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PILOT-SYSTEM INTEGRATION

1. SCOPE:

A recommended pilot-system integration (i.e., crew interface and system integration) approach for concept development is described in Figure 1. The approach emphasizes the fundamental need for a top-down design methodology with particular focus on clear operational performance requirements and functional integration. While this document is primarily aimed at aircraft systems design and integration, the methodology is applicable to a wide range of design and integration situations. It is derived from well established human factors engineering design principles.

1.1 Purpose:

This document provides a concept development guide to the human engineering specialist and the aircraft systems designer for pilot-system integration that will enhance safety, productivity, and cost-effectiveness. It addresses the resulting processes of system development including aspects of interface design and automation philosophy.

2. REFERENCES

2.1 Applicable Documents:

The following publications form a part of this specification to the extent specified herein. The issue of publications in existence at the time of approval of this shall apply. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

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Pilot - System Integration

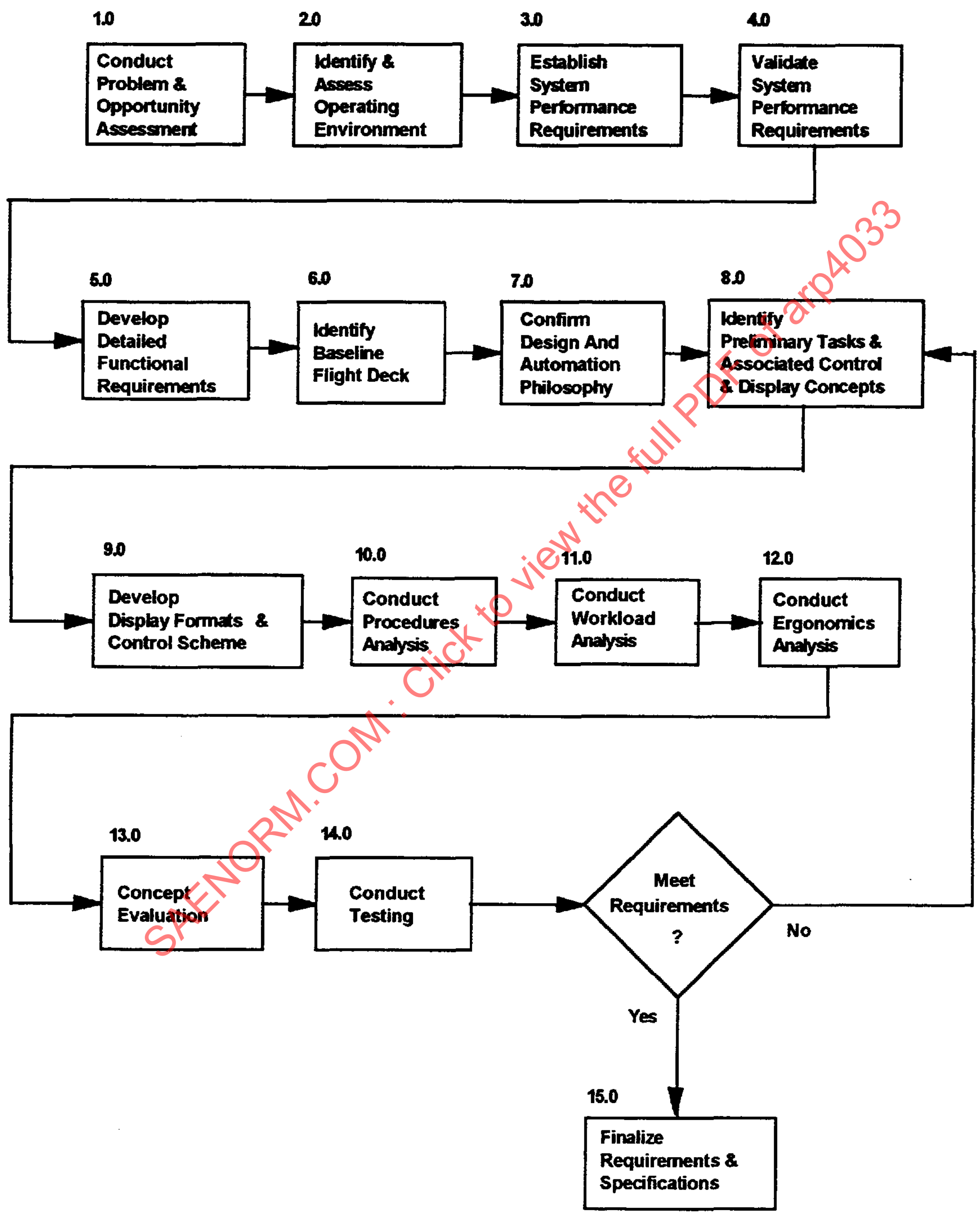

FIGURE 1 - Concept Development for Pilot - System Integration

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

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 DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

