# 9

# Human Factors Engineering and Flight Deck Design

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## 9.1 Introduction

This chapter briefly describes Human Factors Engineering and considerations for civil aircraft flight deck design. The motivation for providing the emphasis on the Human Factor is that the operation of future aviation systems will continue to rely on humans in the system for effective, efficient, and safe operation. Pilots, mechanics, air traffic service personnel, designers, dispatchers, and many others are the basis for successful operations now and for the foreseeable future. There is ample evidence that failing to adequately consider humans in the design and operations of these systems is at best inefficient and at worst unsafe.

This becomes especially important with the continuing advance of technology. Technology advances have provided a basis for past improvements in operations and safety and will continue to do so in the future. New alerting systems for terrain and traffic avoidance, data link communication systems to augment voice-based radiotelephony, and new navigation systems based on Required Navigation Performance are just a few of the new technologies being introduced into flight decks.

Often, such new technology is developed and introduced to address known problems or to provide some operational benefit. While introduction of new technology may solve some problems, it often introduces others. This has been true, for example, with the introduction of advanced automation.[1,2] Thus, while new technology can be part of a solution, it is important to remember that it will bring issues that may not have been anticipated and must be considered in the larger context (equipment design, training, integration into existing flight deck systems, procedures, operations, etc.). These issues are especially important to address with respect to the human operator.

The chapter is intended to help avoid vulnerabilities in the introduction of new technology and concepts through the appropriate application of Human Factors Engineering in the design of flight decks. The chapter first introduces the fundamentals of Human Factors Engineering, then discusses the flight deck design process. Different aspects of the design process are presented, with an emphasis on the incorporation of Human Factors in flight deck design and evaluation. To conclude the chapter, some additional considerations are raised.

## 9.2 Fundamentals

This section provides an overview of several topics that are fundamental to the application of Human Factors Engineering (HFE) in the design of flight decks. It begins with a brief overview of Human Factors, then discusses the design process. Following that discussion, several topics that are important to the application of HFE are presented: the design philosophy, the interfaces and interaction between pilots and flight decks, and the evaluation of the pilot/machine system.

### 9.2.1 Human Factors Engineering

It is not the purpose of this section to provide a complete tutorial on Human Factors. The area is quite broad and the scientific and engineering knowledge about human behavior and human performance, and the application of that knowledge to equipment design (among other areas), is much more extensive than could possibly be cited here.[3–8] Nonetheless, a brief discussion of certain aspects of Human Factors is desirable to provide the context for this chapter.

For the purposes of this chapter, Human Factors and its engineering aspects involve the application of knowledge about human capabilities and limitations to the design of technological systems.[9] Human Factors Engineering also applies to training, personnel selection, procedures, and other topics, but those topics will not be expanded here.

Human capabilities and limitations can be categorized in many ways, with one example being the SHEL model.[6] This conceptual model describes the components *Software, Hardware, Environment, and Liveware*. The SHEL model, as described in Reference 6, is summarized below.

The center of the model is the human, or *Liveware*. This is the hub of Human Factors. It is the most valuable and most flexible component of the system. However, the human is subject to many limitations, which are now predictable in general terms. The "edges" of this component are not simple or straight, and it may be said that the other components must be carefully matched to them to avoid stress in the system and suboptimal performance. To achieve this matching, it is important to understand the characteristics of this component:

- **Physical size and shape** — In the design of most equipment, body measurements and movement are important to consider at an early stage. There are significant differences among individuals, and the population to be considered must be defined. Data to make design decisions in this area can be found in anthropometry and biomechanics.
- **Fuel requirements** — The human needs fuel (e.g., food, water, and oxygen) to function properly. Deficiencies can affect performance and well-being. This type of data is available from physiology and biology.
- **Input characteristics** — The human has a variety of means for gathering input about the world around him or her. Light, sound, smell, taste, heat, movement, and touch are different forms of information perceived by the human operator; for effective communication between a system and the human operator, this information must be understood to be adequately considered in design. This knowledge is available from biology and physiology.
- **Information processing** — Understanding how the human operator processes the information received is another key aspect of successful design. Poor human-machine interface or system design that does not adequately consider the capabilities and limitations of the human information processing system can strongly affect the effectiveness of the system. Short- and long-term memory limitations are factors, as are the cognitive processing and decision-making processes used. Many human errors can be traced to this area. Psychology, especially cognitive psychology, is a major source of data for this area.

