

**Applications of Human Error Analysis to
Aviation and Space Operations**

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Abstract

For the past several years at the Idaho National Engineering and Environmental Laboratory (INEEL) we have been working to apply methods of human error analysis to the design of complex systems. We have focused on adapting human reliability analysis (HRA) methods that were developed for Probabilistic Safety Assessment (PSA) for application to system design. We are developing methods so that human errors can be systematically identified during system design, the potential consequences of each error can be assessed, and potential corrective actions (e.g. changes to system design or procedures) can be identified. These applications lead to different requirements when compared with HRAs performed as part of a PSA. For example, because the analysis will begin early during the design stage, the methods must be usable when only partial design information is available. In addition, the ability to perform numerous "what-if" analyses to identify and compare multiple design alternatives is essential. Finally, since the goals of such human error analyses focus on proactive design changes rather than the estimate of failure probabilities for PRA, there is more emphasis on qualitative evaluations of error relationships and causal factors than on quantitative estimates of error frequency.

The primary vehicle we have used to develop and apply these methods has been a series of projects sponsored by the National Aeronautics and Space Administration (NASA) to apply human error analysis to aviation operations. The first NASA-sponsored project had the goal to evaluate human errors caused by advanced cockpit automation. Our next aviation project focused on the development of methods and tools to apply human error analysis to the design of commercial aircraft. This project was performed by a consortium comprised of INEEL, NASA, and Boeing Commercial Airplane Group. The focus of the project was aircraft design and procedures that could lead to human errors during airplane maintenance.

We are currently adapting our methods and tools of human error analysis to the domain of air traffic management (ATM) systems. Under the NASA-sponsored Advanced Air Traffic Technologies (AATT) program we are working to address issues of human reliability in the design of ATM systems to support the development of a "free flight" environment for commercial air traffic in the United States.

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We are also currently testing the application of our human error analysis approach for space flight operations. We have developed a simplified model of the critical habitability functions for the space station Mir, and have used this model to assess the affects of system failures and human errors that have occurred in the wake of the collision incident last year. We are developing an approach so that lessons learned from Mir operations can be systematically applied to design and operation of long-term space missions such as the International Space Station (ISS) and the manned Mars mission.

ALTITUDE DEVIATION STUDY

Beginning in 1991 NASA sponsored a project at INEEL to investigate pilot errors that occur when using automated systems in advanced technology ("glass cockpit") aircraft. In particular, we investigated the causes and potential corrective measures for pilot errors that resulted in altitude deviation incidents (i.e. failure to capture or maintain the altitude assigned by air traffic control). To do this, we analyzed altitude deviation events that have been reported in the Aviation Safety Reporting System (ASRS), NASA's database of incidents reported by pilots, air traffic controllers, flight attendants, and passengers. We developed models of the pilot tasks that are performed to capture and maintain altitude. Two types of models were developed to provide complementary perspectives of these tasks: sequential models and functional models. The two types of models show different aspects of the errors that occur in actual altitude deviation events in advanced technology aircraft. Incidents from the ASRS database were mapped onto the sequential and functional models. The flight crew's actions and errors were then characterized according to the models, to help understand the potential causes of the different error types.

It is often assumed the introduction of advanced computer-based systems into the operating environment will decrease operator workload and reduce the frequency of errors. Beginning with the introduction of autopilots in the 1930's to today's CRT-based "glass cockpit" aircraft with Flight Management Systems (FMSs) that can automate essentially all phases of flight, the aviation industry has a large experience base with automated systems. Advanced technology in the cockpit has, for the most part, increased pilot efficiency and reduced workload, however, some unexpected results have been observed. It has been found that the primary reduction in workload occurs during periods when workload is already low (e.g., during long periods of cruise), but that workload can actually increase during busy times (e.g., when the landing clearance is changed during descent into a busy terminal control area). In addition, entirely new types of error have been introduced. A significant number of errors have been observed because the pilot does not fully understand how the automated systems function during all modes of operation. Because of these unexpected effects of automated systems on pilot performance, there is a substantial interest in investigating the causes of these new types of error. This was the motivation to perform a systematic assessment of altitude deviation errors in advanced technology aircraft.

Our study of altitude deviation errors (Nelson, et al. 1993) has led us to a number of general observations about the factors that lead to these incidents. It appears that pilots have learned to rely on their automated systems, and have delegated control of not only flight functions, but also monitoring functions, to the automation. Thus, they are not watching for deviations to occur, but tend to assume that the autoflight systems will take care of altitude capture and maintenance. Some pilots seem to be predispositioned to assume that the automated systems will do what they (the pilots) expect them to do, when in some circumstances the automation "wants" to do something else. These factors imply that the role of the pilot has in some circumstances changed so that they are flying the flight management system rather than the aircraft itself. The final result is the relaxation of the pilot's instinct to "stay ahead" of the airplane and decreased vigilance

regarding the maintenance of critical flight functions. In terms that are currently in vogue, advanced technology may in some cases actually reduce the flight crew's situation awareness.

