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Nextgen Flight Deck Human Factors Issues

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This paper describes a project to compile, from a literature review and preliminary analyses, an initial but reasonably comprehensive list of NextGen flight deck human factors issues. It describes the methodology that was used, presents representative issues from the list that resulted, and makes recommendations to continue work to update the list and use it as the basis for suggested NextGen flight deck standards and design requirements.

The goals of the Next Generation Air Transportation System (NextGen) are to significantly increase the safety, security, and capacity of US air transportation operations. The eight key capabilities deemed necessary to achieve those goals (JPDO, 2007a) will bring major changes to the flight deck, including Internet-like information services, access through them to a common weather picture, integration of weather information into flight deck decision making, negotiated four-dimensional aircraft trajectories, means for equivalent visual operations in low visibility conditions, delegated self-separation, and equipment and procedures for super-density arrival and departure operations.

Plans for NextGen development have been driven largely by technology, and human factors considerations do not appear to be a motivating force behind these and other changes. Thus, the NextGen flight deck could harbor many vulnerabilities to pilot error, jeopardizing the very goals NextGen is meant to accomplish. While past research has applied human factors expert opinion to identify general NextGen human factors issues, as yet, little NextGen-specific human factors analysis has been performed and, to our knowledge, no one has attempted to create a reasonably comprehensive list of human factors issues related specifically to the NextGen flight deck.

Objectives

The objectives of this project were to conduct a preliminary review of literature and perform preliminary analyses to compile and organize an initial but reasonably comprehensive list of NextGen flight deck human factors issues.

Methodology

In the interest of clarity, we defined a NextGen flight deck human factors issue as:

> a statement which, if it should become true in the implementation and operation of NextGen, describes a condition or situation related to flight deck operations in which normal pilot characteristics, capabilities, limitations, and tendencies are very likely to lead to significant problems with NextGen effectiveness, efficiency, or safety.

NextGen is in the early stages of development. The issues that we identified are plausible conditions or situations that could develop as NextGen is implemented and, if they materialize, these issues are likely to lead to serious problems. Because NextGen is still being developed, we cannot be certain that the situations or conditions described in the issues will come to be. But based on what we know about the current air transportation system and plans for implementation of NextGen, they are likely to exist in NextGen unless steps are taken to prevent them. The purpose of identifying issues at this time is to head off those problems by providing input to good, pilot-centered design.

NextGen Human Factors Literature Review

Our first step in identifying NextGen flight deck human factors issues was to search for known issues in the literature which is, as yet, rather limited. We reviewed NextGen issues reports (e.g., Sheridan, Corker, and Nadler, 2006a, 2006b; Murdoch and Press, 2008) and reports on human factors issues with Automatic Dependent Surveillance – Broadcast (ADS-B), a key NextGen enabler, in which GPS-based reports of aircraft's own positions drive traffic displays for both air traffic controllers and pilots (e.g.,Williams et al, 2002; MITRE, 2006). Relevant

literature on other aspects of NextGen and Eurocontrol's Single European Sky ATM Research Programme (SESAR) was also examined. We were unable to thoroughly review all of this literature with the time and resources allotted. However, as we reached the end of the project, few new issues emerged as additional literature was examined.

To review this literature, we read the documents for descriptions, either explicitly stated or implied, of conditions or situations that could be related to flight deck operations where normal pilot characteristics, capabilities, limitations, and tendencies would be very likely to lead to significant problems with NextGen effectiveness, efficiency, or safety. We captured these excerpts (in most cases verbatim) in a spreadsheet. To promote consistency in how the issues were posed, we paraphrased distinct issues, as described in our sources, into terse statements having uniform syntax and semantic structure.

For example, Sheridan et al (2006a section 3.1.2.1) suggested that "[m]onitoring and maintaining situation awareness over long and boring periods of nominal operations under automatic control (with a possible need to impose activities for the purpose of maintaining alertness)" was an issue for future NextGen research. From this excerpt (and from others like it in other sources), we identified two NextGen flight deck human factors issues: 1) "Monitoring requirements are excessive" and 2) "Difficult to maintain situational awareness over long, boring periods of nominal operations."