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

2.2 Definitions:

This section contains definitions of terms used in this document:

CONCEPT DEVELOPMENT: This term is used to differentiate development of a system concept from that of a system detailed design. Concept development may include many elements of design but the products of this activity are crew interface, system functions, and human factors engineering requirements for the system.

HUMAN FACTORS ENGINEERING PROCESS: This process encompasses a number of activities that will ensure development, verification, and application of all human factors requirements to enhance overall system performance and integration.

3. BACKGROUND:

In the past, human factors engineering analysis has been mostly accomplished on a case-by-case basis, in a somewhat unstructured manner. This has led to three main problems:

a. Inconsistencies in the design process itself
b. Untimely application of human engineering principles
c. Lack of systems integration

A structured human factors engineering process is an approach to solve the above problems. It takes the mystery out of the design process and helps reduce cost, schedule, and certification risks. Establishment of a more disciplined design and integration methodology will improve the quality of the design recommendations.

It is important to note that this process does not occur in isolation. Many of the steps outlined below are accomplished in close coordination with other design groups. While the process is described in a linear manner, some components, such as the analyses of procedures, workload, and ergonomics may be conducted in parallel. Also, at any point it may be appropriate to "loop back" to a previous step to resolve problems that arise.

3. (Continued):

Furthermore, it is recognized that all process steps described in this document may not be necessary, depending on the level of change in a current system design or the requirements that drive the change. The ability to tailor the design process helps reduce the cost of system development, while still ensuring that an optimal design is achieved through adherence to the applicable steps in the total process.

This document is offered as a first step in expanding the understanding of all who design, integrate, regulate, or specify designs for flight decks and by those who use them. The quality and utility of future versions of this document will benefit from feedback of your comments, insights, and criticisms to the SAE G-10 Committee.

The objectives of the pilot-system integration process are:

a. Facilitate the matching of pilot skills to tasks required to operate the equipment in its environment

b. Identify and sequence the human factors engineering tasks for each new and revised design

c. Ensure consistency in human factors engineering processes and their outputs

d. Facilitate customer involvement by providing customers with information on the nature of the human factors engineering tasks, their processes, output, and expertise

4. DESIGN METHODOLOGY:

The methodological steps shown in Figure 1 are explained in the sections which follow. The reasons for conducting each step in the process is presented along with the objectives behind the step. This is followed by a brief product description.

4.1 Conduct Problem and Opportunity Assessment:

4.1.1 Background: The general tendency during the design of a new system is to identify potential design solutions too early in the process. This tendency is frequently combined with only a limited understanding of what problem the design is supposed to solve.

4.1.2 Goal: This step asks the designer to develop a clear understanding of what the planned design is supposed to accomplish. At least two cases are possible.

In the first case analyses of accident and incident data point out specific operational problems which require a design solution. In this case a detailed in-depth analysis of accident and/or incident data conducted in cooperation with the operational community is required. The primary objective of this analysis is to identify the root-causes of observed problem areas.

4.1.2 (Continued):

In the second case newly available technology or innovations allow the replacement of existing designs with more reliable and/or efficient designs. These innovations may be driven by any one of the manufacturer, equipment supplier, customer airline, government agencies, industry, or other.

In both cases the problem and opportunity assessment has to allow for matching of the resource requirements (cost, weight, and schedule) with the operational requirements.

4.1.3 Product: The product of this step contains a description of the goals and objectives of the planned design including design resource allocations.

4.2 Identify and Assess Operating Environment:

4.2.1 Background: Any design should be developed within the total context of the pilot's task environment. In order to accomplish this objective, the operating environment of the system being designed needs to be identified and then assessed as to any implications this environment has on system requirements.

4.2.2 Goal: This step requires first that operating environment be identified. This may include: routing (e.g., polar, oceanic, non-ICAO), aircraft limitations (e.g., cruise altitude, range, speed), atmospheric conditions, runway types and conditions, desert and/or arctic operations, and type of maintenance support.

4.2.3 Product: The product of this step is an identification of the operating environment in which the system will have to perform and definition of the unique requirements of the system which will provide for safe and efficient operation within that environment.

