evaluation Rationale & Background:

The desire for the aircraft power system is that it be designed to ensure that the electrical power may be controlled appropriately for the operational conditions being requested.

Small aircraft that are not planned to be used for flying in icing conditions, whether or not they are in the Air Traffic System, need little electrical power to safely operate the aircraft. Those aircraft that are intended for other than VFR flight, must have appropriate switching, bus segregation, backup batteries, essential buses, etc. in addition to the master switching requirement. The easiest way to address these issues is through a safety assessment. This allows one to determine the effects of various failure conditions.

7.2 Functional Integration

Compliance with functional integration guidelines is more difficult to determine than with those for Systems and Equipment Design. Functional Integration guidelines tend to be more qualitative and often deal with pilot preferences and workload.

7.2.1. Data Entry

7.2.1.1. Data interface devices and functions
(The devices by which data are communicated to the aircraft systems.)

Performance Based Guideline:
Data interface is a human-machine communication accomplished in a variety of ways with different forms of hardware and software that may also include voice. The data entry interface shall optimize compatibility with users and shall minimize conditions that degrade human performance or contribute to human error. It is highly desirable to provide users with standardized procedures for similar, logically related operations.

Data entry interfaces should communicate their level of functional importance in the installation to the crew. Through analysis, each control is placed in the cockpit reflecting its importance.

Data interface devices can take on many physical forms. Each selected form must account for the range of humans who will be using the device. In order to facilitate user learning, consistency of form is important, both within a given system design and across different systems.

References:
14 CFR PARTS 23.1301; 23.1523; 23.671; and FAA HF design guide, DOT/FAA/CT-96-1; MIL-STD-1472; British Defence Standard 00-25, Part 1

Critical Design Activities:
Data interface is a human-machine communication accomplished in a variety of ways with different forms of hardware and software that may also include voice. Analyses should be conducted to support selection of data entry devices and functional interface approaches. These analyses should also be supported with early interactive tests with the intended users. The analyses should also include an evaluation of errors and their impact on system safety and workload.

HF considerations for data entry:
(Please consult the reference material for a more inclusive list)

- Provide users with standardized procedures for similar, logically related operations.
- Every user input should consistently produce some perceptible response output as feedback from the computer.
- Users shall know the system status at all times, either automatically or upon request.
- Data entry functions shall be designed to establish consistency of input transactions, minimize input actions and memory required by the user, ensure compatibility of data entry with data displayed and provide flexibility of user control of data entry.
- The intended result should be achievable with either no or minimal corrective action (error tolerant). Recovery from data-entry errors shall be achievable in a timely manner. Error messages should be precise and clearly understood.
- Clear and logical data entry schemes should be utilized.
- Data entry messages must be kept short to facilitate short-term memory capabilities of the user.
- System lags and delays should be minimized and not cause reduction in crew performance or increase workload.
- Use simple and natural dialogue presented in a natural order.
- Provide a clearly marked exit to leave an unwanted state in one step.

7.2.1.1. Data interface devices and functions

(The devices by which data are communicated to the aircraft systems.)

Critical Design Activities: (cont.)

There are several techniques that can be used to determine what level of task criticality each type of interface device supports in the cockpit. One such tool is a functional allocation matrix. The tool chosen should relate the following types of considerations:

- Cockpit functions being supported
- Accessibility under normal and abnormal conditions
- Operational Criticality
- Type of data or control interface being provided (direct aircraft control; multiple use controller; soft menu control)

Based on the evaluation of each controller interface element, it can be determined what level of criticality it provides. This in turn will help determine its location in the primary or secondary, or third level field-of-view. It will also help to determine if the input device is a primary, secondary, or third level input device. For example, it may be satisfactory to locate a complex integrated system data interface in the secondary field-of-view. However, some of its functions will be classified as primary; some as secondary; some as third level functions. This latter classification will influence how accessible the specific control interfaces, within this complex data interface itself, should be. MCDUs, cursor control devices, and interfaces with softkey or menu access are examples of complex integrated system data interface devices.

Performance Rationale & Background:

Data entry activities should be designed to minimize ancillary operations and allow the pilots to spend the majority of their time performing the primary mission of safe flight of the aircraft. The use of the interface devices and the tasks associated with their system interface should not compromise control of the aircraft or create unwanted workload for the crew. Best practices have shown that menu structures or controls requiring more than 3 levels of pilot selection have resulted in excessive pilot workload.

Evaluation Procedure:

Establish an acceptable baseline performance level of activity that replicates the appropriate mission sequences and environment to be encountered while performing data entry activity. Gather performance measures such as time to complete versus time allowed per the established baseline. Also collect errors made and the consequences of those errors along with recovery times. Determine the amount of training required if appropriate.

Gather subjective data from evaluators that best fit the intended user population.

Performance is usually measured by having a group of test users perform a predefined set of tasks while collecting time and error data.

7.2.1.1. Data interface devices and functions

(The devices by which data are communicated to the aircraft systems.)

Evaluation Procedure: (cont.)

Typical quantifiable usability measurements include:

- Time users take to perform the task.
- The time spent recovering from errors.
- The number of tasks that can be completed within a given time.
- The ratio between successful interactions and errors.
- The number of immediately subsequent erroneous actions.
- The number of commands or other features that were utilized by the user.
- The number of commands or other features that were never used by the user.
- The number of system features the user can remember during a debriefing after the test.
- The frequency of use of the manuals and/or the help function and the time spent using these system features.
- How frequently the manual and/or help system solved the problem.
- The proportion of user statements during the test that were positive versus critical toward the system.
- The number of times the user expressed frustration or goodness of the system.
- The number of times the user had to work around an unsolvable problem.
- The proportion of users using efficient working strategies compared to the users who use inefficient strategies (in the case there are multiple ways of performing the task).
- The amount of dead time when the user is not interacting with the system. The system can be instrumented to distinguish between two kinds of dead time: response-time delays where the user is waiting for the system, and thinking-time delays where the system is waiting for the user. These two kinds of dead time should be approached in different ways.
- The number of times the user is sidetracked from focusing on the real task.

Evaluation Rationale & Background:

The benefits of iterative evaluation include a higher degree of user acceptance, improved safety and minimization of training. It also minimizes rework of systems after they are fielded. All of these contribute to overall cost savings. Test plans should be developed which consider: Identification of the goals of the test.

- Where, when and how long the test will take.
- Who the testers will be.
- Who the users will be.
- How many users are needed.
- What tasks the users will perform.
- What criteria will be used to determine when the user has finished each of the tasks correctly.
- What aids will be given to assist in performance of the test (manuals, on-line help, training).
- What data will be collected and how it will be analyzed once collected.
- What the criteria will be for saying the interface is successful/certifiable.

7.2.1.2. System response time

(The time required for the system to respond to an input.)

Performance Based Guideline:

Response time to a pilot input is critical and the system design must accommodate user expectations.

References:

DOT/FAA/CT-96-1; Usability Engineering(Jacob Nielson)

Critical Design Activities:

The response time of a system to a user action shall be appropriate to the type of transaction, the time constraints of the task, and any specific data processing requirements. Responses to menu selections, function key presses, and most entries during graphic interaction shall appear to a user to be immediate. Other response times shall match the user's perception of the complexity of the transaction, with apparently simpler transactions having faster responses. Response times need to be evaluated as part of the iterative testing process with appropriate users. System response delays that exceed the human's expectations should provide appropriate feedback.

Performance Rationale & Background:

Systems response time should be as fast as possible. The following is provided as additional basic response time guidance:

– 100 msec is the maximum delay for having the user to feel that the system is reacting immediately.
– 1.0 second is generally considered as the limit for the user's flow of thought to stay uninterrupted, although the delay will be noticed.
– 10 seconds is about the limit for keeping the user's attention focused on the dialogue.
– 100 msec is the maximum acceptable delay between a change in basic aircraft parameters (i.e. attitude, altitude, etc.) and the display of that change.
– Feedback during delays is required.