As background for the study, we read the *NextGen Concept of Operations* (JPDO, 2007a) and flight deck-relevant portions of the *NextGen Enterprise Architecture* (JPDO, 2007b) and we reviewed the online *NextGen Enterprise Dataset* (JPDO, 2008). These documents describe NextGen operations, functions, operational improvements, and enablers. Although they are not intended to directly identify flight deck human factors issues, issues arise in the descriptions of NextGen elements. We did not exhaustively analyze these descriptions for issues, but we captured the human factors issues suggested by them in the spreadsheet.

Flight Deck Automation Human Factors Issues Database Application

The past two decades have seen considerable controversy about the safety of flight deck automation and many human factors issues have been raised (e.g., Wiener, 1989). Funk and his colleagues (1999) undertook a comprehensive review of aircraft automation research, aircraft incident reports, incident report studies, and aircraft accident reports, and surveyed pilots and aviation safety experts to develop a comprehensive list of flight deck automation issues. For each issue so identified, they compiled evidence from their sources to support the assertion that it posed a safety problem, and then performed meta-analyses to prioritize the issues for further research. Their findings and supporting data are available on a website (RII, 2007). We reviewed all of their flight deck automation issues to determine which potentially apply to the NextGen flight deck and captured relevant ones in our spreadsheet.

For example, flight deck automation issue 103 is "It may be difficult for pilots to decide what levels of automation are appropriate in specific circumstances, possibly increasing pilot workload." Applying our syntactical and semantical structure for NextGen issues to that, we added the following NextGen flight deck human factors issue to our list: "Automation level decisions are difficult for pilots."

Failure Modes and Effects Analysis

Failure Modes and Effects Analysis (FMEA) is a proven, prospective safety analysis technique that systematically examines a process representation to identify failure modes (ways in which a system can fail), factors contributing to those failures, and their consequences. Pilot error may be considered a kind of failure mode and, from potential errors, flight deck human factors issues may be identified. So we performed a preliminary FMEA to identify more NextGen flight deck human factors issues.

As preparation for the FMEA, we developed a preliminary flight deck functional model, the Oregon NextGen Flight Deck Functional Model version 0.1 (ONFDFM V0.1). The ONFDFM models a general aviation or on-demand air taxi flight from a small airport with an Automated Virtual Tower to a mid-size airport, with parallel runways, in a metroplex. As this was an initial effort conducted with limited resources in a short time frame, we used a simplified functional modeling approach, roughly equivalent to hierarchical task analysis. Elements of the ONFDFM are verb phrases, each one describing the mission or a function or task (low-level function) within the mission. The model is represented as a hierarchical list, like an outline. We modeled the top-level, mission function as *Conduct NextGen flight*. We analyzed the mission function into subfunctions corresponding to mission phases. For each mission phase function, we broke it down into subfunctions subordinate to that, and so on. Rather than

detail the entire ONFDFM to a uniform depth, we focused on especially important portions of the model, for example, *Perform departure related activities* and *Perform enroute activities*.

We performed a partial FMEA using the ONFDFM. Due to limited resources and the short time available, we applied the analysis to just two representative parts of the model, *Perform departure related activities* and *Fly enroute free-flight*. The latter is part of *Perform enroute activities* and represents free flight, as opposed to flow corridor, operations.

For each subfunction in these parts of the model, we applied our knowledge of NextGen functionality, our knowledge of present day flight deck operations likely to be similar to NextGen operations, and our knowledge of human operator characteristics, capabilities, and limitations, to identify likely failure modes for the subfunction, (i.e., errors that pilots would likely commit in performing the subfunction). For each error we identified likely effects or consequences of the error. For each specific error identified in the FMEA, we generalized it to one or more broader issue statements. As we identified many similar errors, multiple errors mapped to the same issue, so the FMEA did not produce as many issues as errors. As an example, FMEA applied to *Monitor CDTI for other traffic & ground equipment during taxi out* and other subfunctions led to the identification of the issue, "Use of CDTI to maintain surface separation interferes with visual contact with surface traffic".

