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CHAPTER 29

Innovative Flight Deck Function Allocation Concepts for NextGen

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ABSTRACT

Future operations envisioned in the Next Generation Air Transportation System (NextGen) involve more complex and precise operations, more available information for the flight crew and air traffic control, more highly automated and complex systems, and increased flight crew tasks and responsibilities. A major issue of the NextGen concept of operations, particularly in a super density terminal area, is the potential brittleness of the system to disruptions and the reduced potential for humans to supply the needed resilience for non-normal and off-nominal operations. To mitigate these potential NextGen issues, it is necessary to identify the functions of a critical element of future aviation systems—aircraft flight decks, and to allocate those functions among the automated and human components of the flight deck. Two competing flight deck design concepts were developed based on different directions that flight deck designs may take in the future because of unpredictable forces and factors. The first design path embodies pilot roles and responsibilities that represent the "pilot as pilot," and the second design path embodies roles and responsibilities that represent the "pilot as manager." The two flight deck concepts were developed from an analysis of the anticipated operational requirements of the NextGen environment, emphasizing requirements that are likely to have significant impact on flight deck and flight crew functions and responsibilities. The two design concepts were used to generate high level human factors flight deck design guidelines that apply to both design paths in a future "NextGen" air traffic environment, focusing on those that are new or different from traditional human factors flight deck design guidelines.

Keywords: NextGen, Flight Deck, function allocation

1 INTRODUCTION

Emerging Next Generation Air Transportation System (NextGen) operational concepts represent a radically different approach to air traffic management and, as a result, a dramatic shift in the tasks, roles, and responsibilities for the flight crew to ensure a safe, sustainable air transportation system. Future operations envisioned in the NextGen involve more complex and precise operations, more available information for the flight crew and air traffic control, more highly automated and complex systems, and increased flight crew tasks and responsibilities. A major issue of the NextGen concept of operations, particularly in a high-density terminal area, is the potential brittleness of the system to disruptions and the reduced potential for humans to supply the needed resilience for non-normal and off-nominal operations. Off-nominal types of situations, while not involving a system failure or major operational incident, can potentially lead to higher pilot workload, higher stress, and require extremely smooth coordination of flight deck automation and flight crew to equal the resilience of today's systems. To mitigate these potential NextGen issues, it is necessary to identify the functions of a critical element of future aviation systems—aircraft flight decks, and to allocate those functions among the automated and human components of the flight deck. The steps used in the study were to:

- Analyze and summarize the anticipated operational requirements of the NextGen environment, emphasizing requirements that are likely to have significant impact on flight deck and flight crew functions and responsibilities.
- Identify flight deck functional requirements based on operational requirements.
- Develop two alternative flight deck design concepts through different assignments of roles, responsibilities, and functions to the flight crew and flight deck automation. The design concepts took into account the requirements analyses, market forces and factors, and identified safety issues.
- Develop high-level human factors flight deck design guidelines that apply to both design paths in a future NextGen air traffic environment, focusing on those that are new or different from traditional human factors flight deck design guidelines.

It is expected that new flight deck designs supporting new pilot roles and responsibilities will be required to meet NextGen safety and efficiency goals.

2 APPROACH

2.1 Operational Requirements

The goal of the operational requirements task was to define the NextDeck operational requirements that have a major impact on what the future flight deck must be able to do. Due to practical limitations, the scope of the flight deck operational requirements considered in this study was restricted to only those requirements that were judged to have a major identifiable impact on future flight decks in the NextGen environment.

A library of NextGen documents from various sources including the JPDO NextGen Concept of Operations 3.0 (JPDO, 2009) was reviewed to identify NextGen operations relevant to the flight deck. Next, the implications of current flight deck issues on the NextGen environment were derived from current flight safety data. This analysis identified the operational implications and possible human factors issues that need to be addressed in the design of future flight decks. Finally, the most current database of Honeywell's continuously collected Voice of Customer (VOC) data was used to obtain the perspective of airline operators and Original Equipment Manufacturers (OEMs) on future operations and flight deck issues. The requirements were organized in line with the NextGen operational concepts.

2.2 Functional Requirements

Although, in principle, the functional requirements should not make assumptions about function allocation or systems definition, some baseline assumptions were made about flight deck displays, controls, and information inputs/outputs required to accomplish the operational requirements when it was judged that those assumptions would not affect the different design paths.

Two important differences between this flight deck functional analysis and prior ones are (a) expansion of the meaning of systems management and (b) inclusion of task management as a high-level flight deck function (Abbott & Rogers, 1993 and Funk, 1991). Both systems management and task management functionality relate to the attention and effort that pilots will expend in mission management, information management, collaborative decision making, task management, and other "nonflying" functions resulting from the increased automation complexity and NextGen flight deck operational demands.