- **Output characteristics** — Once information is sensed and processed, messages are sent to the muscles and a feedback system helps to control their actions. Information about the kinds of forces that can be applied and the acceptable direction of controls are important in design decisions. As another example, speech characteristics are important in the design of voice communication systems. Biomechanics and physiology provide this type of information.
- **Environmental tolerances** — People, like equipment, are designed to function effectively only within a narrow range of environmental conditions such as temperature, pressure, noise, humidity, time of day, light, and darkness. Variations in these conditions can all be reflected in performance. A boring or stressful working environment can also affect performance. Physiology, biology, and psychology all provide relevant information on these environmental effects.

It must be remembered that humans can vary significantly in these characteristics. Once the effects of these differences are identified, some of them can be controlled in practice through selection, training, and standardized procedures. Others may be beyond practical control and the overall system must be designed to accommodate them safely. This *Liveware* is the hub of the conceptual model. For successful and effective design, the remaining components must be adapted and matched to this central component.

The first of the components that requires matching to the characteristics of the human is *Hardware*. This interface is the one most generally thought of when considering human-machine systems. An example is designing seats to fit the sitting characteristics of the human. More complex is the design of displays to match the human's information processing characteristics. Controls, too, must be designed to match the human's characteristics, or problems can arise from, for example, inappropriate movement or poor location. The user is often unaware of mismatches in this liveware-hardware interface. The natural human characteristic of adapting to such mismatches masks but does not remove their existence. Thus this mismatch represents a potential hazard to which designers should be alerted.

The second interface with which Human Factors Engineering is concerned is that between Liveware and Software. This encompasses the nonphysical aspects of the systems such as procedures, manual and checklist layout, symbology, and computer programs. The problems are often less tangible than in the Liveware-Hardware interface and more difficult to resolve.

One of the earliest interfaces recognized in flying was between the human and the environment. Pilots were fitted with helmets against the noise, goggles against the airstream, and oxygen masks against the altitude. As aviation matured, the environment became more adapted to the human (e.g., through pressurized aircraft). Other aspects that have become more of an issue are disturbed biological rhythms and related sleep disturbances because of the increased economic need to keep aircraft, and the humans that operate them, flying 24 hours a day. The growth in air traffic and the resulting complexities in operations are other aspects of the environment that are becoming increasingly significant now and in the future.

The last major interface described by the SHEL model is the human-human interface. Traditionally, questions of performance in flight have focused on individual performance. Increasingly, attention is being paid to the performance of the team or group. Pilots fly as a crew; flight attendants work as a team; maintainers, dispatchers, and others operate as groups; therefore, group dynamics and influences are important to consider in design.

The SHEL model is a useful conceptual model, but other perspectives are important in design as well. The reader is referred to the references cited for in-depth discussion of basic human behavioral considerations, but a few other topics are especially relevant to this chapter and are discussed here: usability, workload, and situation awareness.

#### 9.2.1.1 Usability

The usability of a system is very pertinent to its acceptability by users; therefore, it is a key element to the success of a design. Nielsen[10] defines usability as having multiple components:

- Learnability — the system should be easy to learn
- Efficiency — the system should be efficient to use
- Memorability — the system should be easy to remember

- Error — the system should be designed so that users make few errors during use of the system, and can easily recover from those they do make
- Satisfaction — the system should be pleasant to use, so users are subjectively satisfied when using it.

This last component is indicated by subjective opinion and preference by the user. This is important for acceptability, but it is critical to understand that there is a difference between subjective preference and performance of the human-machine system. In some cases, the design that was preferred by the user was not the design that resulted in the best performance. This illustrates the importance of both subjective input from representative end users and objective performance evaluation.

#### 9.2.1.2 Workload

In the context of the commercial flight deck, workload is a multidimensional concept consisting of: (1) the duties, amount of work, or number of tasks that a flight crew member must accomplish; (2) the duties of the flight crew member with respect to a particular time interval during which those duties must be accomplished; and/or (3) the subjective experience of the flight crew member while performing those duties in a particular mission context. Workload may be either physical or mental.[11]

Both overload (high workload, potentially resulting in actions being skipped or executed incorrectly or incompletely) and underload (low workload, leading to inattention and complacency) are worthy of attention when considering the effect of design on human-machine performance.

#### 9.2.1.3 Situation Awareness

This can be viewed as the perception on the part of a flight crew member of all the relevant pieces of information in both the flight deck and the external environment, the comprehension of their effects on the current mission status, and the projection of the values of these pieces of information (and their effect on the mission) into the near future.[11]

Situation awareness has been cited as an issue in many incidents and accidents, and can be considered as important as workload. As part of the design process, the pilot's information requirements must be identified, and the information display must be designed to ensure adequate situation awareness. Although the information is available in the flight deck, it may not be in a form that is directly usable by the pilot, and therefore of little value.

