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CRITICAL FUNCTION MODELS FOR OPERATION OF THE INTERNATIONAL SPACE STATION

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ABSTRACT

Long duration and exploration class space missions will place new requirements on human performance when compared to current space shuttle missions. Specifically, assembly and operation of the International Space Station (ISS) will place significant new demands on the crew. For example, maintenance of systems that provide habitability will become an ongoing activity for the international flight crews. Tasks for maintaining space station habitability will need to be integrated with tasks associated with scientific research. In addition, tasks and resources will need to be prioritized and allocated dynamically in response to changing operational conditions and unplanned system breakdowns. This paper describes an ongoing program to develop a habitability index (HI) for space operations based on the critical function approach. This pilot project focuses on adaptation of the critical function approach to develop a habitability index specifically tailored for space operations. Further work will then be needed to expand and validate the habitability index for application in the ISS operational environment.

1. BACKGROUND

A habitability index is needed for ISS operations to support design decisions, procedure development, and flight readiness reviews. This habitability index will provide an objective measure for evaluating the effects of design options on ISS habitability, identifying and evaluating operational lessons learned, and incorporating the results of human factors research in flight operations. The critical function approach is being used to develop a habitability index for ISS operations in a cooperative project of the Idaho National Engineering and Environmental Laboratory (INEEL) and NASA Johnson Space Center (JSC).

The critical function approach was developed in the U.S. commercial nuclear power industry in the wake of the accident at Three Mile Island. This approach has been adapted as a framework to guide design and operational decision making in commercial nuclear power plants. The basic philosophy of the critical function approach is that design and operational decisions should be evaluated based on their effectiveness in maintaining critical safety functions. The same fundamental approach using “critical habitability functions” can be used to objectively guide design and operational decisions for long-duration space missions such as ISS.

When designing, building, and operating space systems it is essential to consider three intersecting perspectives:

- *The Mission Perspective* – Those aspects of the system that describe the goals and objectives of the mission.
- *The System Perspective* – Those aspects associated with the actual hardware and software components that are used to carry out the mission.
- *The Human Perspective* – Those aspects associated with the flight crew and the tasks that they must perform to carry out the mission.

Figure 1 illustrates the three dimensions that must be considered during the development of space systems, and some of the factors that must be considered at the boundaries between the three perspectives. One of the major strengths of the critical function approach is that it allows all three dimensions to be considered simultaneously in an integrated fashion. By involving human factors researchers, mission planners, and system developers at the Johnson Space Center we have started to develop a foundation for integrating all three perspectives in the development of space missions and systems.

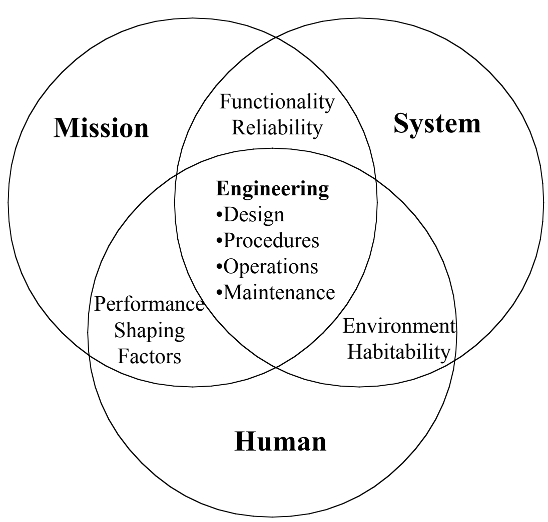

Figure 1: Three dimensions of space systems

Figure 2 shows how the functional models will be embedded in the overall application to ISS design and operation. At INEEL we are in the process of developing an "Intelligent Design Environment" that will utilize functional models as a key component in an integrated set of methods and tools to support the design, construction, and operation of complex systems. The Intelligent Design Environment will combine methods and tools based on functional analysis and risk assessment methods with tools for the systematic evaluation of lessons learned from operational experience. This framework will then provide a comprehensive package for the systematic evaluation of mission, system, and human factors throughout the development cycle of space mission and systems.

