A Comparative Analysis of Flightdecks With Varying Levels of Automation

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Abstract

Under this grant we completed or initiated four tasks to address commercial transport aircraft flight deck human factors. In the first task we identified and compiled evidence related to nearly 100 flight deck automation human factors issues and created a website to disseminate our findings (http://flightdeck.ie.orst.edu/). In the second task we undertook a study of methods for training pilots for automated aircraft, compiled airline and manufacturer training experiences, developed recommendations for future training, and published a report of our findings available at http://www.researchintegrations.com/training-report-1998-bysubject-index.htm. In the third task we began development of a job aid to assist FAA aircraft certification personnel in the identification and resolution of human factors issues early in the type certification process. In the fourth task we began developing materials to support the work of the new Human Factors Harmonization Working Group commissioned to create new airworthiness standards related to flightcrew performance. The first and second tasks are completed. The third and fourth tasks will continue under new contracts to Research Integrations, Inc.

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Introduction

Since "flightcrew error" is the single most common probable cause or contributing factor cited as leading to commercial transport aircraft accidents, it is appropriate that significant effort be given to the study of flight deck human factors issues. That was the purpose of this grant research, and with the support of the Federal Aviation Administration Office of Chief Scientific and Technical Advisor for Human Factors (AAR-100), we were privileged to conduct or initiate four major tasks aimed at improving aviation safety by addressing flight deck human factors.

These tasks were performed under grant 93-G-039 from AAR-100 to Oregon State University and its subcontractors. Beth Lyall, President of Research Integrations, Inc., and Ken Funk, Associate Professor of Industrial and Manufacturing Engineering, Oregon State University, were Co-Principal Investigators. We were joined in the work by our colleagues Vic Riley of Honeywell, Inc., Gary Bakken of Analytica Systems, Inc., and supported by numerous Oregon State University students, and Research Integrations, Honeywell, and Analytica Systems personnel.

Flight Deck Automation Issues

The first task was a study of human factors issues related to the design and use of commercial transport aircraft automation. From the literature and other sources we compiled and documented nearly 100 automation human factors. Based on available evidence we ranked these issues and made recommendations to address them.

Training For Automated Aircraft

Since one of the most significant and pressing issues identified early on was training for automated aircraft, we initiated a separate task to study it. Through extensive interviews with the training departments and pilots of all major US airlines and both large transport aircraft manufacturers, we compiled and documented experience with various training methods and developed recommendations for future training programs.

Certification Job Aid

In parallel with our own study, the FAA commissioned a separate study of the interfaces between flightcrews and modern flight deck systems. One of the recommendations of this FAA Human Factors Team was a more thorough "... evaluation of flight deck designs for susceptibility to design-induced flightcrew errors and the consequences of those errors as part of the type certification process.” Since the first step to such evaluation is the effective use of the tremendous amount of regulatory, guidance, scientific, and reference information available, we began a new task of developing a job aid to assist FAA certification personnel in identifying and addressing human factors issues early in the certification process. Under this grant we began collecting resource material and designing the Job Aid. The first version will be completed soon, under a new contract to Research Integrations, Inc.

FAA/JAA Human Factors Harmonization Working Group

Since our automation work and our development of the Job Aid were so germane to the work of the new Human Factors Harmonization Working Group (HF HWG) tasked to review and develop new flight crew error/flight crew performance standards for the US Federal Aviation Regulations (administered by the FAA) and European Joint Aviation Regulations (administered by the European Joint Aviation Authority, JAA), we began our fourth task, to support the HF HWG. That support will continue under a new contract to Research Integrations, Inc.

These four tasks are described in greater detail in the following chapters, and final products for the completed tasks and interim products for the initiated tasks are presented in the appendices.

Flight Deck Automation Issues

Our first research task was to investigate issues that have been raised about aircraft automation and its effect on the safety of commercial air transportation. A copy of a paper on this task, published in *The International Journal of Aviation Psychology,* is included in its entirety in Appendix A.

Introduction

Flight deck automation has been effective in increasing the efficiency of commercial air transportation and in reducing certain kinds of flightcrew error. But many investigators (e.g., Wiener, 1989; Billings, 1997; FAA Human Factors Team, 1996) have raised a number of human factors concerns including poor interface design, pilot complacency and over-reliance on automation, loss of manual flying skills, and pilots' lack of understanding of the new equipment. These concerns have led to considerable research to investigate specific issues (e.g., Sarter & Woods, 1994). But until our work, there was no comprehensive list of flight deck automation issues, much less a prioritization of those issues to aid in the wise allocation of research, development, and operational resources to address them.

The objectives of our research (Funk et al, 1999) were to

1. develop a comprehensive list of flight deck automation human factors issues;
2. compile a large body of existing data and other evidence related to those issues; and
3. disseminate the list of issues and supporting data to the aviation research, development, manufacturing, operational, and regulatory communities.

To meet these objectives we compiled a large list of automation issues (Phase 1), collected and organized evidence related to those issues (Phase 2), summarized and ranked issues based on several criteria (Meta-Analysis), and created a website to disseminate our findings.

Phase 1: Identification of Issues

To identify flight deck automation issues we compiled a list of possible problems with, or concerns about, flight deck automation, as expressed by pilots, scientists, engineers, and flight safety experts. We reviewed 960 source documents, including papers and articles from the scientific literature as well as the trade and popular press, accident reports, incident reports, and questionnaires filled out by pilots and others. We also surveyed 128 pilots and others experienced with flight deck automation asking them to describe their concerns. In these source documents, we found 2,428 specific citations of problems or concerns with automation and classified them into 114 issues (Funk, Lyall, & Riley, 1995). In Phase 1 we did not attempt to substantiate the claims made about flight deck automation problems. Rather, we merely identified and recorded perceptions of problems and concerns about automation that were described in written documents, presentations, or other sources.