Evaluation Procedure:

Establish an acceptable baseline performance level of activity that replicates the appropriate mission sequences and environment to be encountered while performing data entry activity. Gather performance measures such as time to complete versus time allowed per the established baseline. Also collect errors made and the consequences of those errors along with recovery times. Determine the amount of training required if appropriate.

Gather subjective data from evaluators that best fit the intended user population. Performance is usually measured by having a group of test users perform a predefined set of tasks while collecting time and error data.

Typical quantifiable usability measurements include:

– Time users take to perform the task.
– The number of tasks that can be completed within a given time.
– The ratio between successful interactions and errors.
– The time spent recovering from errors.
– The number of immediately subsequent erroneous actions.

7.2.1.2. System response time

(The time required for the system to respond to an input.)

Evaluation Rationale & Background:

The benefits of iterative evaluation include a higher degree of user acceptance, improved safety and minimization of training. It also minimizes rework of systems after they are fielded. All of these contribute to overall cost savings. Test plans should be developed which consider:

- Identification of the goals of the test.
- Where, when and how long the test will take.
- Who the testers will be.
- Who the users will be.
- How many users are needed.
- What tasks will the users perform.
- What criteria will be used to determine when the user has finished each of the tasks correctly.
- What aids will be given to assist in performance of the test (manuals, on-line help, training).
- What data will be collected and how will it be analyzed once collected.
- What will the criterion be for saying the interface is successful.

7.2.1.3. Data entry system message formatting

(The manner and order that data is presented to the pilot.)

Performance Based Guideline:

Message formats should be simple to use, easily understood and in a language designed for the user.

References:

DOD/FAA/CT-96-1; MIL-STD-1472

Critical Design Activities:

Message formats should be easy to manipulate with few errors These can be enhanced by making the information readily usable and in a readable form such that the user does not have to transpose, compute, interpolate or mentally translate into other units, number bases or languages.

The information should be developed with the following in mind:

- Have a naturally occurring order (chronological or sequential).
- Grouped by importance.
- Grouped by function.
- Grouped by frequency.
- Have adequate separation of information.
- Limit the need for short term memory.

Performance Rationale & Background:

Interpretation of input message formats and system response messages should be designed to minimize ancillary operations and allow the pilots to spend the majority of their time performing the primary mission of safe flight of the aircraft

Evaluation Procedure:

Establish an acceptable baseline performance level of activity that replicates the appropriate mission sequences and environment to be encountered while performing data entry activity. Gather performance measures such as time to complete versus time allowed per the established baseline. Also:

- Collect errors made and the consequences of those errors along with recovery times.
- Determine the amount of training required if appropriate.
- Gather subjective data from evaluators that best fit the intended user population.
- Performance is usually measured by having a group of test users perform a predefined set of tasks while collecting time and error data.

Typical quantifiable usability measurements include:

- Time users take to perform the task.
- The number of tasks that can be completed within a given time.
- The ratio between successful interactions and errors.
- The time spent recovering from errors.
- The number of immediately subsequent erroneous actions.
- The number of commands or other features that were utilized by the user.
- The number of commands or other features that were never used by the user.
- The number of system features the user can remember during a debriefing after the test.
- The frequency of use of the manuals and/or the help function and the time spent using these system features.
- How frequently the manual and/or help system solved the problem.
- The proportion of user statements during the test that were positive versus critical toward the system.
- The number of times the user-expressed frustration or goodness of the system.
- The number of times the user had to work around an unsolvable problem.
- The proportion of users using efficient working strategies compared to the users who use inefficient strategies (in the case there are multiple ways of performing the task).
- The amount of dead time when the user is not interacting with the system. The system can be instrumented to distinguish between two kinds of dead time: response-time delays where the user is waiting for the system, and thinking-time delays where the system is waiting for the user. These two kinds of dead time should obviously be approached in different ways.
- The number of times the user is sidetracked from focusing on the real task.

7.2.1.3. Data entry system message formatting (The manner and order that data is presented to the pilot.)	
	Evaluation Rationale & Background: The benefits of iterative evaluation include a higher degree of user acceptance, improved safety and minimization of training. It also minimizes rework of systems after they are fielded. All of these contribute to overall cost savings. Test plans should be developed which consider: – Identification of the goals of the test. – Where when and how long the test will take. – Who the testers will be. – Who the users will be. – How many users are needed. – What tasks the users will perform. – What criteria will be used to determine when the user has finished each of the tasks correctly. – What aids will be given to assist in performance of the test (manuals, on-line help, training). – What data will be collected and how will it be analyzed once collected. – What the criterion will be for saying the interface is successful/certifiable.

7.2.1.4. Data entry error management
(Devices and system design that minimize unsafe data entries.)

Performance Based Guideline:
The system must not allow catastrophic data entry errors to occur. The system should be designed to minimize all other errors as well. In the event that an error does occur the system should allow for a simple and easy method of recovery. The system should provide for a one step cancel or escape feature to bring the user back to the previous state.

References:
DOT/FAA/CT-96/1; Usability Engineering (Nielson); 14 CFR PART 23.1301

Critical Design Activities:
Error Tolerant Data Entry/Functional Performance. Aircrew task performance efficiency can be maximized via an error tolerant data entry system design approach. Such a system can be developed via a combination of human, hardware, and software based design features, each mitigating the potential for occurrence of erroneous data entry or action initiation. Examples of such features follow:

Human based design features:
- Controls should be located, or sufficiently separated, so that the combination of reach and vibration-induced effects do not cause the selection of the wrong data input control or control position.
- Controls should be located to avoid visual parallax induced input errors in the selection of controls or control positions.
- Instrument displays should be located to avoid visual parallax induced errors in the reading of their output information, which could lead to further entry of erroneous data.
- Warnings/alerts should be designed and located such that they are quickly noticed (heard, seen, felt) and can be quickly interpreted for determining if/when erroneous data has been entered or occurred.

Hardware based design features:
- Hardware controls should be designed to intuitively and unambiguously relate to the functions that are being controlled. An example is when a wheel shaped gear handle that raises/lowers the landing gear when it is placed in the raised/lowered position, respectively, or a desired value goes up with the upward toggle/deflection of a momentary switch and decreases with a downward toggle of the same switch.
- Hardware interlocks or guards should be used when necessary to avoid or prevent critical out-of-sequence operations or selections.
- Anthropometic aids may be used to account for various environmental conditions, e.g. turbulence, to support the arms, hands, etc. as appropriate.
- Push buttons should positively indicate input data acceptance {e.g. tactile response (e.g. mechanical click, detents), aural response (e.g. click sound, beep), visual response (e.g. light flash, data changes)} or position feedback (e.g. in “on” or “off” condition).
- Rate-of-change (sensitivity) of controlled response to input change (position, rotation, or deflection) should be intuitive and controllable.
- Infinitely variable tuning type knobs should operate incrementally when increment based data is being changed (e.g. knob clicks for every 0.025 MHz change in tuning VHF radio frequency).

7.2.1.4. Data entry error management
(Devices and system design that minimize unsafe data entries.)

Critical Design Activities: (cont.)

