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Flight Crew Interface Considerations in the Flight Deck Design Process for Part 25 Aircraft

RATIONALE

ARP5056 has been reaffirmed to comply with the SAE five-year review policy.

TABLE OF CONTENTS

1. SCOPE

This ARP defines recommended flight crew interface design processes and methods for new flight deck designs as well as modifications to the flight crew interface of existing flight decks of transport category aircraft (Part 25), which includes commercial transport aircraft, regional and business aircraft. These processes and methods are intended to be utilized by the design engineers of manufacturers of transport category aircraft or any modifiers to the flight deck system. Modifiers include equipment suppliers, avionics manufacturers, aircraft operators, original equipment manufacturers (OEM), regulatory authorities, or anyone seeking a supplemental type certificate (STC), type certificate (TC), amended TC, field approval, or equivalent approval.

The processes and methods described in this ARP address the integration of human factors/ergonomics, engineering, and flight operations in the design and/or modification of flight crew interfaces. These interfaces provide the flight crew access to the installed systems, using controls, indications and displays, in order to allow them to accomplish the tasks of aviate, navigate, communicate, and manage systems. Included in these processes and methods are considerations for flight crew training, the use and integration of automation, error tolerant designs, and task management.

These processes and methods are designed to yield flight deck designs that are both safe and efficient, in that order of priority. These processes and methods address the issue of creating modifications to existing designs that are compatible with the original intent of the flight deck design.

2. REFERENCE SECTION

The documents listed in 2.1 are referenced for guidance in this document. The documents listed in 2.2 are provided for information purposes only and do not form a part of the recommendations of this document. A bibliography of literature relevant to this document is also presented in 2.2

2.1 Applicable Documents

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

ARP4033 Pilot-System Integration

ARP4107 Aerospace Glossary for Human Factors Engineers

ARP4155 Human Interface Design Methodology for Integrated Display Symbology

2.1.2 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

MIL-HDBK-1908B Definitions of Human Factors Terms

MIL-HDBK-46855A Human Engineering Requirements for Military Systems, Equipment and Facilities

DI-HFAC-80742B Data Item Description for Human Engineering Simulation Concept

DI-HFAC-80746A Data Item Description for Human Engineering Design Approach Document-Operator

DI-HFAC-80747B Data Item Description for Human Engineering Design Approach Document-Maintainer

DI-HFAC-81399A Data Item Description for Critical Task Analysis Report

Human Factors for Flight Deck Certification Personnel, K Cardosi, FAA Report DOT-VNTSC-FAA-93-4, Jul, 1993

The Interfaces Between Flight Crews and Modern Flight Deck Systems, FAA, Jun 1996

A Crew-Centered Flight Deck Design Philosophy for High-Speed Civil Transport Aircraft, NASA TM-109171, Jan 1995

2.1.3 Other Publications

Aviation Automation: The Search for a Human-Centered Approach, C Billings, Lawrence-Erlbaum Associates, 1997

Human Factors Aspects of Flight Deck Design - Issue 2, JAA Interim Policy INT/POL/25/14

International Organization for Standardization. (1981). Ergonomic principles in the design of work systems (1st. ed.) (ISO 6385:1981). Genève, Switzerland: International Organization for Standardization.

Airbus Cockpit Philosophy, Airbus Industrie Document AI/EV-T: 474.0482/01, May 2001.

Human Factors - HWG Final Report June 15, 2004, "Flight Crew Error/Flight Crew Performance Considerations in the Flight Deck Certification Process", Human Factors-Harmonization Working Group, Federal Aviation Administration - USA, European Aviation Safety Agency – Europe.

2.2 Applicable References

2.2.1 Workload References

Garland, DJ, JA Wise, & VD Hopkin (Eds.). (1999). *Handbook of Aviation Human Factors*. Mahwah, NJ: Lawrence Erlbaum Assoc.

Handcock, P. & N. Meshati (Eds.). (1988). *Human Mental Workload*. Amsterdam: North Holland.

Jahns, DW. (1973). Operator workload: What is it and how should it be measured? In KD Cross & JJ McGrath (Eds.). *Crew System Design*. Santa Barbara, California: Anacapa Sciences.

Stamler, JH. (1993). *The Dictionary for Human Factors/Ergonomics*. Boca Raton, FL: CRC Press

Weirwille, WW & FT Eggemeier. (1993). Recommendations for mental workload measurement in a test and evaluation environment. *Human Factors, 35*.

2.2.2 Pilot in the Loop References

Billings, CE. (1996). *Aviation Automation: The Search for a Human-Centered Approach*. Mahwah, NJ: Lawrence Erlbaum Assoc.

Flach, J, P Hancock, J. Caird & K. Vincente (Eds.). (1995). Global Perspectives on the Ecology of Human-Machine Systems. Mahwah, NJ: Lawrence Erlbaum Assoc.

Garland, DJ, JA Wise, & VD Hopkin (Eds.). (1999). Handbook of Aviation Human Factors. Mahwah, NJ: Lawrence Erlbaum Assoc.

Sarter, NB & R Amalberti (Eds.). (2000). Cognitive Engineering in the Aviation Domain. Mahwah, NJ: Lawrence Erlbaum Assoc.

2.2.3 Error Tolerant Reference

Palmer, EA, EL Hutchins, RD Ritter, & I vanCleemut. (1993). *Altitude Deviations: Breakdowns of an Error Tolerant System*. NASA Technical Memorandum, DOT/FAA/RD-92/7. July

2.2.4 Cognitive Complexity References

De Keyser V., Javaux D. (1998). Mental Workload an Cognitive Complexity. In N. Sarter & R. Amalberti (Eds, Cognitive Engineering in the Aviation Domain. Lawrence Erlbaum Associates.

Javaux D. (1997) Measuring Cognitive complexity in Glass-Cockpits. A Generic Framework and its application to autopilots and their modes. In R.Jensen & L. Rakovan(Eds). Proceedings of the ninth Symposium on Aviation Psychology, Colombus, Ohio.

Rauterberg, M., (1992). “A Method of a Quantitative Measurement of Cognitive Complexity”, In: Van der Veer, G., Tauber, M, e.a.: Human-Computer Interaction: Tasks and Organisation. CUD-Publ., Roma, pp. 295-307.

2.3 Definitions

Definitions used in this document shall be as noted in the Glossary of Terms defined in Section 8.

The word “shall” is used to express an essential (mandatory) requirement. Conformance requires that there be no deviation. The word “should” is used to express a recommended requirement. Deviation from the specified recommendation may require justification.

3. INTRODUCTION/BACKGROUND SECTION

This Aerospace Recommended Practices (ARP) document contains information and guidance in the form of best practices on the application of human-factors (HF) principles to the design, implementation and retrofit of aircraft systems within the context of operational requirements and safety in modern civil aircraft. Additionally, the ARP provides a process template to aid the designer in ensuring that human-factors considerations are included in all phases of design, production, operational implementation and any subsequent modification. This document is intended to be utilized by design engineers however, regulatory agencies and customers may use or point to all or part of this document as an example of how to generate acceptable designs from a human factors perspective.

The increased utilization of automated systems, coupled with the increased workload of operating sophisticated aircraft in the modern international airspace system, has made the proper application of sound human-factors design principles more important than ever. The growth in air traffic has placed demands on the airspace and airport infrastructure that are far beyond anything envisioned in original flight deck designs. These demands have increased pilot workload and reduced margins for error.