The outcome of the functional requirements gathering exercise was not intended to be an exhaustive list of flight deck functional requirements. Instead, it was aimed at a subset of functional requirements that will most significantly differentiate the two design paths developed here. For each operational requirement, a functional requirement was derived describing the function(s) that must be performed to fulfill the flight deck operational requirements.

2.3 Function Allocation Framework

It is important to have a function allocation framework with which to characterize the function allocation decisions that are made explicitly or implicitly. A significant amount of literature exists on principled approaches to allocating functions between humans and automation systems (e.g., Palmer, Rogers, Press, Latorella & Abbot, 1995 and Billings, 1991. To categorize the two design paths in terms of function allocation, the framework created by (Rogers, 1996) was used. This framework focuses on four main allocation decisions (i.e., who performs the task, what allocation options are available, what the authority/permission protocol is, and who has final authority and override capability). It also considers six types (based on a generic information processing model): sensing, processing data, assessing situation, setting goals, planning actions and responding.

3 NEXTGEN FLIGHT DECK DESIGN PATHS

3.1 Design 1: Pilot as Pilot

This design path is intended to support the flight crew in their conventional role as pilots—actively engaged in flight control with final authority and responsibility. Generally, pilots will authorize and delegate task performance to the automation and can intervene and take back control and authority at any time. Pilots may not be actively engaged in all functions all the time, but they have the ability and authority to intervene at any time in the performance of any function and direct the automation to perform in different modes or at different levels. For this design path, pilots are physically engaged as much as possible, and for flight control, the level of active engagement could even increase over that on today's flight decks if an envisioned level of simplicity of the flight control laws, control and guidance modes, and control devices can be achieved to minimize workload. The roles of pilot and automation, the overall cockpit layout, as well as display functions and formats, are all designed in ways that support pilots as fully engaged in the tactical execution of flight deck functions as well as in the planning and goal setting related to those functions. Automation will need to assist with information and decision functions more than it does today, as well as with achieving the needed simplicity in the pilot interfaces for all functions, to allow pilots to stay fully involved and take on more tasks and responsibilities without creating workload that is too high.

Assumptions

The key assumption for this design path is that pilots will retain final authority and responsibility for mission success factors: safety, efficiency, and passenger comfort. While use of hard and soft envelope protections will likely continue to increase, and automation will likely be assigned to perform more functions and tasks, the ability of pilots to intervene at any time and take over control of the aircraft must be retained.

Pilot as Pilot Themes

Pilot as Pilot is the more conventional design path where design supports pilot involvement in all functions, including the ability to control the aircraft with minimal use of automation. Pilots have final authority; they authorize and delegate tasks to the automation. Both control automation and information automation are designed in the context of systems to aid pilots in performance of flight deck functions. The themes that embody the Pilot as Pilot design path are listed in Table 1.

Table 1 Pilot as Pilot Design Themes

Design Theme	Example
Flight deck design simplicity	• Intuitive flight controls with simple relationships between inputs (e.g., throttles, stick) and aircraft parameters (e.g., speed, pitch). • Energy management that is achieved automatically through goal-oriented flight control.
Pilot physical engagement	• Manual control that can effectively simplify flying complex operational procedures and in non-normal airplane states (e.g., engine out). • Flight controls that provide physical feedback.
Graphical information display	• Integrated graphical displays for situation awareness. • Graphical presentation of intent/prediction and energy state.
High-bandwidth, low-workload interaction	• Natural human-machine interfaces (speech, touch) to increase pilot input bandwidth, lower pilot workload, and improve pilot input accuracy. • Input checkers to minimize pilot input errors.
Automation as monitor, pilot as final authority	• Automation monitoring of pilot, including monitoring of pilot inputs, pilot state (workload, fatigue), pilot communication, and inference of pilot intent; monitoring of performance requirements. • Pilot has final authority in flight deck decisions and tasks.
Strategic and tactical task support	• Automation aids to support more strategic and tactical tasks performed by pilot; More strategic task aids and mission management aids; more alerts for tactical issues to help pilot transition from strategic to tactical. • Pilot engaged at tactical level, naturally prepared for response to non-normal and off-nominal situations.
Flight deck interaction style	• Automation needs to be more explanatory than today, including communication of automation intent and status of accomplishing pilot intent. • Consistent alerting and notification aimed at bringing situations, events, and states to the pilot's attention.