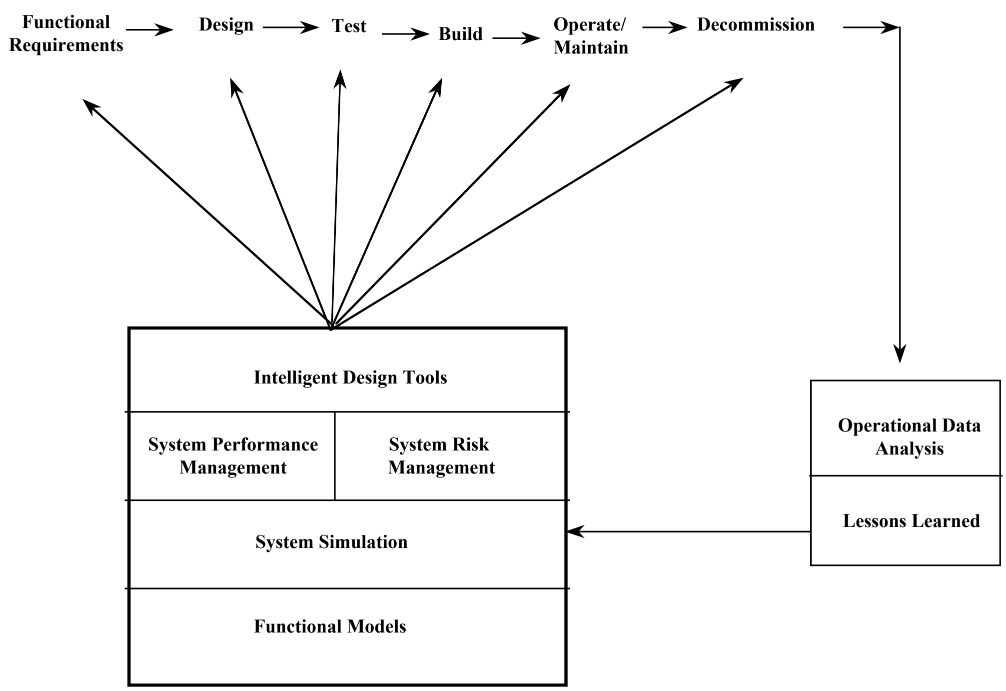

Figure 2: Intelligent design environment for space systems

The approach developed for this program was first tested in a small sample application to the Phase 1 (Mir) program as described in the following sections.

2. DEVELOPMENT OF MIR FUNCTIONAL MODELS

The first step in this project was to develop a sample functional model for the Mir space station. This sample functional model was based on information from publicly available sources. Figure 3 shows a portion of the Mir functional model, as evaluated for the events that occurred following the collision with the Mir supply vessel. As shown on the figure, the functional models can be used to show the effects of component and system failures on the maintenance of the critical habitability functions. Analyses can be conducted during the design phase to identify those factors that must be included in design and/or procedures to ensure that the critical habitability functions can be maintained in all phases of the mission, and during a the full range of potential off-normal and accident situations. The models can also be used to develop contingency planning tools for malfunction response, and to plan on board science and maintenance activities to ensure that the critical habitability functions are maintained at all times.

