2011 Space Human Factors Engineering Standing Review Panel

Research Plan Review Final Report

I. Executive Summary and Overall Evaluation

The 2011 Space Human Factors Engineering (SHFE) Standing Review Panel (from here on referred to as the SRP) met for a site visit in Houston, TX on October 13, 2011 to review the SHFE section of the Human Research Program's (HRP) Integrated Research Plan (IRP Rev. C).

This SRP needs an organized and stable set of gaps and tasks for proper review and commentary. During this review cycle, the SRP was sent a new set of gaps and tasks two days before the meeting. Those gaps and tasks were somewhat redundant with the ones that were sent about a month before the meeting, but mostly just reorganized, renumbered, and rearranged. The SRP was not prepared at the meeting to set aside all the work that had been done reviewing IRP Rev C and start reviewing the new gaps (which were referred to as IRP Rev C') in real time.

Also, as was the sentiment last time this SRP undertook this exercise in 2009, we are not confident that the gaps represent all the research necessary to be successful from the space human factors engineering perspective on long-duration exploratory missions. Members of this SRP are not "space experts," although even from our perspectives as individual experts in various aspects of the human factors discipline, many gaps are missing.

Similarly, the tasks under the IRP Rev. C gaps are not comprehensive, but represent a mere subset of the knowledge necessary to be successful. The tasks that are included take too long to complete, and the rationale for picking one task over another is not communicated. While some of the tasks make a positive contribution, others describe research that is already underway and is not the best contribution to the gap. Several of the more informative tasks are unfunded, and for some there are still no plans to fund.

The tasks do not represent a strategic portfolio of space human factors research projects which will assure successful outcomes of long-duration exploratory missions. Rather, the SRP observes a piecemeal, shotgun approach that will only be enough to reduce some of the risks. Some of the most basic issues, such as standard usability testing methods, common guidelines for human-computer/robot/automation interfaces, and common design patterns for software, display, and control user interfaces in space are not covered.

Much of the incompleteness and uncertainty around the research agenda stems from the lack of a systematic and comprehensive task analysis for these missions. While the SRP understands that many of the tasks that will arise in deep space exploration are emergent or unknown, without specifying even the generic categories of tasks to be carried out, one cannot plan for a satisfactory set of human factors in the equipment or environment that would support humans on these missions.

Moreover, it is apparent that training factors are not being integrated with technology development, and are at best considered very late and after the fact. When training is factored in from the very beginning of systems development, it has been shown to be much more effective for large systems missions such as space exploration.

Though many suggestions are presented in this final report, providing a comprehensive listing of gaps and tasks is out of scope for this SRP. We recommend that future gaps and tasks be proposed in consultation with appropriate communities of experts in habitat modeling and design, human-automation/robotic interface design, human-computer interaction, training design, and task design, to maximize gap coverage and minimize existing research oversights.

II. Critique of Gaps and Tasks for the Risk of an Incompatible Vehicle/Habitat Design (HAB)

The SHFE HAB gaps and tasks generally suffer from a lack of uniformity in their treatment of the multiple ways that suited or shirt-sleeved crew work and interact in a spacecraft habitat. The definition of habitat often includes the extravehicular activity (EVA) space suit but it might be more reasonable to consider it as part of the human environment that supplies its own set of capabilities (e.g., space vacuum operations) and constraints (e.g., internal body mobility, skin trauma, strength changes and dexterity limits). Gaps should be generalized and tasks should be addressed to those gaps and not previous incarnations of crewed vehicles. All environmental factors that affect human task performance in a habitat must be considered and ranked in importance relative to risks and safe task completion. While the gaps point to the need for better digital simulations to model and predict human accommodation to noise, vibration, work requirements, exercise and personal space, and adequate lighting, there is no concerted set of tasks that address an appropriately general and re-usable approach to filling those gaps.

Gaps and Tasks:

SHFE-HAB-01: What validated acoustic model can predict the effects of structures, materials, crew and equipment on the acoustic environment of a spacecraft or habitat?

Tasks:

- Space Craft Internal Acoustic Environment – PI: Christopher Allen, NASA Johnson Space Center (JSC)
  - The SRP thinks that this task is too Orion-specific and fails to be general enough for future crew space designs, nor does it take into account human acoustic absorption parameters.
- **Proposed New Task:** Develop generalized acoustic modeling tools that include and account for the presence of humans, additional stowage, waste, and workload/duty cycles that generate varying amounts and types of noise.

SHFE-HAB-02: What tools can be used to evaluate habitability concepts for on-orbit and planetary missions?

- The SRP thinks that SHFE-HAB-02 is a duplication of much of SHFE-HAB-06 and

suggests removing SHFE-HAB-06.

Tasks:

- Analysis Tools for ISS Performance Data - Planned
  - The SRP thinks this task is a first step to adequate data collection, but has concerns that the information retained may lack annotated video capability and is not easily searchable.