4.3 Establish the System Performance Requirements:

4.3.1 Background: Too often systems (or at least significant aspects of them) get designed without adequately defining the performance or operational requirements for that system. This results in redesign, in adjusting the requirements to fit the design, or in relying on the user of the system to work around its short comings.

4.3.2 Goal: Requirements-driven design within resource constraints embodies the central concept of the human engineering process. Therefore, performance requirements, consisting of both established and derived requirements, must be defined prior to the start of the design. These requirements are based on the analysis of mission scenarios which describe the top-level functions the system must perform successfully in order to achieve the desired operational benefits. Top-level performance requirements form the starting point for the design; however, the requirements may need to be modified or broken down into more detail as the system becomes better understood.

4.3.3 Product: The products of this step are the performance or operational requirements for the system, the procedures or way it will be used, and a requirements/traceability matrix which identify testing feasibility and approach. The requirements are based on descriptions of basic system goals and mission scenarios in which the system will be used. In addition, it contains a breakdown of the flight into phases and segments, with associated objectives and performance measures.

4.4 Validate System Performance Requirements:

4.4.1 Background: At this point it is important to validate the requirements. This step is to insure that the requirements specified are the correct requirements for the system being designed. Validation of the requirements must be done to save costly time and effort from being spent on system development which otherwise may have been lacking in key areas or over designed in other areas. The validation can be done with a traceability matrix of the requirements.

4.4.2 Goal: The goal of this validation effort can be divided into two aspects. The first aspect is to determine that the specified requirements are necessary. Additional requirements can only increase cost, complexity, or lead to a specific design which may or may not be the most efficient. The second aspect is to determine that the requirements are sufficient. This step leads to confidence that any design which meets the requirements will provide for all the operational needs.

4.4.3 Product: The product of this step is a set of validated requirements used for system design that neither artificially constrains the design nor overlooks required functionality.

4.5 Develop Functional Requirements:

4.5.1 Background: One of the key decisions during the design is the allocation of function between the human operator and the systems. Too often these allocations occur by default, based on intuition regarding what functions are traditionally performed by the human or based on what the current technology offers. When systems are redesigned, it is easy for the designers to focus on the current way of doing things, which may disguise the underlying functions. For example, in a current design there might be several related functions combined in a single rotary switch. As systems are redesigned, it may be desirable to separate the functions into separate control activities. Another area which in particular needs function analysis is pilot decision-making, in order to determine what information the pilot needs to make the proper decisions.

4.5.2 Goal: The top level functions should be further subdivided into detailed functions. For example, a top level function of tuning a radio could be broken down into monitoring the current frequency, inputting the new frequency, and then confirming it. The description of these functions is independent of the design. The functions are then tentatively allocated to either the pilot, the systems, or a combination of the two.

4.5.3 Product: The product of this step contains a detailed breakdown of the crew system functions associated with system goals and each of the events in the flight scenarios. Along with the function breakdown is the tentative allocation of the functions.

4.6 Identify Baseline Flight Deck:

4.6.1 Background: Very few, if any, flight deck systems are designed from a blank sheet of paper. At least one of the following almost always applies:

a. There is an existing system which provides the same or similar capabilities.

b. The new system must be integrated into an existing flight deck.

c. For certification purposes, the performance of the new system will be compared to that of existing systems.

Therefore, a baseline configuration is usually needed against which the new system or redesign will be evaluated.

4.6.2 Goal: A baseline configuration must be established. If the project involves a completely new flight deck, an existing flight deck may be chosen for comparison. If a single system or subsystem is being designed, the baseline could be the existing system being replaced. The baseline configuration can also serve as the design starting point. That is, understood deficiencies in the existing design indicate where it needs to be modified in order to satisfy operational requirements.

4.6.3 Product: This product contains information about the layout of the baseline flight deck, its controls and displays, and the operational procedures which are currently employed by the flight crew and any "lessons learned" relevant to the baseline flight deck.

4.7 Confirm Design and Automation Philosophy:

4.7.1 Background: Design solutions which use automation technologies should:

a. Minimize the potential for and the negative effects of human error and unplanned events.

b. Optimize situational awareness through levels of information, feedback, and training which are appropriate to the pilot's task.

c. Provide a level of flexibility which allows the flight crew to balance workload across functions, flight phases, and individual differences.