Software based design features:

- A data dictionary is created to define all allowable data (type, range, resolution, etc.) and its usage (origination, destination, read/write permissions, etc.)
- Incorporate logical checking on all data field entries for valid type (e.g. textual vs. numeric), range (minimum and maximum values), resolution (e.g. radio frequency band increments).
- Use of highlighting and prompts to highlight soft menu selections.
- Visual size for soft menus and dialogue boxes that are compatible with the expected user population.
- Allow for a variation in data entry formatting when the entered data is valid (example: Lat/Lon, waypoint constraints).
- Assure that the logic used in data entry and data selection operations is unambiguous in both the presentation and selection of options.
- Logical hierarchies and levels of indentation for displayed information should be minimized.
- Completion of data entry may be prohibited upon immediate determination of invalidity -OR- active warnings in response to the entry of invalid data should be provided.
- Positive actions should be required to either clear or override invalid data entry warnings.
- Context sensitive help should be made available when invalid data is entered.

Performance Rationale & Background:

The system should be error tolerant such that inadvertent data-entry errors do not cause the system to enter "unrecoverable" states or require excessive attention by the pilot, diverting attention from the primary task of flight control. Problems of this nature in previous semi-automated systems have been observed to contribute to both incidents and accidents by distracting the pilots from primary pilotage duties.

Evaluation Procedure:

Heuristic evaluations can be conducted to look at an interface and try to come up with an opinion about what is good and bad about the interface. Heuristic evaluations should be conducted as part of the iterative testing effort. These evaluations are usually based upon the evaluators experience and common sense; however, experience tells us that any single evaluator will miss most of the usability problems in an interface. (Molich and Nielson 1990). Single evaluators found only 35% of the usability problems in the interface. However, since different evaluators tend to find different problems, it is possible to achieve substantially better performance by aggregating the evaluations from several evaluators. It seems reasonable to utilize at least five and as a minimum three (Nielson 1992). Each evaluator must conduct the evaluation alone. Only after individual inspections are conducted should the evaluators be allowed to communicate and aggregate their findings. A written report should be prepared to document the evaluation. The evaluations should not be excessively long (1-2hrs max). If more time is required the evaluation sessions can be split. It is probably best to go through the interface at least twice with the first pass used to get a feel for the system. The second pass would then concentrate on the interfaces.

Evaluation Rationale & Background:

Designers need to conduct heuristic evaluations as part of their design process. Independent evaluations are needed to ensure evaluators conduct unbiased tests. These evaluations have been found to be of cost benefit.

7.2.2. Label Identification

7.2.2.1. Labeling (The manner that a name or identification of a particular data, mode or function is provided.)	
	Performance Based Guideline: Labels should be located in a consistent fashion adjacent to the data group or message they describe. Labels should be easily read and understood by the expected user population.
	References: 14 CFR PARTS 23.1301 (b); 23.1335; and AC 23.1311-1A; MIL-STD-1472
	Critical Design Activities: Labels should: – Be unambiguously related to the group, field, or message they describe. – Be highlighted or otherwise accentuated to facilitate pilot scanning and recognition. This highlighting scheme must also be unmistakably different than that utilized for display of emergency or critical information. – Be unique and meaningful to distinguish them from data, error messages, or other alphanumerics. – Character size and font shall be readable from the design-eye position by the expected user population under all anticipated illumination conditions. – Abbreviations and acronyms should conform to accepted industry standards. – Be displayed in upper case only, while text may be displayed in upper and lower case. – Reflect the question or decision being posed to the user, when presenting a list of user options.
	Performance Rationale & Background: Hidden, ambiguous or misleading labels contribute to increased pilot workload. Clear and consistent labeling enhances the pilot's ability to transition between different aircraft.
	Evaluation Procedure: Review the labels throughout the cockpit on controls, mode annunciations and functions to ensure that particular functions are labeled consistently on all the system, that labels unambiguously describe each control, mode or function and that all labeled functions are operational. While seated in the normal pilot's position note that all labels are readable.
	Evaluation Rationale & Background: Different names and labels of modes or functions may present a confusing indication to the pilot(s). The same function should have consistent names, labels and icons on the controls, annunciation and modes. Some latitude has been given when generic names and specific names are used together as long as no confusion occurs as to what data is being selected or displayed. An example is where the word NAV may be used on an annunciation when the input may be LOC or VOR when the display is consistent and performance of the aircraft is essentially the same. However, problems may arise if the pilot needs to differentiate between the localizer input and a navigation input that has different scaling and that dramatically affects the approach performance.

7.2.3. Retrofit Of Systems in Old and New Aircraft

7.2.3.1. Retrofit integration (The requirements to put equipment into older aircraft.)	
	Performance Based Guideline: The addition of a system(s) to an existing cockpit should result in the new system(s) operating in a consistent manner with the existing systems. The pilot, under both normal and abnormal conditions, should be able to operate the added system(s) with the existing system(s) without confusion. The combinations of existing and new systems by the pilot should improve the safe and efficient operation of the aircraft over the original cockpit configuration.
	References: 14 CFR PART 23.1309
	Critical Design Activities: The retrofit design should make full use of the criteria defined in other sections of this document concerning: – 7.1.2 Controls – 7.1.4 Display Content and Symbology – 7.2.1 Data Entry – 7.2.4 Workload
	Performance Rationale & Background: An existing aircraft has been certified with cockpit that demonstrates a specific level of harmonization between handling qualities and system displays and controls. The addition of added system(s) and/or functions to the existing cockpit systems should give an enhancement in safety, and overall aircraft and pilot operational capability.
	Evaluation Procedure: Evaluations have been conducted using a variety of subjective surveys with a number of rating schemes, i.e. NASA TLX. Retrofitted aircraft makes it difficult to specific one best evaluation technique or method. The designer needs to establish the rationale for a selected evaluation approach, conduct and complete the evaluation process. Experience has shown that evaluations completed using 5 evaluators, selected to adequately reflect the pilot population that routinely operate the systems and aircraft, has been found to be adequate to uncover sources of error and obtain acceptable results. Scenarios designed to evaluate the systems individually and in appropriate combinations are expected to be developed. Some combination of rating evaluation methodology with subjective written comments provide the best test results.
	Evaluation Rationale & Background: Evaluations should be conducted to meet the requirements of a new system as much as practical. These are contained in other sections of this document in the following sections: – 7.1.2 Controls – 7.1.3 Display Content and Symbology – 7.2.1 Data Entry – 7.2.4 Workload

7.2.4. Workload

7.2.4.1. Aircraft handling
(The difficulty for the pilot to fly the aircraft during typical flight.)

Performance Based Guideline:
Aircraft handling workload has been the traditional focus of aircraft design and the human pilot. It encompasses the basic aircraft stability, control and performance, and the aircraft systems interface necessary for the crew to accomplish these handling functions. It includes compliance with the established regulations in regards to takeoff, cruise, landing and engine out situations.

References:
14 CFR PARTS 23.1309; 23. 143 through 23. 253; and 23. 771 through 23.831; 23. 995.

Critical Design Activities:
The aircraft shall be safely controllable by the minimum pilots in all phases of flight, including normal, abnormal, and emergency operations. The analysis should include the following considerations:
- Reasonably anticipated weather conditions.
- Dispatch criteria, including MMEL (Master Minimum Equipment List) and KOEL (Kinds of Operations Equipment List) considerations.
- Failure conditions.

In addition to compliance with the regulations for controllability, stability and trimability, flight controls should be well harmonized and predictable.

The display format and media also influence the handling workload. The evaluation of the number, size and type of flight displays and the format of presentation should be integrated with the basic aircraft performance and handling qualities.

Performance Rationale & Background:
Minimum levels of stability, difficult to actuate or poorly harmonized flight controls, and systems that do not adequately address abnormal operations increase a pilot's physical workload and increase fatigue. Unpredictable response to flight control inputs (e.g., rolloff with speedbrake deflection) erodes pilot confidence in the system, which results in reduced use of the system, or increased pilot attention when using the system (increased mental workload).