- Habitability - Human Factors and Habitability Assessment Tool PI: Sherry Thaxton, NASA JSC
  - The SRP thinks this task is mostly adequate, but suggests adding considerations of workload (locale and schedule) and waste/stowage accumulation in the assessments.

- Habitability – Habitability Concept Tools - Planned
  - The SRP thinks this task is appropriate, but recommends mindful integration with workload assessment tools.

SHFE-HAB-03: How can we determine the effects of combined vibration and acceleration on task performance?

- Although all the tasks for this gap are completed, the SRP does not think that the gap is closed. The work completed was very design-point-specific, but since NASA is not staying with the Constellation Program, it is not a closed gap.

Tasks:

- Combined Whole-Body Vibration Plus G-Loading Influences on Visual Performance and Operator Ratings – PI: Mary Kaiser, NASA JSC
  - Completed task

- SDBI 1904 - Human Factors Assessment of Vibration Effects on Visual Performance During Launch – PI: Kristina Holden, NASA JSC
  - Completed task

- **Proposed New Task:** Develop appropriate modeling tools for EVA suits and helmets and how they impact human task performance.

SHFE-HAB-04: How can existing models be modified to adequately represent the specified user population (e.g., field of view, visibility) in reduced gravity and be portable to other simulations environments?

- The SRP thinks that this is a well-articulated gap, but the current task will not fill it.
- The SRP thinks that this is a major gap that needs to be more comprehensive in scope, e.g., space tasks beyond view and visibility, repetitive strain prediction, integration of workload analyses.

Task:

- Computational Human Model Development and Integration - Planned

- The SRP thinks that this task is highly appropriate, but insufficiently scoped to model general and required human activities in space. Presently there is no single standard validated digital human model for spaceflight applications, so no integration task alone will fill this gap.

- **Proposed New Task:** Develop digital human modeling tools that directly utilize information in the NASA-STD-3001.

SHFE-HAB-05: What is the effect of microgravity on spinal elongation?

- The SRP thinks that this gap is more of a medical issue rather than an SHFE issue.
- This gap addressed a specific issue with the Orion exploration vehicle that is no longer relevant. The SRP suggests expanding the scope to anthropometric issues in general.

Task:

- Spinal Elongation and its Effects on Seated Heights in a Microgravity Environment – Sudhakar Rajulu, NASA JSC
  - The SRP thinks that this task does not cover the impact of spinal elongation on suit design or general task performance (beyond a seated crew member).

SHFE-HAB-06 (SBIR): How can crews easily document human factors related issues that occur on orbit?

- The SRP thinks that this gap appears to be a subset of and redundant to SHFE-HAB-02. This gap is about human factors rather than habitat issues, but that seems a minor difference. Therefore the SRP suggests removing SHFE-HAB-06 and moving the task to SHFE-HAB-02.

Task:

- Semantic Language and Tools for Reporting Human Factors Incidents – Debra Schreckenghost, Traclabs, Inc.
  - Note that this task is referenced in SHFE-HAB-02 already, but SHFE-HAB-02 is more specific about requiring voice and video data as well as a suitable database search engine.

Proposed New Gaps for SHFE-HAB:

- Study human movements and fatigue and their impact on task workload and performance in microgravity, determining whether fatigue is due to cognitive overload, environmental stressors, or new patterns of muscle recruitment required by microgravity.
- Can motion capture of human subjects inside the EVA suit be used to model EVA suit motions as a function of occupant pose?
- How do hand, foot, and restraint mechanisms predict, impair, or enhance task performance?
- Quantify visual and cognitive effects under high vibration combined with G-loading in the Gx direction.
- Design of occupant protection without affecting ability of crew to reach controls or see displays while restrained.

III. Critique of Gaps and Tasks for the Risk of Inadequate Human-Computer Interaction (HCI)

The SRP thinks that all of the current SHFE-HCI gaps can be matched to at least one of the eight contributing factors:

- Displays & Controls has four gaps
- Spatial Disorientation has one gap
- Environmentally-Induced Perceptual Changes has one gap
- Cognitive Overload/Confusion has one gap
- Acquisition Policies/Design Process has one gap

There are three contributing factors with no gap that matches their needs:

- Informational Resources/Support
- Allocation of Attention
- Misperception/Misinterpretation of Information

Overall, the SHFE-HCI portion of the IRP Rev. C is piecemeal and does not reflect a strategic technology investment plan. Although the definition of gaps must be driven by empirical evidence about risks, the organization and prioritization of SHFE-HCI gaps and tasks should be based on an understanding of the scope of SHFE-HCI. This would include: how it is related to the gaps and tasks under the Risk for Inadequate Design of Human and Automation/Robotic Integration (SHFE-HARI); how the parts within SHFE-HCI are related; and how informative filling each gap would be in comparison to the others. This approach, sometimes called a "technology roadmap," should make clear the role of each gap and at the same time provide an understandable rationale to management to justify the investments. Part of the rationale for some tasks could be immediate customer requests that increase their priority.