Another area that is being increasingly recognized as important is the topic of organizational processes, policies and practices.[12] It has become apparent that the influence of these organizational aspects is a significant, if latent, contributor to potential vulnerabilities in design and operations.

### 9.2.2 Flight Deck Design

The process by which commercial flight decks are designed is complex, largely unwritten, variable, and nonstandard.[11] That said, Figure 9.1 is an attempt to describe this process in a generic manner. It represents a composite flight deck design process based on various design process materials. The figure is not intended to exactly represent the accepted design process within any particular organization or program; however, it is meant to be descriptive of generally accepted design practice. (For more detailed discussion of design processes for pilot-system integration and integration of new systems into existing flight decks, see References 13 and 14.)

The figure is purposely oversimplified. For example, the box labeled "Final Integrated Design" encompasses an enormous number of design and evaluation tasks, and can take years to accomplish. It could be expanded into a figure of its own that includes not only the conceptual and actual integration of flight deck components, but also analyses, simulations, flight tests, certification and integration based on these evaluations.

Flight deck design necessarily requires the application of several disciplines, and often requires trade-offs among those disciplines. Human Factors Engineering is only one of the disciplines that should be part of the process, but it is a key part of ensuring that the flight crew's capabilities and limitations are considered. Historically, this process tends to be very reliant on the knowledge and experiences of individuals involved in each program.

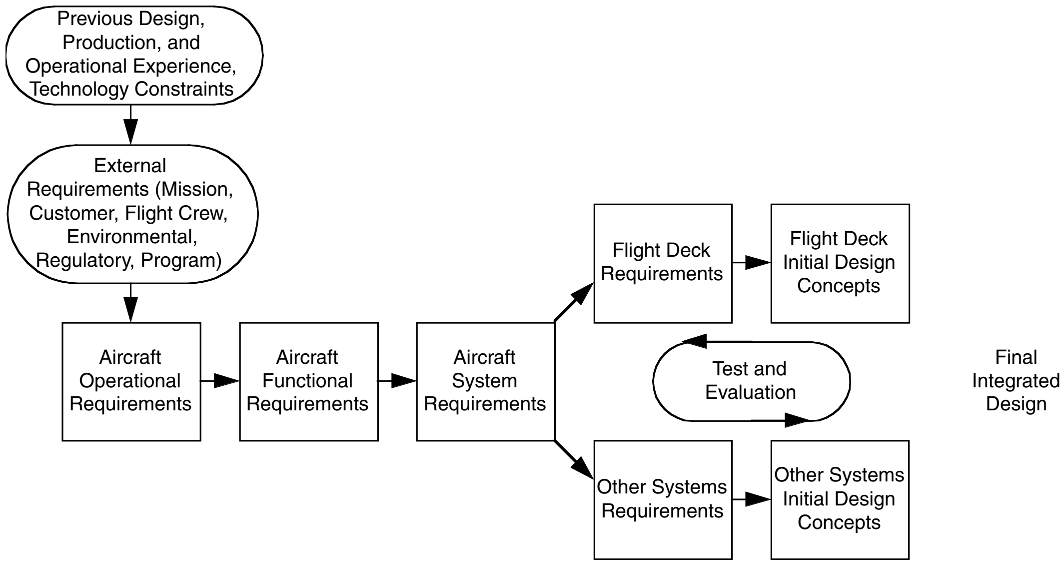


**FIGURE 9.1** Simplified representation of the flight deck design process (from NASA TM 109171).

Human-centered or user-centered design has been cited as a desirable goal. That is, design should be focused on supporting the human operator of the system, much as discussed above on the importance of matching the hardware, software, and environment to the human component. A cornerstone of human-centered design is the design philosophy.

#### 9.2.2.1 Flight Deck Design Philosophy

The design philosophy, as embodied in the top-level philosophy statements, guiding principles, and design guidelines, provides a core set of beliefs used to guide decisions concerning the interaction of the flight crew with the aircraft systems. It typically deals with issues such as allocation of functions between the flight crew and the automated systems, levels of automation, authority, responsibility, information access and formatting, and feedback, in the context of human use of complex, automated systems.[1,11]

The way pilots operate airplanes has changed as the amount of automation and the automation's capabilities have increased. Automation has both provided alternate ways of accomplishing pilot tasks performed on previous generations of airplanes and created new tasks. The increased use of and flight crew reliance on flight deck automation makes it essential that the automation act predictably with actions that are well understood by the flight crew. The pilot has become, in some circumstances, a supervisor or manager of the automation.