Phase 2: Collection of evidence

In Phase 2 we attempted to define flight deck automation problems based on the issues (i.e., perceived problems and concerns) identified in Phase 1. To do so, we compiled evidence -- data and other objective information -- related to the issues from a variety of sources.

Evidence From Experts

We conducted a survey of individuals who have a broad experience or knowledge base related to human factors and flight deck automation. The participants included pilots of several automated aircraft types, university researchers, airline management pilots, industry designers and researchers, and government regulators and researchers. The survey requested general demographics information then presented 114 statements, one for each of the issues identified in Phase 1. Each statement was presented as an unqualified assertion that a problem exists, for example, that pilots do not understand automation adequately. We asked the participants to rate their level of agreement that the assertion was true, to rate the criticality of the problem, and to provide the basis for their judgement (their own data, the data of others, personal opinion, etc.). We used their agreement ratings as evidence of the extent to which the issues represented problems and we used the sources they listed to help guide the remainder of Phase 2 (see below).

Evidence From Accident Reports

We identified 34 aircraft accident reports we thought might contain evidence related to the flight deck automation issues. We were able to obtain 20 of these reports from the US National Transportation Safety Board and other national and international agencies that conduct accident investigations. We reviewed these reports, looking for statements by the investigating board identifying one or more of the flight deck automation issues as contributing to the accident. We found evidence related to flight deck automation issues in 17 of the 20 accident reports we reviewed. In addition to accident reports prepared by official investigating boards, we included several accident reviews in our study. These were reviews conducted by qualified individuals after the official investigations, which benefited from additional information and the perspective offered by the individual's field of technical expertise.

Evidence From Incident Report Studies

We reviewed eight studies of Aviation Safety Reporting System (ASRS) incident reports, including one we conducted ourselves. In each of the incident studies we reviewed, the investigators selected a set of incident reports from the larger ASRS database based on study-specific criteria, then reviewed the narratives for information identifying and/or describing automation-related issues. We reviewed the investigators' summaries and conclusions in search of evidence for the flight deck automation issues identified earlier in our study. We found evidence in three of the eight incident studies.

Evidence from Experiments, Surveys, and Other Studies

Based on our Phase 1 work, recommendations from the experts who participated in our survey, and our review of recently published literature, we identified 63 other studies of flight deck automation. These studies included experiments, surveys, observation studies, and incident studies. We obtained documentation on each study in the form of papers, technical reports, and World Wide Web pages. We analyzed the documents and found evidence related to the flight deck automation issues in 54 of them.

General Phase 2 Methodology and Results

For each instance of evidence found in the above sources we assessed the extent to which it supported one side of an issue or the other, and assigned a numeric strength rating between -5 and +5. We assigned a positive strength rating to evidence supporting that side of the issue suggested by its issue statement (supportive evidence) and a negative strength rating to evidence supporting the other side (contradictory evidence).

For example, consider the issue statement of issue105*: Pilots may not understand the structure and function of automation or the interaction of automation devices well enough to safely perform their duties.* In the Aeromexico DC-10 accident report we found evidence supporting the side of this issue suggesting that pilots do not understand the automation well: "3. CONCLUSIONS ... The flightcrew was not thoroughly knowledgeable of the aircraft's flight guidance and control system." (National Transportation Safety Board, 1980, p. 23). We assigned this instance of supportive evidence a strength of +4 (out of a possible +5) because the investigating board indicated that lack of knowledge of the automation contributed to the accident, but they stopped short of citing it as a probable cause.

In our own expert survey we found contradictory evidence related to issue105: eight of the 30 experts (27%) reported a 1 (=strongly disagree) or a 2 (=disagree) with the assertion that pilot understanding of automation may be inadequate. We assigned a strength of -2 (out of a possible -5) to this contradictory evidence because more than a quarter of the experts disagreed that pilot overconfidence is a problem. Our survey also found supportive evidence for issue105 with 18 of the 30 (60%) respondents reporting a 4 (= agree) or 5 (= strongly agree). We assigned a strength rating of +3 (out of a possible +5) to this supportive evidence.

For each instance of evidence found, we recorded in a database the related issue, an excerpt from the source document describing the evidence, the source document reference information, the type of aircraft and equipment to which the evidence applied (if specified), and a strength rating.

In Phase 2 we reviewed over 100 sources, collecting over 700 instances of evidence. We revised, updated, consolidated, and organized the issues, yielding a final set of 92 flight deck automation issues.

Meta-Analysis: Summarization of Findings

To summarize the findings of Phases 1 and 2, we performed a meta-analysis of all the data we collected. For each issue we compiled the number of citations of the issue collected in Phase 1, the number of instances of evidence collected in Phase 2 (supportive, contradictory, and total), the mean agreement rating given by the experts in our expert survey, the mean criticality rating given by the experts, and the sum of evidence excerpt strengths (i.e., a total "weight" of evidence for each issue). We then ranked the issues by each of these criteria to get different perspectives on the whole set of issues. For example, Table 1 shows the top 10 and bottom 10 issues, ranked by sum of evidence strengths. Finally, we developed a composite ranking (which we called a "meta-ranking") of the issues based on multiple criteria: number of citations, expert agreement rating, expert criticality rating, and sum of strengths. Table 2 shows the top 10 issues, ranked by multiple criteria, and the individual rankings from which this meta-ranking was derived.