Issues Management

As we collected issues using the aforementioned methods, we added them to the spreadsheet. For each issue, we recorded an issue statement (worded using syntactical and semantic structure designed to be reasonably consistent across issues), the source of the issue, a reference (section identifier, page number, item number, or other locater), an excerpt from the text that suggested the issue, additional source and reference information (if the issue was found in more than one source), an optional comment, and information as to whether the issue appeared to be redundant with one or more issues that had already been recorded. To aid in issue classification and organization, we attached one or more descriptive tags or labels to each issue. Because tags were not mutually exclusive and they covered several dimensions of the flight deck domain, they allowed us to categorize and organize the issues in several ways. The tag system will permit more flexible use of the issues list in future research and development.

Because many tags were identified and used in the process, a higher level of organization was required for clarity. So we organized the tags themselves and, by extension, the issues which they designated, into 10 categories. Then for each tag in each category, we formulated a broad issue statement, intended to represent all issues marked with that tag. We organized and set up the issues spreadsheet to present broad issue categories and broad issues, and to filter specific issues by the issue tags and other criteria. We reviewed all the specific issues, edited the specific issue statements for accuracy, clarity, and uniform syntax and semantic structure, then identified and removed redundant specific issues.

Findings and Discussion

Initially, our reviews and analyses yielded 250 specific issues, which, by removing redundant issues, were reduced to 225 specific issues. The specific issues were marked by 81 tags reflecting broad issues, with those broad issues/tags organized into the 10 categories. The following sections present, for each of nine of the categories, a tag (in square brackets) and broad issue representative of that category, a specific issue subsumed by the broad issue, and a list of tags for other broad issues falling in the category. Because these representative issues are also what we believe to be some of the most important ones, we additionally include brief discussions of their significance.

Design, Development, Testing, and Certification Issues

Broad issue:	[development] There is insufficient and inadequate human factors engineering input in the development of NextGen functions and subsystems.
Specific issue:	Inadequate human-in-the-loop fidelity used in development and certification.
Other broad issues:	certification, testing, human-centered design

Although human factors research and design is mentioned in JPDO documentation, it is not clear how NextGen planners intend to address these issues. We are concerned that human-centered design will not be a development priority and that NextGen engineers will rely on their intuition rather than on a comprehensive set of human factors tools and guidelines when designing pilot-system interfaces and tasks.

Issues Related to Pilot-Pilot and Pilot-ANSP Interaction

Broad issue:	[collaboration] NextGen pilot-Air Navigation Services Provider (ANSP) collaboration processes are poorly designed, poorly defined, inefficient, and ineffective.
Specific issue:	Flight plan negotiation processes and mechanisms are poorly designed.
Other broad issues:	voice/data, communication, team

Unless pilot roles, responsibilities, authority, and procedures with respect to collaboration and, especially trajectory negotiation, are clearly defined, designed, and trained, there will be operational confusion, misunderstandings, delays, and errors.

Pilot-Subsystem Interface Issues

Broad issue:	[information] Information on the NextGen flight deck is insufficient or, when available, difficult to access, inadequate, poorly presented to pilots, and often overwhelming.
Specific issue:	Pulled net-centric information is difficult to access.
Other broad issues:	inconsistency, feedback, representation, displays, CDTI, interface, cues, controls

NextGen is an information system. Knowing what information is important to a pilot under a given set of circumstances, how to filter and prioritize it based on context, and how to present that information effectively presents a daunting challenge.

Subsystem-Subsystem Interaction Issues

Broad issue:	[datalink] Pilots lack adequate awareness of automated data exchanges between NextGen ground and air subsystems.
Specific issue:	Pilots lack situational awareness due to automated exchange of flight plan and ... 4DT data.
Other broad issues:	uplink

In the context of a complex flight deck in which multiple tasks are being performed concurrently under a variety of operational stressors, simply giving pilots the option to review and approve automated information exchanges does not guarantee that they will do so, or, if they do, do it quickly and accurately.