Moreover, the automation must be designed to function in a manner that directly supports flight crews in performing their tasks. If these human-centered design objectives are not met, the flight crew's ability to properly control or supervise system operation is limited, leading to confusion, automation surprises, and unintended airplane responses.

Each airplane manufacturer has a different philosophy regarding the implementation and use of automation. Airbus and Boeing are probably the best-known for having different flight deck design philosophies. However, there is general agreement that the flight crew is and will remain ultimately responsible for the safety of the airplane they are operating.

Airbus has described its automation philosophy as:

- Automation must not reduce overall aircraft reliability, it should enhance aircraft and systems safety, efficiency, and economy
- Automation must not lead the aircraft out of the safe flight envelope and it should maintain the aircraft within the normal flight envelope

- Automation should allow the operator to use the safe flight envelope to its full extent, should this be necessary due to extraordinary circumstances
- Within the normal flight envelope, the automation must not work against operator inputs, except when absolutely necessary for safety

Boeing has described its philosophy as follows:

- The pilot is the final authority for the operation of the airplane
- Both crew members are ultimately responsible for the safe conduct of the flight
- Flight crew tasks, in order of priority, are safety, passenger comfort, and efficiency
- Design for crew operations based on pilot's past training and operational experience
- Design systems to be error tolerant
- The hierarchy of design alternatives is simplicity, redundancy, and automation
- Apply automation as a tool to aid, not replace, the pilot
- Address fundamental human strengths, limitations, and individual differences — for both normal and nonnormal operations
- Use new technologies and functional capabilities only when:
  - They result in clear and distinct operational or efficiency advantages, and
  - There is no adverse effect to the human-machine interface

One of the significant differences between the design philosophies of the two manufacturers is in the area of envelope protection. Airbus' philosophy has led to the implementation of what has been described as "hard" limits, where the pilot can provide whatever control inputs he or she desires, but the airplane will not exceed the flight envelope. In contrast, Boeing has "soft" limits, where the pilot will meet increasing resistance to control inputs that will take the airplane beyond the normal flight envelope, but can do so if he or she chooses. In either case, it is important for the pilot to understand what the design philosophy is for the airplane being flown.

Other manufacturers may have philosophies that differ from Boeing and Airbus. Different philosophies can be effective if each is consistently applied in design, training, and operations, and if each supports flight crew members in flying their aircraft safely. To ensure this effectiveness, it is critical that the design philosophy be documented explicitly and provided to the pilots who will be operating the aircraft, the trainers, and the procedure developers.

### 9.2.2.2 Pilot/Flight Deck Interfaces

The layout, controls, displays and amount of automation in flight decks have evolved tremendously in commercial aviation.[15,16] What is sometimes termed the "classic" flight deck, which includes the B-727, the DC-10, and early series B-747, is typically characterized by dedicated displays, where one piece of data is generally shown on a dedicated gage or dial as the form of display. These aircraft are relatively lacking in automation. A representative "classic" flight deck is shown in Figure 9.2. All of these aircraft are further characterized by the relative simplicity of their autopilot, which offers one or a few simple modes in each axis. In general, a single instrument indicates the parameter of a single sensor. In a few cases, such as the Horizontal Situation Indicator, a single instrument indicates the "raw" output of multiple sensors. Regardless, the crew is generally responsible for monitoring the various instruments and realizing when a parameter is out of range. A simple caution and warning system exists, but it covers only the most critical system failures.

The first generation of "glass cockpit" flight decks, which include the B-757/767, A-310, and MD-88, receive their nickname due to their use of cathode ray tubes (CRTs). A representative first-generation "glass cockpit" flight deck is shown in Figure 9.3. A mix of CRTs and instruments was used in this generation of flight deck, with instruments used for primary flight information such as airspeed and altitude. A key innovation in this flight deck was the "map display" and its coupling to the Flight Management System (FMS). This enabled the crew to program their flight plan into a computer and see their planned track along the ground, with associated waypoints, on the map display. Accompanying the introduction of the map

**FIGURE 9.2** Representative “classic” flight deck (DC-10).

**FIGURE 9.3** Representative first-generation “glass cockpit” (B-757) flight deck.

**FIGURE 9.4** Representative second-generation "glass cockpit" (Airbus A320) flight deck.

display and FMS were more complex autopilots (added modes from the FMS and other requirements). This generation of aircraft also featured the introduction of an integrated Caution and Warning System, usually displayed in a center CRT with engine information. A major feature of this Caution and Warning System was that it prioritized alerts according a strict hierarchy of "warnings" (immediate crew action required), "cautions" (immediate crew awareness and future action required), and "advisories" (crew awareness and possible action required).[17]