Website: Dissemination of Findings

To disseminate this information, we created the *Flight Deck Automation Issues* website, http://flightdeck.ie.orst.edu/. A hardcopy of the home page of this website is included in its entirety in Appendix B.

The website covers all of work related to automation issues in detail. In particular, the methodology for each component of Phase 2 (including strength rating assignment) is described, a list of flight deck automation issues is presented, several taxonomies organizing the issues under different sets of categories are included, and access to a searchable, read-only version of our database containing all the evidence is provided.

We have been pleased to find that this website is widely used by pilots, aviation safety professionals, and university professors and their students all over the world. Each month, we receive numerous inquiries regarding website contents and commendations on its usefulness. The website was included on the Aviation Week Online Safety Resource Center Editor's Picks page (no longer in existence), it is included on the Links2Go website (http://www.links2go.com/more/flightdeck.ie.orst.edu/), and selected as a featured site in StudyWeb (http://www.studyweb.com/) as one of the best educational resources on the web by StudyWeb's researchers. We solicited none of these postings. Our website has also served to motivate discussion in the Bluecoat Forum.

In summary, the *Flight Deck Automation Issues* website has made our findings useful to a wide range of users, many of whom are in positions to apply our findings to improve commercial transport aviation safety.

Conclusions and Recommendations

As we have presented these results, we have encouraged readers to keep in mind several limitations to our study. First, in spite of our broad approach and our best efforts to identify all relevant evidence, there is certainly some that we missed. Second, the nature of some of the issues and the nature of the sources we reviewed to discover evidence may have reduced the opportunity for obtaining contradictory evidence. Third, the criteria we chose to apply in our meta-analysis and the way we chose to apply them reflect just one approach to attempt to summarize the large and complex set of data. Other perspectives are possible and further meta-analysis is desirable. Fourth, the database and website contents and our conclusions reflect evidence collected as of September 1997. There has been much work in automation research and development since then that should appear on the website but do not. This does not invalidate the website, but does limit its usefulness in the current aviation environment.

Table 1. Top 10 and bottom 10 flight deck automation issues, ranked by sum of evidence strengths. Supportive evidence is the number of *instances* of supportive evidence found, contradictory evidence is the number of *instances* of contradictory evidence found. Sum of strengths is the sum of the *strength ratings* given to all instances of evidence related to the issue (positive for supportive, negative for contradictory).

issue ID	issue statement	supportive evidence	contradictory evidence	sum of strengths	rank
issue105	Pilots may not understand the structure and function of automation or the interaction of automation devices well enough to safely perform their duties.	37	14	63	1
issue083	The behavior of automation devices -- what they are doing now and what they will do in the future based upon pilot input or other factors -- may not be apparent to pilots, possibly resulting in reduced pilot awareness of automation behavior and goals.	18	4	35	2
issue131	Pilots may become complacent because they are overconfident in and uncritical of automation, and fail to exercise appropriate vigilance, sometimes to the extent of abdicating responsibility to it. This can lead to unsafe conditions.	16	4	33	3
issue092	Displays (including aural warnings and other auditory displays), display formats, and display elements may not be designed for detectability, discriminability, and interpretability. This may cause important information to be missed or misinterpreted.	32	7	32	4
issue133	Training philosophy, objectives, methods, materials, or equipment may be inadequate to properly train pilots for safe and effective automated aircraft operation.	25	12	31	5
issue106	Pilots may use automation in situations where it should not be used.	10	1	27	6
issue040	Automation may be too complex in that it may consist of many interrelated components and may operate under many different modes. This makes automation difficult for pilots to understand and use safely.	15	3	21	7
issue108	Automation may perform in ways that are unintended, unexpected, and perhaps unexplainable by pilots, possibly creating confusion, increasing pilot workload to compensate, and sometimes leading to unsafe conditions.	16	5	21	8
issue099	Important information that could be displayed by automation is not displayed, thereby limiting the ability of pilots to make safe decisions and actions.	16	3	20	9
issue065	Pilots may lose psychomotor and cognitive skills required for flying manually, or for flying non-automated aircraft, due to extensive use of automation.	14	12	20	10

(11th- through 82nd-ranked issues omitted -- see website)

issue ID	issue statement	supportive evidence	contradictory evidence	sum of strengths	rank
issue136	The presence of automation may make pilot selection more difficult, possibly resulting in the selection of pilots not suited or not adequately prepared for their jobs.	1	1	0	83
issue166	Company policies and procedures for the use of automation may be inappropriate or inadequate in some circumstances, possibly compelling pilots to use automation when they prefer not to and/or leading to pilot confusion or frustration.	6	4	-1	84
issue123	It may be too easy for the pilot to inadvertently disengage the autopilot. When this happens, control may be lost.	2	1	-1	85
issue115	Automation may not be thoroughly tested before use and therefore not perform correctly under certain conditions.	1	1	-1	86
issue084	The use of automation may adversely affect crew coordination, possibly leading to unsafe conditions.	10	6	-3	87
issue156	Automation may induce fatigue, possibly leading to poor pilot performance.	3	4	-6	88
issue046	Pilots may lack confidence in automation due to their experience (or lack thereof) with it. This may result in a failure to use automation when it should be used.	16	12	-9	89
issue139	The presence of automation may reduce inter-pilot communication, possibly resulting in less sharing of information.	5	5	-9	90
issue079	Automation may increase overall pilot workload, or increase pilot workload at high workload times and reduce pilot workload at low workload times, possibly resulting in excess workload and/or boredom.	19	25	-11	91
issue013	Automation may reduce challenges that are the source of job satisfaction, which may adversely affect pilot performance.	4	6	-14	92