SHFE-HCI-01: What are the effects of vibration and acceleration on crew task performance and how can those effects be mitigated?

- The SRP thinks that this gap is appropriate.

Task:

- Robust Human-System Interface Design for Spaceflight-Induced Environments - PI: Lee Stone, NASA Ames Research Center (ARC)
  - The SRP thinks that this task is appropriate.

SHFE-HCI-02: BHP Campaign Integrated Gap: What aspects of cognitive function change during long-duration missions and are they related to neural structural changes?

- The SRP thinks that this gap is appropriate.

Task:

- SHFE Task Integration with BHP Findings for Cognitive Function – Unfunded
  - The SRP thinks that this task would be appropriate.

SHFE-HCI-03: Given the design constraints for cockpits and workstations, what HCI guidelines (e.g., display configuration, screen-navigation) will enable the crew to perform tasks in a timely manner with minimal ergonomic problems, even when fatigued or deconditioned?

- The SRP thinks that this gap is appropriate.

Task:

- Information Architecture for Surface Operations Data – Planned
  - The SRP thinks that this task would be appropriate.
  - The task addresses information architecture, which in needed, but the SRP thinks it should also address display configuration and migration through displays.

SHFE-HCI-04: What are recommended applications of multi-modal or other displays and controls based on new technologies, within nominal and off-nominal conditions of the spacecraft environment? (display modalities?) (What's the best display for situation?)

- The SRP thinks that this gap is appropriate.

Tasks:

- Advanced Concepts for Information Integration and Presentation – Planned
  - The SRP thinks that this task would be appropriate.

- Advanced Multi-Modal Solutions for Alerting and Directing – Planned
  - The SRP thinks that this task would be appropriate.

SHFE-HCI-05: How can we develop standard measurement techniques and metrics for evaluating the quality of user interfaces with specific attention to the usability of an interface?

- The SRP thinks that this gap is appropriate.

Tasks:

- Human Factors Analysis Support Tool (H-FAST) – PI: Terence Andre, TiER1 Performance Solutions
  - The SRP thinks that this task is appropriate.

- Usability Evaluation – PI: Aniko Sandor, NASA JSC
  - This task is really about methods and measures for legibility, not usability. The SRP thinks that this task would be better suited under SHFE-HCI-06.

- **Proposed New Task:** A task to develop more sensitive usability evaluation measures for efficiency and effectiveness than the standard time-on-task and task-completion rate, respectively.

- **Proposed New Task:** A comprehensive task analysis is needed of tasks expected to be performed in space, in order to develop methods and measures to perform realistic usability testing relevant to long-term exploration missions.

SHFE-HCI-06: How do we ensure that the displays and control designs and technology developed for the operational environments improve performance and reduce errors?

- The SRP thinks that this gap is appropriate, but HCI research on information displays should be coordinated with needs to compensate for physiological effects of space travel, and cognitive and perceptual changes, including loss of spatial orientation, when those needs have been clarified.

Tasks:

- Displays and Controls Interfaces - PI: Aniko Sandor, NASA JSC
  - The SRP thinks that this task is appropriate.

- Information Integration for Electronic Procedures - Unfunded
  - The SRP thinks that this task is appropriate.

- Information Presentation - Electronic Procedures and Fault Management – PI: Kritina Holden, NASA JSC
  - This task seems at least partially met by the "Usability Evaluation" task already completed in SHFE-HCI-05.

- Information Presentation – Controls Technology Survey and Testing – PI: Kritina Holden, NASA JSC
  - The SRP thinks that this task is appropriate.

- Information Presentation – Displays Development (Visual and Auditory) – PI: Kritina Holden, NASA JSC
  - The SRP thinks that this task is appropriate.

- Information Presentation – Human Performance Modeling– PI: Kritina Holden, NASA JSC
  - The SRP thinks that this task is appropriate.

- Sensorimotor Displays and Controls to Enhance the Safety of Human/Machine Cooperation During Lunar Landing – PI: Lawrence Young, MIT
  - The SRP thinks that this task is appropriate.

SHFE-HCI-07 (SM11): Can crewmember spatiomotor abilities be more accurately predicted and countermeasures and training techniques developed to mitigate spatial disorientation during spaceflight?

- The SRP thinks that this gap is appropriate.

Tasks:

- Enhancement of Spatial Orientation Capability of Astronauts on the Lunar Surface – PI: Rongxing Li, The Ohio State University
  - The SRP thinks that this task is appropriate.

- Modeling and Mitigating Spatial Disorientation in Low-g Environments – PI: Ron Small, Alion Science & Technology Corp.
  - The SRP thinks that this task is appropriate.