Evaluation Procedure:
Conventional handling qualities rating systems should be used to evaluate specific tasks for acceptability. Evaluation of the entire aircraft/crew system is traditionally conducted with minimum crew determination tests, which evaluate the aircraft in anticipated conditions under reasonable anticipated operating environments. This type of test, including subjective evaluations, rank-order evaluations and comparisons to existing designs, should be accomplished as soon in the design and test process as possible, including high fidelity simulation as necessary. Traditionally, these minimum crew determination tests are conducted late in an aircraft certification program in order to use production systems, equipment, flight controls, etc. While acceptable for certification, conducting these tests this late prevents modification of anything that is certifiable as is. Tailoring, improvement, and optimization to reduce workload may not be possible due to schedule constraints. Conducting similar tests early in the program, including use of simulation during the design process, allows desirable changes and the optimization of the aircraft handling qualities to minimize workload.

Evaluation Rationale & Background:
The impact on crew workload of a poor design lasts for the life of the airframe. The cost impact of design changes made late in the development effort are considerably more costly than those made nearer the beginning.

7.2.4.2. Cockpit systems (The difficulty for the pilot to use the aircraft systems during typical flight.)	
	Performance Based Guideline: The systems human interface workload is to be designed such as to allow the crew to successfully accomplish the aviate, navigate, communicate, and manage systems tasks from within the cockpit. These are to lead to a safe and effective accomplishment of the mission intended for the aircraft and the crew. This safe and effective completion is to occur under ideal conditions; and under abnormal conditions. Finally the systems workload should be such that under highly improbable catastrophic failure conditions, the aircraft systems workload should not prevent aircraft recovery. Evaluation of cockpit systems workload is to determine if each of the above tasks can be accomplished, as noted above, for: – Each individual system. – The combined systems. – Various expected combinations of systems to be used.
	References: 14 CFR PARTS 23.1309; 25.1309; and 23.1309 through 23. 1337
	Critical Design Activities: The design process should apply a family of human centered design tools to minimize the cockpit systems interface workload. Early definition of systems functions and mission requirements is very useful. Some analysis of the criticality of each function to be provided should be accomplished, including: – Frequency, importance and sequence of use. – Accessibility of controls and displays under normal and abnormal conditions. – Type of control interface. – The available display medium. – Spatial layout and functional depiction needs to be consistent with actual aircraft system organization. This analysis is equally applicable to the design of a full cockpit or the addition of a single subsystem control of an existing cockpit. Refer to 7.1.2, Controls.
	Performance Rationale & Background: Early design focus on functional definitions and the placement and distribution of the display and controls to carry out the function, places the design attention where end item and operational workload can be most effected. With the functions and the means to monitor and carry out those functions properly placed, the specific controls and display details more naturally support the pilot's prime tasks with a lower workload.

7.2.4.2. Cockpit systems

(The difficulty for the pilot to use the aircraft systems during typical flight.)

Evaluation Procedure:

Workload evaluations have been conducted using subjective surveys, various rating schemes (Cooper – Harper rating adaptations, NASA TLX); and other techniques. The nature of the topic makes it impossible to select one best evaluation method. The designer needs to establish the rationale for such evaluation and then conduct and complete the specified process. Experience has shown that evaluations done by at least 5 evaluators, selected to adequately reflect the crew population that is to routinely operate the systems and the aircraft, as being an adequate means to uncover sources of error and obtain acceptable results. Scenarios designed to evaluate the systems individually and in appropriate combinations are expected to be developed. Some combination of a rating evaluation methodology and subjective written comments provide the best results.

Evaluations can be conducted in part or full task flight training devices. However, some portion of the evaluation will need to be conducted with scenarios in the actual aircraft. The evaluation scenarios, especially in the aircraft, should require a reasonable length of time (1 to 2 hours). The expected mission of the aircraft can influence the time each evaluator is exposed to the scenario tasks.

Much of the systems workload evaluations could take place as part of an iterative design process during the development of the human & system interfaces. This iterative design process, if properly documented, could reduce the amount of design test and evaluations. It has been found that the recognition of the iterative design process throughout the design can lead to a more efficient and effective end product. This is especially true if a cross-functional team of evaluators provides the design feedback during this time. This team should include regulatory pilots.

Evaluation Rationale & Background:

Cockpit systems controls and displays allows the pilots to properly operate the aircraft. Systems that impose an unnecessary or excessive workload on the pilot reduce the level of situational awareness. This in turn can contribute to unnecessary delays, pilot errors and other effects.

7.2.5. Environmental Considerations

7.2.5.1. Temperature (Effects of cockpit environmental temperatures on human performance.)	
	Performance Based Guideline: Provide suitable climate controls for the pilot/crew. 14 CFR PART 23.771 states that the pilot compartment must allow the crew to perform duties without unreasonable concentration or fatigue.
	References: 14 CFR PART 23.771 (a); ARP 4101/4; MIL-STD-1472
	Critical Design Activities: Cockpit design must take into consideration the effects of extreme temperatures (cold and heat) on crew performance. Cockpit/canopy configuration, ambient external temperatures, sunlight/shade, tarmac radiation, and other factors significantly affect the temperature within the cockpit. Climate controls should be provided which allow suitable heating, and at a minimum provide a good source of ventilation for the pilot/crew. Controls, controllers and data entry devices should not achieve temperatures which would inhibit the human operator from using them, nor degrade operation significantly in cold or hot conditions.
	Performance Rationale & Background: Crew performance can be degraded with continuous temperature extremes with no ability to offset their effects. Therefore, for cold days a cockpit heat source is needed, and for hot days at least a good source of airflow is necessary during flight, with a cooling source being desirable (although it is not required by regulation). Optimally, steady-state temperatures within the pilot compartment would be kept within a range of 50 degrees F to 85 degrees F during any given flight. Control interfaces that are excessively cold or hot to the human touch limit their usability under all conditions.
	Evaluation Procedure: Test pilots should be given the task of verifying proper climate control effectiveness, under the aircraft's expected temperature operating range, during flight testing of the aircraft. A temperature survey of the pilot/crew work area is recommended as well, and should take into account temperatures and airflows at the pilot's head and feet. If the various data interface devices and controls will be used at the aircraft's extreme temperatures, their evaluation need to be conducted under those conditions. Evaluation under these extreme conditions would be required if it is determined that these devices and controls would be impacted.
	Evaluation Rationale & Background: Climate control tests should be used to verify that there is a satisfactory work environment for the crew.

7.2.5.2. Vibration

(The impact of internal (aircraft) induced vibration and external (turbulence) induced vibration on aircraft systems operations.)

Performance Based Guideline:

There should be not internally or externally generated vibration in any normal flight condition that would interfere with the satisfactory control of the airplane or cause excessive fatigue to the pilots. Additionally, high vibration levels, even when they don't interfere with satisfactory control or cause excessive fatigue, impair a pilot's ability to detect and/or diagnose aircraft anomalies. These anomalies may cause vibrations that are abnormal that may be masked by high ambient vibration levels. The vibration environment must allow the crew to correctly interface with all necessary aircraft systems.

References:

14 CFR PART 23.251; ARP-4101/4; MIL-STD-1472

Critical Design Activities:

The effects of vibration should be minimized to prevent degraded crew performance. Analyses or testing should be conducted to establish the vibration environment of the crew station(s). Designs should not compromise the crew's ability to operate flight controls, read displays and perform other cockpit duties satisfactorily. The design should keep transmission of whole body vibration to safe levels (MIL-STD-1472 Section 5.8). Designs should account for the crew's ability to operate necessary controls, read displays, react to changing flight scenarios and interact with all necessary cockpit systems in a satisfactory manner.

Performance Rationale & Background:

High vibration environments can impact crew performance, cause discomfort and even motion sickness, and can degrade health with long term exposure in extreme cases. Therefore the design should minimize the negative impact of vibration experienced by the crew. Evidence of a device being tested in its intended environment as part of a TSO approval is not necessarily sufficient to ensure that the crew can adequately operate the device while in flight. Vibration must also be taken into consideration in the selection and display input method such as cursor control devices, keyboards, joysticks, etc.