This ARP provides recommendations to support the accomplishment of the highest level of safety, while obtaining the greatest benefit and efficiency from modern flight deck designs. The need to ensure that modification and upgrade to existing flight decks recognize, and are compatible with, the original flight deck design, systems operation and systems integration are also covered.

The human-centered design process described in this document is a proven practice that accommodates the inclusion of human factors principles along with engineering and flight crew operations expertise early enough in any product design cycle to be effective such that human engineering principles are “designed in” rather than “reviewed in”. Incorporating human-centered design from the beginning of a project and through to its conclusion will result in a cost-effective, safe and acceptable flight crew interface as well as enhancing the overall aircraft system efficiency. The process is adaptable and amenable to alteration as appropriate to the design effort. It is applicable throughout any stage of the product life cycle from initial design and certification on through any future supplemental type certificates, modification and/or alteration activities subsequent to the initial certification.

The need to allow innovation and systems enhancements is recognized as a valid requirement. All manufacturers have proprietary designs that they must protect and continue to develop, so the ARP recommendations are targeted at high-level principles that will encourage and foster future development and progress. A look at the published human-factors design guidelines of the two largest aircraft manufacturers clearly show that, even though they traditionally have taken different approaches to aircraft and systems design, their high level human-centered design principles are surprisingly similar. These have been included in Section 7 for reference.

Utilization of the processes and methods described in this ARP will help ensure that the flight crew interface design will be acceptable to both customers and regulatory agencies. However, this ARP does not define what the flight crew interface design attributes of the system or aircraft should be. Finally, the guidance presented in this document includes both human interface considerations as well as recommended best practices.

4. FLIGHT DECK DESIGN PROCESS OVERVIEW AND EXPLANATION OF USAGE OF THIS DOCUMENT IN THE DESIGN PROCESS

4.1 Flight Deck Design Process Overview

The flight crew interface design processes detailed in this document are an integral part of systems engineering as depicted in Figure 1. Although the processes outlined in this document appear to be linear, the design process is actually iterative in nature. Hence the linear steps outlined here only represent major phases of development but many items like requirement discovery, concept or solution development and evaluation happen in iterative cycles typically spiraling into greater and greater design details until a final design is implemented. It is also important to note that depending on the design novelty and complexity, the same steps should be appropriately tailored. For example, while all steps should be considered even for simple design changes, the amount of and level of evaluation, analysis, and testing will vary significantly depending on the size, complexity, and novelty of the design project.

4.2 Structure of This Document

Section 5 contains details on five important process steps for integrating human centered design into the flight deck engineering process. For each process step, the rationale and scope are defined. In addition, four items are included for each process step: Inputs, Outputs and Deliverables, Human Machine Interface (HMI) Considerations, and Best Practices.

Inputs include both externally generated inputs as well as HMI generated requirements and requirements from previous steps.

Output and Deliverables are items that are either flowed into the next process step or that feed into other engineering process steps.

HMI considerations are items that need to be included in this step of process in order to ensure an adequate coverage of human factors principles in the design process.

Best Practices are those items that have been found to lead to effective HMI designs in the most efficient manner.

Each of these four items is identified in the tables appearing in each of the five process step sections. While parts or processes belonging to the four categories (i.e., Inputs, Outputs and Deliverables, HMI Considerations and Best Practices) are identified in the table, the purpose of the comments sections is to provide additional detailed information for those parts of the process that are not self-explanatory. Items having this additional information as comments are designated in each of the tables with a reference to the appropriate section in the document.

Since a flight deck design philosophy is a major component of human centered design, Section 6 of this document contains details and considerations for the development of a flight deck design philosophy. Section 7 contains separate examples of high level human centered flight deck design philosophies from two major aircraft manufacturers.

5. FLIGHT CREW INTERFACE DESIGN PROCESS

Five major process steps for including human centered design within the overall flight deck and engineering design process are depicted in Figure 1 in approximate relationship to the overall engineering design process. While the five steps, requirements capture, concept of operations, interface solution, detailed design and implementation and integrated test and evaluation, are shown as linear, the actual design process is more complex and often iterative. However, these five major steps must be part of the overall design process.

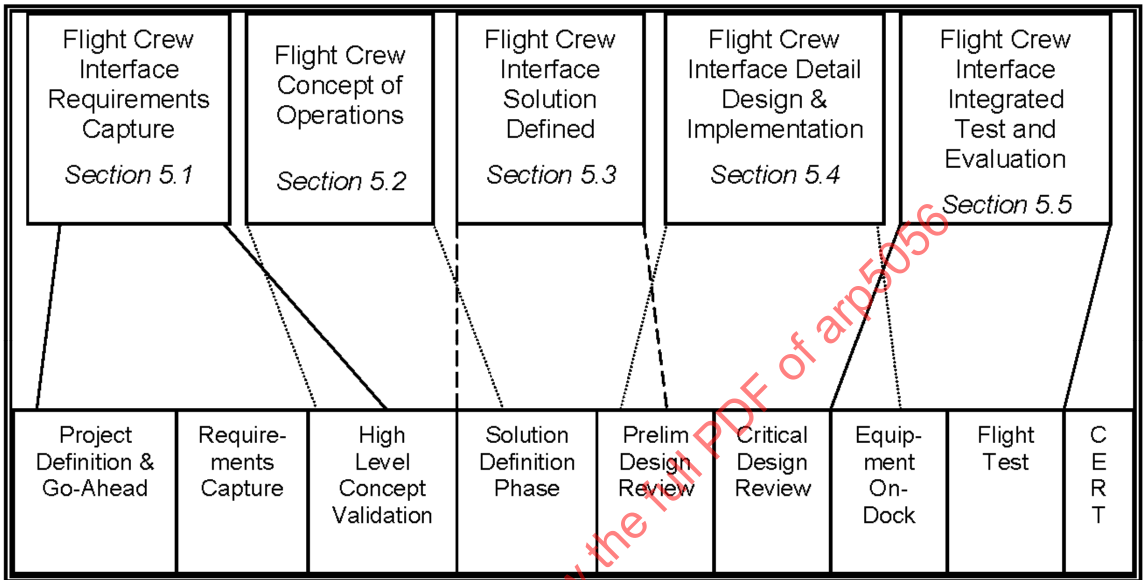

FIGURE 1 - BASIC FLIGHT CREW INTERFACE DESIGN PROCESSES SHOWN IN RELATION TO OVERALL ENGINEERING DESIGN PROCESSES

5.1 Flight Crew Interface Requirements Capture/Discovery

5.1.1 Rationale/Scope

The flight deck design process should begin with gathering of all external and internal constraints and requirements that may affect the flight crew interface design (includes all flight crew functions). These are typically higher level types of requirements. Where requirements are missed, the final design can not meet the customer expectations.