The second generation of "glass cockpit" flight decks, which include the B-747-400, A-320/330/340, F-70/100, MD-11, and B-777, are characterized by the prevalence of CRTs (or LCDs in the case of the B-777) on the primary instrument panel. A representative second-generation "glass cockpit" flight deck is shown in Figure 9.4. CRT/LCDs are used for all primary flight information, which is integrated on a few displays. In this generation of flight deck, there is some integration of the FMS and autopilot — certain pilot commands can be input into either the FMS or autopilot and automatically routed to the other.

There are varying levels of aircraft systems automation in this generation of flight deck. For example, the MD-11 fuel system can suffer certain failures and take corrective action — the crew is only notified if they must take some action or if the failure affects aircraft performance. The caution and warning systems in this generation of flight decks are sometimes accompanied by synoptic displays that graphically indicate problems. Some of these flight decks feature fly-by-wire control systems — in the case of the A-320/330/340, this capability has allowed the manufacturer to tailor the control laws such that the flying qualities of these various size aircraft appear similar to pilots. The latest addition to this generation of flight deck, the B-777, has incorporated "cursor control" for certain displays, allowing the flight crew to use a touchpad to interact with "soft buttons" programmed on these displays.

**FIGURE 9.5** Gulfstream GV flight deck.

Of note is the way that this flight deck design evolution affects the manner in which pilots access and manage information. Figure 9.2 illustrates the flight deck with dedicated gages and dials, with one display per piece of information. In contrast, the flight deck shown in Figure 9.4 has even more information available, and the pilot must access it in entirely different manner. Some of the information is integrated in a form that the pilot can more readily interpret (e.g., moving map displays). Other information must be accessed through pages of menus. The point is that there has been a fundamental change in information management in the flight deck, not through intentional design but through introduction of technology, often for other purposes.

An example is shown in Figure 9.5 from the business aircraft community illustrating that the advanced technology discussed here is not restricted to large transport aircraft. In fact, new technology is quite likely to be more quickly introduced into these smaller, sophisticated aircraft.

Major changes in the flight crew interface with future flight decks are expected. While it is not known exactly what the flight decks of the future will contain or how they will function, some possible elements may include:

- Sidestick control inceptors, interconnected and with tailorable force/feel, preferably "backdriven" during autopilot engagement.
- Cursor control devices, which the military has used for many years, but the civil community is just starting to use (e.g., in the Boeing 777).
- Multifunction displays.
- Management of subsystems through displays and control-display units.
- "Mode-less" flight path management functions.
- Large, high-resolution displays having multiple signal sources (computer-generated and video).

- Graphical interfaces for managing certain flight deck systems.
- High-bandwidth, two-way datalink communication capability embedded in appropriate flight deck systems
- Replacement of paper with "electronic flight bags."
- Voice interfaces for certain flight deck systems.

These changes will continue to modify the manner in which pilots manage information within the flight deck, and the effect of such changes should be explicitly considered in the flight deck design process.

#### 9.2.2.3 Pilot/Flight Deck Interaction

Although it is common to consider the pilot interfaces to be the only or primary consideration in human factors in flight deck design, the interaction between the pilot(s) and the flight deck must also be considered. Some of the most visible examples of the importance of this topic, and the consequences of vulnerabilities in this area, are in the implementation of advanced automation.

Advanced automation (sophisticated autopilots, autothrust, flight management systems, and associated displays and controls) has provided large improvements in safety (e.g., through reduced pilot workload in critical or long-range phases of flight) and efficiency (improved precision of flying certain flight paths). However, vulnerabilities have been identified in the interaction between the flight crews and modern systems.[2]

For example, on April 26, 1994, an Airbus A300–600 operated by China Airlines crashed at Nagoya, Japan killing 264 passengers and flight crew members. Contributing to the accident were conflicting actions taken by the flight crew and the airplane's autopilot. During complex circumstance, the flight crew attempted to stay on glide slope by commanding nose-down elevator. The autopilot was then engaged, and because it was still in go-around mode, commanded nose-up trim. A combination of an out-of-trim condition, high engine thrust, and retracting the flaps too far led to a stall. The crash provided a stark example of how a breakdown in the flight crew/automation interaction can affect flight safety. Although this particular accident involved an A300–600, other accidents, incidents, and safety indicators demonstrate that this problem is not confined to any one airplane type, airplane manufacturer, operator, or geographical region.

