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Applying Lessons Learned to Enhance Human Performance and Reduce Human Error for ISS Operations

William R. Nelson

Idaho National Engineering and Environmental Laboratory
P.O. Box 1625
Idaho Falls ID 83415-3855
Wnr@inel.gov

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Abstract. A major component of reliability, safety, and mission success for space missions is ensuring that the humans involved (flight crew, ground crew, mission control, etc.) perform their tasks and functions as required. This includes compliance with training and procedures during normal conditions, and successful compensation when malfunctions or unexpected conditions occur. A very significant issue that affects human performance in space flight is human error. Human errors can invalidate carefully designed equipment and procedures. If certain errors combine with equipment failures or design flaws, mission failure or loss of life can occur. The control of human error during operation of the International Space Station (ISS) will be critical to the overall success of the program. As experience from Mir operations has shown, human performance plays a vital role in the success or failure of long duration space missions. The Department of Energy's Idaho National Engineering and Environmental Laboratory (INEEL) is developing a systematic approach to enhance human performance and reduce human errors for ISS operations. This approach is based on the systematic identification and evaluation of lessons learned from past space missions such as Mir to enhance the design and operation of ISS. This paper will describe previous INEEL research on human error sponsored by NASA and how it can be applied to enhance human reliability for ISS.

BACKGROUND

One of the most powerful strategies for preventing human errors is to effectively identify and utilize the lessons learned from past experience, such as the Mercury, Gemini, Apollo, Skylab, Space Shuttle, and Mir programs. While human errors have occurred in the past, crews have responded to achieve mission success. The lessons learned, both positive and negative, from these experiences can serve to improve the design of equipment, procedures, and operational practices for future missions. A framework is needed to systematically extract lessons learned from past experience, understand the conditions that contribute to human error, and apply this knowledge to prevent future errors from threatening the safe completion of highly complex missions such as the International Space Station and missions beyond earth orbit.

The Idaho National Engineering and Environmental Laboratory (INEEL) has formulated a framework to develop methods and tools to reduce the risk of human error for future space missions. This approach builds upon a series of projects performed by INEEL for the NASA Ames Research Center to apply human error analysis methods to commercial aviation. The most recent project, entitled Structured Human Error Analysis for Aircraft Design, developed a framework for evaluating human error called FRANCIE (Framework Assessing Notorious Contributing Influences for Error) and a software package THEA (Tool for Human Error Analysis) for assessing human error for airplane maintenance tasks (Ostrom et al., 1997).

The INEEL lessons learned program for ISS utilizes the products developed for commercial aviation, adapting and extending them to characterize types of human errors that can occur in space operations and the factors that contribute to their occurrence. A systematic approach for obtaining lessons learned from past space operations will be developed. This will be applied to information being gathered as part of the ongoing ISS lessons learned program. The first step is to identify lessons learned from operation of the space station Mir. Guidance aimed at preventing or mitigating human errors on future missions will be developed, focusing on the International Space Station. Finally, a lessons learned

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repository will be developed to allow lessons learned information to be stored in a form accessible by mission planners and designers for future space missions.

NEED

Human error is a significant contributor to accidents and incidents in the design, operation and maintenance of all complex technologies. For example, it is estimated that human error is a primary contributor to at least 60% of accidents in commercial aviation. Fortunately, the number of serious accidents attributable to human error in space flight has been very low. This is due to rigorous design, construction, and operational practices that ensure that if human errors occur they do not lead to catastrophic life-threatening failures. While individual human errors are probably not significantly less frequent in space operations than other human activities, design redundancies, rigorous training, and quality control practices allow for recovery before other errors or hardware failures lead to serious consequences. However, as flight rates increase and longer missions become more common, the likelihood that human errors will lead to mission failure or loss of life will also increase. Thus, there is a significant need to develop systematic methods to identify and mitigate (through design or operational practices) human errors in space operations.

One of the most critical factors in the ability to identify and correct human errors and other system failures in space operations is to effectively extract lessons learned from previous operational experience. Past experience is probably the most effective teacher for planning future missions. Unfortunately, to date it has been very difficult to effectively gather and utilize operational experience. While debriefing methods and statistical tools can be used to assess operational experience, it is often very difficult to apply the experience gained for the practical planning of future missions. Debriefing and incident data are often too situation specific for broad generalization for the design of equipment, operational practices, and procedures for other missions. On the other extreme, statistical information can be too general for application to specific operational issues. Analytic techniques are needed that can be used to systematically assess operational experience in context, identify and categorize practical lessons learned, and retain the information in a form usable by future system designers and mission planners.