Proposed New Gaps for SHFE-HCI:

Acquisition Policies/Design Process Contributing Factor:

- Gap for integrating available HCI technology and standards. For example, the greatest leverage for NASA to improve HCI is to adopt ISO 25062 for summative test reports to make standard usability measures part of the RFI/RFP process.
- Gap for a standard definition model of an HCI system that will:
  - describe what is common and what is distinct from HARI
  - provide taxonomy for systematically identifying HCI gaps
  - provide rationale for prioritizing tasks
- Gap for design patterns that can rapidly and consistently be configured into applications.

Informational Resources/Support Contributing Factor:

- Gap for tools to define information requirements in context of the conceptual work product, the user's tasks and crew workflows.
- Gap for a tool to allocate functions effectively among crew and computer to meet information requirements.
- Gap for methods to coordinate design of tasks with design of user interfaces
- Gap for tools to validate information requirements have been met.
- Gap for learning by systems for better support.

Allocation of Attention Contributing Factor:

- Gap to address multi-tasking.

Cognitive Overload/Confusion Contributing Factor:

- Gap for tools to analyze and support human understanding of complexity.
- Gap for identifying overhead tasks in the user interface that add unnecessary complexity.

Misperception/Misinterpretation of Displayed Information Contributing Factor:

- Gap for tools to support distributed cognition and computer-mediated teamwork.
- Gap for tools to design and validate for situation awareness, including shared awareness during collaboration across different job roles.

IV. Critique of Gaps and Tasks for the Risk of Inadequate Design of Human and Automation/Robotic Integration (HARI)

The SRP thinks that the gaps identified in IRP Rev. C are indeed relevant, but not complete. In addition, some of the existing gaps should be supplemented with additional tasks. As more of the mission activities will be accomplished by automation systems and teams of humans, automation and robots, the crew will have more displays to monitor, more controls for interactions and more robots to utilize in their missions. This plethora of potentially diverse user

interfaces could be a source of inefficiencies, confusion and potential mission failures. Therefore, the SRP has suggested an additional gap in knowledge: integration of the necessary displays and interactions appropriately into the on-board information systems.

SHFE-HARI-01: What guidelines and tools can we develop to enable system designers and mission planners to conduct systematic task/needs analyses at the appropriate level of detail to allocate work among appropriate agents (human and automation)?

- The SRP thinks that this gap is appropriate.

Tasks:

- Needs Assessment and Work Allocation Tools for Mission Operations and Procedures - Planned
  - The SRP thinks that this task would be appropriate.

- Needs Assessment/Work Allocation Tools for Mission Operations and Procedures - Pilot Study - Unfunded
  - The SRP thinks that this task would be appropriate.

- Space Human Factors and Habitability MIDAS-FAST: Development and Validation of a Tool to Support Function Allocation – PI: Angela Sebok, Alion Science and Technology
  - The SRP thinks that this task is appropriate.

- **Proposed New Task:** Identification of operational tasks/conditions most suited to automation and appropriate levels of automation to support those tasks.

SHFE-HARI-02: How can performance, efficiency, and safety guidelines be developed for effective information sharing between humans and automation, such that appropriate trust and situation awareness is maintained?

- The SRP thinks that this gap is appropriate.

Tasks:

- Advanced Displays for Efficient Training and Operation of Robotic Systems – PI: Charles Oman, MIT
  - The SRP thinks that this task would be appropriate.

- Automation Trust and Complacency - Planned
  - The SRP thinks that this task should be modified to include methods for appropriately calibrating trust in automation. These would include understanding what the automation is doing, the data being used to make decisions, and any input that the human can provide.

- Design Tools for Automation Architectures in Support of Distributed Control Teams - Planned
  - The SRP thinks that this task would be appropriate.

- Information Visualization and Controls for HRI - Planned
  - The SRP thinks that this task should be expanded. It is currently limited to synthetic vision. It should be modified to include common standards for displays and controls for human/robot interaction, including the necessary information for humans to maintain task and robot situation awareness (SA). Naturalistic controls such as voice, haptics, and gestures should be researched. Two-dimensional as well as 3D graphics should be investigated. There are additional visualization issues that should be considered as well.

- Verification Tools for Successful Human-Automation Integration in Operational Space Systems - Planned
  - The SRP thinks that this task should be modified to include tools for evaluating HARI designs in a wide variety of tasks and conditions associated with space operations. Conditions to be addressed should include: normal operations; automation failures and unforeseen conditions; transition support between different levels of automation; levels of SA and workload provided by the designs; suitability of resulting tasks for human performance; and human performance at differing levels of reliability.

- **Proposed New Task:** Guidelines for HARI design for space operations that can be supplied to vendors. This would include common design patterns.

- **Proposed New Task:** Operating policies, including decision-making rules and process management guidelines, for teams of humans and robots for space exploration.

- **Proposed New Task:** Identification of similarities and differences between control of stationary and movable robots.

SHFE-HARI-03: How can performance, efficiency and safety guidelines be developed for appropriate task automation and the effective allocation of tasks between humans and automation?

- The SRP thinks that this gap is appropriate.