APPLICATION TO AIRCRAFT DESIGN AND MAINTENANCE

The "Structured Human Error Analysis for Aircraft Design" program was conducted to explore potential applications of human error analysis to identify potential human errors in airplane maintenance activities, and to identify potential corrective actions to prevent or mitigate such errors. This program was sponsored by the NASA Advanced Concepts Program and was conducted by a partnership comprised of INEEL, NASA Ames Research Center, Boeing Commercial Airplane Group, and America West Airlines.

The first major activity of the program was to determine whether the human error analysis methods that have been developed in the nuclear industry are applicable to aviation tasks, especially those associated with airplane maintenance. To this end, we analyzed procedures for engine maintenance for three models of Boeing aircraft- the 737, 757, and 767. We wanted to determine whether the analysis methods could be applied to these tasks, whether the error categories and performance shaping factors could be adapted, and whether the modeling methods could distinguish between the design features of the different aircraft. Finally, we wanted to see if the predicted error rates were consistent to data obtained for in-flight shutdowns for those three aircraft types.

In order to perform the analyses, it was first necessary to become familiar with the design features of the Boeing aircraft and the practices used to maintain them. Thus, familiarization trips were conducted to Boeing facilities in Seattle (to review aircraft design and procedure development characteristics) and to America West Airline's maintenance facilities in Phoenix. Boeing also provided copies of all the relevant maintenance procedures, and responded to relevant questions about design and procedure characteristics.

Following the familiarization phase, the human error analysis of the three aircraft designs was conducted. The procedures were modeled using HRA event trees to show how the maintenance tasks were related, the consequences of failures on individual subtasks, possibilities for recovery from sub-task errors, etc. When the trees were complete, human error probabilities were assigned to the individual subtasks. For purposes of this preliminary analysis, the error rates prescribed by the THERP (Technique for Human Error Rate Prediction) procedure were used (Swain and Guttman, 1983).

Once the individual values were attached to the basic errors contained on the HRA event trees, the overall error rates were calculated for each tree. These error rates were then compared to the values obtained for the analyses for the other aircraft models, and to data obtained from Boeing for historical in-flight shutdowns for these three aircraft types. Comparison of these values showed that the calculated values for the three airplane types were consistent with the data obtained from operational experience.

The next steps focused on the development of an error analysis framework for applying HEA to airplane maintenance, specification of a software tool, and development and user testing for the software tool. User needs were identified through a series of discussions with potential users at Boeing, NASA, and America West Airlines. A major focus of these discussions was to identify tool functions that would allow it to be used by people who are not experts in human factors or human reliability analysis, for example procedure developers and airplane designers. It was also

decided to place major emphasis on the development of a framework of performance shaping factors that have a major impact on the occurrence of human errors in airplane maintenance. This approach makes it possible to incorporate domain-specific knowledge in the software tool that can be effectively utilized to identify potential human errors and develop corrective measures to eliminate or mitigate them. The resulting framework is called FRANCIE, or Framework for Notorious Contributing Influences for Error (Ostrom, et al. 1997).

Along with the development of FRANCIE, methods for incorporating quantification of error rates and methods for conducting the human error analysis using software and displaying the analysis results were developed. Once the functional specification for the software was developed, the software tool THEA (Tool for Human Error Analysis) was implemented and delivered to Boeing and NASA for user testing (Ostrom et al., 1997). This testing phase resulted in suggestions for software modification to enhance functionality and usability. These changes were made and the software was developed and provided to additional users within Boeing and NASA. We are currently identifying additional projects within NASA, Boeing, and the commercial aviation industry to allow more rigorous testing and application of FRANCIE and THEA.

This project has demonstrated that human error analysis can be adapted to the analysis of aviation tasks, and that the results can be used to develop strategies for design or procedure modifications to prevent or mitigate potential human errors. A software tool was developed and tested for application of human error analysis by airplane designers and procedure writers. Based on the positive results from this project, we are looking ahead to develop strategies to introduce these methods and tools into the commercial aviation industry, with the objective of significantly reducing the problem of human errors associated with airplane maintenance and other aviation tasks.

ADVANCED AIR TRANSPORTATION TECHNOLOGIES

The Advanced Air Transportation Technologies (AATT) reliability and safety project was initiated at INEEL in late 1996 under sponsorship of the NASA Ames Research Center. The AATT program is part of a national program sponsored by NASA and the Federal Aviation Administration (FAA) to develop next generation technologies and systems for Air Traffic Management. Our role in AATT is to incorporate consideration of human reliability and safety in the development of ATM systems.

The overall direction of efforts to develop next-generation ATM systems is to develop an operating environment in the United States known as "free flight". Under free flight individual pilots will have the freedom to define their own flight path under certain conditions, and will be supported by a group of computerized systems both onboard their aircraft and on the ground to prevent airspace conflicts. Air traffic controllers will only intervene when the computerized systems and the pilots fail to effectively intervene in potential conflict situations. Such a mixture of computerization and human decision making raises significant issues relative to the prevention and mitigation of potential human errors, software errors, and potential hardware failures. We have developed an integrated program using methods of functional analysis, human error analysis, operational data analysis, system simulation, and field testing to ensure that issues of human reliability and safety are adequately considered in the development of these advanced systems for air traffic management. The AATT program is expected to be completed in 2004, when advanced ATM systems have been validated through field testing and are ready for implementation in the United States' national airspace system.