Table 2. Top 10 flight deck automation issues ranked by multiple criteria (meta-ranking). The rankings are the positions of the issue when ranked by each of the individual criteria. The sum of rankings is the numerical sum of the individual rankings. The meta-rank is the combined ranking based on these multiple criteria.

issue ID	abbreviated issue statement	rankings				sum of rank-ings	meta -rank
		by citations	by expert agreement	by expert criticality	by sum of strengths		
issue102	The attentional demands of pilot-automation interaction may significantly interfere with performance of safety-critical tasks. (e.g., "head-down time", distractions, etc.)	1	2	10	17	30	1
issue108	Automation may perform in ways that are unintended, unexpected, and perhaps unexplainable by pilots, possibly creating confusion, increasing pilot workload to compensate, and sometimes leading to unsafe conditions.	3	23	18	8	52	2
issue131	Pilots may become complacent because they are overconfident in and uncritical of automation, and fail to exercise appropriate vigilance, sometimes to the extent of abdicating responsibility to it. This can lead to unsafe conditions.	2	32	23	3	60	3
issue083	The behavior of automation devices -- what they are doing now and what they will do in the future based upon pilot input or other factors -- may not be apparent to pilots, possibly resulting in reduced pilot awareness of automation behavior and goals.	7	20	34	2	63	4
issue025	It may be difficult to detect, diagnose, and evaluate the consequences of automation failures (errors and malfunctions), especially when behavior seems 'reasonable', possibly resulting in faulty or prolonged decision making.	16	6	17	27	66	5
issue044	Automation may change modes without pilot commands to do so, possibly producing surprising behavior.	25	4	11	29	69	6
issue095	Pilots may not be able to tell what mode or state the automation is in, how it is configured, what it is doing, and how it will behave. This may lead to reduced situation awareness and errors.	11	54	3	11	79	7
issue145	Pilots may inadvertently select the wrong automation mode or fail to engage the selected mode, possibly causing the automation to behave in ways different than intended or expected.	33	21	13	16	83	8
issue114	Reliance on automation may reduce pilots' awareness of the present and projected state of the aircraft and its environment, possibly resulting in incorrect decisions and actions.	17	50	7	14	88	9
issue105	Pilots may not understand the structure and function of automation or the interaction of automation devices well enough to safely perform their duties.	4	57	35	1	97	10

Training For Automated Aircraft

Even before we had completed the meta-analysis of our automation issues findings (see above), it became clear that some automation human factors problems did in fact exist and they could not be addressed in a timely manner by equipment design alone. That led to the second task of our project, an investigation of the training strategies used by airlines and their relative effectiveness in addressing automation issues.

Introduction

Therefore, this task was initiated to gather information about the current state of US airlines' training for automated aircraft. Prior to the initiation of this study many training developers and researchers had identified challenges associated with creating training programs for automated aircraft. Though the challenges inherent in developing effective training for the automated aircraft were recognized, it was also recognized that despite the challenges the airlines and other training organizations were developing and implementing these types of training programs every day based on their own experiences and needs. In other words, training departments and personnel address the challenges of training development in their jobs daily, as well as face new challenges that have not previously been recognized. Therefore, the objective of this task was to gather information about current knowledge related to developing these programs from those who are creating them at the airlines and aircraft manufacturers. The task was not meant to be an exhaustive review of all training methods and, therefore, our findings do not address all of the methods available. The report from this task, included in its entirety in Appendix C, summarizes the training methods currently being used to develop and deliver training for automated aircraft at the major US airlines and aircraft manufacturers. Information is presented about the training methods and approaches that have been found effective by organizations developing training programs for automated aircraft along with descriptions of methods that were abandoned or modified because they did not prove to be effective. The intent of this task was to gather information that would be valuable to organizations modifying their training programs or developing new programs for automated aircraft. Therefore, the report is not meant to be a scientific research paper, but instead it is meant to be a reference document for developers and managers of training programs for automated aircraft. This report was developed as an electronic document and includes hyperlinks between related sections to make it more useful. The electronic version is available at http://www.researchintegrations.com/training-report-1998-bysubject-index.htm

General Methodology for Gathering Information

All major United States airlines participated in this task by sharing their experiences related to developing and conducting training programs for their automated aircraft fleets. Airline personnel involved in management, development, and instruction in these programs, as well as pilots who had been trained with the programs, were interviewed. In addition, training managers and instructors of aircraft manufacturers were interviewed. Prior to conducting the interviews, questions were developed for each function within the training organizations. The questions addressed issues related to the experiences and expertise that the individual responsible for that function would possess. At all of the organizations visited, the same set of function-related questions was asked to the people responsible for those functions. For example, at each of the organizations all of the training program managers were asked the same set of questions and, this set of questions differed from the set of questions asked of training instructors. In total 107 people were interviewed at 12 different organizations between May and December 1997. Two to four days were spent at each organization while conducting the interviews. All organizations were very generous in giving us their time, helping us understand their programs, and sharing their experiences with us. The anonymity of the participating organizations and their personnel are protected in this report.