4.7.2 Goal: In order to improve safety and efficiency, a human centered design must be used to enhance the pilot's abilities, overcome pilot limitations, and receive pilot acceptance. This can best be achieved through consistent adherence to the design and automation approach of the aircraft in which the system will be installed. Therefore, we need to have a clear understanding of the approach in order to ensure that the system design fits within and enhances the overall design environment of the aircraft in which it is to operate.

4.7.3 Product: The product of this step is a documented design and automation philosophy of the aircraft and a confirmation that the requirements support these philosophies.

4.8 Identify Preliminary Tasks and Associated Control and Display Concepts:

4.8.1 Background: As more and more information becomes available to the flight crew from an increasing number of sources, integration of that information demands the evaluation of new ways to present it. Key decisions about the need for head-up operations also affect the basic decisions about the types and numbers of display devices. In addition, strategies for how the flight crew is to control the increasing number of systems must be carefully considered. The desire for an integrated, coherent flight deck amidst changing technology and operational requirements makes the choice of display and control devices critical.

4.8.2 Goal: It is important to review the current technology in order to determine the types of displays and controls that will be available. Selection of the controls and displays must then be made based on requirements and constraints, rather than selecting the technology and adjusting the operational requirements to fit the technology. The controls and displays must be selected so that not only are they appropriate for their associated functions, but that they also present the pilot with an overall integrated flight deck.

4.8.3 Product: This product contains a preliminary list of controls and displays, in terms of their general type, function, and approximate location. This descriptive list will be the starting point in the development of more detailed control and display hardware and software.

4.9 Develop Preliminary Display Formats and Control Concept:

4.9.1 Background: Historically, control and display technology severely constrained the ways in which the pilot could interact with the aircraft. However, today's designer is faced with the opposite problem. There is exponential growth in the way that information can be presented to the flight crew, and similar growth in the ways that the flight crew could control the systems. Integration of controls and displays and the ability to represent information in pictorial formats have introduced whole new ways of designing the crew interface, while at the same time, have greatly magnified the complexity of the design trades.

4.9.2 Goal: This step is where the system requirements and function analysis come together. The functions are further analyzed to identify the specific information which must flow from the systems to the flight crew (display) and that which must flow from the crew to the system (control). Each of these information items is assessed to determine the best way to make the flow happen. This makes it possible to decide how to organize and present information to the pilot (e.g., analog versus digital, separate versus integrated, continuous versus demand driven) and how the flight crew will use the controls (e.g., control shape, size, direction of movement, forces, logic).

4.9.3 Product: This product contains a detailed description of displays, including "hard" (e.g., fault lights, dedicated gauges), and "soft" (e.g., graphic formats, page layouts) displays, plus the preliminary control utilization scheme. It is a key input for hardware and software requirements definition. It should identify all candidate formats and list message content, display states, modes, and corresponding hardware assignments. Switching protocol, audio, and voice advisories are to be included as part of this product. A detailed list of the dedicated controls, their functional grouping, and anticipated installation data (e.g., sketches of the primary controls and their location and design) are also included.

4.10 Conduct Procedures Analysis:

4.10.1 Background: As the flight deck controls and displays are changed, so may the procedures that the flight crew will use. As systems are added or functions are integrated, pilots will follow a different series of steps to monitor and control the flight. These differences need to be evaluated in terms of such factors as pilot workload, training, and mixed fleet operations.

4.10.2 Goal: In this step, each of the operational procedures which were identified for the baseline flight deck (see 4.6) are examined to determine where they need to be modified to match the tasks for the candidate redesign. This relationship between procedures and tasks is dependent on the flight deck arrangement as tasks are at the level of the activation of specific controls and monitoring of individual display elements. Then, the procedure data base is updated to reflect the changes in the crew tasks and procedures. The procedures are adapted to the flight scenario so that they describe the actual sequence of flight crew tasks that would occur.

4.10.3 Product: This product contains descriptions of the sequence of pilot and system tasks performed when each procedure is executed during the flight scenario. This procedure and task sequence will be used when analyzing scenario time lines.

4.11 Perform Workload Analysis:

4.11.1 Background: Workload is a perennial concern in flight deck development. Waiting until actual hardware and software is available to evaluate workload in flight simulations severely impacts costs and schedules. Therefore, a preliminary workload analysis needs to be completed when design alternatives are being considered. This helps to prepare workload estimates early in order to identify any high risk designs.