Implications and Potential Issues

The Pilot as Pilot flight deck design has several positive and negative implications. The key positive implications are related to the consistency of this design and function allocation approach with traditional human-centered design principles. Namely, humans perform better in non-normal or off-nominal events if they have been actively involved in performing relevant tasks during normal conditions. Humans also can develop and maintain better situation awareness if they are intimately involved in relevant task performance. The Pilot as Pilot design inherently keeps pilots more involved and actively engaged in performance of various tasks and functions than the second design path, so the benefits of that more intimate involvement should be greater for this design path.

Further, pilots traditionally have final authority not only for legal reasons, but also because humans perform better in dynamic, unanticipated situations where knowledge and skill may need to be applied in unforeseen ways beyond the capability of automation. Therefore, this design path would be expected to be more robust and resilient in terms of handling unforeseen situations that are not only unanticipated by the flight crew, but are also unanticipated by designers.

On the negative side, the key issues likely to manifest themselves with this design path relate to workload and the ability of pilots to perform in an increasingly complex environment with greater demands for precision and efficiency with inherently smaller margins of safety. The types of traps that are observed today in terms of pilot errors (e.g., due to misunderstanding of the operational environment, miscommunications, lack of situation awareness, or lack of understanding of the state or mode of the flight deck automation), and the human performance constructs underlying those errors (e.g., attention and memory limitations, perceptual errors, poor judgment, inadequate knowledge), could be exacerbated in the NextGen environment with greater demands on pilot resources and more time pressures where pilots still need to be engaged in all functions and retain authority and responsibility for all functions.

3.2 Design 2: Pilot as Manager

Pilot as Manager (PAM) is the alternate design path where forces and functions push the pilot toward the role of manager. This design path is intended to support the flight crew in the role of NextGen flight deck information managers and collaborative decision makers with automation. In this design path, automation is responsible for the majority of aircraft control and navigation tasks, as well as information processing tasks for which the pilot is responsible in the Pilot as Pilot design path. A key to this design path is how to support the pilots as managers and monitors in an active, engaging way. This might be characterized as intentionally designing the flight deck in a way that encourages the pilot to be a micro-manager (without the negative connotations). The allocation decisions between pilot and automation for task performance, authority, and override capability are all designed to support this design path. To establish a plausible solution, much more analysis will be required to determine exactly how pilots and automation can share authority in a dynamic way and which has final authority in different situations.

Assumptions

The key assumptions for this design path are that pilots will share authority and responsibility with automated systems for mission success factors such as safety, efficiency, and passenger comfort. Furthermore, most functions will be executed by automation and overseen/managed by the pilots. This, in turn, assumes that extremely reliable and highly capable automation (e.g., high-integrity hardware and software technologies that can reason about uncertainty and unexpected events) exists to perform most NextGen flight deck functions. Automation is responsible for the following information processing tasks: sensing, data processing, planning, and response execution. Situation assessment and goal setting are shared responsibilities between the pilot and automation.

Pilot as Manager Themes

Pilot as Manager is the more novel design path in which design supports the pilot in managing, monitoring, and collaborating with automation to effectively perform flight deck tasks. The pilot will share authority and responsibility with the automation for mission success factors such as safety, efficiency, and passenger comfort. The themes that embody the Pilot as Manager design path are listed in Table 2.

Table 2 Pilot as Manager Design Themes

Design Theme	**Example**
Shared authority between pilot and aircraft automation	• Automation and pilots can set goals and override each other. • Clearly defined commanded authority transitions from pilot to pilot, pilot to automation, and automation to pilot.
Function allocation between pilot and aircraft automation	• Automate low-level tasks as much as possible since the list of functions that "machines are better at" continues to grow. • Tactical tasks and most aviate/navigate tasks executed by automation and mission management, setting goals executed by pilot.
Design to maintain pilot engagement	• Pilot involved in all functions; Automation provides goal and execution options from which pilot selects. • Status displays to explain automation behavior.
Tactical task support	• Manual intervention mode for emergencies and unexpected tactical events needs to be simple, quick, and error-tolerant. • Awareness and decision aids for identifying and responding to failure, anomalous, and off-nominal conditions across the flight deck functions.

Flight deck design simplicity	• Automation needs to integrate information and make diverse and complex operations more understandable to pilots. • Design needs to be easy to train through knowledge-based and rule-based techniques.
Flight deck interaction style	• More active automation, e.g., prompting, challenging, explaining—generally more communicative about what it's doing and why. • Flexibility to change interaction style based on situation.
Strategic, management, and cognitive task support	• Information content needs to support more strategic tasks and goal setting with longer time horizons; more predictive, trend, and "what-if" information. • More strategic alerts and reminders and mission management aids.