Findings

The findings of this task are presented in the report contained in Appendix C. The report is organized to follow a general training development process. The purpose of this organizational scheme is to make it easy to find information of particular interest relative to any particular stage of training development. This structure was intended to make the report a useful resource during the development or modification of training programs by identifying training methods that may be valuable to consider at all stages of development. In addition to providing information about what other organizations have found effective, training methods that have not worked for some organizations and the reasons these organizations believe the methods were ineffective are also discussed. Following an introductory section, the second section describes the training development process in general terms to provide the framework for the remainder of the report. This section also presents information gathered about the various training development processes being used by the training organizations and their assessment of the effectiveness of those processes. The twelve subsequent sections are organized according to the twelve steps presented in this general description of the training development process. Refer to the full report for details.

Summary and Recommendations

The final section of the report includes a summary of our observations and recommendations based on the training methods that the training organizations described as effective or ineffective. This information is reproduced below. It summarizes the broad lessons learned and presents recommendations based on them. These recommendations represent those items that were consistently mentioned as effective or stated to be important across several organizations, or were described as very effective or important by at least one organization. These recommendations were made upon completion of the interviews that occurred in 1997. It should be noted that some of them may not continue to be relevant because of the on-going changes that airlines are making in their training programs.

The first general lesson learned is that automated aircraft have complexities that are not present on traditional aircraft. These complexities create challenges for training development and implementation. Training managers and developers must carefully determine how to design training programs to present the complex systems while still teaching the necessary information to fly the basic aircraft without the automation.

Recommendation 1: Ensure that the information for flying the basic aircraft is effectively included in the training program.

Because of its complexity, it is difficult to teach automation with static displays (slides and text) and lecture alone. Hands-on experience is very important for learning the dynamic and complex systems. Each student needs to be able to perform the tasks on high fidelity equipment or devices with enough realism that they provide the appropriate feedback to the pilot's inputs. This allows them to begin to integrate the information and understand the systems.

Recommendation 2: Pilots should be provided hands-on experience with the automation as early in the program as possible.

It is also important for the pilots to be able to build their conception of the automation as the training progresses. The most effective method is to present the automated systems throughout the training program as the knowledge and understanding of their complexities is built. Covering a concept in more than one way and using a variety of methods to train helps the pilots integrate the information and develop a mental model. It is important that the pilots be taught how the components work together in the overall system.

Recommendation 3: Automated systems should be taught throughout the training program. Training automation should be integrated into multiple modules of the program rather than as only a stand-alone module.

Hands-on free-play interaction with the automated systems can be very effective by allowing the pilot to explore and learn the system himself/herself. However, this free-play must have some structure so that the complexity of the systems is not overwhelming. It is also important that the program only allows the pilots to learn correct information and procedures. Having to unlearn incorrect information wastes valuable training time. Allowing too much experimentation without guidance, presenting unrealistic systems or documentation, or allowing students to teach themselves makes the pilots vulnerable to learning incorrect information.

Recommendation 4: Hands-on interaction with the automated systems by whatever means should be structured in a manner that ensures effective progression through the training program and does not encourage the learning of improper practices or understanding of the automated systems.

Integrating the training program using a building block approach to choosing training devices and the topics addressed in those devices has been shown to be an effective method of training the complexities of the automated systems. Integration of training devices and topics has been effectively accomplished by integrating across the entire program where the program starts with the basics, and then builds upon the information previously presented as it continues. It also has been effective to integrate the use of devices within a one or two-day training block in which topics are taught through the different methods of classroom, CBT, and FBS to help pilots fully understand aspects of the automation. These blocks are then integrated across the training program. When using this approach, it is important that the student understands one block before moving on to the next. It is also critical for the instructor to follow the syllabus closely and not introduce information prematurely.

Recommendation 5: Consider using a building block approach to integrating the training programs for the automated aircraft. Ensure that the objectives of each block of the program are defined along with how the pilots will accomplish that block using particular training devices. Also include the specific training objectives and approach to integration in the instructor-training program.

Instructor availability when the pilots are learning or practicing the automation is also important. As mentioned previously, the complex and dynamic nature of the automated systems cannot be effectively taught using traditional training aids such as static slides and rote memorization. However, it is also not effective to have pilots interact with devices or computer-based training (CBT) without an instructor available or leading the session. Hands-on experience coupled with extensive interaction with an instructor is much more effective for teaching the complexities and dynamic nature of the automated systems.

Recommendation 6: Instructors should be available during all training events when the pilots are learning about or interacting with the automated systems.

Pilots in training for the automated aircraft have a wide variety of individual needs. Each student, even those with prior automation experience, has individual needs as they try to effectively understand and use the automation. Each crew in training seems to have unique challenges to overcome. An effective training program allows for individual pilot experiences and attitudes and is able to adapt given the current needs of each pilot. To do this, the program must train the instructors to identify these needs and respond to them consistently. Instructor training is especially important on the automated aircraft because it is critical for the material to be presented in a consistent and standardized way throughout the program. Interaction between the instructors and the pilots is particularly important because of the stress associated with accomplishing these programs. Effective instructors appreciate the difficulty of learning the automated aircraft, are nurturing, pay attention to the details of each pilot's concerns, and are able to identify and respond to the needs of individual students. Special care should also be taken not to ignore the needs of pilots with automation experience while being responsive to the needs of those without that experience.

Recommendation 7: The training programs for instructors on the automated aircraft should be enhanced to teach them techniques for consistently recognizing and responding to pilot needs as they arise during the program.