Issues Related to Pilot Behavior and Performance

Broad issue:	[attention] Pilots do not properly allocate their attention among information sources and tasks on the NextGen flight deck.
Specific issue:	Both pilots often become involved with NextGen subsystems, which diverts their attention from safety-critical tasks.
Other broad issues:	errors, monitoring, manual skill, overload, decision making, awareness

The number of concurrent tasks on the NextGen flight deck will make it more difficult for pilots to assess the current status of all ongoing tasks and their relative importance and urgency. This will make it more difficult for the flight crew to correctly choose how to allocate their attention and efforts at any given time.

Issues Related to Pilot Roles, Responsibilities, Capabilities, Limitations, and Attitudes

Broad issue:	[authority] Pilot authority on the NextGen flight deck is unclear and/or overly restricted.
Specific issue:	Action responsibility/authority of net-centric information are poorly represented.
Other broad issues:	understanding, reliance, workload, oversight, pilot capabilities, trust, satisfaction, risk, roles, training, stress, responsibility, memory, culture, acceptance

Unless pilot authority is demarcated in general and operationally defined by the design of specific procedures, pilots will be uncertain as to their flight management and control authority in NextGen and therefore less likely to take full advantage of the autonomy, flexibility, and efficiency it promises.

Process and Procedure Issues

Broad issue:	[procedures] Many NextGen processes lack defined procedures or those procedures are poorly designed.
Specific issue:	Temporal and spatial variations in NextGen function require pilots to recognize the need for and use different procedures.
Other broad issues:	processes, intervention, multi-tasking, tasks, flight plan, negotiation

To operate in NextGen, a large number of tasks must be performed using a great deal of equipment. Under these conditions, flight deck procedures cannot be left to the pilots to design *ad hoc*. To avoid inefficiencies and errors, a systematic approach to procedure development should be used.

Flight Deck Subsystem Issues

Broad issue:	[automation] NextGen flight deck automation is overly complex and hard to understand, and its logic and interfaces are poorly designed.
Specific issue:	Automation changes modes without pilot commands to do so, sometimes producing surprising behavior.
Other broad issues:	failure, system control, decision support tools, equipment selection, equipage, standardization, manuals, modes, databases, data entry, complexity, functionality, performance, integration

The level and complexity of automation on the NextGen flight deck will be higher than that of today and even more care must be taken in the development process to assure its usability.

System Issues

Broad issue:	[variations] Temporal and spatial variations in NextGen functionality and subsystems make it difficult for pilots to adapt to different circumstances.
Specific issue:	Temporal and spatial variations in NextGen function require pilots to recognize the need for and use different procedures.
Other broad issues:	trajectory, organization, delay, justice, macroergonomics, system dynamics

NextGen will be a large and complex system, and variations in its functionality over space and time will present challenges to pilots.

Conclusions and Recommendations

Our study was necessarily limited by the short time frame in which it was conducted, by our ability to manage a large number of issues, by the limited amount of definitive information on the NextGen flight deck, and by our own personal knowledge limitations and biases. Nevertheless, we believe that the 81 broad issues, representing the 225 specific issues identified in this project, strongly suggest that the human factors challenges to the effectiveness, efficiency, and, especially, the safety of the NextGen flight deck may be greater than anticipated. With that in mind, we offer the following recommendations for further development of and action on these issues.

1. Create a team of human factors scientists and engineers, flight deck engineers, pilots, and aviation safety experts to collaboratively identify and recommend remediations for NextGen flight deck human factors issues.
2. Create and maintain a web-accessible NextGen flight deck human factors issues database.
3. Create and maintain a NextGen flight deck human factors website to facilitate team collaboration and the dissemination of findings and recommendations.
4. Review other sources for additional issues.
5. Clarify and edit the text of the issues and organize them.
6. Build and maintain a detailed NextGen flight deck functional model (NFDFM), consistent with the emerging NextGen architecture.
7. Use the NFDFM to perform more extensive FMEAs to identify additional issues.
8. Validate and prioritize the issues.
9. Use the NFDFM and FMEA findings to develop detailed NextGen flight deck scenarios for system research, development, and testing.

10. Use the issues list, FMEA results, scenarios, and other findings to develop suggested standards or design requirements for NextGen flight deck equipment and procedures.

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