A lesson to be learned here is that design of the interaction between the pilot and the systems must consider human capabilities and limitations. A good human-machine interface is necessary but may not be sufficient to ensure that the system is usable and effective. The interaction between the pilot and the system, as well as the function of the system itself, must be carefully "human engineered."

### 9.2.3 Evaluation

Figure 9.1 showed test and evaluation (or just evaluation, for the remainder of the discussion) as an integral part of the design process. Because evaluation is (or should be) such an important part of design, some clarifying discussion is appropriate here. (See Reference 18 for a more detailed discussion of the evaluation issues that are summarized below.)

Evaluation often is divided into verification (the process of demonstrating that the system works as designed) and validation (the process of assessing the degree to which the design achieves the system objectives of interest). Thus, validation goes beyond asking whether the system was built according to the plan or specifications; it determines whether the plan or specifications were correct for achieving the system objectives.

One common use of the term "evaluation" is as a synonym of "demonstration." That is, evaluation involves turning on the system and seeing if it basically resembles what the designer intended. This does not, however, provide definitive information on safety, economy, reliability, maintainability, or other concerns that are generally the motivation for evaluation.

It is not unusual for evaluation to be confused with demonstration, but they are not the same. In addition, there are several different types and levels of evaluation that are useful to understand. For example, **formative** evaluation is performed during the design process. It tends to be informal and subjective, and its results should be viewed as hypotheses, not definitive results. It is often used to evaluate requirements. In contrast, **formal** evaluation is planned during the design but performed with a prototype to assess the performance of the human/machine system. Both types of evaluations are required, but the rest of this discussion focuses on formal evaluation.

Another distinction of interest in understanding types of evaluation is the difference between **absolute** vs. **comparative** evaluations. **Absolute** evaluation is used when assessing against a standard of some kind. An example would be evaluating whether the pilot's response time using a particular system is less than some prespecified number. **Comparative** evaluation compares one design to another, typically an old design to a new one. Evaluating whether the workload for particular tasks in a new flight deck is equal to or less than in an older model is an example comparative evaluation. This type of evaluation is often used in the airworthiness certification of a new flight deck, to show its acceptability relative to an older, already certified flight deck. It may be advantageous for developers to expand an absolute evaluation into a comparative evaluation (through options within the new system) to assess system sensitivities.

Yet another important distinction is between **objective** vs. **subjective** evaluation. **Objective** evaluation measures the degree to which the objective criteria (based on system objectives) have been met. **Subjective** evaluation focuses on users' opinions and preferences. Subjective data are important but should be used to support the objective results, not replace them.

Planning for the evaluation should proceed in parallel with design rather than after the design is substantially completed. Evaluation should lead to design modification, and this is most effectively done in an iterative fashion.

Three basic issues, or levels of evaluation, are worth considering. The first is **compatibility**. That is, the physical presentation of the system must be compatible with human input and output characteristics. The pilot has to be able to read the displays, reach the controls, etc. Otherwise, it doesn't matter how good the system design is; it will not be usable.

Compatibility is important but not sufficient. A second issue is **understandability**. That is, just because the system is compatible with human input-output capabilities and limitations does not necessarily mean that it is understandable. The structure, format, and content of the pilot-machine dialogue must result in meaningful communication. The pilot must be able to interpret the information provided, and be able to "express" to the system what he or she wishes to communicate. For example, if the pilot can read the menu, but the options available are meaningless, that design is not satisfactory.

A designer must ensure that the design is both compatible and understandable. Only then should the third level of evaluation be addressed: that of **effectiveness**. A system is effective to the extent that it supports a pilot or crew in a manner that leads to improved performance, results in a difficult task being made less difficult, or enables accomplishing a task that otherwise could not have been accomplished. Assessing effectiveness depends on defining measures of performance based on the design objectives. Regardless of these measures, there is no use in attempting to evaluate effectiveness until compatibility and understandability are ensured.

Several different methods of evaluation can be used, ranging from static paper-based evaluations to in-service experience. The usefulness and efficiency of a particular method of evaluation naturally depends on what is being evaluated. Table 9.1 shows the usefulness and efficiency of several methods for each of the levels of evaluation.

As can be seen from this discussion, evaluation is an important and integral part of successful design.