5.1.2 Major Process Components for Flight Crew Interface Requirements Capture and Discovery

TABLE 1

Inputs	Output/Deliverables
• Flight deck design philosophy (see Section 6) • Aircraft mission and operational requirements (see 5.1.3.1.2) • Appropriate regulations • Market strategy drivers (see 5.1.3.1.3) • Flight deck configuration (see 5.1.3.1.4) • Pilot operational experience and pilot capabilities (see 5.1.3.1.5) • Applicable lower level guidelines and conventions (see 5.1.3.1.6)	• Documented organized consistent set of requirements • List of unresolved issues associated with HMI requirements
HMI Considerations	**Best Practices**
• Requirements capture - per Input Box above • HMI requirements categorization, prioritization, and validation (see 5.1.3.3.1) • Identification of conflicting HMI requirements	• Engage appropriate multi-disciplinary team (see 5.1.3.4.1) • Determine level of complexity and novelty (see 5.1.3.4.2) • Identification of conflicting requirements: use of flight deck design philosophy to de-conflict or prioritize

5.1.3 Process Comments

5.1.3.1 Inputs

5.1.3.1.1 Flight deck design philosophy - see Section 6.

5.1.3.1.2 Aircraft Mission and Operational Requirements

Examples of mission and operational requirements that are affected by or affect the flight crew interface include but are not limited to mission range and duration, airline company standard operating procedures, as well as landing capability and dispatch requirements. It is also important to define all of environments in which the aircraft is to operate.

5.1.3.1.3 Market Strategy Drivers

Examples of items that make up the market strategy include cost targets, training and proficiency goal, safety goal, maintainability strategies, functionality requirements and objectives.

5.1.3.1.4 Flight Deck Configuration

Constraints include: ergonomic, flight deck environmental issues, lighting controls, coding (e.g., color, shape), arrangement rules of overhead panel, glareshield, main instrument panel, central pedestal and other installation factors.

5.1.3.1.5 Pilot Operational Experience and Pilot Capabilities

Pilot characteristics to consider include pilot operational characteristics, composition of the flight crew as well as overall pilot capabilities. Pilot operational experience includes demographics (including national cultural background and differences), experience base, and qualifications of the intended pilot population. Crew composition characteristics include the number of pilots, expected flight durations and any relief crew requirements. Pilot capabilities include general human anthropometry, perceptual and cognitive abilities. In the area of anthropometry, issues of strength, size, reach, accessibility, and controllability must be considered, although many of these are governed by regulatory documents. With respect to perceptual issues, key areas include color perception (especially the effects of aging on color perception), perceptual attention, human auditory capabilities, and general visual processing especially in the areas of contrast and brightness perception. In the area of cognition, the historical key attributes of interest have been workload (both high and low workload levels) and the pilots' understanding of system automation.

5.1.3.1.6 Applicable Lower Level Guidelines and Conventions

Lower level guidelines and conventions include those which flow out of the Top Level Flight Deck Design Philosophy (Section 6), constraints imposed by the Design Organization's Human Interface Design Specifications, the Customer's Human Interface Design Specification (if any), and regulatory considerations such as AC/AMJ 25-11. The lower level guidelines include but are not limited to information on use of color, control accessibility and lighting. For modifiers, the original Flight Deck Design philosophy, if available, may be beneficial.

5.1.3.2 Output/Deliverables

From a process perspective, flight crew interface requirements should be documented along with the rest of the design requirements.

5.1.3.3 HMI Considerations

5.1.3.3.1 HMI Requirements Categorization, Prioritization, and Validation

HMI considerations requiring categorization, prioritization, validation and conflict identification include but not necessarily limited to:

a. Crew tasks

b. Cognitive and physical ergonomics

c. System error detection and recovery

d. Human error, its mitigation and recovery

e. Mode awareness of system state

f. Automation

g. Alerting

h. Information coding (e.g., color, symbology, auditory, and tactile)

5.1.3.4 Best Practices

5.1.3.4.1 Engage appropriate multi-disciplinary team.

An effective skill set includes:

a. Flight operations (line pilots are important in uncovering unintended uses of prior designs)

b. Human factors

c. Systems engineering

d. Certification

e. Airspace operations, e.g., Air Traffic Management (ATM), Airport and/or Airline Operational Communications (AOC), Dispatch

Attributes/expertise desired:

a. Broad skills with small teams to make decisions

b. Comfortable with ambiguity for some period of time

c. Ability to generate probing questions of users and requirement generators

5.1.3.4.2 Determine level of complexity and novelty.

Complexity and novelty determine how much and what kind of analysis, evaluation, testing, etc is necessary during development, and implementation. Complexity and novelty will also drive the level of training required to operate the system.

5.1.3.4.2.1 Novelty

The Human Factors - HWG Final Report June 15, 2004 defines four factors to consider when determining degree of novelty associated with a design:

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

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

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

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

Novelty is generally considered a very subjective measurement. People of different experience levels, and different general backgrounds, will generally perceive the novelty of a specified task differently. However, the relatively consistent and well established conventions present in aircraft flight deck environments do provide a reference by which to measure novelty.

The key measurement here is also strongly related to how "well known" a task may be in terms of the expected user community. Appendix A contains a suggested method for deriving a measure of novelty.

5.1.3.4.2.2 Complexity

Measuring the complexity of tasks in a given environment is generally considered to be a subjective process and can be measured in various ways. Typically this involves the expert opinions of subject matter experts within the design team.

One practical measure of task complexity is the amount and level of detail required in a flight crew procedure document to explain the operation of a function. Simple tasks and functions will require very short documented procedures while more complex tasks and functions will require longer and more involved flight crew procedures. If it is too complex, design changes should be considered.

A number of methods for measuring the complexity of tasks exist in the literature. Reference to some examples can be found in 2.2.4 of this document.

5.1.3.4.2.3 Other Considerations for Complexity

Considerations for defining and dealing with level of complexity have increased as automation and multi-function devices on the flight deck have increased. The more complex the operational rules are for governing the behavior and/or use of this equipment, the harder it will be to learn and remember how to use the equipment. There is an inverse relationship between how many rules are required to operate a system and how effective and acceptable the system interface will be to the user and hence the rules that govern system interfaces should be relatively small in number, simple, and consistent.

A major factor that needs to be considered in complex systems is the match between the pilot's expectation of how the system should behave and how the system actually behaves, i.e., matching the pilot’s mental model with the actual system functional logic. This is true even for novel system interfaces where apparent complexity can be reduced and hence ease of use enhanced, if positive transfer of function from other system behavior can be utilized to make the new interface more intuitive to the pilot.

5.1.3.4.2.4 Applying the Results

Pilot tasks that are determined to be either highly complex or highly novel require the greatest scrutiny during the design process with respect to analysis, test and evaluation. Plans for human factors aspects of certification should address each of these tasks with equal scrutiny. Tasks that are determined to be medium or higher in both complexity and novelty should receive similar scrutiny. Other tasks should be considered as part of the composite or overall general evaluation and of the acceptability of the flight deck.

5.2 Flight Crew Operational Concept Definition

5.2.1 Rationale/Scope

The flight crew operational concept provides the design team the opportunity to organize the many human interface, economic, training, and operational inputs and considerations from the data collection phase of the process. The organization and clarity of the material that is provided as output will serve as the roadmap to all of the several design teams to follow that shape the human interface to the flight deck. As the details of the design unfold, these teams will regularly refer to the product of this phase to insure consistency with the goals and human interface functional objectives.

The output of this step is commonly called the Flight Deck Operational Requirements document. The certification authorities use the Flight Deck Operational Requirements roadmap as the first deliverable or artifact of the applicant’s human factors process.