Tasks:

- Assessment, Evaluation, and Development of Methodologies, Metrics, and Tools Available for Use in Multi-Agent (human and robotic) Teaming – Planned
  - The SRP thinks that this task would be appropriate.

- Assessment, Evaluation, and Development of Methodologies, Metrics, and Tools Available for Use in Multi-agent (Human and Robotic) Teaming - Pilot Study – Planned
  - The SRP thinks that this task would be appropriate.

- Automation Interface Design Tools Development – PI: Michael Feary, NASA ARC
  - The SRP thinks that this task should be modified to include methods to eliminate modes from interaction designs.

- Development of Safety and Efficiency Metrics for Human-Automation Systems – Planned
  - The SRP thinks that this task would be appropriate.

- Human – Automation Interactions and Performance Analysis of Lunar Lander Supervisory Control – PI: Kevin Duda, The Charles Stark Draper Laboratory, Inc.
  - The SRP thinks that this task is appropriate.

- **Proposed New Task:** Development of adaptive automation appropriate for space exploration.

- **Proposed New Task:** Guidelines for supporting human understanding of complex systems created by automation and robotic teams.

- **Proposed New Task:** Identification of methods to support development of accurate mental models of automation.

- **Proposed New Task:** Methods to support human understanding of automation level transitions, and decision-making on when to transition between manual and automated support.

- **Proposed New Task:** Identification of methods for compensating for loss of SA associated with out-of-the loop syndrome from automation.

SHFE-HARI-04: What are the effects of the delays typical of different mission regimes on teleoperations and how do we mitigate these effects?

- The SRP thinks that this gap is appropriate.

Task:

- Assessing and Mitigating the Impact of Transmission Delays on Teleoperations, PI: Bernard Adelstein, NASA ARC
  - The SRP thinks that this task is appropriate but questions whether the time delays being investigated are too short to be useful (e.g., less than 10 seconds).

Proposed New Gap for SHFE-HARI:

- How should we design human-automation/robotic controls and displays, so that they are appropriately integrated into on-board information systems and adhere to the same evaluation criteria as HCI systems? (See SHFE-HCI-03 through SHFE-HCI-06).

  - **Proposed New Task:** Developing external robot controls so that controls and displays are in-line with HCI guidelines.
  - **Proposed New Task:** Ensuring that the architecture for human-automation is integrated with the human-computer information architecture, so that the appropriate information can be obtained at the right time using a standard set of interactions and displays.

V. Critique of Gaps and Tasks for the Risk of Performance Errors Due to Training Deficiencies (TRAIN)

All of the SHFE-TRAIN gaps identified in IRP Rev. C are certainly relevant, but could greatly benefit by addressing some cross-area issues and the increased need for earlier consideration of training-related concerns during technology development, particularly the case for robotics and advanced automation. The current SHFE-TRAIN gaps do not consider the need for in-depth education to deal with unknown, emergent situations (e.g., when communication delays are long).

The tasks listed are somewhat relevant. However, given the gaps, and particularly the suggested additional gaps, the tasks listed are clearly incomplete and very late to address training issues to bridge the gaps. Only six tasks are identified, three of which are already completed and the remainder scheduled far in the future, and those apparently not even in a funding plan due to their remote start dates. The three near-term tasks appear to have been force-fit from prior efforts to address the gaps, and it is unclear what their products were. The three planned tasks are responsive to current gaps, but do not effectively address the suggested new gaps associated with long-duration, long-return-time missions.

The current SHFE training focus deals primarily with individual training and very little with teams. There is nothing involving collaboration with future robots and advanced automation that display high levels of autonomy. If earlier collaboration with technology development programs is undertaken, then tasks for training how best to make effective use of mixed-initiative capabilities of humans, agents, and robots should be considered. This early interaction could also serve to assist in increasing the potential utility of such systems, by facilitating early experimentation and development of appropriate training methods for this very new capability.

SHFE-TRAIN-01: How can we develop objective training measures to determine operator proficiency during and after ground training?

- The SRP thinks that this gap is appropriate.

Tasks:

- Spaceflight Resource Management Training – PI: Immanuel Barshi, NASA ARC
  - The SRP thinks that this task is redundant in intent to SHFE-TRAIN-02: Medical Proficiency Training.
  - While this task is listed as completed, there appears to be only a single paper as a product, and a number of planned issues do not appear to have been addressed.
  - Even if completed, this effort does not seem adequate to meet the stated objective of SHFE-TRAIN-01.

- Tools and Methods to Ensure Training Retention for Long-Duration Missions - Planned
  - There are no simulation platforms identified for this training, and the use of serious game technology to both maintain skills and to provide some degree of intellectually engaging recreation does not appear to have been considered. An important concern about this task is that it is also planned to begin well in the future.

- The SRP thinks that this topic is important enough that a nearer-term start should be made, by engaging with the operational community, and investigating the significant progress made by the defense community in mobile learning and serious games.