The training environment is also important. Treating pilots as professionals and clearly indicating what is expected of them results in the pilots working hard and achieving very high performance. Negative responses to performance such as yelling or intimidation is not effective, especially in this already high stress situation. Observing the use of the automated systems is helpful. An environment in which the pilots are not afraid to make mistakes on the training equipment should be created. Allowing pilots to make mistakes and discussing them later helps the pilots learn from their mistakes. Learning from not only their own mistakes but also the mistakes of other crewmembers can also be very instructive.

Recommendation 8: During training, a comfortable atmosphere should be established that clearly communicates training objectives and provides opportunities for pilots to ask questions and develop their own understanding of the automated systems.

Training devices used to teach the automated systems must include the full functionality of those systems. Using part task trainers for training specific topics is effective for interactive exploration when the device utilized has the functionality of the system it represents. Devices that lack the functionality to explore the systems they represent or require one specific set or path of responses are not effective.

Recommendation 9: Ensure that all training devices used to teach the automated systems include full functionality of those systems and allow pilots to use them in all the ways that they would be able to use them in the aircraft.

Well-designed CBT can be effective in presenting automated systems and automation concepts. However, it has been shown that effective CBT should be interactive, self-paced, and non-threatening. It should provide immediate feedback, tie together the modules it teaches, and present information in a manner that is relevant to use during line operations. CBT is not as effective when an instructor is not available for answering questions and monitoring the pilots' performance. CBT also must present accurate information and do so in a manner that keeps the pilot engaged. CBT can effectively augment automation training but should not be the only way automation is trained.

Recommendation 10: Attention should be given to the development and use of CBT in the training programs for automated aircraft so that it includes those characteristics that have been shown to be effective. In particular the CBT should be interactive and present information in a manner that facilitates use of the automated systems later in line operations.

The building block approach to automated aircraft training program structure seems to be effective. Crew Resource Management (CRM) -related topics are important in training for the automated aircraft. To effectively train CRM, it needs be integrated and used throughout training rather than being taught as a separate module.

Recommendation 11: CRM-related topics should be taught throughout the training program.

Crew-based training is important. A training program enforcing the concept of the crew functioning as a team throughout the program is effective. The complexities of the automated systems and the procedures requiring interaction with those systems make it especially important to have crew-based training for the automated aircraft.

Recommendation 12: Crew-based training should be used whenever possible in automated aircraft training programs.

A realistic and consistent scenario-based presentation of the information is important when teaching automated systems because it makes the information easier for the pilot to learn, and will not require the pilot to unlearn unrealistic information. The training experience should be based on real-world line operations. Providing the pilots with scenario-based training allows them to relate their training experience to their experience in line operations. This helps build their confidence for performing well on the line. It is important that the pilots see the big picture and understand what their goals are.

Recommendation 13: Training exercises and events that are scenario-based should be included throughout the training program.

The amount of information included in the training program should also be carefully decided. Attempting to present too much information and rushing the pilots tends to overwhelm and confuse them. Information should be presented in related and manageable chunks. Care should also be taken to only add items to the syllabus that are necessary.

Recommendation 14: Do not add information and requirements to the training program unnecessarily.

The pilots should be trained (to an appropriate degree) about the underlying logic of the automation. Complex details should be simplified to make them understandable, but care should be taken so that this simplification does not obscure the underlying logic of the system. Pilots should also be taught explicitly about the limitations of the automation, specifically where its failings are and how to cope with them. Giving the pilots specific examples and exposing them to subtle failures are effective ways to equip them to deal with unexpected situations when they arise later in line operations.

Recommendation 15: To the extent possible, the logic underlying the automation and the limitations of the automation should be explicitly taught in the program.

Certification Job Aid

From our own studies of automation issues and training for automated aircraft as well as from other ongoing studies and many developments in commercial air transportation, it became clear that flight deck human factors issues and problems are not confined to automation. Most aircraft accidents are due, in part to flightcrew error. Human performance on the flight deck is strongly affected by the design of all flight deck equipment and procedures. So addressing the primary cause of aircraft accidents means properly addressing human factors considerations in the aircraft certification process. This became the focus of our third task.

Background

Aircraft certification requires judgments about whether new aircraft designs will be safe to be flown in the global airspace by current and future pilots. Many of these judgments must relate to the likelihood that the new design will contribute to human performance errors committed by pilots or others who interact with the aircraft (e.g., mechanics, ground personnel). Although experience has shown that design-induced human performance errors have contributed to many aviation incidents and accidents, there are few methods currently available to certification personnel to help them predict the future occurrence of such errors based on analysis of the aircraft design.

In addition to the lack of methods available to certification personnel, there is also a lack of guidance describing what human performance areas should be evaluated. The development of guidance and the methods to follow through on that guidance must go hand in hand. The FAA chartered a team to address human factors issues with aircraft automation (FAA, 1996). The team evaluated aircraft automation design, flightcrew training and qualifications, and operational issues for potential safety problems, and made recommendations to address the problems that were identified. The problem of certification evaluation for human performance concerns is related to the following recommendations of the FAA Human Factors Team Report.

Recommendation Processes-2

"The FAA should establish regulatory and associated advisory material to require the use of a flight deck certification review process that addresses human performance considerations."

Recommendation Criteria-1

"The FAA should require evaluation of flight deck designs for susceptibility to design-induced flightcrew errors and the consequences of those errors as part of the type certification process."

Objectives

Our third research task, then, had two objectives:

1. To determine how existing human performance information can be systematically applied to aircraft certification, and
2. To develop, demonstrate, and test a Job Aid to assist certification personnel (and design personnel) with human factors decisions and assessments.

The Job Aid

Under this grant and supplementary FAA contracts to Research Integrations, Inc., we began the development of a Job Aid for use by certification personnel (and designers) to identify and address human performance considerations during the aircraft certification process. The Job Aid will help certification personnel (and designers) assess designs for their susceptibility to design-induced errors and the consequences of those errors. The contents of the Job Aid will be based on existing knowledge (data) from psychology and other human performance disciplines as well as related methodologies being used in other domains. The requirements for the Job Aid are being developed from needs identified through observation of the certification process and interviews with certification and design personnel.

The work to develop the Job Aid includes developing the content and designing the interface. Both of these rely on a thorough knowledge of the task requirements and work environment of those involved in the certification process. Observations and interviews were conducted at the FAA Aircraft Certification Offices and Directorates to gather this information. The full list of tasks being conducted to develop the Job Aid are:

- conduct observations and interviews at Aircraft Certification Offices, Directorates, and manufacturers,
- conduct an analysis of flightdeck design-related accidents and incidents to identify and summarize needs for human performance information in the certification process,
- develop and refine human performance considerations taxonomies to organize considerations for development and inclusion in the Job Aid,
- review Federal Aviation Regulations, FAA Advisory Circulars, and industry standards and identify those related to human performance considerations,
- review pertinent certification literature to identify needs,
- systematically identify questions that would need to be addressed related to the interaction of flight deck components and human performance considerations,
- identify resources available in aviation and other domains for addressing human performance considerations in the certification process,
- develop the information database for the Job Aid,
- develop the Job Aid interface,
- conduct tests of the Job Aid, and
- participate in FAA fielding of the Job Aid.

Benefits of the Job Aid

The Job Aid will provide a means for FAA certification personnel to better evaluate aircraft designs for possible human performance concerns. It will also help certification personnel and designers identify possible design changes to alleviate human performance concerns.

Interim Products

Based on observations and interviews at Aircraft Certification Offices, Directorates, and manufacturers, we developed and documented the aircraft certification process. We identified and analyzed design-related accidents and compiled a database of that information. We developed a list of general human performance considerations (HPCs) addressed in Federal Aviation Airworthiness Standards (FARs), Advisory Circulars (ACs), and Industry Standards. The list of HPCs is included in Appendix D. Along with our analysis of FARs, ACs, and Standards we identified the aircraft equipment to which these regulations and recommendations apply and prepared a preliminary taxonomy of aircraft equipment, based on the numbering convention in *ATA Specification 100 - Specification for Manufacturers' Technical Data*. This preliminary taxonomy is included in Appendix E. We have also identified over 700 human factors documents that may describe data or other information useful for inclusion in the Job Aid. We chose 82 of the highest priority documents related to display design and evaluation to review and classify according to human factors considerations for Version 1 of the Job Aid. See Appendix F.

Since the full scope of design-related human performance issues is so broad, we narrowed our focus for the first version of the Job Aid to the development of an aid to facilitate human performance assessment related to flight deck displays. After substantial work with the HPCs, the display equipment identified earlier, and the human factors documents reviewed and a more developed understanding of the needs of certification personnel for information to be included in the Job Aid, we developed a set of display-related human *factors* considerations, that is, aircraft certification assessment considerations related to expected flight deck display design influences on pilot performance. These human factors considerations will be used to organize and present information in version 1.0 of the Job Aid and are presented in Appendix G.

Based on the above and in close cooperation with FAA certification personnel, we developed a set of functional requirements for the first working version of the Job Aid. Appendix H contains a summary of Job Aid version 1.0 functions.

Ongoing Work

The above work was completed primarily under this grant. Work will continue under separate contract to Research Integrations, Inc. A pre-release version of Version 1.0 has been delivered to the FAA in May 2000 for configuration management testing, to be sure that the program will be compatible with FAA computer systems. A completed Version 1.0 will be delivered to the FAA in August 2000. Prior to this full release, a workshop will be conducted to train FAA certification personnel in its use.

Further development will continue based upon user content. Scope and functionality will be revised under FAA supervision. A second version of the Job Aid, covering more than just display considerations, will be delivered to the FAA in September 2001.

FAA/JAA Human Factors Harmonization Working Group

On 22 July 1999, the *Federal Register* announced a new task for the FAA Aviation Rulemaking Advisory Committee to form a Harmonization Working Group (HWG) to review and develop new flight crew error/flight crew performance standards for the US Federal Aviation Regulations (administered by the FAA) and European Joint Aviation Regulations (administered by the European Joint Aviation Authority, JAA). This effort is commonly being referred to as the Human Factors Harmonization Working Group (HF HWG).

Our work already underway for the Job Aid promised to be extremely useful to the HF HWG. Several of our team members have become members of the HF HWG and have contributed to HF HWG meetings. Specifically we have been requested to provide information developed during our work on the Job Aid when needed to support HF HWG work, attend meetings and provide meeting facilitation support, and develop and maintain a website for providing group information and planning documents to the distributed international HF HWG membership.

The HF HWG is scheduled to continue their work through September 2002. Support of the HF HWG will continue under a separate contract to Research Integrations, Inc. RII maintains a webpage to support the HF HWG. See Appendix I.