Evaluation Procedure:

The contribution of on-board equipment to the overall vibration level of the aircraft is difficult to determine, as vibration levels that are imperceptible on a given piece of equipment can combine to create an undesirable overall level. In these cases, total vibration levels in the aircraft should be evaluated.

Initial flight evaluations of the pilot to satisfactorily use and operate the aircraft and its systems should be conducted throughout the aircraft operating envelope, including light and moderate turbulence. Subjective evaluations should be sufficient to detect unreasonable vibration levels. Accelerometers, located at the pilot's seat and on instrument panels have also been used to measure vibration levels. A scenario should be generated for each evaluation sequence to allow each evaluator pilot to experience similar conditions. A subjective survey is used to collect the data and feedback.

Some portion of the scenario should account for all phases of flight, including taxi operations. Specific evaluations of the human interface to systems and sub-systems under vibration conditions can be accomplished in a motion simulator or vibration lab environment.

Evaluation Rationale & Background:

Testing must be done to insure the usability of necessary equipment under expected conditions prior to certification of the installation. Designs should not compromise the crew's ability to operate flight controls or read displays. It should not impair reaction time or detract excessively with pilot interaction with all cockpit systems in a satisfactory manner.

7.2.5.3. Ventilation (The adequacy of breathable airflow through the inhabited areas of the aircraft.)	
	Performance Based Guideline: Cockpit ventilation must be adequate to preclude a toxic environment in the cockpit or cabin.
	References: 14 CFR PART 23.831; ARP-4101/4
	Critical Design Activities: 14 CFR PART 23.831 states that each passenger and crew compartment must be suitably ventilated, and that carbon monoxide concentration may not exceed one part in 20,000 parts of air. Other fumes may cause nausea, dizziness, or distraction as well.
	Performance Rationale & Background: Crew performance can be severely degraded, or even precluded, by the long-term presence of toxic or noxious fumes. Therefore, an adequate source of ventilation must be provided, both to remove such fumes, and to provide the pilot/crew and passengers with a good supply of air/oxygen. O2 masks may be used for breathing; however, ventilation must be able to evacuate smoke from the compartment for adequate visibility if this approach is taken, and crew communications must be taken into account as well.
	Evaluation Procedure: Design the aircraft and environmental systems to preclude development of any toxic or hazardous conditions in the cockpit, and to evacuate fumes while providing breathable air to the crew and passengers. Simulation tests by flight test pilots are recommended, along with the necessary development of smoke evacuation procedures.
	Evaluation Rationale & Background: Cockpit ventilation is necessary to ensure an environment free of harmful or distracting fumes.

7.2.5.4. Noise
(The level of undesirable sound in the inhabited areas of the aircraft.)

Performance Based Guideline:
Provide a cockpit environment that is quiet enough to permit accomplishment of all duties required for flight and does not generate health hazards for short or long term operations.

References:
14 CFR PART 23.771; ARP-4101/4; SAG-NAWCADPAX-96-268-TM; MIL-STD-1472

Critical Design Activities:
14 CFR PART 23.771 states that the pilot compartment and its equipment must allow the pilot to perform his duties without unreasonable concentration or fatigue. A design should therefore limit unavoidable background noise to a reasonable level. The cockpit noise environment should not exceed 80db, as this level has been shown to draw strong complaints from people within confined areas. At 85 db, one can expect cognitive performance decrements. Background noise should not mask auditory signals or messages when headsets are not considered to be required equipment. Sound levels of communications and audio signals should be adjustable, when possible, to compensate for ambient conditions, but care must be taken to avoid masking auditory signals that cannot be adjusted but must still be heard (i.e., stall warnings, etc.). Headsets may be used to accomplish these goals; however, if they are required, all necessary communications and aural signals must either be included in the audio signal to the headsets, or be easily distinguishable while wearing them.

Performance Rationale & Background:
Noise testing is required to determine compliance with performance guidelines.

Evaluation Procedure:
Evaluate the noise level of the cockpit within the approved operational envelop using pilots representative of the anticipated pilot population, and if necessary establish noise levels by measurements using audiometric equipment. During tests, typical factors should be considered such as pilot age, use of sound amplification devices, height (a shorter person's head will be located differently from that of a taller person while at the controls), various combinations of cockpit environmental control settings (vents, airflow rates), and various combinations of operational settings (power, airspeed, altitude and aircraft configuration), etc. Auditory signals and messages should be evaluated for clarity and perception under all expected conditions.

Evaluation Rationale & Background:
An environment that reduces distractions to the crew and allows effective audio communications and signals is necessary for safe operations.

APPENDIX A

REFERENCE AND RELATED DOCUMENTS

The following documents are divided into two categories. The Reference Documents list contains HF documents that are referenced within this specification. The Related Documents list are not directly referenced in this publication. They provide additional information that will be helpful in understanding the Human Factors guidelines contained in this publication. When using these documents, it is advisable to use the latest version available. An asterisk (*) at the end of a reference is a recommendation to read that document.

1.0 Reference Documents

1.1 Federal Aviation Regulations

14 CFR PART 23 Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes, Latest change.(*)

14 CFR PART 91 General Operating and Flight Rules, Latest change.

14 CFR PART 121 Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft, Latest change.

14 CFR PART 135 Air Taxi Operators and Commercial Operators, Latest Change.

1.2 FAA Advisory Circulars

AC 23.1309-1C Equipment, Systems, and Installations in Part 23 Airplanes, dated 8/27/98 or later.(*)

AC 23.1311-1A Installation of Electronic Displays in Part 23 Airplanes, dated 8/17/98 or later.(*)

AC 23.1329-2 Automatic Pilot Systems Installation in Part 23 Airplanes, dated 3/4/1991 or later.(*)

AC 25.773-1 Pilot Compartment View Design Considerations, dated 1/8/93 or later.(*)

AC 27-1B Certification of Normal Category Rotorcraft, dated 9/30/99 or later.

AIM: Aeronautical Information Manual

1.3 Military Standards

British Defence Standard 00-25, Human Factors for Designers of Equipment. The web address is http://www.dstan.mod.uk/ (*)
MIL-HDBK-87213 Electronically/Optically Generated Airborne Displays

AMS-G-25871B, Glass, laminated, aircraft Glazing,

MIL-P-25374B Plastic Sheet, Acrylic, Modified, Laminated, CANCELLED.

MIL-STD 411E Aircrew Alerting System, dated 1 March 1991.

MIL-STD 1776A Aircrew Station and Passenger Accommodations, dated 25 Feb 1994.

MIL-STD-1472F Human Engineering, dated August 23, 1999.(*) See document at http://astimage.daps. dla.mil/quicksearch/

NASA Report 177642 On the Design of Flight Deck Procedures.

NAWCADPAX-96-268-TM Situational Awareness Guidelines, dated 8 January 1997.(*)

Systems Engineering Management Guide, Defense Systems Management College (DSME), Technical Management Department, dated December 1989.

1.4 <u>Industry Documents</u>

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

ARP-1068B Flight Deck Instrumentation, Display Criteria and Associated Controls for Transport Aircraft, dated 09/30/85.

ARP-1782 Photometric and Colorimetric Measurement Procedures for Direct View CRT Displays, dated 01/09/89

ARP-4033 Pilot-System Integration, dated 1995-08.(*)

ARP-4101 Flight Deck Layout and Facilities (Core Document), dated July 88.

ARP-4101/2 Pilot Visibility from the Flight Deck, dated Feb 88.

ARP-4101/4 Flight Deck Environment, dated July 88.

ARP-4102 Flight Deck Panels, Controls and Displays (Core Document), dated July 88.