5.2.2 Major Process Components for Flight Crew Operational Concept Definition

TABLE 2

Inputs	Output/Deliverables
• Documented, organized, and consistent set of requirements • List of HMI issues associated with requirements • Baseline flight deck definition and operational procedures (for STC applications) (see 5.2.3.1.1) • Flight deck design philosophy • Evolution roadmaps as appropriate (see 5.2.3.1.2)	• Baseline Flight Deck Definition (for STC this would be a change to baseline) (see 5.2.3.1.1) • Concept of Operations (see 5.2.3.2.2)
HMI Considerations	**Best Practices**
• Functional allocation of tasks among crew members and aircraft systems, i.e., automation (see 5.2.3.3.1) • Identify crew tasks with the appropriate level of task analysis/task definition (see 5.2.3.3.2) • Use flight deck design philosophy to develop the concept of operations (see 5.2.3.3.3) • Consider the concept of operations impact on crew training • Utilize baseline flight deck	• Validate concept of operations using appropriate set of experts (pilots, human factors, and systems expertise) and operational scenarios (see 5.2.3.4.1) • Consider technology evolution and future operational environment that will impact flight crew operations and training

5.2.3 Process Comments

5.2.3.1 Inputs

5.2.3.1.1 Baseline Flight Deck Definition and Operational Procedures

A baseline is typically defined by arriving at a configuration that can only be changed via some change control process. Although the baseline may be declared at any time, there are reasons why it should be declared at a particular point in the design process. If the baseline is declared too early, innovation may be stifled, and unnecessary overhead may be incurred tracking changes to the baseline. If the baseline is declared too late, the ripple effects of uncontrolled changes may become very costly and could actually place the project at risk. The major physical components of a baseline flight deck definition include but are not limited to: general flight deck layout including crew seat position, design eye position for each crew member, main instrument panel dimensions, and pedestal dimensions. In addition, top level operational philosophies such as checklist philosophy, user input methods and devices as well as pilot authority philosophies need to be defined before the baseline definition and hence become part of that baseline.

5.2.3.1.2 Evolution Roadmaps

A flight deck evolution roadmap is a timeline-based description of a new flight deck design in terms of both its heritage and more importantly, its future development evolution. The flight deck evolution roadmap is important because it (1) helps the designer identify new or novel design features, and their associated means of compliance, in a timeline context, (2) assists the designer in planning for retro-fit and forward-fit consistency as new features are added to the flight deck, and (3) aids the designer in planning for compatibility between the flight deck and anticipated changes in the operational environment. In many respects, the flight deck evolution roadmap simply organizes design artifacts that are already being generated into a chronological order to facilitate the analysis and planning for flight deck design evolution over time. For more information on creating and utilizing flight deck evolution roadmaps, see Appendix B.

5.2.3.2 Output/Deliverables

5.2.3.2.1 Baseline flight deck definition - see 5.2.3.1.1

5.2.3.2.2 Concept of Operations

Defines how the flight crew is expected to carry out the functions and tasks detailed within the requirements. It nominally contains:

a. Proposed crew methods to carry out the task by phase of flight

b. Allocation of task between the flight crew and automatic systems

c. All unique operational considerations (e.g., long-range operations versus short-haul)

d. Definition of how the system should be used and what the limitations are (e.g., a Runway Awareness and Advisory System (RAAS) should not be used for guidance)

5.2.3.3 HMI Considerations

5.2.3.3.1 Functional Allocation of Tasks Among Crew Members and Aircraft Systems, i.e., automation

Two parameters to consider in allocating tasks between crew members and aircraft systems are keeping both the pilot workload and "pilot in the loop" activities at the appropriate level.

5.2.3.3.1.1 Pilot Workload Considerations

Pilot workload is defined as an indicator of the level of total mental and/or physical effort required to carry out one or more tasks at a specific performance level. While flying modern aircraft can impose a certain level of physical demand, generally these are well within the range of abilities of a reasonably fit pilot. Therefore, in most cases when addressing workload, it usually refers to the combined cognitive and physical pressures associated with time critical limitations. Historically, the human factors research literature has focused on five general issues:

a. Given the current workload level can the pilot do more tasks safely?

b. Could the pilot perform emergency tasks if one arose?

c. Can one modify the crew station to reduce workload?

d. Can one modify pilot behavior, for example through training, to reduce workload?

e. Will the modifications be sufficient to have a positive overall impact?

In addition to the above, other items that need to be considered from a pilot workload perspective include:

a. Have any of the tasks normally carried out by the flight crew been modified, and if so by how much?

b. Have any new tasks been introduced?

c. How many multiple tasks are required to be carried out at the same time?

Most analysis tools currently used to estimate workload performance tend to overly simplify workload parameters and are therefore dependent on the judgment of the analyst. In addition, these tools are sometimes conservative in their estimates and can lack sufficient precision and/or reliability in driving decisions as whether to incorporate automated functions. For example, automation could reduce workload as measured by hand and eye motion but, if the automation were poorly implemented, it could actually increase cognitive workload and increase opportunities for un-anticipated errors or the detection and recovery from errors. Conversely, a given workload tool may estimate higher workload for a system that provides obvious safety benefits such as an electronic checklist. See Appendix C of this ARP for discussion of workload measurement issues and pilot response to overload conditions.

5.2.3.3.1.2 Pilot-in-the-Loop Considerations

The pilots' ability to remain in-the-loop is dependent on their ability to gather relevant information and process it in an effective and efficient way, which in turn is dependent on their having an effective mental model not only of the aircraft's practical dynamic performance but also of the environment in which they are operating. This model and knowledge set have recently been organized around the concept of situation awareness. Current thinking argues that there are four basic information domains of which the flight crew need to be aware: (1) the relation of the aircraft to the terrain, other aircraft, navigation fixes, etc.; (2) basic flight dynamics, e.g., airspeed, altitude, and attitude, for both the current conditions and predicted conditions (e.g., velocity vector); (3) environmental conditions (e.g., metrological, mission); and (4) the dynamics and intentions of the other players. Thus, information needs to be available, in an intuitive and readily accessible manner, to support all four domains. Another parameter to consider for "pilot-in-the-loop" is whether the design provides an appropriate level of awareness of the status of automated systems, e.g., mode annunciation, failure alerting, awareness of who's in control, etc.

5.2.3.3.2 Identify Crew Tasks with the Appropriate Level of Task Analysis/Task Definition

Task analysis should be accomplished at level of task granularity depending on the design or evaluation goal that is being supported by the task analysis. For example, an analysis to determine if everything associated with radio tuning can be physically accessed by a single crew member would be done at a different level of granularity than an analysis to determine if the pilot tasks associated with failure management while using a new flight warning system. In the first, the evaluator would only need to verify that all controls are located in an area reachable by an appropriately restrained crew member. While the second would require an extensive listing of serial and parallel tasks including ability to reach controls but more importantly, the aviate, communication, and system management tasks that must be performed.

5.2.3.3.3 Use Flight Deck Design Philosophy to Develop the Concept of Operations

At this stage, the flight deck design philosophy constitutes a number of principles that have strong impact on the operational concept. As an example, key HMI considerations such as a head up/eyes out philosophy will influence the use and operational concept for new control features such as voice control as an alternative to manual control. Ultimately the concept of operations must be tested for compliance against all of the higher level flight deck philosophies. New flight deck philosophies specific to the project may need to be identified. This is sometimes the case where new functionality is added that is not covered by the existing philosophies or principles.

5.2.3.4 Best Practices

5.2.3.4.1 Validate Concept of Operations Using an Appropriate Set of Experts and Operational Scenarios

This is typically performed using paper analysis (story boarding) of operational scenarios, i.e., operation of the aircraft. These scenarios need to consider normal and non-normal conditions (including failures) under all phases of flight. In addition, the use of computer based flight deck simulation and rapid prototyping can add a level of fidelity and confidence in the development and validity of the concept.

5.3 Flight Crew Interface Solution Definition

5.3.1 Rationale/Scope

This phase entails the derivation of a flight crew interface design definition through the use of analyses, evaluations, tests and prototyping. These activities are based upon the entire set of requirements, design philosophies, technology capabilities and operational concepts previously defined and/or captured. During this stage, alternative design concepts are evaluated and a single design is ultimately selected.

This stage, also includes a check-back of the design against requirements and objectives which leads to an initial validation of the acceptability of the design is accomplished.

5.3.2 Major Process Components for Flight Crew Interface Solution Definition

TABLE 3

Inputs	Output/Deliverables
• Entire set of requirements (Output from 5.2) • Operational Concept (see 5.2.3.3.3) • Baseline FD Definition (see 5.2.3.1.1) • Flight Deck Design Philosophy (see Section 6) • Technology capabilities (see 5.3.3.1.1)	• Documentation of all HMI assumptions, risks, decisions and rationale for decisions • HMI Functional description (see 5.3.3.2.1) • Initial drafts of crew procedures, training recommendations and other operational documents.
HMI Considerations	**Best Practices**
• Follow flight deck design philosophy and applicable guidelines, and where appropriate, develop new ones specific to the project • Identify and conduct appropriate level of HMI evaluations and analyses (see 5.3.3.3.1) • HMI items to be considered in design trade offs include: operational safety, workload and operational efficiency, training, crew procedures, pilot performance and user acceptance • Evaluate the interfaces and functionalities for the controls, displays and alert indications to ensure consistent and conflict free flight deck operation	• Include a multi-disciplinary team for both design and regulatory agency teams (see 5.3.3.4.1) • Validation through appropriate representation of Flight Deck environment and flight environment (see 5.3.3.3.1) • Generate the approach for human factors aspects that will be included in the certification plan(s) and coordinate with regulatory agency specialist team. • Quick iteration of solutions and evaluations

5.3.3 Process Comments

5.3.3.1 Inputs

5.3.3.1.1 Technology Capabilities

This represents a list of those technologies that enable or hinder the ability to implement a given function. Often these capabilities are not flight deck technologies but are related to airspace infrastructure such as communications and or information transfer.

5.3.3.2 Output/Deliverables

5.3.3.2.1 HMI Functional Description

Refers to the functional description of the flight crew interface. This includes a definition of the crew interface to the devices on the flight deck including location, look, feel, and behaviors of the system and flight crew operation of the system and/or component. It also includes how the devices interact with each other as well as how the overall system behaves. This functional description is a subset of the overall system functional description and is meant to completely define the human interface. The HMI functional description in whole or in part can be used as input to various system description/specification and/or system requirements documents.

5.3.3.3 HMI Considerations

5.3.3.3.1 Identify and Conduct Appropriate Level of HMI Evaluations and Analyses

Various analysis and evaluation types include engineering evaluations and analyses, mock-up evaluations, part-task evaluations, simulator evaluations, and in-flight evaluations. The major difference between the types of evaluations is the level of fidelity, time and cost; generally there is an increase as one progresses from a part-task evaluation to a full-mission simulator, and then finally to an in-flight evaluation. For more information on these types of analyses and evaluations see Appendix D. In addition to identifying the appropriate type and level of evaluation, one also needs to identify the appropriate evaluators and prototyping devices.

Prior to the selection of an appropriate means of evaluation or analysis, the design team needs to consider a number of factors including those listed below. This list is not exhaustive, but provides a useful initial check-list.

5.3.3.3.1.1 Program Constraints

It is important for the design team to recognize that several evaluation methods may be acceptable for any given requirement. The team should select methods that best fit the program schedule and cost considerations. In many cases, the time and costs associated with conducting evaluations on an aircraft or full-mission flight simulator may be beyond the scope of the program. The point in the development cycle in which the method is to be used is also important. Some methods are more suited to early design phases, some to the later phases, and others can be used in any phase.

5.3.3.3.1.2 Degree of Integration/Independence

If the interface being evaluated is a stand-alone system that does not interact with other flight deck systems, less integrated methods of evaluation may be acceptable. However, if the target system is highly integrated, either directly or by the means that a crew uses it, it may be necessary to use methods that allow the testing of those interactions within the integrated system(s). An example of a more stand alone system is the display and control unit for a weather radar system. An example of a more highly integrated system would be an integrated surveillance system that includes weather, traffic, and terrain display and control.

5.3.3.3.1.3 Novelty/Complexity

If the technology is mature and well understood, less rigorous means of evaluation and/ or analysis may be appropriate. However, for new complex and/or novel systems, more rigorous methods are likely to be required.

5.3.3.3.1.4 Criticality

Systems that are central to the interface design may require testing in a realistic environment (high-quality simulation or flight test) because any design problems are likely to have serious consequences.

5.3.3.3.1.5 Dynamics

If the control and display features of the system are highly dynamic, the evaluation methods should be capable of replicating those dynamic conditions.

5.3.3.3.1.6 Crew Training/Pilot Tasks

If the system introduces new crew tasks and/or likely to require new crew training, the interfaces may need to be evaluated in an environment that replicates the full spectrum of activities in which the crew may be involved.

5.3.3.4 Best Practices

5.3.3.4.1 Include a multi-disciplinary team.

The team should consist of pilots (test pilots, demonstration pilots who represent the line pilots, training pilots and certification pilots) simulation/prototyping engineers, avionics/systems engineers, mechanical engineers, and human factors engineers.

5.3.3.4.2 Validation Through Appropriate Representation of Flight Deck Environment and Flight Environment

The same considerations defined in 5.3.3.3.1 for selecting the appropriate evaluations are appropriate for validation methods as well.

5.4 Flight Crew Interface Detailed Design and Implementation

5.4.1 Rationale/Scope

This part of the process entails going from the documented specification of the flight crew interface design to an actual hardware and software implementation that the flight crew will interact with. The detailed design process entails deriving more and more detailed requirements to ensure that parts and behaviors of those parts can be built in order to accomplish the flight crew interface specification. The implementation involves the actual build, generation and integration of parts (hardware or software) that will enable the flight crew to carry out their intended mission and tasks. There is often a continued interaction between the designers who collected the initial set of requirements and developed the design solution and the implementers who are responsible for the final product development (both hardware and software) to ensure that the original intent of the interface solution is met by the final implementation. Within the overall engineering process the items usually associated with this step are Preliminary Design Reviews, Critical Design Reviews and Parts On-dock.

This step is extremely important since there are often many compromises made at this point in order to implement the concept. Hence the continued involvement of designers with the implementation team is very useful.

5.4.2 Major Process Components for Flight Crew Interface Detailed Design and Implementation

TABLE 4

Inputs	Output/Deliverables
• Flight Crew Interface Design Specification (Output from 5.3)	• Rationale for detailed decisions that affected the HMI (see 5.4.3.2.1) • Flight deck HMI functional description (see 5.4.3.2.2) • Proposed Minimum Equipment List
HMI Considerations	**Best Practices**
• Check that the implementation meets the concept of operations • Evaluate that the detailed Flight deck implementation is consistent and conflicts have been resolved (see 5.4.3.3.1) • Incremental evaluation of HMI with actual H/W and S/W is used to address usability of the interface. (see 5.4.3.3.2) • Use high level Flight Crew operational philosophy for ensuring operational procedures are consistent with the flight deck design philosophy (see 5.4.3.3.3)	• Continued and iterative interaction between the design and implementation teams (in cases where design and implementation teams are different) • Provide the higher level documents such as the Flight Deck Design Philosophy and Flight Crew Operational Requirements, and rationale/assumption document to all team members. • Continue to involve multi-disciplinary team in the evaluations. • Where system is complete enough, involve currently flying line pilots in evaluations.

5.4.3 Process Comments

5.4.3.1 Inputs (No additional comments for this section)

5.4.3.2 Output/Deliverables

5.4.3.2.1 Rationale for Detailed Decisions That Affected the HMI

The rationale should include a description of the human factors methods and principles utilized in the generation of the final detailed design that is defined in the flight deck HMI functional description.

5.4.3.2.2 Flight Deck HMI Functional Description

This description includes the specific HMI definition of the crew interface to the devices on the flight deck such as location, look, feel, and behaviors of the system and flight crew operation of each system and/or crew interface component. This information needs to be captured at a level sufficient to support system specifications, as well as flight crew operations, training and maintenance manuals. The content of this information needs to include:

a. Schematics: diagrams showing the functional architecture of the system.

b. Controls: detailed description of the function of all switches, selectors, line select key prompts, and soft buttons (for cursor controlled interfaces).

c. Indicators: detailed behavior of all panel lights, displayed messages, and displayed numeric and graphic indications.

d. Intended crew procedures for the interface:

   1. Normal procedures for routine operations

   2. Supplemental procedures (used occasionally for special operating conditions; for example, cold weather)

3. Non-normal procedures (steps to ensure continued safe flight and landing in the event of system failures or emergency operating conditions)

4. Techniques (suggested methods for well-practiced users to optimize operation; for example, shortcuts)

e. Certification limitations, if any.

f. Proposed allowable dispatch relief with associated procedures.

The above material is often useful to the development of maintenance documents even though those documents may not be used by the flight crew.

5.4.3.3 HMI Considerations

5.4.3.3.1 Evaluate that the detailed flight deck implementation is consistent and conflicts have been resolved.

The flight deck design philosophy can often be used to determine the priority between conflicting requirements. Consistency should also be evaluated against the flight deck design philosophy as well as the flight crew operational philosophy. An example of looking at flight deck consistency is performing an analysis to ensure that input devices are designed appropriately for the function, there are dedicated input devices where appropriate (e.g., altimeter setting or altitude pre-selector) and that input devices are not overburdened with too many function controls (especially true for cursor control devices).

5.4.3.3.2 Incremental evaluation of HMI with actual H/W and S/W is used to address usability of the interface.

Incremental evaluations typically involve the use of part-task usability testing and evaluation as well as human modeling techniques**.** Iterative human center design processes have already been described in the literature (see Foyle et.al., 1996). Tools used for test and evaluation during this phase involve the use of rapid prototyping systems and flexible generic part-task simulators. Methods for test and evaluation are detailed in section 5.5.3.3 below.

5.4.3.3.3 High Level Flight Crew Operational Philosophy

A flight crew operational philosophy defines the high level objectives for how the aircraft is to be operated by the flight crew. Components of this operational philosophy include items related to how the flight crew is expected to aviate, navigate, communicate and manage systems on the aircraft. Examples of the types of information that may be included in this crew operational philosophy are:

a. How the aircraft is meant to be handled, for example “Fly this aircraft as any other aircraft” and

b. Prioritization of tasks, for example “Aviate, navigate, and communicate are to be performed in that priority”

c. Delineation of task duties among the flight crew, for example, “pilot flying” versus “pilot monitoring” responsibilities.

d. Validate critical mission data, for example crosscheck the accuracy of indications of aircraft location and energy state (e.g., Flight Management System (FMS), altitude, and airspeed).

e. Adequately monitor automation state, for example, “Know your Flight Mode Annunciation at all times.”

f. When to override automation, for example, “When the automation does not perform as expected, take over.”

g. How to coordinate crew tasks, for example, “Practice task sharing and back up each other.”

5.4.3.4 Best Practices (No additional comments for this section)

5.5 Integrated Test and Evaluation

5.5.1 Rationale/Scope

This phase entails implementation and testing to verify and revalidate against the functional requirements. While test and evaluation is normally carried out throughout the entire design process, the integrated verification and validation is where all of the flight deck components are tested together as a whole system rather than as separate components in part-task evaluations.

5.5.2 Major Process Components for Integrated Test and Evaluation

TABLE 5

Inputs	Output/Deliverables
• System Components and/or Flight Deck Implementation (see 5.5.3.1.1) • Overall HMI test plan (see 5.5.3.1.2) • Entire set of flight crew interface requirements and concept of operations	• HMI test results supporting certification • Key flight crew training issues (for training development team) • Description of standard operating procedures to support EIS
HMI Considerations	**Best Practices**
• In order to carry-out full integration testing of HMI evaluations (physical ergonomics as well as cognitive) need to consider: 1. Choice of appropriate tool, use of normal and non-normal procedures, performance criteria, appropriate test participants (see 5.5.3.3.1) 2. Appropriateness of test methodology for evaluating function and interface (see 5.5.3.3.2)	• The flight deck simulator complements real aircraft tests for more complex, in-situation tasks since the environment is more controllable than on the aircraft. • Considerations for scenarios for both ergonomic and cognitive evaluations (see 5.5.3.4.1) • Organized list of HMI decision rationale and assumptions

5.5.3 Process Comments

5.5.3.1 Inputs

5.5.3.1.1 System Components and/or Flight Deck Implementation

The implementation to be tested is representative of the final aircraft configuration with respect to the flight crew interfaces and all aircraft system behaviors that result in flight deck effects. This testing includes consideration of environmental effects such as the effect of turbulence on ability to operate controls. Testing under minimum equipment list configurations is also to be included under this integrated testing phase.

5.5.3.1.2 Overall HMI Test Plan

While the HMI test plan is often embedded in other verification and validation plans, it is necessary to ensure that all flight crew interface requirements are tested and evaluated. This sometimes requires separate flight crew interface tests and evaluations. While the test plan considers certifications standards and criteria, the testing for the flight crew interface goes beyond just that required for safety of flight certification criteria and includes evaluation of the ability of the flight crew interface to meet mission requirements as well as customer acceptance.

5.5.3.2 Output/Deliverables (No additional comments for this section)

5.5.3.3 HMI Considerations

5.5.3.3.1 Choice of Appropriate Tool, Use of Normal and Non-normal Procedures, Performance Criteria, Appropriate Test Participants

The Human Factors - HWG Final Report June 15, 2004, chapter 8.3, intended to be included in a new Advisory Circular (AC}that is currently in draft, addresses the description of the means of compliance amongst others the conditions under which the tests or evaluations should be conducted (applicant and/or Agency, bench, lab, simulator, or aircraft). This description is provided in rather general terms in the AC.

Each step of the HF process might require tests and evaluations for which various tools are best adapted. See Appendix D for additional information and considerations on these tools.

In addition to evaluation tools, the test subject must be considered. There are several types of evaluation experts that should be included in the integrated test and evaluation phase. It is important to include those in the evaluation who have a comprehensive understanding of the entire system to be evaluated as well as those who are more typical of the end-user population. In looking at the end-user population, consideration should be given to individual differences (e.g., piloting expertise and proficiency) as well as cultural differences (e.g., national, corporate, and operating environment). Consequently the following types of subjects should be included in the overall test and evaluation phase:

a. Engineering test pilots (they are typically involved in all phases of the design process until the final validation and certification)

b. Airline pilots (line pilots and airline technical pilots) for operational evaluation of systems as well as assessment of operational needs. Instructor pilots are valuable for operational evaluation of systems and controls so as to determine potential training requirements

c. Regulatory pilots can also play a useful role in the evaluations.

d. Usability and sub-system experts also can play a role in these evaluations.

5.5.3.3.2 Appropriateness of Test Methodology for Evaluating Function and Interface

5.5.3.3.2.1 Testing Under Nominal Conditions

Nominal operational conditions refer to those conditions that the flight crew normally encounter during their day-to-day flight and ground operations for all phases of flight. The purpose of this testing is to ensure that the flight crew can carry out their tasks in all phases of operations effectively and that the equipment meets its intended function.

5.5.3.3.2.2 Testing in Adverse Operational Conditions

Adverse operational conditions refer to those conditions that the flight crew does not normally encounter and usually result from either equipment failures or environmental conditions, such as severe weather, but which can be foreseen and expected to happen sometime during the operation of an aircraft. The purpose of this testing is to ensure that the flight crew can still safely carry out the task of operating the aircraft under conditions that are not normally encountered. General criteria include the ability to carry out the task of operating the aircraft without excessive workload, without making unrecoverable errors, and being able to accomplish all required tasks in a timely manner.

5.5.3.4 Best Practices

5.5.3.4.1 Considerations for Scenarios for Both Ergonomic and Cognitive Evaluations

The two main tools for this type of test and evaluation are flight deck simulators and the aircraft. The flight deck simulator is often a better device than the aircraft to test more complex, in-situation tasks since the environment is more controllable than on the aircraft. Many different types of failure modes and non-normal situations can be run in the simulator to look at workload and manageability of the flight deck interfaces under high stress conditions. Of course the aircraft represents the most realistic setting for human factors and ergonomic evaluations of the flight deck.

5.5.3.4.1.1 Scenario Considerations

Operating the flight deck in nominal or normal conditions, where the crew is by definition able to handle planned activities, falls short from what is necessary to achieve safety goals. The use of failure scenarios that increase crew stress and complicate the crew task should be used to exercise the human interface. The shortcoming of failure scenarios is that they are often expected, albeit non-normal, events. Hence robust testing includes scenarios that contain failures that the flight crew is not expecting while operating the system at the bounds of the operational environment. Determining the appropriate crew behavior indices (observables) that are relevant to how well the flight deck features are used by the crew is a key element in this process.

Scenarios should consider single and multiple relevant failures (include reversionary items) as well as failures during adverse environmental conditions. Scenarios should also consider situations that are complex and conditions where workload is high. Examples of high workload conditions are the inclusion of distractions and/or task interruptions as well as other contributing factors such as weather and Air Traffic Control (ATC) demands.

One key to ensuring that the evaluation plan covers the various aspects of effective performance is developing scenarios that broadly sample the types of skills that pilots require. Evaluation scenarios for both ergonomic and cognitive evaluations need to consider the following:

a. A representative set of normal tasks and procedures

b. A representative set of emergency (non-normal) procedures

c. Existing functional hazard analysis, failure mode effects analysis, and probabilistic risk assessment scenarios that identify critical safety situations

d. Minimum equipment list (MEL) conditions

e. Continued safe flight and landing

f. Situations in which aircraft control is highly constrained

g. Situations that are complex because task management becomes difficult

h. Other contributing factors: weather, ATC demands, etc

i. Distractions that reduce the ability to attend to the situation under consideration

j. Creation of flight crew mental set that would increase difficulty in assessing the appropriate situation and response

5.5.3.4.1.2 Performance Measures Considerations

In general the performance measures selected should be minimally obtrusive so as to not impact the behavior being investigated, e.g., the evaluation tool should not increase workload and thus possibly influence overall task performance. In addition a metric which is applicable to many different types of tasks and a variety of human information channels are more valuable because they will allow direct comparison of performance on a variety of otherwise different tasks. Similarly, a metric which is culturally independent will assist in the identification of issues that are culturally based, e.g., differences in understanding based on different skills in the semantic interpretation of English. Finally, the metric must remain valid when applied in operational conditions.

The selection of the appropriate performance measure from the subset that meets the above criteria further depends on both nature and goal of the evaluation. For example, the technique used to determine if pilots from around the world would all correctly interpret a warning message would be different from a metric used to determine if a physically difficult task could be accomplished by a 5th percentile female crew member, or to determine if a series of tasks could be performed within a given system critical time limit.

Finally, there are a number of very subtle but extremely important issues that can sometimes dramatically impact the validity of an evaluation. For example, certain cognitive evaluation tools focus on a subset of cognitive skills (e.g., mental rotation, processing of semantic strings of symbols, inferences based on minimal information). The selection of a metric that focuses on the wrong set of skills would result in totally irrelevant data.

6. FLIGHT DECK DESIGN PHILOSOPHY

This section gives the definition of a Flight Deck Design Philosophy and identifies human factor characteristics that need to be addressed within that philosophy.

6.1 Rationale/Scope

The Flight Deck Philosophy is a document that provides the designers with a referential basis for developing a new flight deck or implementing modifications. It provides guidance during the generation of design concepts and implementation principles to ensure consistent HMI and operations. It serves an important bridge to be applied to future modifications of existing designs to facilitate consistency with the current flight deck concept.

6.2 Definition of a Flight Deck Design Philosophy

The Flight Deck Philosophy is primarily an outline of the top level operational and HF design principles that will dictate the design of the flight deck or of the modification of a system in the flight deck. As such, it should list the objectives of the design:

a. in terms of the needs of the flight crew and their main tasks of aviating, navigating, communicating and managing aircraft systems;

b. in terms of possible strategic choices of the manufacturer/provider;

c. in terms of the airspace environment constraints existing and expected, that the design will have to take into account.

The overall goal is to define the design concept that will fulfill the above objectives for the flight deck layout, flight controls, automation, as well as the alerts and alarms.

6.3 Components of the Flight Deck Design Philosophy

The top level operational and HF related design principles should address, among others, the following essential topics: Pilot or flight crew responsibility, authority of the pilot, pilot or flight crew characteristics, automation, use of new technology and functionality, human error, communication, design priorities, and crew task simplification. These are discussed in more detail, along with examples of derived guidelines and principles as well as some top level human centered philosophies in the following sections.

6.3.1 Pilot Responsibility

By regulation, the pilot is responsible and is designated as the final command authority for the safe and proper operation of the aircraft. This requires a flight deck design that provides adequate information and features to support the designated responsibility and authority.