## 9.3 Additional Considerations

### 9.3.1 Standardization

Generally, across manufacturers, there is a great deal of variation in existing flight deck systems design, training, and operation. Because pilots often operate different aircraft types, or similar aircraft with different equipage, at different points in time, another way to avoid or reduce errors is standardization of equipment, actions, and other areas.[19]

**TABLE 9.1** Methods of Evaluation[18]

| Method | Levels of Evaluation: Compatibility | Understandability | Effectiveness |
|---|---|---|---|
| Paper Evaluation: Static | Useful and Efficient | Somewhat Useful but Inefficient | Not Useful |
| Paper Evaluation: Dynamic | Useful and Efficient | Somewhat Useful but Inefficient | Not Useful[a] |
| Part-Task Simulator: "Canned" Scenarios | Useful but Inefficient | Useful and Efficient | Marginally Useful but Efficient[a] |
| Part-Task Simulator: Model Driven | Useful but Inefficient | Useful and Efficient | Somewhat Useful and Efficient |
| Full-Task Simulator | Useful but Very Inefficient | Useful but Inefficient | Useful but Somewhat Inefficient |
| In-Service Evaluation | Useful but Extremely Inefficient | Useful but Very Inefficient | Useful but Inefficient |

[a] Can be effective for formative evaluation.

It is not realistic (or even desirable) to think that complete standardization of existing aircraft will occur. However, for the sake of the flight crews who fly these aircraft, appropriate standardization of new systems/technology/operational concepts should be pursued, as discussed below.

*Appropriate* standardization of procedures/actions, system layout, displays, color philosophy, etc. is generally desirable, because it has several potential advantages, including:

- Reducing potential for crew error/confusion due to negative transfer of learning from one aircraft to another;
- Reducing training costs, because you only need to train once; and
- Reducing equipment costs because of reduced part numbers, inventory, etc.

A clear example of standardization in design and operation is the Airbus A320/330/340 commonality of flight deck and handling qualities. This has advantages of reduced training and enabling pilots to easily fly more than one airplane type.

If standardization is so desirable, why is standardization not more prevalent? There are concerns that inappropriate standardization, rigidly applied, can be a barrier to innovation, product improvement, and product differentiation. In encouraging standardization, known issues should be recognized and addressed.

One potential pitfall of standardization that should be avoided is to standardize on the lowest common denominator. Another question is to what level of design prescription should standardization be done, and when does it take place? From a human performance perspective, consistency is a key factor. The actions and equipment may not be exactly the same, but should be consistent. An example where this has been successfully applied is in the standardization of alerting systems,[16] brought about by the use of industry-developed design guidelines. Several manufacturers have implemented those guidelines into designs that are very different in some ways, but are generally consistent from the pilot's perspective.

There are several other issues with standardization. One of them is related to the introduction of new systems into existing flight decks. The concern here is that the new system should have a consistent design/operating philosophy with the flight deck into which it is being installed. This point can be illustrated by the recent introduction of a warning system into modern flight decks. In introducing this new system, the question arose whether the display should automatically be brought up if an alert occurs (replacing the current display selected by the pilot). One manufacturer's philosophy is to bring the display up automatically when an alert occurs; another manufacturer's philosophy is to alert the pilot, then have the pilot select the display when desired. This is consistent with the philosophy of that flight deck of providing the pilot control over the management of displays. The trade-off between standardization across aircraft types (and manufacturers) and internal consistency with flight deck philosophy is very important to consider and should probably be done on a case-by-case basis.

The timing of standardization, especially with respect to introduction of new technology, is also critical.[4] It is desirable to deploy new technology early, because some problems are only found in the actual operating environment. However, if we standardize too early, then there is a risk of standardizing on a design that has not accounted for that critical early in-service experience. We may even unintentionally standardize a design that is error inducing. However, attempt to standardize too late and there may already be so many variations that no standard can be agreed upon. It is clear that standardization must be done carefully and wisely.

### 9.3.2 Error Management

Human error, especially flight crew error, is a recurring theme and continues to be cited as a primary factor in a majority of aviation accidents.[2,20] It is becoming increasingly recognized that this issue must be taken on in a systematic way, or it may prove difficult to make advances in operations and safety improvements. However, it is also important to recognize that human error is also a normal by-product of human behavior, and most errors in aviation do not have safety consequences. Therefore, it is important for the aviation community to recognize that error cannot be completely prevented and that the focus should be on error management.

In many accidents where human error is cited, the human operator is blamed for making the error; in some countries the human operator is assigned criminal responsibility, and even some U.S. prosecutors seem willing to take similar views. While the issue of personal responsibility for the consequences of one's actions is important and relevant, it also is important to understand why the individual or crew made the error(s). In aviation, with very rare exceptions, flight crews (and other humans in the system) do not intend to make errors, especially errors with safety consequences. To improve safety through understanding of human error, it may be more useful to address errors as *symptoms* rather than *causes* of accidents. The next section discusses understanding of error and its management, then suggests some actions that might be constructive.