Implications and Potential Issues

This design path has several positive and negative implications. The main positive implication is that the flight crew will have greater bandwidth to manage all aspects of the flight and stay aware of all important events and situations because they are not spending attention and effort performing lower level manual tasks. With the pace, complexity, and diversity of NextGen operations, this ability to maintain a higher level perspective and perform at a strategic level may be essential. However, workload could still be an issue because of the need for the pilot to monitor more automation and manage more flight deck information.

On the negative side, a major concern with the role of the Pilot as Manager is how to keep him or her engaged. Actively performing tasks is known to be more engaging than monitoring or managing tasks. The key is how to make pilots behave as active rather than passive managers and be fully involved, skeptical, and challenging, even when the automation is highly reliable and non-normal and off-nominal events are rare. Further, the extensive use of reliable automation could mean infrequent and unexpected automation failures. Such failures could be difficult to detect when they occur. Also, complacency could lead to less monitoring of the flight deck system by the Pilot as Manager, resulting in loss of situation awareness. As a result, even when a failure is detected, the pilot could be less likely to deal appropriately with a situation.

Finally, there are many more unknown implications of the Pilot as Manager design than the Pilot as Pilot design. For example, due to the differences in the roles of the Pilot as Manager, special training may be required for pilots to effectively perform their new role. New standard operating procedures (SOPs) may also be required for pilot interaction with automation systems, especially in authority sharing and in emergencies. Additionally, procedures addressing how pilots allocate tasks between them would be very different since both pilots would normally be in "Pilot Monitoring" roles.

Perhaps the largest potential issue with PAM is how to safely share authority in a dynamic way. It is not certain whether a simple, workable protocol can be established that provides an unambiguous means for pilots to have final authority in some situations and automation to have it in others. The legal issues for shared authority also need to be addressed.

3.3 Design Guidelines

The development of the guidelines consisted of a review of current human-factors-focused flight deck design guidelines, particularly those that seemed important for the challenging characteristics of the NextGen operational environment. This review provided context and ideas not only for guideline content, but also for the granularity and wording of the guidelines. The main elements of the two design paths and the associated pilots tasks were also reviewed.

4 CONCLUSION

Two distinct design paths were developed as a result of operational and functional analysis as well as function allocation. The design paths for the flight deck differ mainly in the allocation of functions between human operator and automation—Pilot as Pilot and Pilot as Manager. For the Pilot as Pilot (PAP) design path, the pilot performs roles similar to a pilot on a flight deck of today. The main concern of this design path is pilot workload due to increased information processing requirements and task responsibilities. The pilot is primarily responsible for conventional aviate, navigate and communicate tasks. In the Pilot as Manager design path, the pilot is responsible for management of automated systems and flight desk tasks, with the majority of flight deck functions performed by automation. The major concern for this design path is keeping the pilot engaged and maintaining his or her situation awareness.

The themes that emerged for the two design paths were used to develop conceptual flight deck design descriptions. Function allocation decisions for information processing tasks assigned task performance, flight deck authority, and override capability for the two designs to the pilot and the automation. The descriptions of the design paths were presented in terms of assumptions about the nature of information input and output on the flight deck, cognitive and information demands of pilot tasks, as well as assumptions about the general role of automated systems and the pilot–automation interactions required. Characteristics of each design path were captured in a set of design themes. The two design paths, albeit intentionally reflecting end points of a continuum of function allocation possibilities, are intended to describe plausible future flight deck designs that account for NextGen flight deck operational requirements, available technologies, and pilot capabilities.

Based on the high-level design concepts developed for the Pilot as Pilot and Pilot as Manager paths, a key conclusion is that no matter which direction future flight deck designs evolve in, very significant flight deck design changes will be required to meet the safety and efficiency needs of envisioned NextGen operations. The two designs and their accompanying guidelines identify important flight deck design concepts and issues that will need to be addressed to maintain or improve NextGen safety while increasing air traffic capacity and efficiency. The designs were intentionally developed to be end points of a continuum of possible human–automation function allocation strategies; the Pilot as Manager design, in particular, may not be practical for a number of reasons, including liability uncertainties, unachievable automation reliability levels, and the difficulty in preserving the ability of the flight crew to supply needed resilience for unexpected situations. However, the PAP and PAM design themes illustrate potentially useful design concepts and highlight potential issues that will need to be solved regardless of the direction of future flight deck changes.

It is expected that many of the concepts and guidelines are expected to be difficult to realize, and with further analysis, it may become clear that some of them are not feasible. However, these design concepts should be developed in more detail so that modeling analyses and empirical studies can be conducted to evaluate performance tradeoffs, workload issues, risks and benefits of new technologies, and pilot engagement issues. Ultimately, flight deck designs will likely take a path somewhere between the end points described here, but many of the issues identified and the design concepts described here are expected to still be applicable.

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