6.3.1.1 Considerations

Philosophy needs to recognize that the basic flight crew tasks are to aviate, navigate, communicate and manage systems.

6.3.1.2 Examples of derived guidelines or principles:

a. Information required by the pilot should be clear and unambiguous

b. The flight crew should be able to manage all information on the flight deck

c. Operational philosophies examples:

1. Head up versus head down operational philosophy, including what information should be presented heads up versus heads down

2. Crew alerting philosophy that addresses alerts and alarms associated to unexpected events such as system failures, such as aircraft safety related events, or such as automatic system status changes. This philosophy also defines the classification of failures by severity, hierarchy between systems, and inhibition of alerts by phases of flight. Visual and aural prioritization, as well as stand-alone or integrated alerts should be covered in the crew alerting philosophy.

6.3.1.3 Top level examples (From Table 6 in Section 7): A-1, B-1, and B-8

6.3.2 Physical Authority of the Pilot

Full authority of the pilot, when required, for control of major aircraft systems (e.g., flight controls, engines, and brakes) should be obtainable from those systems with simple intuitive crew actions, while minimizing (or even eliminating) the risks of system over control and overstress.

6.3.2.1 Considerations

Consideration must be given as to when and how much authority to grant the flight crew. For example the philosophy needs to address issues concerning envelope protection versus envelope limiting.

6.3.2.2 Examples of derived guidelines or principles:

a. Principles regarding flight controls including desired aircraft flying characteristics, flight control authority issues and adaptive interfaces and controls.

b. Principles regarding feedback on approaching, reaching, or exceeding aircraft system limits.

6.3.2.3 Top level examples (From Table 6 in Section 7): A-10 and B-1.

6.3.3 Pilot Characteristics

The design should accommodate and take into account the fundamental characteristics of the pilot population.

6.3.3.1 Considerations

a. Fundamental characteristics of the pilot population include ergonomic considerations (anthropometry), culture (e.g., national, corporate, operating environment) and language.

b. One needs to consider fundamental human capabilities and limitations such as cognitive and perceptual abilities for both normal and non-normal (e.g., failure) related operations.

c. Consideration should also be given to the large variation in the skills among flight crew members, including past experience on previous generation aircraft.

6.3.3.2 Examples of derived guidelines or principles:

a. Assumptions of pilot differences (like cultural background) and experience.

b. Assumptions of flight crew composition - this also includes any assumptions made about type ratings of the flight crew and the type certificate of the aircraft.

c. Use of display characteristics - color, functionality, aesthetics

d. Input devices/Inceptors (includes switchology such as meaning of movement e.g., up is ON; philosophy of cursor control devices and text entry devices)

e. Accessibility and information layout: In general, accessibility and display of items on the flight deck is driven by level criticality and frequency of usage.

6.3.3.3 Top level examples (From Table 6 in Section 7): A-3, A-5, B-3, and B-5

6.3.4 Automation

Automation should be designed as a complement and/or as an aid to the flight crew who decide when and how to use it.

6.3.4.1 Considerations

a. Automation concepts should answer the three essential questions of why, what and how to automate.

b. The flight crew should be given sufficient information to allow monitoring and management of the automation. These indications may be visual, tactile, or auditory.

c. The goal of automation is not to bring crew workload to zero but rather to achieve an optimal level of workload. Too little workload can be as hazardous as too much workload.

6.3.4.2 Examples of derived guidelines or principles:

a. Principles concerning when to implement automatic versus manual reversions and re-configurations.

b. Principles concerning reliability, override capabilities, back up means, adequate control and information requirements

c. Authority/ability of the flight crew to override automation

d. Principles concerning automatic reversions under failure conditions

e. Principles concerning automatic re-configurations under non-failure reversions, i.e., system mode changes

f. Principles concerning pop-up philosophy such as alerting functions on displays

g. A system that has a direct effect on safety should not be automated unless it can be made reliable

h. A system that has a direct effect on safety should not be automated unless it can be made reliable

6.3.4.3 Top level examples (From Table 6 in Section 7): A-4 and B-4

6.3.5 Use of New Technology and Functionality

The use of new technologies and new functional capabilities should only be used in cases where:

a. there are clearly identified safety and operational benefits and/or solve identified pilot needs, and

b. there are no adverse effects to the HMI

6.3.5.1 Considerations

Integration of new technologies for control or information display into an existing design may pose a number of problems. Beyond difficulties linked to “physical integration” (mechanical, electronics, software) care should be taken in checking that the new functionalities are compatible with and do not alter existing functionalities in regard of operators tasks and activities. Appropriate testing methodologies should be used to this effect in order to make sure that there is no regression between the existing and the new system.

6.3.5.2 Top level examples (From Table 6 in Section 7): A-6 and B-6

6.3.6 Addressing Human Error

State of the art HF considerations should be applied in the system design process to:

a. avoid the potential for pilot error

b. manage potential flight crew errors by supporting detection of and recovery from errors

6.3.6.1 Considerations

a. The concept of error-tolerance refers to the ability to detect errors and correct them before they result in undesired consequences. Error tolerance therefore depends heavily on systems that provide readily interpretable feedback to the flight crew of the results of their actions. Error tolerance of a flight crew interface design also relies on the ability of the pilots to take corrective action.

b. Eliminating human error completely is impossible and may also create an extremely cumbersome and impractical design. Therefore, error tolerance and the ability to recover from an error is an important aspect of every design

6.3.6.2 Examples of derived guidelines or principles

a. Support appropriate level of mode awareness to the pilot, i.e., prevent hidden modes that could impact crews ability to understand status of a system where that status is necessary for proper operation of automation

b. Ensure that designs make use of positive transfer of learning from other or previous designs or at least ensure there is no negative transfer, i.e., same pilot action results in two different system responses

c. Actions of any automated system should be clearly understandable and manageable by the flight crew

6.3.6.3 Top level examples (From Table 6 in Section 7): A-7 and B-7

6.3.7 Communication

Flight deck layout and flight deck systems/HMI design should favor efficient flight crew communication as well as between the flight crew and the ground (ATC, Airline Company, Dispatch, Ground Services, etc.).

6.3.7.1 Considerations

The fact that multiple communications often occur simultaneously with little or no prioritization needs to be considered. This is often outside the control of the flight crew.

6.3.7.2 Examples of Derived Guidelines or Principles

Principles concerning the prioritization of communications and associated tasks on the flight deck

6.3.7.3 Top level examples (From Table 6 in Section 7): A-8 and B-8

6.3.8 Design Priorities

Factors that dictate the design and/or modification of flight decks or systems to support flight crew tasks in order of priority are: safety, passenger comfort, and efficiency.

6.3.8.1 Top level examples (From Table 6 in Section 7): A-2 and B-2

6.3.9 Designing for Crew Task Simplification

Simplification of the flight crew's task is achieved by designing for system simplicity, redundancy, or automation, in that order.

6.3.9.1 Considerations

The flight deck design aims at simplifying the flight crew’s task by enhancing situational and aircraft status awareness.

6.3.9.2 Examples of derived guidelines or principles:

a. Simplify panel design

b. De-clutter and remove data not requires for crew decision-making procedures in-flight

c. Provide centralized, prioritized crew alerting system

6.3.9.3 Top level examples (From Table 6 in Section 7): A-9 and B-9