ARP-4102/7 Electronic Displays, dated July 88.

ARP-4102/7 Appendix A – Electronic Display Symbology for EADI/PFD, dated Dec 91.

ARP-4102/7 Appendix B – Electronic Display Symbology for EHSI/ND, dated Jan 93.

ARP-4102/7 Appendix C – Electronic Display Symbology for Engine Displays, dated Sep 93.

AS-4103 Flight Deck Lighting for Commercial Transport Aircraft, dated Feb 89).

ARP-4256 Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft, dated 1996-12.

AS-8034 Minimum Performance Standards for Airborne Multipurpose Electronic Displays, dated 12-30-82 (TSO).

1.5 Other Standards

DOT/FAA/AM-91/7-The Use and Design of Flightcrew Checklists and Manuals.

DOT/FAA/CT-96-1 Human Factors Design Guide for Acquisition of Commercial-Off-the-Shelf subsystems, Non-Developmental Items, and Developmental Systems-Final Report and Guide, January 1996.

FAA and Industry Guide to Product Certification, dated January 25, 1999.(*)

FAA, GAMA & AIA Report on Redesigned FAA-Industry Partnership for Product Certification, dated 19 September 1999.

RTCA TSO-C113 Airborne Multipurpose Electronic Displays, dated 10-27-89.

Usability Engineering, Jacob Nielson, Copyright 1993 by Academic Press Inc.(*)

2.0 Related Documents

2.1 Federal Aviation Regulations

14 CFR PART 25 Airworthiness Standards: Transport Category Airplanes, Change 13, dated 4/30/98 or later

14 CFR PART 27 Airworthiness Standards: Normal Category Rotorcraft, Change 5, dated 11/28/97 or later

14 CFR PART 29 Airworthiness Standards: Transport Category Rotorcraft, Change 7, dated 11/28/98 or later

2.2 FAA Advisory Circulars

AC 25-7 Flight Test Guide for Certification of Transport Category Airplanes, Change 1, dated 6/6/95 or later

AC 25.11 Transport Category Airplane Electronic Display Systems, dated 7/16/87 or later.

AC 25.1309-1A System Design Analysis, dated 6/21/88 or later.

AC 29-2CB Certification of Transportation Category Rotorcraft, dated 9/30/99or later.

2.3 Industry Documents

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

AIR 850A, dated 7-30-65; "Jet Blast Windshield Rain Removal Systems for Commercial Transport Aircraft.

ARP-1068B Flight Deck Instrumentation, Display Criteria and Associated Controls for Transport Aircraft, dated 09/30/85.

AIR-1093 Numeral, Letter, and Symbol Dimensions for Aircraft Instrument Displays, dated December 31, 1969.

ARP-1874 Design Objectives for CRT Displays for Part 25 (Transport) Aircraft, dated 26 May 1988.

ARP-4032 Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays, dated 04/04/88.

ARP-4067 Design Objectives for CRT Displays for Part 23 Aircraft, dated 11/16/89.

ARP-4102/4 Flight Deck Alerting Systems, dated July 88.

ARP-4102/8 Flight Deck Head-Up Displays, dated July 88.

ARP-4105A Abbreviations and Acronyms for Use on the Flight Deck, dated July 92.

ARP-4107 Aerospace Glossary for Human Factors Engineers, dated August 88.

ARP-4115 Human Interface Design Methodology for Integrated Display Technologies, dated Jan 89.

ARP-4153 Human Interface Criteria for Collision Avoidance Systems in Transport Aircraft, dated Nov 88.

ARP-4260 Photometric and Colorimetric Measurement Procedures for Airborne Direct View Flat Panel Displays (when approved).

ARP-5288 Transport Category Airplane Head Up Display (HUD) Systems, In Draft.

ARP-5365 Human Interface Criteria for Cockpit Display of Traffic Information Technology, dated Jan 99.

ARP-5364 Human Factors Criteria for the Design of Multifunction Displays for Civil Aircraft, dated In draft.

AS-4105A Nomenclature and Abbreviations for Use on the Flight Deck, dated July 92.

2.4 Other Documents

Aviation Human-Computer Interface (AHCI) Style Guide, Version 2.2, May 1998. Report No. 64201-97U/61223.(*)

DOT/FAA/PS-89/1 Flight Status Monitor Design Guidelines (Anderson, etal. 1989)

DOT/FAA/RD-93-4, DOT-VMTSC-FAA-93-4, Human Factors for Flight Deck Certification Personnel, dated July 1993.

FAA-RD-81-38II Aircraft Alerting System Standardization Study: Volume II Aircraft Alerting System Design Guidelines (Berson, etal.,1981).

Federal Aviation Administration Human Factors Team Report on: The Interfaces Between Flightcrews and Modern Flight Deck Systems, dated June 18, 1996. (*)

Human factors in engineering design, M Sanders and. McCormick

Human Factors Guidance for Multifunction Display Evaluation, MTI report no. 20.986601.03, dated May 1, 2000.

NASA Report 177549 Human Factors of Flight-Deck Checklists: The Normal Checklist.

RTCA Document DO-229B MOPS GPS WAAS, dated 6 October 1999.

Wickens, C. D. (1984). Engineering Psychology and Human Performance, Columbus Ohio, Merrill. See pages 310-329 for workload definition.

Sanders and McCormick, E.J. (1993). Human Factors in Engineering and Design, New York: McGraw-Hill Inc.

Hackos, J.T. & Redish, J.C. (1998). User and Task Analysis for Interface Design. New York: John Wiley & Sons

Mayhew, D.J, (1999), The Usability Engineering Lifecycle: A Practitioner"s Handbook for User Interface Design. Morgan Kaufman Publishers

Salvendy, G. (Ed). (1997). Handbook of Human Factors and Ergonomics (2nd ed.). New York: John Wiley & Sons Inc.

3.0 Human Factors Contacts

The following provides information regarding persons or organizations that may be contacted concerning human factors subjects, e.g. testing, modeling, simulation, performance activities, etc.

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APPENDIX B

GENERAL HUMAN CENTERED DESIGN CONSIDERATIONS

1.0 GENERAL

The implementation of systems to provide safe operational use of the whole aircraft requires that, as much as possible, the pilot intuitively understands the system operation and that no surprises occur under normal, abnormal or failure conditions that would induce the pilot to take the wrong action. The system should be designed in a manner that a minimally skilled pilot will be able to use it correctly. A Human Centered Design philosophy provides a method to ensure that pilot expectations are met in the avionics suite performance and operation when it is installed in an aircraft

1.1 PILOT IS RESPONSIBLE FOR SAFETY OF FLIGHT

It is understood that the pilot has the primary responsibility for the safety of a flight. It must be appreciated that a system can confuse the pilot or limit his or her ability to control the aircraft safely. This condition may not be immediately obvious to the pilot. If the pilot cannot effectively understand, oversee and retain management authority over the system functions, then the pilot has lost the ability to safely operate the aircraft.

1.2 PILOT MUST BE INVOLVED

The pilot must be consistently involved in all phases of system and aircraft operations. This important aspect of involvement is required for all phases of flight. Designs where the pilot can easily become preoccupied with details (such as Flight Management System (FMS) data entry) at the expense of maintaining control of the aircraft's flight path creates safety problems. Accommodating this, in order to remain involved, the pilot must be an essential part of the normal operational flow and not be only the solver of anomalies. Pilot involvement is required to be in control of the aircraft.