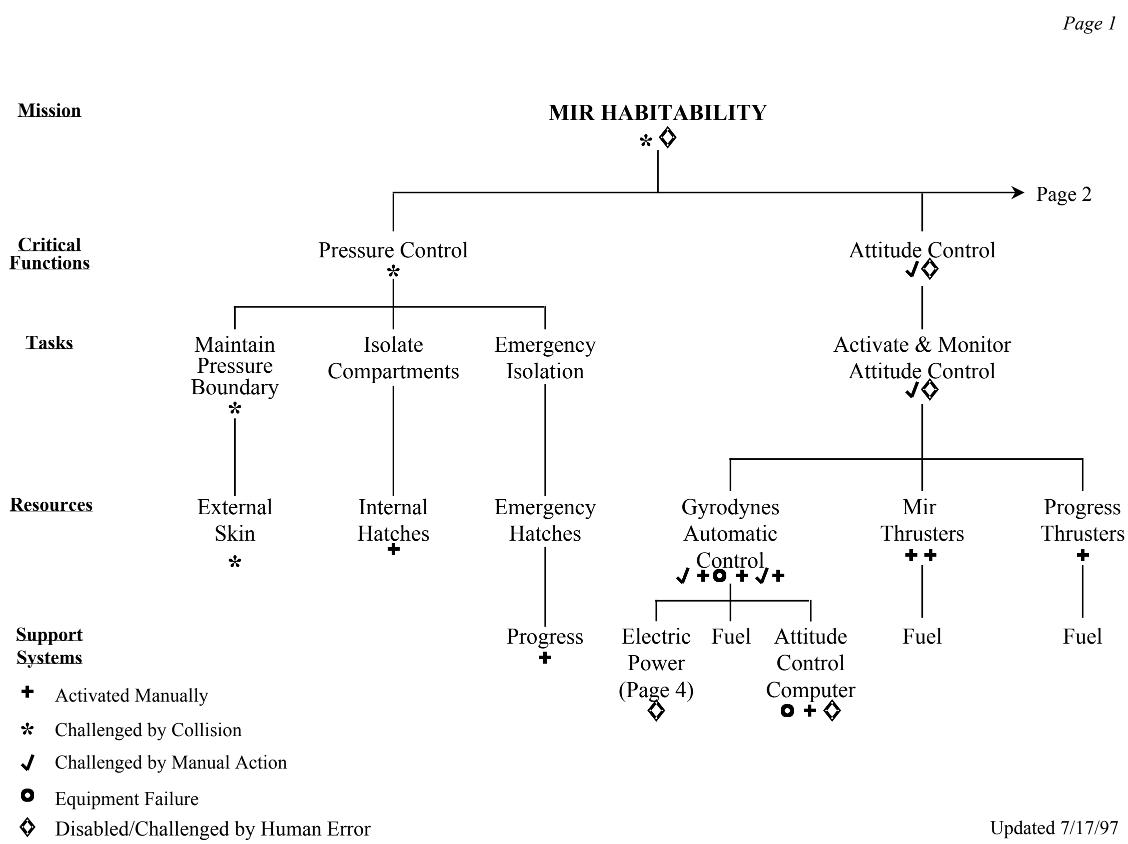

Figure 3: Functional model of Mir habitability

3. PSYCHOLOGICAL AND PHYSIOLOGICAL PERFORMANCE SHAPING FACTORS

Figure 1 shows that at the intersection of "mission" and "human" perspectives of space systems are the performance shaping factors that influence the crew's abilities to carry out mission critical tasks. The functional models can be used to identify those tasks that are critical for mission success. In the second phase of this project the psychological and physiological performance shaping factors that influence the successful performance of these tasks will be identified as well as the relative strength of the performance shaping factors on task accomplishment. These performance shaping factors will then be integrated with the functional models to form an initial habitability index for space operations.

4. APPLICATION TO ISS DESIGN AND OPERATION

The next step in this pilot project will be the application of the functional analysis method to the design and operation of the International Space Station (ISS). Functional models will be developed for the key systems that are used to maintain the habitability critical functions on board the ISS. Then, currently available operational experience and lessons learned will be evaluated to identify important design and procedural factors that influence maintenance of the habitability critical functions on ISS. A mission-specific habitability index will be developed for ISS based on the critical functions.

5. FUTURE DIRECTIONS

A number of possible applications for the critical function-based habitability index will be explored including:

- Identification of parameters that influence habitability
- Support of ISS design and procedure development
- Support flight readiness reviews
- Monitor and control habitability index during ISS buildup phases
- Framework for lessons learned evaluation
- Facilitate long term operation and maintenance of critical habitability functions
- Support contingency planning and real-time contingency response
- Prioritize operations, maintenance, and science activities that influence habitability
- Incorporate results of human factor research into space operations.

The long-range goal for this research is to develop a relative or quantitative habitability index that would enable crew tasks and functions to be managed according to changing habitability conditions. The capability to assess the habitability of the station at all times, and to evaluate the effects of possible management strategies, will enable flight directors to make informed decisions in scheduling crew activities.

In order to achieve the goal of managing crew activities in response to changing habitability conditions, it will be necessary to link various habitability states with the resulting crew performance. Thus, once the relationships that define habitability are established, additional research will be needed to determine how variation of the parameters that define habitability influence crew performance. If this goal can be achieved we will have made significant progress in understanding the relationships between the three dimensions of space flight (mission, system, human) and how to manage them through design, procedures, and real-time decision making to ensure that mission goals are achieved.

6. SUMMARY

The habitability index currently under development is based on a model of the critical habitability functions, showing the relationships among the critical functions, the systems that maintain them, and the human tasks that influence the maintenance of the critical functions. For the initial phase the focus is on the critical functions that are necessary for life support. Experience from operation of the Russian Mir space station has been evaluated using the critical function models to show how operational events and human performance influence the critical functions. Based on this trial application, a qualitative habitability index is being developed and evaluated using Mir experience. Based on the successful application of the habitability index to Mir, a critical function model and associated habitability index will be developed for the initial increments of ISS. Possible follow on work includes validation of the habitability index in the BioPLEX ground based mission test bed at Johnson Space Center, and assessment of the dynamic habitability environment during ISS assembly.

NOMENCLATURE

HI	Habitability index
INEEL	Idaho National Engineering and Environmental Laboratory
ISS	International Space Station
JSC	Johnson Space Center
NASA	National Aeronautics and Space Administration

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