The experience of U.S. crew members onboard the Russian space station Mir has highlighted the significance of human performance for successful space operations, and the need to identify and mitigate the effects of potential human errors. The Mir crew was able to compensate for the effects of the Progress collision and reestablish the critical functions of the spacecraft. The information gained from Mir operations will be invaluable for planning operational procedures for the International Space Station. One specific performance issue revealed by the Mir experience has been the need for effective guidance for long-term system maintenance. Space station missions lasting years have entirely different requirements for system maintenance when compared with Space Shuttle missions lasting two weeks at most. The difficulty of providing repair equipment on short notice when systems fail, and the impossibility of returning major components to earth for repair make it vitally important to reduce the occurrence of human error to the greatest degree practical. The most effective way to accomplish this is through a systematic lessons learned program to ensure that lessons learned are effectively transferred from Mir to the International Space Station. The Young Task Force review of the NASA Inspector General's Report on Mir stated "...the safety and mission success inputs of the U.S. astronauts who have flown as Mir crew members need to be included as part of the review process for critical Shuttle/Mir functions and as critical inputs for the International Space Station." The Inspector General's review of the astronaut debriefing and post-mission report processes concluded, "The lessons learned from the experiences, observations, and impressions of our long-duration astronauts are vital in ensuring safety and productivity in the development of the ISS."

APPROACH

The overall objective of ISS lessons learned framework is to systematically identify pertinent lessons learned from Shuttle-Mir operations for application to the design and operation of the International Space Station. Since the design of the major modules of the ISS is essentially complete, the greatest emphasis will be given to the operations and maintenance practices for ISS.

The approach that will be used to apply lessons learned for the reduction of human error for ISS includes the following elements:

Develop System Functional Models-

The pertinent critical functions for mission success will be identified and high-level functional models will be developed for the space shuttle, Mir, and ISS. These models will be used as templates for the evaluation of operational experience from Shuttle-Mir missions and development of lessons learned for application to ISS.

The functional modeling approach previously developed at INEEL will be employed to perform this activity. This approach entails the systematic identification of the critical functions (safety, performance, programmatic, etc.) that are required for mission success. Then the tasks (performed by humans, hardware, and/or software) that must be performed to maintain the critical functions are identified. Next, the resources (hardware, software, procedures, etc.) that can be used to perform the tasks are identified. Finally, the support systems (electrical power supplies, etc.) that must function for the resources to function are identified.

The next major activity will be to arrange the information identified above on a hierarchical logic structure to illustrate their interconnections, dependencies, and multiple success paths. This logic model can then be exercised to explore the effects of different postulated challenges to the critical functions, and the success paths that can be utilized to maintain the critical functions in the face of these challenges. These analyses can then be repeated for alternative designs or operational protocols to help explore and identify the effects of potential human errors, and to identify design or operational changes that could enhance the system's resistance to failures. The models can also be exercised to identify information and instrumentation needs for maintaining system operation during malfunction scenarios. This information can then be used to support system design or the development of operating or contingency procedures, or the development of computerized operational aids to support task performance.

Figure 1 shows a segment of a functional model that was developed for the critical functions required for habitability of the Mir space station. The figure shows a portion of the functional model as it was evaluated for the events following the collision with the Progress supply vehicle in June 1997.

Perform Operational Data Analysis-

Incident reports and operational experience from the Shuttle-Mir program will be assembled from currently available sources including incident reports and mission debriefings. Operational experience and event data pertinent to important operational issues for ISS will be selected for detailed evaluation. These events will be evaluated using the functional models and other analytic techniques to identify and categorize the human errors that occurred, the critical functions that were challenged or compromised, potential consequences if additional failures had occurred, and the performance shaping factors that contributed to the human errors. These analyses will then be categorized and summarized so that individual events and the personnel involved cannot be identified.

Perform Lessons Learned Analysis-

The results obtained from the operational data analysis will be collected and summarized across a range of operational incidents and events and evaluated to identify event-specific and generic lessons learned. Using the functional models and analytic tools, the lessons learned will be categorized regarding the systems involved, the types of human errors and performance shaping factors that led to system compromise, the nature of the critical function challenges that were experienced, the corrective actions that were attempted, and the relative success of these attempts to correct the situation.

This task will be performed by gathering the results of the operational data analysis across a range of operational events and critical function challenges. The results will be categorized to identify where in the functional hierarchy the critical breakdowns occurred, and to identify general trends that could lead to more serious consequences in the future if the chain of events is not broken. The performance shaping factors that predominately contribute to these potentially serious conditions will also be identified.

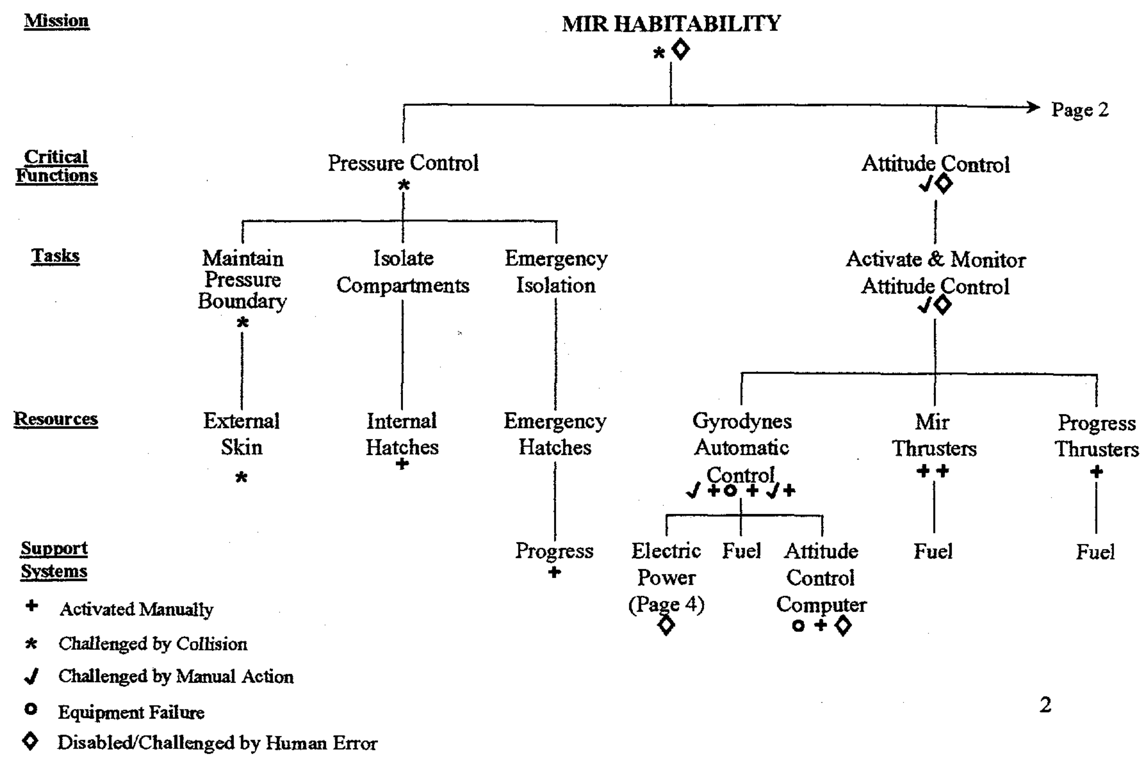

FIGURE 1. Functional model for Mir habitability.

Develop Design and Operational Requirements-

Design and operational requirements will be developed for the ISS based on the results of the lessons learned analysis. These requirements will describe operational practices and design features that will minimize the occurrence of human errors that could lead to serious consequences such as personnel injury, equipment damage, or mission failure. Because design of the ISS elements is essentially complete, these requirements will emphasize ISS operational practices and the design of those equipment items for which the detailed design has not been finalized.

Develop Maintenance and Contingency Procedures-

Based on the functional models developed for ISS and the outcome of the lessons learned analysis, prototype function-oriented procedures for long term system maintenance and contingency planning will be developed for ISS. These prototype procedures are intended to explore the validity of function oriented contingency procedures for certain aspects of ISS operations and maintenance. Recommendations for testing and implementation of the procedures will also be developed.

Develop High Level Lessons Learned Architecture for Space Operations-

An overall framework and data structure will be developed to consistently assess lessons learned across programs and domains. It is anticipated that this architecture will be based on the methods developed for previous lessons learned programs, including functional models and methods of human error analysis. The architecture will be specifically designed to facilitate all aspects of lessons learned, from initial data collection to final use in design or operational requirements.

The overall concept for the lessons learned architecture is shown in Figure 2. The primary objective for the architecture is to support systematic extraction and characterization of lessons learned from operational experience so that the insights gained can be applied to improve the performance of space systems at any stage of system development. As shown in the figure, the lessons learned approach will be applicable during the following stages of system development:

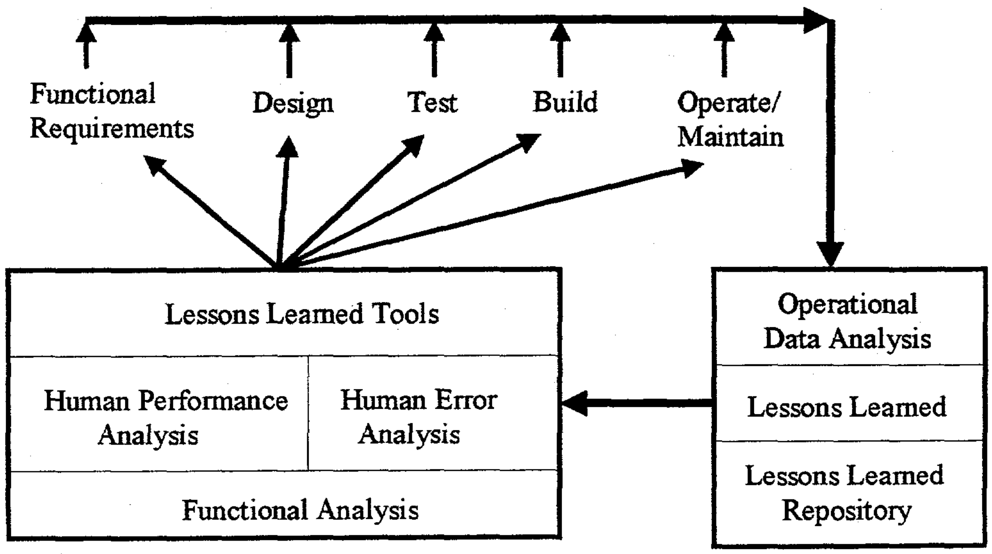

FIGURE 2. Lessons learned architecture.

- Setting functional requirements
- System design
- System testing
- System construction/manufacturing
- System operation and maintenance

The lessons learned architecture will include the following elements:

- *Functional models of space operations-* Logic models will be developed that describe relationships between the critical functions that are necessary for mission success, the tasks that must be performed to maintain the critical functions, and the resources that are available to perform the tasks. These functional models can then be evaluated for specific incidents to determine what critical functions were challenged, how the resources were used to compensate for the situation, and what success paths were used to maintain or restore the affected critical functions.

- *Human Error Analysis Methods for Space Operations-* Analytic methods developed for human error analysis for commercial aviation will be adapted for application to identification of lessons learned for space operations and maintenance. The FRANCIE (Framework Assessing Notorious Contributing Influences for Error) structure that was developed for the NASA Advanced Concepts program for airplane maintenance will be adapted for space application. FRANCIE links typical error types with the performance shaping factors that contribute to their occurrence. Error types and performance shaping factors will be identified for space operations through review of operational experience and interviews with subject matter experts. The new FRANCIE framework for space operations will then be linked to models of the tasks associated with safety critical functions. The resulting functional and task sequence models will then be used to interpret specific events from actual operating experience onboard Mir.

- *Lessons Learned Methodology-* The methodology developed at INEEL for identifying lessons learned from operational experience will be adapted for space operations. This approach has been developed at INEEL while performing incident investigations and operational data analysis for nuclear power plant operations, and in evaluating lessons learned regarding cockpit automation in a study for NASA Ames Research Center. It is based on the use of functional and sequential models of task performance, which are then used to interpret actual operational incidents. The steps of the lessons learned approach are as follows. Functional and sequential models are developed for operational scenarios of interest. Then, the operational incidents are mapped onto the models. Finally, the models are interpreted to identify where in the task sequences the specific errors or performance problems occurred, and where in the hierarchy of critical functions the errors occurred. The models can then be used to test the effectiveness of potential strategies for preventing or mitigating the errors identified. Such mitigating strategies can be identified in two ways. First, the sequential models can be examined to determine where in the event sequences barriers can be placed to intervene in the chain of events that could lead to unacceptable consequences. Secondly, the functional models can be examined to determine what additional resources or success paths could be provided to prevent challenges to the affected critical functions.

CONCLUSIONS

The systematic identification and treatment of potential human errors will be very important for the success of the International Space Station program. The Idaho National Engineering and Environmental Laboratory (INEEL) has developed a framework to systematically identify lessons learned from past space operations to help reduce human error in the design and operation of ISS. If successful experience is obtained in applying this approach to ISS, then it can be extended for application to other long-duration space missions such as the proposed Mars reference mission.

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