1.3 PILOT MUST BE INFORMED

The pilot must be clearly informed of the aircraft altitude, airspeed, heading and position, but not overloaded with data. The amount of data presented is critical. Latest generations of aircraft provide a plethora of information to the pilot. It is essential that the design does not produce displays that are cluttered or difficult to interpret. Large amounts of data do not inherently provide useful information. Data becomes information only when it is transformed and presented in a way that is meaningful to the pilot. Without adequate information, the pilot cannot control or manage the aircraft and its systems in a consistent predictable manner. Only the precise information needed at each phase of the flight gives the pilot the information to stay adequately informed. A simple rule-of-thumb is to display to the pilot the required basic information needed for each phase of flight and little more. Other supplemental or advisory information may be pilot selectable, but it must be easily removed to revert back to a basic display presentation. Without displaying correct and timely information in a way that minimizes the cognitive process and workload, the pilot's task of remaining constructively involved in the process is made difficult.

1.4 Pilot Must Be Able To Monitor The Automation

The pilot must be able to monitor what is occurring in the automatic operation of the aircraft and its systems. Where automation is employed in the cockpit, it is essential that the pilot be aware of the status of the automated functions at all times. Complex automation can be powerful and silent, leaving the pilot unaware of what is occurring in the system or aircraft. Therefore, it is important that designs are implemented in a manner so that the pilot understands that the automation is correctly performing each function that has been commanded.

1.5 Automated Systems and Functions Must be Able To Monitor The Pilot

Automated systems should be able to effectively monitor pilot responses. In human centered designs, it is crucial to recognize and understand the merits of both the automation and the system functions concerning the pilots activities associated with the overall operation of the cockpit/flight deck. An example is how the takeoff configuration warning system should verify the pilot's actions to select the proper configuration for takeoff.

1.6 Automation Must Be Predictable

The aircraft's automated functions must be predictable and intuitive to the pilot. System designs that inform the pilot when there is a discrepancy between parameters within the systems that is sufficient to disrupt or disable the operation of the function without resulting in consistent and intuitive responses by the pilot are not acceptable. The pilot may need to "take immediate control" of that function. To be able to transition from the automated system to the pilot without delay, the pilot must be continually aware of the function or dysfunction of each automated task and the status of the aircraft and its systems. The pilot's mental model of the system must be accurate and reinforced by the operation so that he or she consistently remains in the loop of the active functions. Cues or annunciation used to alert the pilot to "take control" must be clear and unambiguous.

1.7 Intelligent Systems Must Know Intent of Other Intelligent Systems

It is paramount that effective communication be maintained among each of the global systems involved in aircraft operations, such as pilots, aircraft systems, and Air Traffic Controllers (ATC), to allow safe flight operations. Each of the intelligent systems must know the intentions of the other intelligent systems. Correct integration of the global system is essential in improving the overall operation of the aircraft. The design should provide feedback to the crew in a manner that is clear, consistent, and unambiguous. The crew must appreciate the inputs required for the use of automation in each particular phase of flight (for example, the operational criteria and inputs required for CAT II operation need to be well understood).

1.8 Enhancing HF Criteria For New Technology

HF guidelines and HF design and evaluation processes must be defined in an appropriate manner to ensure that safety improvement does occur in the finished aircraft. The guidelines must be general enough to allow innovative improvements in the design to be made using new technology and new concepts and yet specific enough to ensure that critical parameters are properly implemented. New system implementations can improve safety of the operation of the aircraft, reduce procurement costs and provide increased capability to move the aircraft from one point to another. However, it should be realized that using a new technology does not ensure that these improvements will occur. It is necessary for the designer who uses new technology to evaluate the impact of its use.

1.9 Evolving of Human Factors Guidelines

HF guidelines have changed as new technologies are available and experience is gained. Simple cockpit systems used by experienced pilots allowed considerable flexibility in avionics designs to produce an acceptable operational capability. As aircraft have become a common means of transportation, the number of aircraft in the air traffic systems and the complexity of the avionics systems necessitate improved human machine interfaces to give adequate safe operation. It would be expected that further evolution of products and their optimum usage by pilots will continue to present the need for revised HF evaluation techniques and guidelines. Some of the generic philosophies that need to be considered are listed below.

– New avionics on advanced cockpits/flight decks should be easier to operate than that on existing conventional aircraft. Avionics functions need to operate in a consistent manner in each aircraft tail number into which it is installed. Intuitive operation of systems is highly desired. The design should be optimized for situational awareness, preventing information overload and minimizing the crew difficulty in assuming control from the automation. The systems used should provide sufficient capacity for future growth with an aim to reduce pilot workload (e.g., self-healing systems) in appropriate phases of flight. Training requirements of pilots need to be included to enhance the use of the system.

– New technology that is correctly applied may be used to enhance safety. Upgraded cockpits/flight decks need to be designed to accommodate safe dispatch capability with inoperative functions by addressing minimum equipment list requirements (MMEL and MEL). Adequate priority should be given to addressing total aircraft safety assessment and maintenance issues.

– Certification risks should be identified and minimized. This is accomplished by having early meetings and agreements with the regulatory agencies and by applying HF design concepts early in the product development. Lessons learned from previous certifications should be incorporated into revised HF guidelines.

APPENDIX C

ACRONYMS AND ABBREVIATIONS

Acronym or Abbreviation	Meaning
14 CFR	Title 14 Code of Federal Regulations formal called Federal Aviation Regulations
AC	Advisory Circular
AIA	Aerospace Industries Association
ARP	Aeronautical Recommended Practice
AS	Aeronautical Specification
ATC	Air Traffic Control
CAS	Central Alerting System
CAT II	Category II approach
CATIA	A computer aided design system
CDU	Control Display Unit
CFR	Code of Federal Regulations
CRT	Cathode Ray Tube
D	In formula = distance to eye
DOT	Department of Transportation
F	Fahrenheit
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations now called Title 14 Code of Federal Regulations
FOV	Field-of-View
GA	General Aviation
GAMA	General Aviation Manufacturers Association
HART	Hazard Air Traffic Report
HCD	Human Centered Design
HF	Human Factors (Not to be confused with High Frequency)
HFT&E	Human Factors Test & Evaluation
hrs	Hours
HUD	Head Up Display
Hz	Hertz
IFR	Instrument Flight Rules
KOEL	Kinds of Operations Equipment List
L	In formula = size of object
LCD	Liquid Crystal Display
MAX	Maximum
MCDU	Multifunction Control Display Unit
MEL	Minimum Equipment List
MFD	Multifunction Display
MHz	Megahertz
MIL	Military
MIL-HDBK	Military Handbook
MIL-STD	Military Standard
mm	Millimeters
MMEL	Manufacturer’s Minimum Equipment List

Acronym or Abbreviation	Meaning
MR	Milli Radian
Msec	Millisecond
NASA	National Aeronautics and Space Administration
PFD	Primary Flight Display
RTCA	An association of aeronautical organizations of the U.S. from both government and industry. This organization develops commercial specifications involving the application of electronics and telecommunications to aeronautical operations.
SAE	Society of Automotive Engineers
STC	Supplemental Type Certificate
TC	Type Certificate
TLX	Task Load Index
TSO	Technical Standard Order
VHF	Very High Frequency

APPENDIX D

HUMAN FACTORS EVALUATION PLAN

(Outline Example)

A. Introduction

This section should briefly describe the test and evaluation plan approach.

B. Background

This section should include a brief description of the system(s) being assessed and its relationship, if any, to other systems. Also include a discussion of any previous evaluations that were accomplished along with significant problems and results.

C. Program Schedule

This section of the plan should include the major milestones of the program with emphasis on the milestones specific to the Human Factors evaluation. The schedule should provide dates for planned; conceptual and design reviews, coordination and meetings, and testing/evaluation of components and systems. Include the dates for tests, evaluations and approvals scheduled on bench setups, in mockups, simulators, and the actual aircraft. The following milestone chart provides the type of high level program milestones that should be considered.