SHFE-TRAIN-02: How do we develop training methods and tools for space medical application if time is minimal?

- The SRP thinks that this gap is appropriate.

Tasks:

- Evaluation of Task-Skill-Knowledge Just In Time (JIT) techniques for medical and other emergency events - Planned
  - While the task title indicates that it will deal with training for medical and other emergencies, only medical appears to have been addressed.
  - The value of this as a completed task is unclear, since the important overall objective of task-skill-knowledge JIT was addressed for only a portion of the problem domain, and will be very out-of-date by the time it is required.
  - As noted in comments on SHFE-TRAIN-01, this task even if completed does not adequately address the stated risk and gaps.

- Medical Proficiency Training – PI: Immanuel Barshi, NASA ARC
  - It is unclear why SHFE-TRAIN-02 is specific to medical. While medical is clearly important, it is only one of the important problems that may require training in minimal time given the missions envisioned.
  - Similar to the comments in SHFE-TRAIN-01, the SRP is concerned about the significant time gap between the completed task and far future task.

SHFE-TRAIN-03: How can on-board training systems be designed to address Just in Time (JIT) and recurrent training needs for nominal and off nominal scenarios?

- The SRP thinks that this gap is appropriate.

Tasks:

- Just in Time Simulation Platform – PI: Abe Megahed, Planet LLC/Orbital Technologies Corporation
  - The SRP found the products and level of documentation from this task to be unclear.
  - This appears to have been a Phase 2 Small Business Innovation Research (SBIR), but there doesn't appear to have been any follow-on effort, and without that there is little value from the project.

- Long-Duration Cross-Training Feasibility and Methods (Pre-flight and On-board) - Planned
  - This effort appears to be designed to address the gap. However, as previously noted, this task is to begin well into the future, while significant useful progress should be made much sooner, and important benefits derived in both directions through engagement with the technical development teams.

Proposed New Gaps for SHFE-TRAIN:

- Guidelines for training for advanced automation and robotic challenges due to increased reliance on high levels of autonomy, especially when dealing with limited numbers of crew.
- Team training for issues such as social, medical, and psychological problems that may emerge in long-duration missions.
- Training methods to support ongoing skill refreshment on long-duration missions.
- Training methods to support higher-level, cognitive skill training and system functionality education for exploration, unknown, and emergent tasks and situations.
- Strategies and methods for specialty cross-training.
- Contribution of team communication to accidents and incidents.

VI. Critique of Gaps and Tasks for the Risk of Poor Critical Task Design (TASK)

The SRP thinks that gaps proposed for this risk are relevant but not complete. Specifically, work on the development of workload measures and tools needs to be tailored to incorporate those changes that are expected to occur due to the physiological, cognitive, and psychological changes associated with long-duration space missions, and need to support more than strictly procedural tasks on these missions. In addition, it will be highly important to validate any models used and the assumptions in those models. Currently unfunded work, such as the task to "Tailor Information Processing Models to NASA-Specific Requirements and Environments" is critical and needs to be moved up in the schedule as much of the other work depends on it.

SHFE-TASK-01: How can workload measures and tools be developed to unobtrusively monitor and trend workload throughout the mission design and verification cycle in a consistent manner?

- The SRP thinks that this gap is appropriate.

Tasks:

- Integration of Workload Metrics as Constraints into NASA scheduling tools - Planned
  - The SRP thinks that this really is directed at a workload model (not metrics).
  - The task needs to specify where the model data is coming from.

- Spaceprint: Development and Validation of a Tool to Predict, Evaluate, and Mitigate Excessive Workload Effects – PI: Angela Sebok, Alion Science and Technology
  - The SRP does not think the outcome of task is clearly defined.
  - There needs to be more details on what this model will include (e.g., will predicted changes due to long-term missions be included?).

- Workload Tools and Guidelines – PI: Brian Gore, NASA ARC
  - The work on this task is completed, but it is not clear to the SRP that it addressed the stated need for unobtrusive, long-duration workload measures.
  - This task seems dependent on workload metrics and part of the Integration Performance Measures with Behavioral Health. How is SHFE involved in the

Integrated Performance Measures?

SHFE-TASK-02: What model-based HF Tools can assist with the design and evaluations of spacecraft systems and task procedures?

- The SRP thinks that this gap is appropriate.

Tasks:

- Advanced Procedures for Autonomous Missions – Planned
  - This task is really about computerized procedures.
  - The SRP thinks that this task has a lot of overlap with computerized procedures task in the SHFE-HCI Risk area, but linkages are not specified. The SRP suggests these two tasks get collocated either here or in the SHFE-HCI risk area.

- Integrating Externally Developed Models into HRP's "Virtual Astronaut" – Unfunded
  - The SRP does not think there is a high benefit to combine these models.

- Tailor Information Processing Models to NASA-Specific Requirements and Environments – Unfunded
  - The SRP thinks that this is a key task for filling critical gaps in human performance understanding and models under projected conditions.
  - The SRP is concerned that this task is not funded and many other tasks in this risk area are dependent on it.
  - The SRP thinks that this task needs to address:
    - OpTempo[1]/Workload sustainability over long-term missions.
    - Effect of longer days on fatigue and workload models.
    - Perceptual, cognitive and physiological changes associated with long duration in space.

- Validation of Human Factors Modeling Tools – Planned
  - The SRP thinks this is a very important task.
  - This task seems dependent on workload metrics and part of the Integration Performance Measures with Behavioral Health. How is SHFE involved in the Integrated Performance Measures?

SHFE-TASK-03: How can a capability for semi-autonomous planning and dynamically replanning of crew schedules be developed?

- The SRP thinks that this gap is appropriate.

Task:

- Crew Scheduling Tools (SPIFE Scheduling) – PI: Michael McCurdy, NASA ARC
  - This task is shown as completed, but the SRP does not think it is sufficient to close the gap.
  - This tool will likely need to get updated as the results of other tasks in this risk area get completed.

[1] Operations Tempo: military jargon for a measure of the pace of (an) operation(s) in terms of equipment usage

- Needs further extension for the tool to accommodate the projected greater independence and flexibility of crew in future missions. This may have a significant effect on current highly procedural approaches.

Proposed New Gaps for SHFE-TASK:

- Workload metrics as valid predictors of long-term mission task performance.
  - **Proposed New Task:** Determine what is an acceptable op tempo/workload level for long duration missions.
  - **Proposed New Task:** Determine inter-relationship between current task procedural approach and adaptive automation as researched under HARI Risk
  - **Proposed New Task:** Determine suitability of current approach to task procedures for long duration missions with greater need for autonomy and agility.
  - **Proposed New Task:** Determine effects on fatigue and workload due to difference in day length.
- Workload models' correlation with actual task performance/productivity. Good validation of the workload models (including how the individual task workloads combine) is the Achilles heel of these models. It will be particularly important to extend the validation to address how the environmental and physiological changes associated with long-duration missions may change assumptions in the models.
- Task design for multiple operators, including mixed human/automation/robotic teams. Current models tend to concentrate on the workload incurred by a given individual. The optimal means of task-shedding or distributing workload across multiple team members, including robotic team members, needs to be addressed.
- Effect of longer and more variable time delays on task execution on longer missions. In longer-duration missions, greater time delays will occur in human-human communications and/or automated instructions relayed from Earth. These time delays will have an impact on human task performance, and the tendency to try to perform tasks or parts of tasks without waiting for delayed communications. These factors need to get worked into human performance models and procedures.
- Effect of much greater reliance on automation (vs. human mission control) on task execution. Given that a critical factor for the design of tasks is that of function allocation between the human and the automation, this linkage with HARI is critical. As humans become more reliant on automation, they also become less capable of performing the tasks manually (skill degradation). They may also experience out-of-the-loop problems in understanding when it will be important to do the task manually and when to rely on the automation. These factors will affect task performance assumptions regarding task time, error rates and perceived workload.
- Assessment of possible trade-offs between paper and electronic media, to determine the criteria for media use in task aids to support task procedures.

VII. Discussion on the strengths and weaknesses of the IRP

There were five SHFE risks addressed in the IRP Rev. C. All these risks were missing gaps and tasks. These were obvious simply by reading the evidence books, which were not that comprehensive either, but seem to reflect more the research interests and backgrounds of the

writers (see the 2011 SHFE SRP Evidence Review report). It was good to see that a new risk was added around automation/robotic-human factors (SHFE-HARI), as per our recommendation in 2009.

SHFE-HCI and SHFE-HARI currently have the most gaps and tasks, and the SRP added even more to these areas than the other risks. Major areas of HCI such as information architecture are untouched.

The SRP got no sense that standardized common user interfaces for spacecraft are an important goal of the research. The SHFE-TRAIN risk does not reflect modern approaches to large system, human-in-the-loop training, which strongly recommends training be considered early in system design. The SHFE-HAB research has not been updated and pruned to reflect that limitations of the Constellation/Orion Program (e.g., seating) will not be a factor for future exploration missions. The SHFE-TASK research is greatly limited by the fact that there is still no comprehensive task analysis for exploration missions.

As mentioned earlier, the research on any SHFE risk does not constitute a strategically designed portfolio of projects to address the risk. Rather, the IRP Rev. C is a loosely-related confederation of existing research projects already funded by NASA, and future research projects proposed by researchers who historically get NASA funds, reflecting historical, career, and academic research interests in SHFE. It is a piecemeal, shotgun approach that aspires to reduce the risk. Some of the most basic issues, such as standard usability testing methods, common guidelines for human-computer/robot/automation interfaces, and common design patterns for software, display, and control user interfaces in space are not covered.