Summary and Conclusions

This grant started as an investigation of issues related to flight deck automation. It expanded to address training for automated aircraft, aircraft certification, and human performance rulemaking. Our findings are widely acknowledged as making significant contributions to aviation safety. Besides the products of this project described in the preceding pages and presented in the appendices already mentioned, many articles, papers, and presentations have resulted from this work. A list of these is presented in Appendix J.

Under FAA AAR-100 sponsorship we have identified and confronted human performance issues, taken steps to address them, and disseminated our findings to the people and organizations that can -- and we hope will -- make a difference.

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Appendix A: Automation Issues Paper

"Flight Deck Automation Issues," by the Co-PIs and our colleagues, was published in the special issue on Aircraft Automation of *The International Journal of Aviation Psychology*, Volume 9, Number 2, 1999.

Appendix B: Automation Issues Website Home Page

Our *Flight Deck Automation Issues* website (http://flightdeck.ie.orst.edu/) has been the major means for disseminating the findings of our automation issues study. A hardcopy of the home page of the website appears on the following pages.

Appendix C: Training For Automated Aircraft Report

The final report from our Training For Automated Aircraft study was published by Research Integrations, Inc. and appears in its entirety on the following pages. It is available in electronic form at http://www.researchintegrations.com/training-report-1998-bysubject-index.htm.

Appendix D: Human Performance Considerations

As one of the first steps in developing the certification Job Aid, we reviewed relevant Federal Aviation Regulations, FAA Advisory Circulars, industry standards, and other documents, and compiled a list of important human factors considerations (HPCs) to be addressed in the certification process. The HPCs are listed on a website accessible only by the project team members, pending completion of the Job Aid under separate contract.

Appendix E: Draft Equipment Taxonomy

To prepare for development of the certification Job Aid, it was also necessary to identify and organize names of all equipment referred to in Federal Aviation airworthiness standards and related documents. The equipment is listed on a website accessible only by the project team members, pending completion of the Job Aid under separate contract.

Appendix F: Core Resources for Job Aid Version 1.0

We have identified over 700 sources of human factors information for the certification Job Aid. The Core Resources are listed on a website accessible only by the project team members, pending completion of the Job Aid under separate contract.

Appendix G: Human Factors Considerations

From interviews with FAA certification personnel, the human performance considerations, the equipment taxonomy, and other sources we developed a list of human *factors* considerations related specifically to display design. The human factors considerations are listed on a website accessible only by the project team members, pending completion of the Job Aid under separate contract.

Appendix H: Job Aid Version 1.0 Functions

The Job Aid Version 1.0 functions are listed on a website accessible only by the project team members, pending completion of the Job Aid under separate contract.

Appendix I: FAA/JAA Human Factors Harmonization Working Group Website (Partial)

To support the HF HWG, Research Integrations is maintaining a website at http://www.researchintegrations.com/hf-hwg/.

Appendix J: Publications and Selected Presentations from the Project

We have attempted to fulfill our responsibility to disseminate our results to the aviation community through the following book chapter, articles, papers, theses, websites, and presentations.

Book Chapter

Funk, K., Lyall, B., & Niemczyk, M. (1997). Flightdeck automation: perceptions and reality. *Human-Automation Interaction*, (M. Mouloua & J.M. Koonce, Eds.), Mahwah, NJ: Lawrence Erlbaum Associates, pp. 29 - 34. Available at http://www.researchintegrations.com/funk-lyall-niemczyk-1997-bysubject-index.htm

Refereed Journal Articles and Conference Proceedings Papers

Funk, K., Lyall, B., & Riley, V. (1995). *Perceived human factors problems of flightdeck automation*. Corvallis, OR: Oregon State University, Department of Industrial and Manufacturing Engineering.

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Funk, K., Lyall, B., Wilson, J., Vint, R., Niemczyk, M., Suroteguh, C., & Owen, G. (1999). Flight deck automation issues. *International Journal of Aviation Psychology, 9*(2), 109-123.

Theses

Wilson, J.R. (1998). *The Effect of Automation on the Frequency of Task Prioritization Errors On Commercial aircraft Flight Decks: An ASRS Incident Report Study*. Unpublished thesis, Oregon State University. Available at http://www.researchintegrations.com/wilson-thesis-bysubject-index.htm.

Suroteguh, C.B. (1999). *The Effect of Flight Deck Automation and Automation Proficiency on Cockpit Task Management Performance*. Unpublished thesis, Oregon State University. (See summary at http://flightdeck.ie.orst.edu/CTM/automationCTMSim.html.)

Websites

Flight Deck Automation Issues, http://flightdeck.ie.orst.edu/

Tool Kit [now Job Aid] *Website* (password protected and currently accessible only to Job Aid team members).

Flight Crew Error/ Flight Crew Performance Considerations in the Flight Deck Certification Process [HWG website], http://www.researchintegrations.com/hf-hwg/

Selected Presentations

Funk, K. (1998). Human factors and risk in advanced technology aircraft, presented at the *Risk-Based Performance Assessment and Decision Making Conference* held in Pasco, Washington, 5 - 8 April 1998.

Lyall, B. (1998). Autoflight mode awareness issues: an overview, presented at the *FAA Autoflight Mode Awareness Workshop* held in Renton, Washington, July 14-16, 1998.

Lyall, B. and Hecht, S. (1998). Human factors considerations in aircraft certification, presented at the *17th Digital Avionics Systems Conference*, Bellevue, Washington, 31 October - 6 November 1998.

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