4.11.2 Goal: This step involves analytical estimates of pilot workload. Computer-based human engineering tools use the results of the procedure analysis and the cockpit geometry database to assist in the analysis. The tools predict the time available for pilots' tasks as compared to the estimated time needed to complete the tasks. In addition, pilot workload can be evaluated based on input channels (visual/auditory) and output channels (manual/verbal). Comparisons between the new design and the (certified) baseline can be used for certification. Additional workload analyses may involve pilot subjective assessments based on computer-based rapid prototypes.

4.11.3 Product: This product contains analytical workload predictions for the flight scenarios. Its primary focus is on flight segments in which high levels of crew workload occur. This analysis will identify high risk areas of design in terms of human performance.

4.12 Conduct Ergonomic Analysis to Verify Layout Concept:

4.12.1 Background: It is important that the design (i.e., controls, displays, and procedures) be functionally operational by the user population. The ergonomic analysis includes analysis of internal vision, reach, and external vision. During this step the population of flight crew members who must be able to operate the aircraft is identified. Pilots must be able to quickly identify, read, and interpret relevant information; they must be able to reach the controls with seat belts fastened, without contorting themselves, and sometimes while restrained by their shoulder harnesses; and they must have a clear undistorted view outside of the aircraft to allow safe operations under all anticipated operating conditions.

4.12.2 Goal: This portion of the human engineering process is an evaluation of the ergonomic aspects of the system design relative to existing established standards. The goals are to ensure:

a. An effective and reliable information flow from the system to the pilot.

b. Controls are placed so that the appropriate crew members can reach and operate them in a manner consistent with safe and efficient operation of the aircraft.

c. External vision from the flight deck meets requirements for all aircraft operations.

4.12.3 Product: This product contains a number of analyses as may be applicable to the extent of the design change. Analyses may include lighting analysis, reach analysis, and vision polars referenced to the design eye reference point. Also included are analyses of viewing angles, contrast, brightness, jitter, flicker, colors, symbology, text fonts, glare, control forces, switch design, control layout and labeling, and landing vision.

Contemporary ergonomic design techniques, such as three-dimensional electronic mockups, computer-based anthropometric models, and virtual prototypes may be used in lieu of the more conventional full-scale mockups or physical prototypes.

4.13 Concept Evaluation:

4.13.1 Background: During the initial development of requirements, numerous assumptions and estimates may be necessary. It is critical that these be documented and validated so that one can be confident that the requirements are appropriate (i.e., so that the design is neither underconstrained nor overconstrained), and that they capture the real mission needs.

4.13.2 Goal: The test objectives may seem self-evident to the designer but they are not necessarily obvious. It is not enough to say, for example, that the purpose of the test is to determine if the pilot can operate the system. This purpose is entirely too general and abstract without defining what operability means. Instead, the purpose of the test must be defined in terms that specify the operations needed to satisfy the system requirements. For example, an operational requirement may be that a system alert must be recognized and responded to within 5 seconds while the pilot is manually flying the aircraft and continuing to navigate on a complex standard terminal arrival route. The question needs to be answered, what does the designer want and expect out of the test.

4.13.3 Product: The product of this step includes the following information: test purpose, system description, experimental comparisons, criteria and measures, data collection methods, subject characteristics, and constraints. This information is to be formulated into a test plan used for testing.

4.14 Conduct Testing:

4.14.1 Background: Proper testing and evaluation is performed throughout the design/integration process and extends also into system operation. It emphasizes the measurement of human performance in the context of both hardware and software.

4.14.2 Goal: This step involves execution and reporting of concept testing. In general, this validation effort will focus initially on any technical high risk requirements. The requirements are validated by inspection, analysis, simulation, test, similarity, or demonstration. Simulation may involve a range of different levels of fidelity from simple mockups, to rapid prototype, to part-task simulation, to full-flight simulation. The level of simulation is determined by the types of requirements to be validated, equipment available, level of system definition, and schedule. If there are requirement shortfalls, they are identified and the design and integration process loops back to the appropriate step (e.g., function analysis and allocation, control/display selection, etc.) to resolve the problem.

4.14.3 Product: This product contains the documented results of the requirements concept studies. The initial releases are intended to increase confidence in the requirements.

4.15 Document Requirements:

4.15.1 Product: This product contains the human factors engineering inputs to the systems requirements and objectives documents or other similar requirements documents.

4.16 Document Specifications:

4.16.1 Product: This product contains the human factors engineering inputs to the various design documents (e.g., system descriptions, drawings, specifications, operation manuals, etc.).

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