The SRP was told by the NASA SHFE Project Scientists that these are already available in the literature as standards and guidelines (i.e., it's an engineering problem). That may be a good starting point, however, there will probably be different solutions given the various constraints and situations expected in space. Interactions between SHFE risks and other HRP risks are not adequately addressed. Interactions between the SHFE risks themselves are not even adequately addressed.

These are bread-and-butter issues in the human factors discipline, and if they are not addressed comprehensively, in-depth, and starting soon with reference to space applications, the humans on these exploration missions will not be able to use the equipment or the habitat provided by NASA.

The SRP brought these issues out in 2009 and we are seeing them again on this review.

VIII. Additional Comments

- Many of the research projects we reviewed for the 2009 SHFE SRP have continued, and seem to be unaffected by comments we made then. The SRP would like to know how our feedback affected the course of the research. Instead, we have witnessed some changes to the conceptual or organizing framework for the SHFE research programdue to

HFACS adoption[2], which have taken a long time for NASA to document and the SRP to absorb, but there is little evidence that anything is being done differently from our 2009 SRP meeting on existing gaps and tasks.

- It would be extremely helpful if there were a preliminary task analysis of possible tasks that could occur in space. This would help reviewers to determine if the appropriate knowledge gaps were being considered.
- It would also be helpful if the SRP could receive documents in the future that would not be changed substantially by NASA between the start and end of the review period, which is about 4-6 weeks. Not having frozen content makes it almost pointless for the SRP to put time and effort into pre-meeting review preparation, and makes the meeting disorganized and excessively long.
- The SRP is composed of individuals with expertise in particular aspects of human factors engineering. No one on the SRP is an expert on the space program, and we are not able to keep up with the changes in this program between meetings. Communicating set mission goals, schedules, and resource allocations would greatly increase our ability to make useful comments in this setting. Furthermore, it would give us a framework in which to find applicable research in our own fields, which we could bring to these reviews in a timely way.
- It would be better to hold two separate meetings, one for the evidence review, and one for the IRP review, rather than try to do it all in one meeting. The evidence review could feasibly be done via web conferencing.
- NASA SHFE personnel do not have to present the content of either the evidence or the IRPs to the SRP in the meeting. The SRP members read the material before coming to the meeting. Being available for questions and answers is sufficient.

[2] Shappell, S.A. and Wiegmann, D.A. Human Factors Analysis and Classification System, DOT/FAA/AM-00/7, February 2000; specifically the "Swiss cheese" model of human error causation.

IX. SHFE SRP Research Plan Review Statement of Task

The 2011 Space Human Factors Engineering (SHFE) Standing Review Panel (SRP) is chartered by the Human Research Program (HRP) Program Scientist at the NASA Johnson Space Center (JSC). The purpose of the SRP is to review the SHFE section of the HRP's Integrated Research Plan (IRP). Your report will be provided to the HRP Program Scientist.

The 2011 SHFE SRP is charged (to the fullest extent practicable) to:

1. Evaluate the ability of the IRP to satisfactorily address the risk by answering the following questions:
   A. Have the proper Gaps been identified to address the Risk?
      i) Are all the Gaps relevant?
      ii) Are any Gaps missing?

   B. Have the proper Tasks have been identified to fill the Gaps?
      i) Are the Tasks relevant?
      ii) Are any Tasks missing?

2. Identify the strengths and weaknesses of the IRP, *and* identify remedies for the weaknesses, including answering these questions:
   A. Is the risk addressed in a comprehensive manner?
   B. Are there obvious areas of potential integration across disciplines that are not addressed?

3. Address (as fully as possible) the questions provided in the charge addendum and to provide comments on any important issues that are not covered in #1 or #2 above.

Additional Information Regarding This Review:

1. Expect to receive review materials at least four weeks prior to the site visit.

2. Participate in a 2011 SHFE SRP teleconference to discuss any issues, concerns, and expectations of the review process approximately three weeks prior to the face-to-face meeting.
   A. Discuss the 2011 SHFE SRP Statement of Task and address questions about the SRP process.
   B. Identify any issues the 2011 SHFE SRP would like to have answered prior to the site visit.

3. Attend the 2011 SHFE SRP at NASA JSC in October 2011.
   A. Attend Element presentations, question and answer session, and briefing.
   B. Prepare a draft report, including any recommendations. Debrief the HRP Program Scientist on what will be included in final report and should address #1, #2, and #3 above.

4. Prepare a final report that contains a detailed evaluation of the risks organized by Items #1,

#2, and #3 above and provides specific recommendations that will optimize the scientific return to the HRP. The report will be sent to the HRP Program Scientist. A copy of the report will be provided to the Space Human Factors and Habitability Program Element at NASA JSC that sponsors the SHFE Project. Once the report is finalized it will be made available to the public.

5. Consider the possibility of serving on a non-advocate review panel of a directed research proposal or on a solicited research peer review panel; or otherwise advise the Program Scientist.

X. SHFE SRP Roster

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