MIR HABITABILITY ANALYSIS

Following the successful application of human error analysis to aviation programs, we are currently exploring whether our approach can be applied to space operations, procedures, and mission planning. We are in the process of developing a program at the NASA Johnson Space Center to identify lessons learned from operations of the Mir space station for application to design and operation of the International Space Station (ISS). In order to explore the feasibility of this application, we have developed a model of the critical functions that are required to maintain the habitability of the Mir space station. Then, the model was evaluated for the events that occurred following the collision with the Progress supply ship in 1997. A notation was developed to show the effects of the initial collision, subsequent equipment failures, actions of the Mir crew, and crew errors. A portion of this functional model is shown in Figure 1.

We plan to build on this functional model to perform a systematic evaluation of Mir operations. Lessons learned, especially pertaining to the occurrence of human error, will be systematically identified, and implications for ISS design and operations will be developed. We have developed contact with a group at the Institute for Biomedical Problems (IBMP) in Russia that is collecting and analyzing human error data from Mir operations. Together we are developing an approach to identify lessons learned from human error onboard Mir for application to the design of the International Space Station (ISS). We are currently exploring possibilities for such a program with the Space Station Program Office at the NASA Johnson Space Center. Long term plans include the use of functional models to help establish mission and crew requirements for the manned Mars mission.

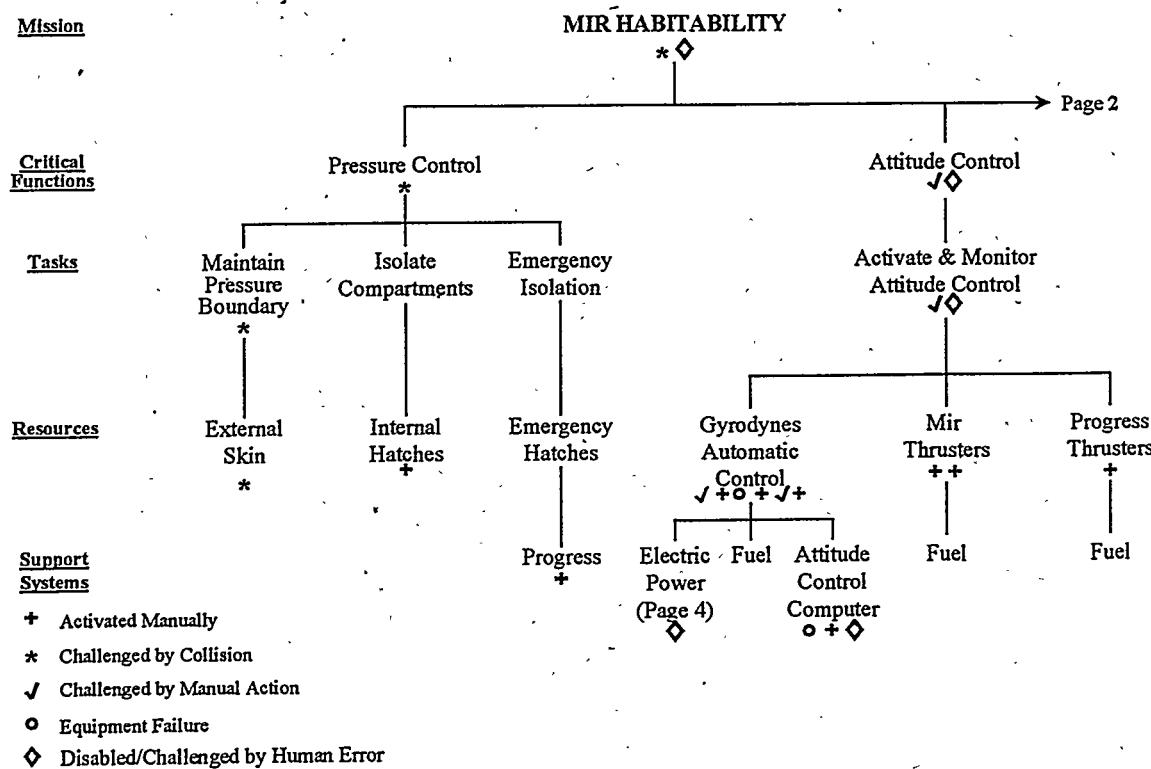


Figure 1. Functional Model for Mir Habitability

CONCLUSIONS

A series of projects performed at INEEL over the past few years has demonstrated that human error analysis can be applied in the aviation domain. In particular, we have focused on the development of new methods so that human errors can be systematically identified, their consequences in combination with other human errors and equipment failures assessed, and the performance shaping factors that contribute to their occurrence can be cataloged. A major motivation for this work has been to adapt methods of human reliability analysis so that they can be more effectively applied as proactive tools to help make decisions during system design. A series of applications to NASA-sponsored aviation and space programs is providing the platform to test the effectiveness of these methods and tools.

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