Human error can be distinguished into two basic categories: (a) those which presume the intention is correct, but the action is incorrect, (including ***slips*** and ***lapses***), and (b) those in which the intention is wrong (including ***mistakes*** and ***violations***).[21–23]

***Slips*** are where one or more incorrect actions are performed, such as in a substitution or insertion of an inappropriate action into a sequence that was otherwise good. An example would be setting the wrong altitude into the mode selector panel, even when the pilot knew the correct altitude and intended to enter it.

***Lapses*** are the omission of one or more steps of a sequence. For example, missing one or more items in a checklist that has been interrupted by a radio call.

***Mistakes*** are errors where the human did what he or she intended, but the planned action was incorrect. Usually mistakes are the result of an incorrect diagnosis of a problem or a failure to understand the exact nature of the current situation. The plan of action thus derived may contain very inappropriate behaviors and may also totally fail to rectify a problem. For example, a mistake would be shutting down the wrong engine as a result of an incorrect diagnosis of a set of symptoms.

***Violations*** are the failure to follow established procedures or performance of actions that are generally forbidden. Violations are generally deliberate (and often well-meaning), though an argument can be made that some violation cases can be inadvertent. An example of a violation is continuing on with a landing even when weather minima have not been met before final approach. It should be mentioned that a "violation" error may not necessarily be in violation of a regulation or other legal requirement.

Understanding differences in the types of errors is valuable because management of different types may require different strategies. For example, training is often proposed as a strategy for preventing errors. However, errors are a normal by-product of human behavior. While training can help reduce some types of errors, they cannot be completely trained out. For that reason, errors should also be addressed by other means, and considering other factors, such as the consequences of the error or whether the effect of the error can be reversed. As an example of using design to address known potential errors, certain switches in the flight deck have guards on them to prevent inadvertent activation.

Error management can be viewed as involving the tasks of error avoidance, error detection, and error recovery.[23] Error avoidance is important, because it is certainly desirable to prevent as many errors as possible. Error detection and recovery are important, and in fact it is the safety consequences of errors that are most critical.

It seems clear that experienced pilots have developed skills for performing error management tasks. Therefore, it is possible that design, training, and procedures can directly support these tasks, if we get a better understanding of those skills and tasks. However, the understanding of those skills and tasks is far from complete.

There are a number of actions that should be taken with respect to dealing with error, some of them in the design process:

**Stop the blame** that inhibits in-depth addressing of human error, while appropriately acknowledging the need for individual and organizational responsibility for safety consequences. The issue of blaming the pilot for errors has many consequences, and provides a disincentive to report errors.

**Evaluate errors in accident and incident analyses**. In many accident analyses, the reason an error is made is not addressed. This typically happens because the data are not available. However, to the extent possible with the data available, the types of errors and reasons for them should be addressed as part of the accident investigation.

**Develop a better understanding of error management tasks and skills** that can support better performance of those tasks. This includes:

- Preventing as many errors as possible through design, training, procedures, proficiency, and any other intervention mechanism;
- Recognizing that it is impossible to prevent all errors, although it is certainly important to prevent as many as possible; and
- Addressing the need for error management, with a goal of error tolerance in design, training, and procedures.

System design and associated flight crew interfaces can and should support the tasks of error avoidance, detection, and recovery. There are a number of ways of accomplishing this, some of which are mentioned here. One of these ways is through user-centered design processes that ensure that the design supports the human performing the desired task. An example commonly cited is the navigation display in modern flight decks, which integrates information into a display that provides information in a manner directly usable by the flight crew. This is also an example of a system that helps make certain errors more detectable, such as entering an incorrect waypoint. Another way of contributing to error resistance is designing systems that cannot be used or operated in an unintended way. An example of this is designing connectors between a cable and a computer such that the only place the cable connector fits is the correct place for it on the computer; it will not fit into any other connector on the computer.

### 9.3.3 Integration with Training/Qualification and Procedures

To conclude, it is important to point out that flight deck design should not occur in isolation. It is common to discuss the flight deck design separately from the flight crew qualification (training and recency of experience), considerations, and procedures. And yet, flight deck designs make many assumptions about the knowledge and skills of the pilots who are the intended operators of the vehicles. These assumptions should be explicitly identified as part of the design process, as should the assumptions about the procedures that will be used to operate the designed systems. Design should be conducted as part of an integrated, overall systems approach to ensuring safe, efficient, and effective operations.

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