PROGRAM SCHEDULE →	Start → Approval **Time** (Weeks, Months or Years)
Capture Field Requirements	
Define HF Concepts & Philosophies	
Establish Safety and HF Design Criteria	
Meet With & Brief Regulatory Agencies	
System Overview	
Human Factors Plan	
Certification Plan	
Tentative Schedule	
Issues Resolution	
Evaluation Basis and Agreement	
Final System Definition	
Regulatory Update	
Issues Resolution	
Start Major Design Tasks	
Regulatory Update	
Continuing Review and Evaluation	
Issues Resolution	
Internal Design and Management Reviews	
Regulatory Update	
Specific Evaluations	
Demonstrations	
Simulations	
Studies	
Flight Tests	
Equipment Airworthiness Approvals	
Issues Resolution	
Present HF Approval Package	
Present System for Approval	

GENERIC SCHEDULE FOR
HUMAN FACTORS DEVELOPMENT AND EVALUATION PROGRAM

The following descriptive sections delineate other specifics of a generic test plan. For evaluation programs on simple functions, all of these items may be contained in one plan. However, this does not preclude a "master" plan supported by a number of lower level plans. These lower level plans may have significant detail included in them.

D. System Description

In this section the system being tested & evaluated should be briefly described. In addition to a brief description, picture or other graphical presentations may be beneficial. Since each component in the cockpit has a specific purpose and function to perform, it is important to describe the component's purpose and function along with the total cockpit integration aspects, from the human factors perspective.

The introduction of a new system into a cockpit, a new set of human behaviors may be created due to different tasking or interface configuration. It is, therefore, essential that there is a clear understanding of the implications the installation will have on the pilot. Identifying the new behaviors and roles the human pilot must assume helps focus the evaluation on the key human-vehicle interface and human performance issues.

E. Evaluation Participants

This section of the plan should discuss how the system is designed to accommodate a range of human physical, perceptual and cognitive characteristics and capabilities. In terms of the physical characteristics, systems must accommodate a range of sizes, reach and strength capabilities to safely fly the aircraft. Determine design-to population considerations to include all critical physical dimensions (e.g. sitting eye height, arm reach, leg length, stature, etc.) Refer to 7.1.1.1. These qualities primarily guide the physical design of controls and displays and the final geometry of the cockpit.

Users' skills vary significantly because of differences in inherited abilities and experiences. Since it is not practical to evaluate individual cognitive capabilities as a screen for identifying test participants, the test conducted must rely on differences in training and experience. Subjects should be selected to represent both the low-end, novice user, and the more experienced user.

F. Environmental Conditions

The plan should also consider varying conditions of the operational environment. The system may be operated in a myriad of environments including hot, cold, dry and wet climates. Each of these environments affects the human-system interface capabilities.

An important environmental aspect is the ambient lighting conditions. Controls and displays must provide for effective and consistent performance under all potential ambient lighting conditions.

Another condition often neglected is the operation of the system under degraded modes of functionality. Since systems do not function optimally indefinitely, it is important to evaluate system performance under degraded functionality.

G. Test Objectives

In this section, the specific objectives of the evaluation should be delineated. For complex test and evaluation programs, this section may also reference one or more documents containing detailed test objectives.

Test objectives are qualitative statements of system performance goals with respect to individual characteristics associated with each aspect of the system. The test objectives should be comprised of short definitive statements beginning with an action verb (such as verify, evaluate, determine, demonstrate, or compare). Objectives should be written in a form that will permit an achievable and executable result.

It is important that specific test objectives capture and stipulate, in detailed terms, the areas and concerns at issue. The areas identified previously by analysis, preliminary evaluations and/or experience should be the focus. A specific test objective may read – Evaluate the capability for inserting and removing waypoints or changing type of approach or runways.

H. Measures of Performance

Describe in this section the measures of performance that will be used. There are two major types of measures of performance - objective and subjective performance measures. Objective measures are measurements taken of some quality or quantity that are absolute; that is without any distortion by personal perceptions, feelings, or interpretations. Some objective measures include the following: the time required to perform a task, the number of control inputs, error rates, altitude and airspeed deviations. Subjective measures are focused on the personal perceptions, feelings, and interpretations. Data for this measure are usually collected using surveys, questionnaires, and interviews.

Objective measures are usually preferred over subjective measures. In most cases, a combination of both is desirable. The measures of performance must be directly related to the test objective. The data collected should qualify a test objective.

I. Success Criteria

Success criteria are developed to define the end point of the evaluation. It establishes the amount of data that must be collected to qualify the measure of performance. It is used to determine when sufficient testing and data acquisitions have been accomplished to perform the required evaluation of the system under test.

Basically a test is successful when sufficient data have been collected in accordance with guidelines and criteria delineated in the test plan. However, while conducting the test, more data may be required when there is significant data scatter or varying results such that no clear conclusion can be drawn. More frequently for human factors evaluations, the test is successful when sufficient samples have been collected under the conditions and criteria set in the test plan. For example, it may be that when the stipulated number of pilots from various experiences and training backgrounds have performed the task and completed the questionnaire.

J. Evaluation Criteria

In this section a description of the standard, guideline or measure the test results will be compared against is stipulated. Evaluation criteria are used to evaluate each measure of performance in terms of the specified or desired system design or performance. Conclusions are drawn based on the assessment of the evaluation criteria. Sometimes there is no clear definitive criterion that can be referenced. In these cases, experience and engineering judgement may have to be used to determine whether the system meets its design and performance goals.

K. Test Methodology

The test methodology element briefly describes the test equipment, conditions, and procedures that will be used in the conduct of a test associated with a particular measure of performance. Methods should be chosen that provide the best predictive measure of human-system performance. Of particular importance is the selection of the type of device that will be used to conduct the test. The following is a list of different devices that may be used to evaluate a design. Detailed test plan documents may be referenced in this section.

– Bench Tests – Bench tests are tests performed on individual components in a laboratory environment.

– Mock-up Evaluations – A mock-up is a three-dimensional model fabricated to represent the physical configuration of the system or component

– Simulator Evaluations –The difference between mock-ups and simulators is that simulators provide for some level of functionality.

– Static Ground Tests – These are tests that are conducted in the actual airplane, while stationary.

– In-flight Evaluations – These types of evaluations are made in the actual airplane, while flying.

L. Results, Conclusions & Recommendations

Test results form the bases for conclusions. Conclusions present the substantiated findings, and provide a discussion of the implications for the systems and/or functions being evaluated.

It is important to differentiate between test results and conclusions. Test results simply present and describe the data, with no amount of interpretation of the data. For example, if 5 out of 7 pilots rated a particular system feature "very good", then that is what is reported as a result. The interpretation of this result in terms of, for example, system usability and acceptability is a conclusion.

Recommendations suggest a course of action. This is where the evaluator provides suggested actions based on the factual evaluations that have been conducted. There should be a recommendation associated with each issue and deficiency. Recommended courses of action include the following; further testing should be conducted, the component should be redesigned to correct the deficiency, the deficiency should be documented and a warning provided in the manual, and special training should be provided to compensate for the deficiency (ideally, manual entries and training need to be minimized). Regardless of the recommendation provided, as a minimum, it should either mitigate the affects or establish an avenue for a future resolution.

APPENDIX E

CROSS REFERENCE

Primary Topical Area	
Sub Topical Area	Page

APPENDIX F

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APPENDIX G

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Attached are my comment sheets concerning GAMA Publication No. 10.

SPECIFIC COMMENTS OR REQUEST FOR CHANGES/REVISIONS TO GAMA PUBLICATION NO. 10

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Date: **Ref No.**

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My comment concerns:
A typographical error ___________ **Suggested revision______________**
Content clarification_____________ **Other_________________**

Comment for Publication No. 10 Location:

Page______ ***Section__________*** ***Paragraph_________***

Original wording:

Revised wording:

Rationale for change: