Space Human Factors Engineering Gap Analysis Project Final Report

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TABLE OF CONTENTS

ACKNOWLEDGMENTS

ACRONYMS

ARC   Ames Research Center

BHP   Behavioral Health and Performance

CEV   Crew Exploration Vehicle
CLV   Crew Launch Vehicle
CM   Countermeasures

D&C   Displays and Controls

ESAS   Exploration Systems Architecture Study
EVA   Extravehicular Activity

FCS&I   Flight Crew Systems and Integration
FY   Fiscal Year

GAP   Gap Analysis Project
GNC   Guidance, Navigation, and Control

HCI   Human Computer Interaction
HF   Human Factors
HFE   Human Factors Engineer
HRP   Human Research Program
HSI   Human System Interaction
HSIR   Human Systems Integration Requirements
HSIS   Human Systems Integration Standards

ISS   International Space Station

JSC   Johnson Space Center

LM   Lockheed Martin

NASA   National Aeronautics and Space Administration

POP   Program Operating Plan

SBIR   Small Business Innovative Research
SHFE   Space Human Factors Engineering

VHMS   Vehicle Health Maintenance System

LIST OF TABLES AND FIGURES

List of Tables:

List of Figures:

Space Human Factors Engineering
Gap Analysis Project Final Report

BACKGROUND

Humans perform critical functions throughout each phase of every space mission, beginning with the mission concept and continuing to post-mission analysis (Life Sciences Division, 1996). Space missions present humans with many challenges - the microgravity environment, relative isolation, and inherent dangers of the mission all present unique issues. As mission duration and distance from Earth increases, in-flight crew autonomy will increase along with increased complexity. As efforts for exploring the moon and Mars advance, there is a need for space human factors research and technology development to play a significant role in both on-orbit human-system interaction, as well as the development of mission requirements and needs before and after the mission.

As part of the Space Human Factors Engineering (SHFE) Project within the Human Research Program (HRP), a six-month Gap Analysis Project (GAP) was funded to identify any human factors research "gaps" or knowledge needs. The overall aim of the project was to review the current state of human factors topic areas and requirements to determine what data, processes, or tools are needed to aid in the planning and development of future exploration missions, and also to prioritize proposals for future research and technology development.

INTRODUCTION

This six-month project (October 2005 through March 2006) was a collaborative effort between human factors personnel from the National Aeronatics and Space Administration (NASA) Johnson Space Center (JSC) and Ames Research Center (ARC). The gap analysis included literature reviews, database searches, interviews with NASA personnel, and then, a survey of NASA program and project managers as stakeholders. The primary focus of the GAP was on tools and methods to aid in the development of requirements and guidelines for the Crew Exploration Vehicle (CEV), since there was an immediate need for such information. However, the GAP is seen as a long-term effort, and therefore, future Lunar and Mars exploration missions, as well as ground support needs for all missions, were also considered.

The project was divided into four parts, two phases for data gathering, and two for compiling and prioritizing results. Each phase along with the deliverables accomplished during that phase are detailed in Table 1.

The Human Factors Background Review focused on the results of space program literature searches, review of human factors documents, and interviews of human factors personnel. The Field User Review focused on interviewing people outside the

human factors area, but who work with crew interfaces. The results from these phases were then complied and categorized into logical human factors topic areas. Using this compiled list, the Gap Evaluation phase began. In this phase the categories and description of potential research topics were rated by GAP personnel on seven different factors to create a reduced list to present to stakeholders. A more concise list of topic areas were then sent to NASA stakeholders (e.g., Crew Office, Engineering Directorate, Mission Operations Directorate) to obtain their prioritization and buy-in of the important areas for human factors research. Last, the identified gaps were prioritized using four factors: CEV need, interview significance, stakeholder rating, and relevance to the Exploration Systems Architecture Study (ESAS). Each part of the project contributed significantly to these results, and will be discussed in detail in separate sections below.

Table 1: GAP phases and deliverables.

Phase	Deliverables
Human Factors Background Review	Space Program Literature Review
	Human Factors Document Review
	Human Factors Personnel Interviews
Field User Review	Field User Interviews
Gap Evaluation	Consolidation/Duplication Elimination
	Decision Analysis Factor Rating
	Stakeholder Ranking
Final Prioritized Gap Results	Prioritized Evaluation based on: (1) early CEV need in the areas of design and operations (2) interview significance (3) stakeholder rankings (4) ESAS recommendations

HUMAN FACTORS BACKGROUND REVIEW

Human-system performance is critical to all mission phases. The GAP Human Factors Background Review began with a summary of vehicle development and on-orbit mission phases to determine what aspects of human factors research and knowledge, as well as interaction with other disciplines, are needed during certain phases of vehicle or mission development. The phases were defined as:

- Phase 1: Feasibility
- Phase 2: Project Definition and Approval
- Phase 3: Requirements Definition
- Phase 4: Preliminary Design
- Phase 5: Detailed Design
- Phase 6: Flight Production and Certification
- Phase 7: Deployment
- Phase 8: Operations and Support

(Adapted from EA-WI-023, 2004)

Traditionally, human factors personnel are involved in Phases 3 through 6 – requirements definition through design and certification. However, with the development of new space vehicles and longer duration mission planning, it was clear that human factors involvement should be throughout all phases of development – from the conceptual stages, where feasibility studies of crew interaction with the vehicle are critical for defining the general mission parameters to in-flight and post-flight operations, where real-time support could benefit mission efficiency and success.

Review of Literature and Databases

To determine human factors topic areas that were underrepresented or requirements that needed updating, GAP personnel initiated a literature search of both NASA requirement documents and traditional literature sources.

GAP personnel reviewed the current Human Systems Integration Requirements (HSIR) and Human Systems Integration Standards (HSIS) chapter headings, as well as the older version of the document, the Man-Systems Integration Standards (NASA-STD-3000). This review generated a list of topic areas that had "gaps" and thus required a requirements update. In some cases, (e.g., the displays and controls sections) requirements needed updating to reflect current technology. In other cases, areas such as automation and robotics were missing from the requirements documents.

To further determine human factors topic areas that were underrepresented or requirements that needed updating, GAP personnel initiated a traditional literature search. The search included human factors documents from space, aeronautics, and other domains, such as "The 21st Century Jet: The Boeing 777 Multimedia Case Study" by S. Shokralla (1995) and "Emerging Needs and Opportunities for Human Factors Research" by R. Nickerson (Ed.) (1995). The search also included 66 documents from the Apollo, Space Shuttle, and ISS programs, such as the "Apollo 12 Technical Crew Debriefing", "STS-35 Flight Control Teams and Mission Evaluation Room Technical Crew Debrief", and "Increment 11 Lessons Learned Matrix". For a full list of documents reviewed, see Appendix A.

This review resulted in the identification of many issues/gaps. As an example, one item gathered from the review of the International Space Station (ISS) Lessons Learned database is that poor display and control design is a top concern in ISS crew debriefs. Furthermore, ISS and Space Shuttle crew debriefs indicated that rescheduling items and real-time changes in the schedule are not managed as efficiently as they could be. In addition, the short length of crewmember mission training was identified as a major issue in various crew reports and debriefs.

Another source of information was the results of a separate CEV Task Analysis project. The interview data from this project revealed that research is needed on crew capability to interact with crew station displays under the high and variable g-forces that will accompany CEV and Crew Launch Vehicle (CLV) ascents and entries. Specifically, research is needed to examine the methods for manual reaching switches or pushing

edge keys. Another topic discussed was the lack of a method to determine which tasks should be one- or two-crewmembers. Additional open questions focused on anthropometry concerns, such as the size of hatches to fit as yet undetermined extravehicular activity (EVA) and flight suits, as well as the types and design of hand rails and foot loops for crewmember restraint.

Finally, an important reference was the ESAS report. The ESAS report provides an assessment of the plans for crew and cargo launch systems to support the lunar and Mars exploration programs. It also defines top-level requirements and identified key technologies required to enhance the exploration programs. The report was reviewed and sections referring to human performance were noted, such as section 7.2.2.2 Design for Human Operatbility; "Crewed vehicles will provide the flight crew with insight, intervention capability, control over vehicle automation, authority to enable irreversible actions, and critical autonomy from the ground."

<u>Human Factors Expert Interviews</u>

The first phase of data collection began with interviews of human factors discipline experts. It was decided that the project team would start with human factors personnel, while in parallel, determining the best persons to interview from outside disciplines. In addition, it was expected that the human factors interviewees would provide the team with points of contact from other disciplines.

The human factors experts were personnel from the NASA JSC Habitability and Human Factors Office and NASA ARC Human Systems Integration Division. A total of 52 human factors personnel were interviewed. A list of interviewees can be found in Appendix B. The interviews were informal, with one or two GAP personnel interviewing an individual person or a small group. The interview was unstructured, letting the interviewees discuss the topics of most interest or concern to them. Interviews with human factors experts were conducted over approximately a month and a half time period. The interviews resulted in over half of the 286 Original Database entries and were a significant source of research and technology development needs.

FIELD USER REVIEW

Field users represent the end user of any technology for which human factors may have an impact and includes crewmembers as well as others. Multiple disciplines were identified as having "field users" of human factors requirements and work relating to human factors and crew interfaces. The seventeen areas combine several disciplines, since the topics they would be addressing were similar:
1. Guidance, Navigation, and Control (GNC)/ Avionics/ Displays and Controls
2. Power/ Thermal
3. Robotics
4. Medical Operations/ Behavior Health and Performance (BHP)
5. Exercise/ Countermeasures Hardware

6. Life Support/ Environmental Monitoring/ Radiation
7. Engineering/ Flight Crew Systems and Integration (FCS&I)
8. Food
9. Extravehicular Activity (EVA)
10. Structures/ Mechanical
11. Stowage
12. Safety
13. Procedures/ Training
14. Mission Support (ground)
15. Mission Planning
16. Systems Engineering/ Project Management
17. Crew Office

Field User Interviews

In preparation for the field user interviews, an "Interview Guide" was created. The interviews were informal, with one or two GAP personnel interviewing an individual person or a small group. As before, the interview was unstructured, letting the interviewees discuss the topics of most interest or concern to them, however, the Interview Guide was available as a tool to initiate the conversation if necessary. The Interview Guide is provided in Appendix C. The guide provided focus for the interviewee by offering prompting questions, such as: "Are you aware of any human factors open issues/areas of concern in your field that may require future research before Exploration (e.g., CEV, Hab Module) implementation?" A companion to the Interview Guide was the "Topics Table". The Topics Table listed human factors topic areas adapted from the Human Systems Integration Requirements (HSIR) for the CEV Launch Segment (NASA-STD-3000, Volume VIII) in the areas of Human Performance Characteristics and Capabilities, such as cognitive and environmental factors, and Human-System Interactions, such as safety and hardware and equipment. This list of topics helped prompt interviewees to think about the variety of topics affected by human factors.

A total of 62 field users from NASA JSC were interviewed The list of interviewees can be found in Appendix B. Interviews with field user personnel were conducted over approximately a month and a half time period. The interviews resulted in a substantial amount of data, approximately 70 line items in the Original Database, regarding human factors research and technology development needs.

GAP EVALUATION

The data gathered during the literature review and interviews were incorporated into a spreadsheet including columns to describe the following:
1. **Topic Area** (e.g., lighting, anthropometry, procedures)
2. **Research Question**
3. **Expected Product** – brief description of product

4. **Description of Product and Capabilities** – details on the expected product and its capabilities
5. **Expected Benefits** – expected benefits, such as cost savings, etc.
6. **Evidence Supporting Claims for Benefits** – any written or anecdotal evidence of successful product use
7. **Source (Interviewee(s))**
8. **Interviewer(s)**
9. **User Group** – the users of the product
10. **Customer** – potential customer organization
11. **HSIS Impacts** – updates to current HSIS or a new area
12. **Related Products and Lessons Learned**
13. **When is the Product Needed?** – product development or mission phase
14. **Comments**
15. **Notes from ESAS**

A more in-depth description of the column contents can be found in the supplemental file "GAP all files combined.xls" under the "Column Description" tab. Note that a distinction was made between User Group and Customer, since they may not be the same in all cases. For example, the customer for a timelining tool would potentially be the Mission Operations Directorate, however, the User Group is the Crew Office. Ultimately, it would be important to obtain buy-in from both groups on the need for the research topic and the final product.

GAP Database

A total of 114 people representing 18 different disciplines (including the human factors discipline) were interviewed. In addition, 75 documents were reviewed. The result was a database consisting of 286 research questions. See Table 2 for a sample of the database. The full results can be found in the supplemental file "GAP all files combined.xls" under the "Original Database" tab. A wide variety of topics were represented, ranging from controls and displays, communications, stowage, and labeling. For example, one research question was "What lighting design tool features and methods would be most helpful to designers/requirements developers for determining the number and placement of light sources?" Another research topic was, "More needs to be known about human interactions with automated systems such as pilot awareness, how awareness is affected, what's the right amount of information to provide to crews, and how much do they need to understand."

The first step with the database was to reduce the number of different topic area names by grouping them into common disciplines. For example, "Human System Interaction (HSI) Evaluation Metrics and Criteria" became "General Human Factors" and "Human Computer Interaction (HCI)" and "Display design" became "Displays and Controls". Sorting by topic area allowed the GAP team to eliminate duplicates or combine very similar research questions. A list of the research topics is presented below.

- Acoustics
- Adaptive Data Presentation
- Anthropometry and Biomechanics
- Automation
- Autonomy
- Behavioral Health and Performance
- Communication
- Decision Making
- Design Tools
- Displays and Controls
- Extravehicular Activity (EVA)
- Exercise/ Countermeasures (CM)
- Function Allocation
- General Human Factors
- Habitability
- Human Factors and Usabililty
- Human Reliability
- Information Management
- Inventory System
- Labeling
- Lighting
- Maintainability
- Oculometric Feedback
- Operations Planning
- Procedures
- Restraints
- Robotics
- Stowage
- Teleoperations
- Training
- Vehicle Maintenance and Processing
- Verification Tools for Human Factors (HF)
- Windows
- Workload

Decision Analysis

Once the research question topic areas were re-defined, GAP personnel used decision analysis as a process by which to assess the important aspects of the research questions and recommend the topics to pursue. The first step of the decision analysis was to ensure the identified research questions were appropriate for human factors, such that human factors is the primary driver of the research – not, for example, engineering or medical operations. The second step was to ensure the questions were appropriately research or technology-driven, as opposed to a programmatic decision. The research questions that received an answer of "yes" for both the "Human Factors (HF)?" and "Research?" decision analysis questions, and a select few that received a positive response for the "HF?" question and could be redirected towards research, were selected for further analysis; all other research questions were deselected. The resulting reduced database totaled 150 research questions. For the results of the decision analysis and the reduced database, please see the supplemental file "GAP all files combined.xls" under the "Initial Reduced Database" tab.

A restructuring of the database was performed to ensure that the GAP team had eliminated/combined all duplicates, that the research questions were well-categorized and concise, and, finally, that the additional database information, such as "Expected Product" and "Expected Benefits" was as complete as possible. Throughout the database reduction process, the original line item numbers were recorded so that one could refer to the Original Database if necessary. The results of the restructuring can be found in the supplemental file "GAP all files combined.xls" under the "Final Reduced Database" tab.

Table 2. A sample of the Original Database.

Topic Area	Research Question	Expected Product	Description of Product and Capabilities	Expected Benefits	Evidence supporting claims for benefits	Source [Interviewee(s)]	Interviewer	User Group	Customer	Related Products and Lessons Learned	When Is Product Needed
Functional Strength Data	More research is needed to create functional strength capabilities data, especially when wearing space suits.	Design guidelines.	Table showing minimum and maximum strength of personnel wearing space suits (both pressurized and unpressurized)	Guidelines for designers that will set upper limits on operating force requirements -- to assure all personnel will be able to operate systems. Also guidelines for designers to strengthen hardware so that it is not broken by personnel exerting high forces	Present guidelines in MSIS are useful but incomplete.	Sudhakar Rajulu (SF3)/ ABF	B. Tillman / J. Gonzalez	Hardware/ Vehicle developers	Program Office (potential future)	MSIS has strength data for unsuited personnel.	CEV

Internal Ranking. For the remaining part of the decision analysis, the GAP personnel generated a list of objective criteria on which to rank the 150 remaining research questions. The criteria were:

- **Start By** – the Fiscal Year (FY) in which the research would need to begin in order to have a set of requirements or a product ready for implementation
- **Risk for Development Success** – how risky the research is depending on technology development level
- **Multi-discipline Applicability** – the number of NASA disciplines commenting on the topic
- **Development Costs** – the estimated cost of the research or technology development in person-years. Plus one person-year added for large material costs.
- **Safety** – how much the topic may impact on-orbit crew safety
- **Crew Performance** – how much the topic may impact on-orbit crew speed and accuracy
- **Long-term Cost Savings** – how much the research or technology development will impact ground operations and performance

The criteria and rating levels can be found in Table 3. Rating Level "3" always represented the most beneficial outcome, and Level "1" the least beneficial. The results of each criteria rating were summed and weighted. The final results were sorted based on the research questions that received the highest value. A total of 31 items received the highest scores (17 and above), including verification tools for human factors requirements, procedures, and function allocation. Items ranked the lowest (scores of 14 or below) included exercise countermeasures and windows. This internal ranking allowed GAP personnel to focus on the research questions providing the most benefit to Exploration programs for NASA higher-level stakeholders to consider in their ranking.

Table 3. Decision analysis objective criteria.

Criteria	Rating Level
Start By	3 = Before FY'08
	2 = FY'09 or FY'10
	1 = After FY'10
Risk for Development Success	3 = Low Risk
	2 = Medium Risk
	1 = High Risk
Multi-discipline Applicability	3 = High Applicability (more than 2 groups)
	2 = Medium Applicability (2 groups)
	1 = Low Applicability (1 group)
Development Costs	3 = < 5 person-years
	2 = 5-10 person-years
	1 = > 10 person-years
Safety	3 = High
	2 = Medium
	1 = Low

Crew Performance	3 = High
	2 = Medium
	1 = Low
Long-term Cost Savings	3 = High
	2 = Medium
	1 = Low

STAKEHOLDER REVIEW

One of the most important aspects of the GAP process was the stakeholder review. The purpose of the stakeholder review was to ensure that higher-level NASA program managers and non-human factors discipline managers agreed that the research tasks to be identified by the GAP process were the most important areas of concern to them.

In preparation for the stakeholders' review, research topic areas in the top half of the internal decision analysis ranking were combined into 33 structured paragraphs. The structured paragraphs included the proposed research questions and products, making it more efficient for the stakeholders to review instead of the individual questions. The topic areas for the 33 structured paragraphs are listed below:

- Teleoperations
- Communications
- Crew Scheduling Tools

- Behavioral Health and Performance - Cognition
- Human Performance Models for Display Evaluation
- Medical Procedures
- Training
- Procedures
- Procedure Development
- Display Sizes
- Display Information Content
- Non-traditional Multi-modal Displays
- Alarms

- Displays and Controls Ergonomics
- Extravehicular Activity

- Anthropometry – Space Suits

- Anthropometry – General Design Guidelines

- Robotics
- Function Allocation
- Automation Evaluation Tools Development
- Robotics Anthropometry – Human Models
- Acoustics – Requirements Development
- Acoustics – Modeling
- Lighting Design Aid
- Lighting Tool Development
- Labeling
- Inventory Management
- Stowage
- Maintainability
- Human Factors Engineering Tools
- Design Capture
- Usability Evaluation Center and Tools
- Human Reliability and Risk Management

10

The complete information for the structured paragraphs can be found in Appendix D. An example of the Displays and Controls Ergonomics structured paragraph is shown in Table 4.

Table 4: Example Structured Paragraph

Gap Topic	Research Questions/Products
Displays and Controls Ergonomics	Develop guidelines and requirements for displays and controls (D&C) ergonomics: 1. What are the minimum size requirements (clearances) and location requirements for displays and controls for personnel wearing space suits (both pressurize and unpressurized). 2. Designing for sensory-motor deconditioning -- how can workstations and controls, be configured to minimize ergonomic problems involving variations in the operator's state (e.g., sensory-motor deconditioning, fatigue)? Products: Guidelines and requirements on D&C ergonomics. Emphasis should be on physical requirements for different mission phases and how displays and controls should be tailored to mitigate sensory-motor deconditioning.

The structured paragraphs were sent to stakeholders from various disciplines at NASA JSC, as well as NASA Headquarters, and represented a cross section of experienced managers. The stakeholders were asked to rate the paragraphs on the level of interest to their programs – High, Medium, or Low – and were also asked to provide comments.

Six discipline stakeholder groups responded to the call for review: NASA Headquarters, Crew Office, Constellation Office, Engineering Directorate, Mission Operations Directorate, and Space and Life Sciences Directorate. Display Information Content, Display Sizes, and Displays and Controls were the topics ranked highest by the stakeholders. The next highest group of topics included: Behavioral Health and Performance – Cognition, Alarms, and Crew Scheduling Tools, and Training. The complete results of the stakeholder ratings can be found in Appendix E.

FINAL PRIORITIZED GAP RESULTS

The final prioritization of the GAP results focused on four factors: (1) early CEV need in the areas of design and operations, (2) stakeholder rankings, (3) the frequency human factors personnel and field users (interviewees) identified the need ("interview significance"), and (4) ESAS recommendations. Finally, tasks were chosen based on other rationale within the JSC and ARC human factors groups, such as work with the CEV Cockpit Team, ISS lessons learned, and opportunities to further develop on-going

Small Business Innovative Research (SBIR). The top ten topics are listed below. The complete table of results can be found in Table 5.

1. Display Information Content
2. Behavioral Health and Performance – Cognition
3. Caution and Warning – Alarms
4. Anthropometry – General Design Considerations
5. Anthropometry – Human Models
6. Display Sizes
7. Displays and Controls
8. Function Allocation
9. Crew Scheduling tools
10. Training

Since four of the prioritized results focused on aspects of display information content (topics 1, 3, 6, and 7 mentioned above), they were combined into one large project called "Information Presentation". Similarly, the two anthropometry topics were also combined into one project.

Table 5. Final prioritized GAP results.

#	GAP topic	Early CEV need Design	Early CEV need Ops	Interview Significance	Stakeholder Rating	Relevant ESAS sections	Rationale
1	Display Information Content	X		6 of 18	High	7.2.2.2, 9.3.1.2	Displays and controls are top issue from ISS debriefs. Cockpit Team members requesting products.
2	Displays and Controls	X		4 of 18	High	9.3.1.2	With #1
3	Display Sizes	X		2 of 18	High	7.2.2.2, 9.3.1.2	With #1
4	Caution and Warning – Alarms	X		2 of 18	Med	7.2.2.2	With #1
5	Behavioral Health and Performance – Cognition	X		2 of 18	Med	12.10.8.2.1, 7.2.1.4	Window of opportunity to team with BHP. Psychologists and flight surgeons in Behavioral Medicine requesting products.
6	Anthropometry – General Design Guidelines	X		3 of 18	Med	4.2.3.2.1	Need became obvious from work with Cockpit Team on mockups and layout.
7	Anthropometry – Human Models	X		1 of 18	Low	4.2.3.2.1	With #6; Need also identified during HSIR verification development.
8	Human Factors Engineering Tools	X		6 of 18	Med		Most frequently identified topic – multiple interviewees in six disciplines. Can aid with design throughout the development process.
9	Function Allocation	X		5 of 18	Med	7.2.2.9, 7.2.1.4.3	Many people asked for assistance with function allocation, incl. Cockpit Team, Med Informatics, Robotics
10	Automation Evaluation Tools Development	X		1 of 18	Med		With #9
11	Crew Scheduling Tools		X	3 of 18	Med	12.10.8.2.1, 7.2.1.4.3	Flight surgeon interest. Modify tools developed for Mars exploration for CEV – considered 'low-hanging fruit'
12	Training		X	3 of 18	Med	6.5.4.1, 7.2.1.1.2, 7.2.1.2.3	Potential to leverage aeronautics HF work and Medical Operations work.

#	GAP topic	Early CEV need Design	Early CEV need Ops	Interview Significance	Stakeholder Rating	Relevant ESAS sections	Rationale
13	Acoustics – Requirements Development	X		2 of 18	Med		Noise is major problem on ISS. Need to eliminate noise from designs
14	Acoustics – Modeling	X		2 of 18	Med		With #13
15	Human Performance Models for Display Evaluation		X	3 of 18	Med	7.2.2.2, 9.3.1.2	Opportunity to develop Phase III of SBIR
16	Lighting Design Aid	X		1 of 18	Med		Make in-house tools available to designers
17	Lighting Tool Development	X		1 of 18	Low		With #16
18	Non-Traditional Multimodal Displays		X	2 of 18	Low	7.2.2.2, 9.3.1.2	Heads-Up Display work supported by Advanced Technologies group in Exploration
19	Communications		X	4 of 18	Med	7.2.1.4.3	
20	Anthropometry – Space Suits		X	3 of 18	Med	4.2.3.2.1	Work is being supported by EVA. Possible future need for joint work.
21	Extravehicular Activity (EVA)			2 of 18	Med		Work is being supported by EVA. Possible future need for joint work.
22	Human Reliability and Risk Management		X	3 of 18	Med	7.2.2.2	
23	Teleoperations			3 of 18	Med		
24	Procedures			3 of 18	Med	7.2.2.2	
25	Inventory Management			2 of 18	Med		
26	Labeling			2 of 18	Med	7.2.2.9, 7.2.1.4.3	
27	Procedure Development			3 of 18	Low	7.2.2.2	
28	Medical Procedures			2 of 18	Med	7.2.2.2	
29	Maintainability			2 of 18	Med	7.2.2.4.1	
30	Robotics			2 of 18	Med		
31	Stowage			2 of 18	Med		
32	Design Rationale Capture			1 of 18	Low	7.2.1.2	
33	Usability Evaluation Center and Tools			2 of 18	Low		

CONCLUSIONS

The GAP concluded with a presentation of the Space Human Factors Engineering integrated research plan to the Human Research Program Operating Plan (POP) in April 2006. The HRP POP ensures that the funded research mitigates risks to the program included in the Bioastronautics Roadmap (NASA/SP-2005-6113). Given personnel resources available in the JSC and ARC human factors groups, eight tasks were chosen to go forward. The eight tasks identified by the GAP were shown to address potential risks to crew performance and well-being, namely, the failure of performance due to system mismatches with crewmembers' cognitive and physical capabilities (see Table 6). In addition, the eight tasks are critical to supporting Exploration (Constellation) program milestones. The following paragraphs describe the final selected tasks. The first three, "Information Presentation," "Anthropometric Verification Tools", and "Behavioral Health and Performance – Cognition", have been approved to begin immediately. The other five tasks are currently undergoing review for start in the next fiscal year.

Table 6. Tasks and their relation to Human Research Program identified risks.

TASK	RISK		
	Cognitive Mismatch	Physical Mismatch	Multi-Agent Tasking
Information Presentation	X	X	
Anthropometric Verification Tools		X	
Behavioral Health and Performance - Cognition	X		
Acoustic Requirements and Models		X	
Design and Evaluation Tools	X	X	
Crew Scheduling Tools	X	X	X
Training	X	X	X
Function Allocation Tools and Techniques			X

Information Presentation. The goal of the Information Presentation task is to develop guidelines and requirements for: (1) displays and controls ergonomics, (2) proper sizing of physical display screen and screen formats within screens, (3) advanced caution and warning system integrated with Vehicle Health Maintenance System (VHMS), and (4) proper display of information content and usability of procedures for time-critical tasks. This task addresses the gaps of poor display and control design and the need for new requirements and strategy for reduced CEV display and control real-estate. In addition, it advances integrated crew information presentation with VHMS. The expected products include guidelines and requirements for display sizes and layout, display information content, and the characteristics of alarm events.

Anthropometric Verification Tools. The goal of the Anthropometric Verification Tools task is to develop databases and computer models that describe the size, strength, and movement characteristics of crewmembers to meet the needs of designers. This task addresses the gap that existing strength data is inadequate for CEV requirements, as well as providing reach models that are currently not available. The resulting database and preliminary human modeling software will be available to the NASA community, as well as providing requirements to optimize the efficiency of crew stations through better assessments of reach and visibility tasks.

Behavioral Health and Performance – Cognition. The importance of cognitive loads and failures has increased as active control of systems has passed more and more to automated systems and the role of the human operator has increasingly become that of a monitor. The goal of the Behavioral Health and Performance – Cognition task is to develop metrics for cognitive performance and readiness to perform for specific tasks in space flight. This task addresses the gap that current tools are limited in ability to predict crewmember readiness to perform. A self-assessment tool, adaptable to the range of expected activities for the crew, would provide a better match between actual capabilities and task demands. In addition, such a tool will provide an assessment of human-system interfaces during hardware development, and used during operations to assess just-in-time training.

Acoustics Requirements and Models. The goal of the Acoustics Requirements and Models task is to identify appropriate guidelines and requirements for the CEV and future Constellation program vehicles and to develop verification tools capable of predicting noise levels of integrated systems, including thermal protection system and environmental control. This task addresses the lack of ability to predict integrated noise levels and the need for acoustic tools and models for requirements verification. Guidelines and requirements for noise levels, as well as a computer-based acoustic model, will allow designers to test design alternatives, resulting in better acoustic environments for the crew.

Design and Evaluation Tools. The goal of the Design and Evaluation Tools task is to create requirements and guidelines for task analysis, usability evaluations, and the demonstration of a design rationale capture system. This task addresses the lack of tools to support human-centered design process and a lack of agreed-upon methods to evaluate requirements such as 'usability', and 'workload' typically used with human-system interaction evaluations. The products, which are tools to evaluate designs for human-system integration, will lead to improved design of spacecraft and habitats and will be flexible enough to be applied to various systems (e.g., medical, food, maintenance).

Crew Scheduling Tools. The goal of the Crew Scheduling Tools task is to evaluate tools used previously to schedule Mars rovers, and adopt them to crew scheduling to capture multiple constraints and goals for mission planning. This task addresses the gap that with longer-duration missions, ground support needs to evaluate

greater crew responsibility for scheduling. A constraint-based planning and scheduling tool for both dynamic and non-dynamic flight phases will improve crew efficiency.

Training. The goal of the Training task is to develop just-in-time training and decision support tools that can address the most efficient methods of training and the best media for presenting refresher training and just-in-time training in flight. This task addresses the lack of objective measures for proficiency in training, and methods to mitigate the short time available for training on the ground. Providing guidelines for the most efficient methods of training will improve training efficiency and reduced training load for crewmembers.
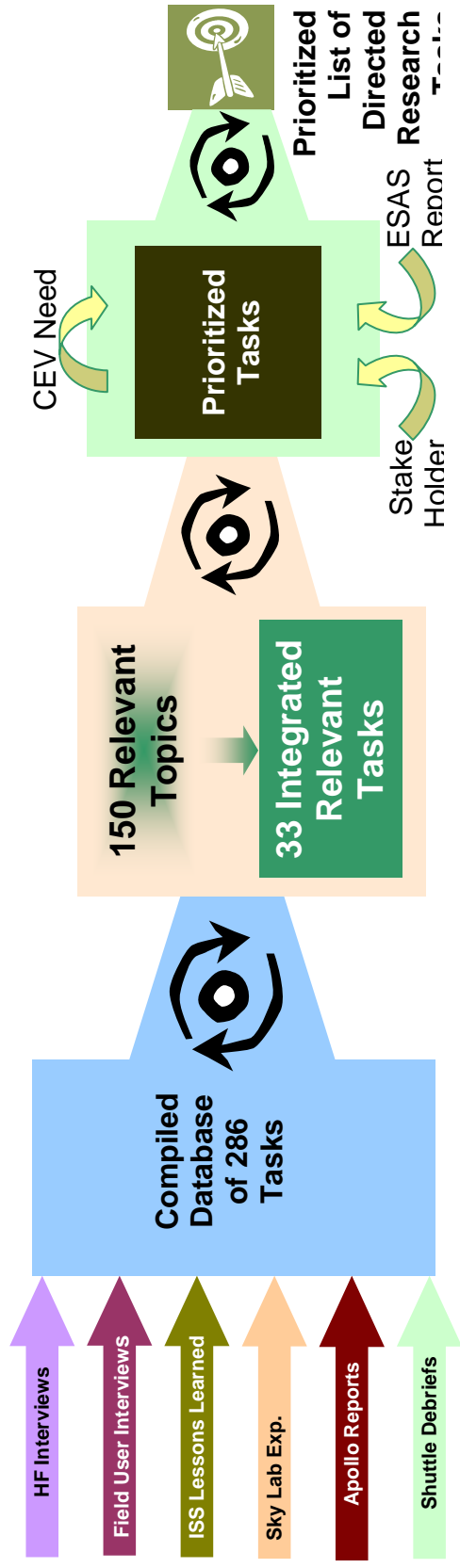
Function Allocation Tools and Techniques. The goal of the Function Allocation Tools and Techniques task is to develop guidelines and requirements for function allocation, as well as developing evaluation tools for the performance of human-automation teams. This task addresses the lack of research in determining which tasks should be performed by crew or ground and determining which tasks should be automated. Such tools will provide guidance to assist in ensuring that the functions that require human judgment and are not cost-effective to automate are designed to optimize the human contribution.

DISCUSSION

The objective of this six-month project was to determine the requirements, guidelines, and tools that remained to be created in order to meet the needs of various customers, end users, and stakeholders within the Exploration (Constellation) Program. Figure 1 represents the GAP process graphically. As a result of the GAP, SHFE has established a set of prioritized customer needs and a link back to stakeholders in the SHFE products. This project has also generated ongoing collaborations across NASA JSC organizations. Namely, the Habitability and Human Factors group is working more closely with NASA ARC Human Systems Integration Division personnel to incorporate both centers' strengths, as well as opening opportunities for Habitability and Human Factors personnel to work with other NASA JSC directorates.

Research and technology development provides effective inputs to the Exploration program's goals and provides useful knowledge, tools, and technologies to assist developers in reaching these goals (Life Sciences Division, 1996). The work performed and recommendations made this report will provide the HRP and the Exploration (Constellation) program with a significant advantage towards mission safety and success.

Figure 1. Representation of the Gap Analysis process

HF Interviews

Field User Interviews

ISS Lessons Learned

Sky Lab Exp.

Apollo Reports

Shuttle Debriefs

Compiled Database of 286 Tasks

150 Relevant Topics

33 Integrated Relevant Tasks

CEV Need

Prioritized Tasks

ESAS Report

Stake Holder

Prioritized List of Directed Research Tasks

18

<u>Forward Work</u>

In order to maintain the communication ties back to the Exploration (Constellation) Program and all of the SHFE stakeholders, a delta gap analysis project will be conducted each year in order to verify that the research being performed still meets the needs of the customer and to identify any new habitability and human factors challenges (Space Human Factors Engineering Project Management Plan, 2006). There is potential for the research questions deemed too programmatic and, therefore, deselected during the decision analysis to be written up as special topic white papers. Finally, the combined JSC and ARC GAP process will aid SHFE efforts in building upon existing projects and to ensure work done in support of one program is readily applied to concurrent or subsequent endeavors (Life Sciences Division, 1996).

REFERENCES

Bioastronautics Roadmap: A Risk Reduction Strategy for Human Space Exploration. (2005). NASA Johnson Space Center (NASA/SP–2005–6113).

Engineering Office. (2004). *Project Management of GFE Flight Projects, Rev. D.* NASA Johnson Space Center. (EA-WI-023)

Habitability and Environmental Factors Division. (2006). *Space Human Factors Engineering Project Management Plan.* NASA Johnson Space Center.

Life Sciences Division. (1996). *Space Humn Factors: Critical Research and Technology Definition.* NASA Johnson Space Center.

APPENDIX A
List of Documents Reviewed

Program	Document Name	Document Number	Author	Date
Apollo	Apollo 16 Flight Journal Day 1 - First Earth Orbit.htm			
Apollo	Apollo Flight Journal - The Apollo On-board Computers.htm			
Apollo	Abort Planning	NASA TND-6847		
Apollo	Acceptance Checkout Equipment	NASA TN D-6736		
Apollo	Aerodynamics Evaluation	NASA TN D-6843		
Apollo	Mission Planning for Apollo Entry	NASA TN D-6725		
Apollo	Ascent Propulsion System	NASA TN D-7082		
Apollo	Command & Service Module Reaction Control Systems	NASA TN D-7151		
Apollo	Command & Service Module Controls & Displays Subsystem	NASA TN D-8301		
Apollo	Command & Service Module Electrical Power Distribution Subsystem	NASA TN D-7609		
Apollo	Command & Service Module Environmental Control System	NASA TN D-6718		
Apollo	Command & Service Module Instrument subsystem	NASA TN D-7374		
Apollo	Command & Service Module Sequential Events Control Subsystem	NASA TN D-7951		
Apollo	Application of a Computerized Visualization Capability to Lunar Missions	NASA TN D-6853		
Apollo	Crew Station Integration Volume V - Lighting Considerations	NASA TN D-7290		
Apollo	Cryogenic Storage System	NASA TN D-7288		
Apollo	Launch Escape Propulsion Subsystem	NASA TN D-7083		
Apollo	Spacecraft Heating Environment & Thermal Protection for Launch Through Atmosphere	NASA TN D-7085		
Apollo	Protection of Life & Health	NASA TN D-6856		
Apollo	Apollo 12 Technical Crew Debriefing			
Apollo	Lighting & Approach Angle Considerations for Manned Lunar Landings	NASA CR 70818 (Bellcomm TM 65-1012-13)		
Apollo	Lunar Lighting Conditions for the Apollo Lunar Landing Mission	NASA CR 75839 (Bellcomm TM 66-1012-6)		
Apollo	Ranger Preflight Science Analysis and the Lunar Photometric Model	NASA TR 32-384 (Revised)		
Apollo	Photometric & Polarimetric Properties of the Lunar Regolith	NASA SP-235		
Apollo	An Analysis of Lunar Site Survey by the Unmanned Program	Bellcom Report 01/31/1964		
Apollo	Lunar Photographic Orbiter: Lighting & Viewing Conditions	NASA CR-59192		

Program	Document Name	Document Number	Author	Date
Apollo	The Effects of Lunar Dust on EVA Systems During the Apollo Missions	NASA TM 2005-213610		
Apollo	Apollo Space Suit Interface Specification	NASA SID 62-319		
Apollo	Lunar Receiving Laboratory	NASA CR-109164		
Apollo	Bacterium Isolated from Lunar-Retrieved Television Camera	CASI 19720019118		
Apollo	The Lunar Quarantine Program	N76-12668 pp. 407-424		
Apollo	Protection Against Radiation	NASA-TN-D-7080		
Apollo	Real-time Display System	NASA-TN-D-8316		
Apollo	Simulation of manned space flight for crew training	NASA-TN-D-7112		
Apollo	Spacecraft pyrotechnic systems	NASA-TN-D-7141		
Apollo	Systems and flight procedures development	NASA-TN-D-7436		
Apollo	Television system	NASA-TN-D-7476		
Apollo	Development flight instrumentation; telemetry equipment for space flight test program	NASA-TN-D-7598		
Apollo	Voice communications techniques & performance	NASA-TN-D-6739		
Shuttle	STS-26 Crew Debriefing		D. Bergeron	10/7/1988
Shuttle	STS-27 Crew Debriefing Issues		H. Tabibian	12/29/1988
Shuttle	STS-27 Crew Debriefing Notes			
Shuttle	STS-28 Crew Debrief Notes			
Shuttle	STS-29 Crew Debrief Notes		T. Canada	3/27/1989
Shuttle	STS-29 Debriefing		M. Minchew	3/23/1989
Shuttle	STS-30 Crew Debrief Notes		T. Canada	5/12/1989
Shuttle	STS-31 Debriefing Notes		M. Minchew	5/4/1990
Shuttle	STS-31 Crew Debrief Notes		T. Canada	5/8/1990
Shuttle	STS-32 Crew Debrief Notes			1/25/1990
Shuttle	STS-33 Crew Debriefing		T. O'Briant	12/4/1989
Shuttle	STS-34 Crew Debrief Notes			
Shuttle	STS-35 Crew Debrief Notes		T. Canada	12/27/1990
Shuttle	STS-38 Crew Debrief Notes		T. Canada	11/30/1990
Shuttle	STS-41 Crew Debrief Notes		T. Canada	10/22/1990
Shuttle	Review of the STS-26 Crew Debriefing Comments		D. Bergeron	10/20/1988
Shuttle	STS-27 Flight Crew Equipment Crew Debriefing Questions and Answers		J. Blumentritt	
Shuttle	Synopsis of /STS-27 Flight Crew Equipment Crew Debriefing Questions and Answers			
Shuttle	Review of the STS-29 Crew Debriefing Comments		D. Bergeron	4/21/1989

Program	Document Name	Document Number	Author	Date
Shuttle	STS-31 Technical Crew Debriefing		D. Bergeron	5/4/1990
Shuttle	CFE Action List STS-34		T. O'Briant	10/30/1989
Shuttle	STS-35 Flight Control Teams and Mission Evaluation Room Technical Crew Debrief			12/19/1990
Shuttle	STS-4 Crew Report		T. Mattingly	8/30/1982
Shuttle	Modeling Human Error in the Space Shuttle Probabilistic Risk Assessment		T. Hamlin & M. Stewart	
ISS	Increment 11 Lessons Learned Matrix			
ISS	Operational Habitability Corrective Action Tracking Log			
ISS	ISS Crew Comment Database			
Exploration	Stowage Technology Development Project		M. Whitmore, R. Ornan, L. Norris, & R. Wright	
Exploration	Rethinking Stowage: Standardizing and Organizing to Save Volume and Time		R. Ornan & R. Wright	
Exploration	Food Packaging Redesign to Improve Stowage Management on ISS and Beyond		R. Wright & R. Ornan	
Exploration	Exploration Medicine Capabilities Information Technology Architecture		Engineering Directorate	9/5/2006
Other	Human Research Program - Program Plan		Space Life Sciences Directorate	12/5/2005
Other	The 21st Century Jet: The Boeing 777 Multimedia Case Study		S. Shokralla	12/18/1995
Other	Bioastronautics Roadmap A Risk Reduction Strategy for Human Space Exploration	NASA/SP-2005-6113		2/5/2006
Other	Emerging Needs and Opportunities for Human Factors Research		R. Nickerson (Ed.)	1995
Other	Space Human Factors: Critical Research and Technology Definition		Life Sciences Division	10/96

APPENDIX B
GAP Interviewees

Discipline	Interviews Conducted	
JSC Human Factors (all topics)	M. Whitmore	
	J. Maida	J. Beierle
	S. Rajulu	L. Duvall
	S. Baggerman	S. Stealey
	K. Stroud	C. Rando
	J. Hamilton	J. Beno
	M. Soltis	J. Solem
	D. Russo	V. Byrne
	D. Fitts	L. DeSantis
	F. Mount	T. Holden
	T. Mayes	R. Hoffman
	C. Keller	D. Smith
	R. Wright	C. Hudy
	R. Szabo	J. Adolf
	E. Twyford	
ARC Human Factors (all topics)	S. Casner	J. McCandless
	B. Burian	J. Mulligan
	K. Dismukes	M. Feary
	L. Stone	S. Paletz
	A. Hobbs	J. Caldwell
	B. Parke	M. Kaiser
	P. Cowings	S. Ellis
	W. Toscano	I. Barshi
	R. Welch	M. Connors
	A. Andre	R. McCann
	B. Hooey	J. Orasanu
	D. Foyle	B. Kanki

Discipline	Interviews Conducted	
Guidance, Navigation, and Control (GNC)/ Avionics/ Displays and Controls	M. Hartgerink/ USA	G. Salazar/ EV
	G. Hill/ EV2	R. Miller/ EV2
Power/ Thermal	G. Raffoul/ MO	
Robotics	D. Overland/ ER	J. Rochlis/ ER
	J. Malin/ ER2	N. Currie/ ER
	C. Thronesberry/ ER	B. Magh/ OM
Medical Operations/ Behavioral Health and Performance	J. Clark/ SD	S. VanderArk/ Wyle
	J. Jones/ SD	E. Kalla/ SD4
	J.D. Polk/ SD	
	W. Sipes/ SD	K. Johnson-Throop/ SD4
Exercise/ Countermeasures Hardware	M. Rapley/ SK	J. Hayes/ SK
	D. Hagan/ SK	J. Bloomberg/ SK
	J. Charles/ SA	M. Reschke/ SK
	B. Paloski/ SK	
Life Support/ Environmental Monitoring/ Radiation	J. Goodman/ SF	
	C. Allen/ SF	
Hab Accommodations/ Flight Crew Support and Integration	B. Behrendsen/ DX3	
	T. Mills/ ARES/ OB3	
Food Systems	V. Kloeris/ SF3	
	M. Perchonok/ SF3	
Extravehicular Activity	E. Oshel/ KX	
	C. Harvey/ SF3	
Structures/ Mechanical	E. Bruno	
Stowage	G. Morgan/ USA/ MO2	
	Y. Carmona	
Safety	R. Rust/ NX	P. Cureton/ NT
	W. Bostick/ NT	G. Priest/ NE
	R. Comin/ NT	J. Gernard/ NT
Procedures/ Training	D. Pogue/ Barrios/ DX3	J. Schmid/ SD2
	J. Alexander/ DX	M. Christgen/ SD
Mission Support (Ground)	J. McKinnie/ DF24	P. Grounds/ MO3
	J. Williams/ DF24	A. Ong
	T. Calhoun/ DX14	R. Adams/ MO3
		R. Galvez/ MO3
Mission Planning/ Program Management	A. Moore/ DO	K. Holmes
Systems Engineering/ Project Management	P. Campbell/ SF	J. Kukla/ Wyle
Crew Office	E. Baker/ CB	M.J. Anderson/ USA/ CB
	L. Polansky/ USA/ CB	J. Stramler/ Barrios/ CB
	R. Faust/ USA/ CB	

Appendix C
Interview Guide and Topics Table

HUMAN FACTORS GAP ANALYSIS – Interview Guide

Interviewee(s) Name: _____

Discipline: _____

Date: _____

INTRODUCTION

The Gap Analysis is being conducted to capture 'hot topics' that have surfaced throughout the life of Station and Shuttle that could benefit from research for future Exploration Activities. In other words, what Human Factors (HF) areas of concern could benefit from research?   Any gaps between research and applied HF Engineering will be identified and presented to Advanced Research (Kathy Laurini, Carl Walz).

GAP ANALYSIS PROCESS

The Gap Analysis team comprises 1-2 members from each of Habitability and Human Factors group and Space Human Factors Laboratories. The teams will gather HF areas of interest that have been identified throughout the NASA community (JSC and Ames). Once the list is compiled, it will be prioritized based on inputs from stakeholders (e.g., MOD, crew, program managers). This will also be an opportunity to identify the customers that would benefit from this research and technology development.

To help determine HF areas of interest, use the following guidelines:
- Identify design requirements that affect the vehicle/crew interface
- Focus on HF issues and human performance determinants in different systems
- Focus on general HF related **research** questions; Some examples are:
    - Human Computer Interaction – presentation of information on a display
    - Communication – feasibility and usability of wireless communication
    - Automation – human interaction with differing levels of automation
    - Privacy – amount of personal space required for each crewmember

1. Briefly describe the type of system/product/service you develop (e.g., O2 scrubber, crew timeline, training).

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2. How does the crew (or ground support) interact with your system/product?
CAN USE TABLE TO IDENTIFY SPECIFIC AREAS.
        2a. What are some of the difficult aspects of the interaction?
        2b. What issues have you heard from your users (crew or ground personnel)?

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3. Are you aware of any human factors open issues/areas of concern in your field that may require future research before Exploration (e.g., CEV, Hab Module) implementation?

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4. Are there any other issues or gaps in your field where human factors can provide assistance?
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5. Does your discipline interface with Human Factors (e.g., do you have to address HF requirements? Are there HF personnel on the project team? Do you consult with HF personnel?)?

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6. Are there any human factors requirements that need to be better written? Of the requirements applicable to your system/product, which requirements may require future research or analysis? **CAN USE TABLE TO IDENTIFY SPECIFIC AREAS**

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7. Are there special analyses that need to be conducted to implement or verify human factors requirements? If yes, describe.

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8. When conducted, what type or to what extent are evaluations conducted? (e.g., trade studies, crew evals, usability studies)

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9. When designing your system/product what trade-offs did you consider in terms of ease of use vs. automation vs. additional crew training? For example, improved user interface to reduce crew training requirements.

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10. Do any of the HF requirements listed above appear to not meet industry standards or address current technologies?

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Human Factors Gap Analysis – Topics Table

What requirements below are applicable to your system/product? Are there any requirement areas that need to be clarified, or information added?

[Reference NASA-STD-3000, Volume VIII, Human Systems Integration Requirements (HSIR), CEV Launch Segment (CEV and CEVLV)]

	Human Performance Characteristics & Capabilities	**Do you have to pay particular attention to any human performance capabilities in the design of your system/product?**
☐	Visual	
☐	Auditory	
☐	Olfactory	
☐	Vestibular	
☐	Kinesthetic	
☐	Human Dimensions	
☐	Strength	
☐	Range of motion	
☐	Physical workload	
☐	Motor skills (e.g., dexterity)	
☐	Response time	
	Cognitive	**Does your system/product require any special cognitive capabilities?**
☐	Attention	
☐	Memory	
☐	Decision making	
	Environmental factors	**Will any environmental factors affect the human's performance with your product/system?**
☐	Atmosphere	
☐	Microgravity	
☐	Acceleration	
☐	Vibration	
☐	Acoustics	
☐	Radiation	
☐	Thermal	

Human-system interactions

	Safety	**Are there any safety hazards associated with your system/product?**
☐	Safety Hazards	
☐	Touch Temperature	
☐	Mechanical	
☐	Electrical	

☐	Decompression	
☐	Fire	
	Health management	**Does your system/product affect any health management issues?**
☐	Nutrition	
☐	Microgravity countermeasures	
☐	Sleep	
☐	Medical	
	Workstations	**Does the crewmember have to interact with any workstation components in using your product/system?**
☐	Layout	
☐	Controls	
☐	Visual displays	
☐	Audio indicators	
☐	Control/display integration	
☐	Communications	
☐	Labeling & coding	
☐	Automation	
	Activity centers	**Does the crewmember have to interact with any particular vehicle areas or activity centers in using your product/system?**
☐	Piloting & systems mgmt	
☐	Maintenance	
☐	Housekeeping	
☐	Training	
☐	Direct and Indirect Viewing	
☐	Body waste management	
☐	Personal hygiene	
☐	Galley	
☐	Stowage	
☐	Exercise	
☐	Medical treatment area	
☐	Crew quarters	
☐	Trash management	
☐	Recreation	
☐	Meeting	
☐	Robotics	
	Static features	**Are there any static design features that may impact how the crewmember uses your system?**
☐	Volumes	
☐	Adjacencies	

☐	Orientation	
☐	Restraints	
☐	Lighting	
☐	Aesthetics - design & decor	
☐	Window integration	
	Dynamic features	**Are there any dynamic design features that may impact how the crewmember uses your system/product?**
☐	Nominal traffic flow	
☐	Translation paths	
☐	Mobility aids	
☐	Location coding	
☐	Doors & hatches	
☐	Emergency egress	
	Hardware & equipment	**Is there any equipment that the crewmember must interact with for your system/product?**
☐	Tools	
☐	Mounting & access	
☐	Packaging	
☐	Fasteners/Connectors	
☐	Cable management	
☐	Closures & covers	
☐	Information management	
☐	Communications	
☐	EVA	
	Crew Management	**Does your system/product involve any other crewmember considerations?**
☐	Crew Skills	
☐	Crew Scheduling	
☐	Crew Training	
☐	Instructional Materials	

Appendix D
Structured Paragraphs Scoresheet

Ref	Gap Topic	Research Questions/Products	Score	Comments
1	Teleoperations	Develop methods for effective teleoperations by mediating transmission latencies and efficiently training the crew members and potential ground personnel. The task will address the following questions: 1. What are the guidelines for performing teleoperations tasks? 2. How do we design for minimum risk? 3. To what level should the task be monitored by a crew member on orbit? 4. How comfortable is the crew in letting someone else perform the task? 5. What is the best way to train for remote medical support? 6. How can we ensure effective teleoperations of lunar-based assets from remote settings? This question is relevant because the ESAS Report (section 7) states that "Some surface assets emplaced on the lunar surface would continue to operate after the crew leaves. Scientific monitoring equipment, robotic systems, and ISRU demonstrations would be teleoperated from Earth." Products: (1) Models for several types of control authority (e.g., inner-loop control, supervisory control), (2) control algorithms that seamlessly fuse predictive filter and predictive filter techniques to effectively mediate transmission latencies, and (3) guidelines for training engineering and medical personnel in teleoperation activities.		
2	Communications	Good communication and positive interactions between ground and crew, and between crewmembers, are critical to assure efficient workload management when dealing with unanticipated problems. Interface design, information finding and utilization, information management, and users' comprehension will continue to be major challenges for research into communications. The questions need to be addressed are: 1. What are operating considerations with respect to various communication latencies in communications/control? How should ground and on-orbit crews be trained to communicate with		

		increasing signal delays?
		2. How can communication procedures be improved, both for CEV, as well as longer duration Lunar and Mars missions?
		3. Opportunities include the development of tools to facilitate interaction with complex databases and interpersonal communication through computer-based systems.
		4. What tools and procedures can foster development of shared mental models for distributed decision making between crew and ground?
		5. Develop tools to support building of shared situation models, assess risks, and evaluate alternative courses of action will enhance distributed team decision making.
		6. How can voice, data, graphics, and images best be exchanged concurrently with the ground, within habitable volumes, and during EVA? How can factors such as bandwidth limitations, changing signal propagation conditions, mobility, and language diversity best be managed?
		Product: (1) Design guidelines/requirement development for optimal methods for planning on-orbit operations (including teleoperations) and anticipating effects of changing latencies in voice and data communication. (2) Communication protocols and technologies to facilitate cooperative decision making between crews in space and on the ground that support human interaction.
3	Crew scheduling tools	Crew debriefs indicate that rescheduling items and real-time changes (rule for rescheduling) in the schedule are not managed as efficiently as they could be. This research project will examine effectiveness and efficiency of enabling the crew to replan their activities: 1. Development of a product to apply heuristics and mission operations knowledge to seamlessly incorporate off-nominal and nominal activities and procedures into a unified timeline 2. Work with flight surgeons and mission planning to evaluate effectiveness of crew scheduling vs. ground scheduling on ISS. Product: Constraint-based planning and scheduling tools for automatic

4	Behavioral Health and Performance - Cognition	generation of activity plans for both dynamic and non-dynamic flight phases.

The importance of cognitive failures has increased as active control of systems has passed more and more to automated systems and the role of the human operator has increasingly become that of a monitor. Therefore, as risk mitigation, readiness to perform should be measured before engaging in tasks. Tasks to be addressed for this topic includes:

1. Identify critical aspects of crewmember tasks.
2. What metric can be used for measuring the effectiveness of human activities? The tool could serve two purposes: predict human work effectiveness during a system development and also would be a metric for assessing human performance during operations.
3. Develop an assessment tool for the crewmembers to measure their own performance to determine "readiness to perform." The "readiness-to-perform" cognitive tool would be tailored to the specific task; the tool must be adaptable to the range of expected tasks/activities for crew.
4. Given the fact that conceptual designs are by definition incomplete, how can NASA better predict human performance (particularly task completion times, workload, SA, error rates)?
5. When should auditory vs. visual alarms be used?

Product: Tool that will model workload, specifically for cognitive task components. This will provide a metric to assess the impact of full training and just-in-time training and leads to a better match between actual capabilities and task demands. |
| 5 | Human Performance Models for Display Evaluation | Designers of displays typically embed attention-attracting features (such as color-coding) in conformance with their knowledge of human information seeking capabilities. However, existing human performance models are not yet capable of predicting display effectiveness because the models lack detailed models of information seeking and visual processing. The following goals will be addressed by this task:

1. Develop, test, and evaluate human performance models to assist developers in designing displays and controls. |

	2. Ensure models make valid quantitative determinations of display quality and usage and the effects of display modification, thereby speeding up and optimizing design/test/redesign/retest cycles. 3. Develop a model of performance moderating factors that predict and recreate short- and long-term effects of stressors (such as fatigue, stress, time pressure, inadequate situation awareness and microgravity) on performance. By matching these predictions against real-time behavioral measurements of crew activity (such as eye movements) the model can function as a real-time classifier of current crew condition and performance capability. Products: Models of human performance
6	Medical Procedures	Develop guidelines for multimedia support of medical procedures (e.g., multimedia enhancement to procedural guides and checklists such as the Emergency Medical Procedures Checklist (EMPC) and other NASA mission procedures and checklists). Use medical procedures as test domain, but derive guidelines for more general applicability. Research questions include: 1. What is the best format of procedures for providing different levels of detail to different people (novice vs. expert)? How can the medical checklist be redesigned? 2. Which characteristics of medical tasks determine whether they would benefit from multimedia support? Which specific components of emergency medical tasks in the current NASA EMPC would benefit from multimedia? 3. Can a complexity index be developed that would facilitate the quick and effective determination of which tasks would benefit from multimedia? 4. What principles of task design, procedures, job aids, tools / and equipment are required to enable crewmembers to accomplish nominal and emergency perceptual and cognitive tasks? 5. How can the decision-making of non-medical crewmembers be aided? How should relevant information be presented in a timely and unencumbered manner to the crew?

		6. What kinds of systems can support the crews' on-board medical activities (e.g., diagnostics, prognostics, scheduling) and decision-making capabilities? Products: (1) Guidelines and operationally efficient checklists, (2) Guidelines for multimedia support, and (3) Medical decision-aiding support system.
7	Training	Develop a training program to resolve the following questions: 1. During the pre-flight phase of a mission, what are the most effective and efficient methods of training? Is the current training model optimum? How do we apply adaptive training methods and achieve generalized skills (rather than particular procedure competence)? 2. During the in-flight phase of a mission, what training methodologies best support cognitive limitations and high-stress conditions? How can on-board systems be designed to address Just In Time (JIT) and recurrent (i.e., refresher) training? What are the impacts of mission duration on retention? 3. For both phases of the mission (pre-flight and in-flight), what is the appropriate mix of skill-based versus task-based training? What standards and proficiency levels can provide a reasonable level of assurance that the training is effective and that retention will be maintained? Products: (1) Training curricula requirements and guidelines, (2) training materials and systems, (3) assessment tools.
8	Procedures	Develop procedure guidelines/ templates to minimize the opportunity for error, maximize the opportunity to detect errors before they become problems, and minimize the consequence of undetected errors: 1. How can procedures be designed such that they build on operators' capabilities and compensate for operators' limitations? What type of information is needed in the procedure (pictures, video, text, etc.)? 2. How to determine the best way to format procedures to have the ability to present different levels of detail to different people (e.g.,

		expert vs. novice, engineer vs. management, and ground vs. on-orbit? 3. How can voice recognition and auditory instructions be implemented in procedures? Product: Tool (template), analysis of tasks and human capabilities, and methodology for procedure and checklist design and help determine procedure guidelines / templates.
9	Procedure Development	Develop guidelines and requirements for procedure development for future human-rated space vehicles: 1. Revisit requirements documents and see where requirements for reversibility of actions might be needed. For example, multiple crewmembers should not be able to execute simultaneous inputs into flight controls. 2. Formatting of procedures: Different levels of detail may be required for different people and operating environments, e.g., expert versus novice, engineer versus a human factors person, on the ground versus on-orbit? 3. Should the procedure be electronic, hard copy, or other? How will updates be handled? 4. How can procedure be standardized to be error-minimized and consistent across systems (when applicable)? Can a template be developed to help procedures writers better understand factors such as reliability, desensitization, and ease of use? 5. How will hard vs. soft switches be determined? How embedded should commands be within a procedure (a switch)? What elements of a particular task would lead to embedded command requirements? Products: Guidelines / requirements for the development of procedures, checklist, and templates
10	Display Sizes	Develop guidelines and requirements for proper sizing of the physical display screen (e.g., liquid crystal display) and the display formats (i.e., display windows) that are contained within each screen. 1. CEV crew station display integration and consolidation -- reduced

display real estate on CEV requires reduced suite of "top-level" display formats. What information should be contained in a group of top-level displays?

2. Shuttle display formats are based on a "single-display-single-Multi-function Display Unit (MDU)" philosophy in which the MDU is roughly the same size as the specified display format size. CEV provides the potential to incorporate larger crew station screens capable of displaying multiple display formats. What should be the dimensions and aspect ratios of the physical display screens and the smaller windows (display formats) within each screen?

3. What are the minimum size requirements (clearances) and location requirements for displays and controls for personnel wearing space suits (both pressurize and unpressurized)?

Products: Guidelines and requirements on display sizes, layout, real estate, and formats.

| 11 | Display Information Content | Develop guidelines and requirements for proper display information content:

1. What combination of flight management display format and stability augmentation software will enable manual flight control?

2. What is the best way to present integrated caution and warning system information to aid the crew in resolving malfunctions? What information should be contained on an advanced caution and warning system?

3. Designing for low cognitive load. There is a need in spacecraft design to compensate for the potential negative operational impacts and disorientations on performance. What intuitive interfaces and low cognitive demand procedures best improve those detrimental impacts?

4. Designing for sensory-motor deconditioning: How can workstations and displays be configured to minimize ergonomic problems involving operator state changes (such as sensory-motor deconditioning and fatigue)?

5. How can usability and readability of procedures be improved? What |

		information is needed in the procedure (pictures, caution and warning, etc.)? 6. What are the pros and cons of direct view (through windows) and indirect view (through displays)? How to integrate computer displays of a view? i.e., what kind of information does one include in an overlay; what is important for the crew to see? How to display an overlay to capture 3-D information? Would sensory augmentation be needed? Products: Guidelines and requirements on display information content. Some of the relevant topics for display information content include stability augmentation, advanced caution and warning system, spatial disorientation mitigation, sensory motor deconditioning, fatigue mitigation, procedure presentation, and automated information presentation.
12	Non-traditional Multi-modal Displays	Develop guidelines and requirements for non-traditional multi-modal displays, such as haptic, voice or head-mounted displays: 1. Determine the extent to which crew performance can be enhanced with non-traditional (multi-modal) displays. 2. What is the best implementation for an electronic visual display for the wearer? What are the requirements of information presentation for alternative displays (e.g., small displays, head-mounted displays)? 3. How can voice recognition and auditory instructions be implemented in emergency procedures for this kind of displays? What type of procedures will be used? 4. What are the requirements for head-mounted displays and information formats needed for the hands-free tasks associated with some of these displays? Products: Guidelines and requirements for non-traditional displays in terms of ergonomics and information display formats. Non-traditional displays examples include: helmet/head mounted displays, flexible displays, haptic displays, audio displays, etc.

13	Alarms	Warning desensitization is a pervasive problem throughout the commercial and NASA spaceflight community. During the previous eleven Expedition Crew Debriefs, crew members repeatedly commented on the overuse of caution and warning blocks within procedures. This project would result in guidelines/requirements recommendations for the characteristics of alarm events (that takes into account sensory modality, perceived urgency, task interruption, operational environment, etc.) and visual characteristics of warning labels within the NASA operational context (including color, font, content, and pictorial guidelines): 1. What is the most effective method of presenting alarms and alerts to a diverse crew? What international considerations will be used? Does the proposed method differ according to what type of activity the crew is engaged in (e.g. critical stages of flight, nominal EVA operations)? 2. When should auditory vs. visual alarms be used? 3. How can alarm desensitization be mitigated (e.g. minimizing false alarms, adequately defining "when to warn" criteria)? 4. Should the cautions and warnings for subsystems be integrated into the overall vehicle architecture (e.g. medical)? Product: Guidelines and requirements for the presentation of alarms.
14	Displays and Controls Ergonomics	Develop guidelines and requirements for displays and controls ergonomics: 3. What are the minimum size requirements (clearances) and location requirements for displays and controls for personnel wearing space suits (both pressurize and unpressurized). 4. Designing for sensory-motor deconditioning -- how can workstations and controls, be configured to minimize ergonomic problems involving variations in the operator's state (e.g., sensory-motor deconditioning, fatigue)? Products: Guidelines and requirements on D&C Ergonomics. Emphasis should be on physical requirements for different mission phases and

		how displays and controls should be tailored to mitigate sensory-motor deconditioning.	
15	Extra-Vehicular Activity (EVA)	The lunar sortie missions will require the crew to divide into two teams to conduct daily (or near-daily) EVAs of up to 8 hours duration. These teams will use the lunar rover vehicle to explore areas up to 20 km from the lander. 1. What information systems will be needed to support these missions? 2. Can these systems be validated with analog applications (such as Self Contained Atmospheric Protective Ensemble, or SCAPE, suits)? Product: (1) Tool that provides human error/system analyses, (2) quantified human reliability data, and (3) a "work effectiveness" metric similar to that being developed by the EVA group.	
16	Anthropometry – Space Suits	Research prototype suit configurations, making measurements to determine designs that will improve suit fit and functionality: 1. How can suits be designed to afford users greater dexterity with less stress and fatigue? This includes identification and classification of the tasks and task drivers that require dexterous performance. 2. Determine the affect of body shape changes on fit and mobility (e.g. 0-G transfer of body fluids, elongation of spine in 1/6 g)? Spinal elongation and its effects on pressure suit sizing -- will we need to resize the pressure suits? 3. What forces are exerted by personnel as they move and work inside a space suit and how to reduce the forces? There is a need by medical personnel of determining loads applied to various muscle groups during the course of an EVA; particularly on a reduced g surface. Products: Suit design guidelines	
17	Anthropometry – General Design Guidelines	Conduct lab studies on the movement, sizes, and strength of personnel in order to develop design guidelines: 1. More research is needed to create functional strength capabilities data, especially when wearing space suits. 2. What is the best design for tools that are to be used in space (under	

		various gravity environments and by personnel wearing space suits)? 3. What will be the translation requirements? (e.g., what is the hatch size requirement to accommodate a crewmember carrying an unconscious crewmember through the hatch?) 4. Crew-cockpit interactions under ascent/entry g loads -- research is needed on crew's capability to interact with crew station displays by the traditional methods of manual reaching / toggling switches and pushing buttons under the high and variable g forces during CLV/CEV ascents and entries. Product: Crew station design guidelines
18	Anthropometry – Human Models	Examine existing anthropometric data and CAD / human modeling software resources to determine the best data and software combination to meet designer's needs: 1. How can we modify existing human models to adequately represent the specified user population (e.g., reach, field of view, and visibility) in reduced gravity and be portable to other simulation environments? Product: Human modeling software and the accompanying anthropometric database
19	Function Allocation	Develop guidelines and requirements on function allocation for future human-rated space vehicles: 1. How should NASA determine which functions / tasks should be performed by flight crew / ground crew? What mission functions should be allocated to humans and what should be automated? When and how should dynamic and adaptive automation be utilized? How can all parties be kept informed of the actions of other agents involved in the procedures? Analysts would input functional requirements, system parameters, and crew resource information into the tool. The tool would make a recommendation (based on human and technology capabilities) for effective function allocation. 2. Procedures and automated checklists: Can the crew override

		inappropriate actions of automation? How can the crew be kept in the loop? What is the best way for humans to interact with the automation? How does the automation prioritize different actions or items such that they don't conflict with each other (e.g., completing checklists in parallel)? 3. What functions should be automated? Provide guidance to assist in ensuring that the functions that require human judgment and are not cost-effective to automate are designed to optimize the human contribution. Come up with more effective and cost efficient tools and processes for design / design analysis and automated monitoring of systems such as habitats, robots, rovers, etc. Products: Guidelines, requirements, and tools for mission function allocation design and correction of faultily executed automated procedures.
20	Automation Evaluation Tools Development	Develop guidelines and requirements on developing automation evaluation tools for future human-rated space vehicles: 1. Tools and techniques for evaluation of human interaction designs of automation systems, including robotic systems, rovers, teleoperated systems, piloting systems, control, monitoring, and fault management systems, scheduling / planning systems, as well as data analysis systems for habitats, health care, manufacturing and science operations. Tools and techniques for evaluating performance of human/automation "teams," with varying levels of autonomy, heterogeneity, distribution and mobility. 2. Adaptive cockpits - Modify information display and crew/automation functional allocations in response to real-time assessment of crew condition, information processing activities, and current capabilities. Software tools are needed to collect and analyze such measures in real time in order to 1) classify these activities as lying in the crewmembers nominal range, or deviating from that range, 2) matching the off-nominal pattern against a known performance moderator factor (i.e. this crewmember is excessively fatigued), and providing appropriate countermeasures (i.e., taking

procedural actions that are normally under crewmember control, automatically bringing up information displays, sounding an alert, etc.)

Products: Develop tools and techniques for evaluation of automation

| 21 | Robotics | Develop a tutorial and design guide to address the following questions: |

Develop a tutorial and design guide to address the following questions:

1. What are the key parameters to address in the design of multi-agent conditions (such as a crew member on a planetary surface working next to a robot that is being teleoperated by ground personnel)?

2. Given the context for a given operational scenario, what guidance can be usefully given to design engineers so that they consider all plausible alternatives within the design space, and minimize alternatives that are likely to result in sub-optimal designs?

3. What guidance can be given to designers regarding latency (delay) and error of communication when teleoperating a robot?

4. What are all known methods of human-robotic interaction, and what are the advantages and drawbacks of each, relative to type of robot and type of operational scenario?

5. Interfaces: Ensuring flexible yet consistent, intuitive, and safe interfaces to information and automation for both flight and ground crews is a fundamental challenge of space human factors. Human interface and interaction technologies for robotics assistants for IVA and EVA activities to perform tasks (boring and repetitious) such as housekeeping, sample collection, as well as be a "third hand" in repairs and exploration. Emphasis should be on handling delays and bandwidth limitations in remote operations and promoting situation awareness, supervision, cooperation, handovers, and phased shifts in autonomy level.

Products: Design guides that would explain the most important elements of the design and how to select design alternatives that are most likely to be successful. This guide would give useful parameters in the design space, such that hardware and software designers can be guided to

		consider a wide range of plausible alternatives during early stages for design. The guide would also point out how multi-agent concepts can be evaluated during early and late stages of development process. That is, the product would guide developers and human factors engineers on how to evaluate early paper prototypes from early in the process and how to evaluate later prototypes with high fidelity simulation.
22	Acoustics - Modeling	Develop computer-based acoustic environment model for known or proposed vehicle systems. The questions needs to be addressed are: 1. How can acoustic environment be modeled for known or proposed vehicle systems? 2. Based on an existing configuration and known acoustic environment, how can we model expected changes due to added equipment or equipment modification? 3. How robust is modeled prediction relative to measured acoustic environment of actual deployed hardware? Product: Computer-based acoustic model that predicts acoustic environment for a given set of installed hardware. The model would be high-fidelity, and verified with actual measurements on ground and on spacecraft. The model would allow easy inputs of proposed vehicle components such as ducting, pumps, fans, etc.
23	Acoustics – Requirements Development	Develop requirements for noise abatement for future space programs: 1. What type of noise abatement requirements, such as hearing protection and noise abatement for multiple-system integrations (e.g., payloads, comms, etc.), will be needed for future space programs? Product: Guidelines and requirements for noise abatement.
24	Lighting Design Aid	Develop a structured list of lighting considerations, guidelines, and questions to be posed to the system designers during initial design of spacecraft, habitations, and workstations. The document would either be useful for building lighting design paper checklists, or form the basis for a computer-based design aid. The user of the document is assumed to be a person with undergraduate education in physics or engineering, and

		terms specific to lighting analysis and design would be defined in the outline document. Useful relationships between units and definitions of lighting metrics would also be provided for review. Lighting considerations addressed in the outline would include the following: 1. Observer characteristics: age, states of adaptation, contrast sensitivity / acuity, and color perception 2. Visual task elements: field of view, contrast, object size (spatial frequency), and luminance contrast (light source luminance and surface reflectance) 3. Operational constraints: task requirements, light source / observer location / interaction, light source adjustability / portability, glare (direct and reflected), viewing equipment (helmet faceplates, windows, etc.), and color rendering Practical examples of issues and applications from spacecraft would be included. Product: Guidelines for design and requirements development
25	Lighting Tool Development	Develop a computer-based lighting simulation tool to assist designers and requirement developers in realistically assessing the effects of dynamic elements in the interior environment of spacecraft and other habitable spaces. Such elements might include the addition of various numbers of personnel, changes in positions of these personnel, placement of stowage items, installation of mobile equipment in the volume under consideration, and interactions with light sources outside the volume. The tool should also comprehend changes in the number and positions of light sources within the volume and first-order interactions with volume and equipment surfaces to predict potential glare sources and the effectiveness of portable lighting. Product: A lighting tool for designers and requirement developers
26	Labeling	Develop design guidelines, requirements, and training procedures for labeling of CEV and Constellation hardware products that address the following issues: 1. What is the proper format for labels to ensure consistent application

		across all Constellation programs? Formatting includes legibility of the labels. 2. How should items be labeled to help crew interface with hardware during the initial familiarization phase while, at the same time, not overloading the hardware with labels that might lead to desensitization of items once the crew is familiar with the environment (e.g., moving from a novice to expert)? Evaluate how novice and expert crew members view labels and see how/if their perception changes. 3. What are guidelines on determining when to use icons (e.g., safety, icons and medical icons)? Develop requirements or guidelines for graphic symbols that can be clearly understood and verified 4. How can or should industry standards be tailored for labeling for Constellation program? Does Constellation provide a unique environment that requires further investigation? Current issues on ISS include: too many labels being used, not operationally relevant, desensitization of labels, and not readable. Are these 'issues' due to weak requirements, lack of compliance to requirements, or requirements that are not tailored to this environment? This would include orientation coding and how crew decision and reaction time are affected.
27	Inventory Management	Product: Guidelines and requirements for labeling and decal icons Develop design guidelines, requirements, and alternatives for stowage and inventory management of CEV and Constellation hardware and consumables: 1. What inventory systems are best for given space flight contexts? What are the key aspects of inventory systems to be considered in designing inventory systems? 2. For a given context, what function allocation is appropriate -- what should be accomplished by crew, automation, and ground support? 3. How can radio frequency identification (RFID) tag technology be used to improve Inventory Management System? 4. What type of tracking system is needed for future vehicles and future

		habitation modules? What are the needs for each? Product: Tutorial-like guidelines to help system designers become more cognizant of the key aspects of their unique space flight context by presenting all the issues to be considered and discussing how to analyze the issues to determine alternative solutions. Based upon consideration of these aspects, an expert-system application would present potential design alternatives. These alternatives would include a specification of the function allocation among crew, automation, and ground support. In addition, an RFID tag system could replace or augment the existing barcode system.
28	Stowage	This research project will examine stowage design efficiency: 1. How to design stowage that allows greatest flexibility in packing by understanding the hardware capacity and changes in orbit? 2. Development of a tool (e.g., 3_D modeling) and design requirements that enables designers to produce better stowage configuration and geometry with enough flexibility. Product: Design Guidelines / Requirement Development Tools
29	Maintainability	This project will develop tools that enable assessment of issues such as lifecycle costs, and maintainability: 1. How can NASA ensure that system designers consider life cycle costs, and maintainability early in the conceptual design phase? 2. Can we develop a suite of advanced inspection technologies that address problems of accessibility, visibility, risk of collateral damage, as well as the lack of proven inspection tools / standards for new materials and processing techniques? Products: (1) guidelines for improved reusability/extensibility of systems; (2) an electronic information system that is adaptable to different work situations (and experience levels), and is linked to supporting information system such as parts catalogs, training modules, operational flow models, and lessons learned; (3) development and validation of advanced inspection technologies for identifying,

30	Human Factors Engineering Tools	measuring and characterizing components that may be damaged.
		Develop Human Factors Engineering (HFE) tools to better implement Human Centered Design and assist the Human Factors (HF) process for CEV and Constellation programs in addressing the following issues:
		1. How can we help design teams confirm estimates of volume, layout, visibility, work flow, and reach requirements relative to the architecture? Development of HFE tools, such as modeling tools (e.g., generic computer-aided design [CAD] modeling templates that would allow engineers to plug their specific data) and task analysis tools (e.g., Task Architect), to improve the accuracy and validity of the estimates.
		2. How do designers know what methodologies are appropriate and optimal for evaluating human-system interfaces? Tools can be developed to aid designers (e.g., a decision-aid using a simple wizard or check-list to determine the best and most efficient method for evaluating a design).
		3. How can tool selection, strength requirements, and location of restraints / mobility aids be used to support crew timelining? What method will be used in determining one-person versus two-person tasks? Crew timeline and crew task tools can be developed that could determine crew timelines, manpower for tasks, and the crew's physical interface with the system (e.g., tool location, need for restraint and mobility aids, accessibility, etc.)
		4. What simple verification tools can be used to help developers verify human factors requirements? What tools can best determine if crew can carry out the necessary tasks during nominal and off-nominal ascent?
		Products: Tools include, but are not limited to, (1) Modeling (e.g., generic CAD modeling templates that would allow engineers to plug in their specific data), (2) Task Analysis (guidelines, how to), (3) Generic Evaluation Plans (allow engineering to tailor it to their design), (4) HF verification (to be conducted by either HF engineers or designers), and (5) Integration (allow hardware developers the ability to look at systems as they are fully implemented into the design)

31	Design Capture	Develop methods for capturing and recording the logic and rationale of decisions made during the design process. This will help enable managers, designers and engineers identify the impact of changing assumptions, technology, or missions. In addition it will help them modify or reuse the design. The expected benefit is improved corporate knowledge and design efficiency. The task will address the following: 1. How can we fully document system designs including design philosophies, assumptions, and rationale, so that design knowledge will be accessible and reusable during operations and for design modifications and design reuse? 2. How can NASA ensure that information about mission objectives, design philosophy, and human operators' needs, limitations, and capabilities are considered early in the design process before design decisions are made? How can this information be better communicated and disseminated to designers, engineers, and researchers? Product: A distributed computer-based system that enables real-time archiving, synthesis, and retrieval of important design decisions and rationale.	
32	Usability Evaluation Center and Tools	Create a key facility to provide cutting-edge technology and expertise for designing and evaluating optimum human system interaction (HSI) for complex systems. Specifically, this project will develop standardized usability methods and tools: 1. Research into human factors evaluation methods and tools: In order to provide center of excellence in usability and HSI design / evaluation, the facility should provide expertise in system as well as human performance and workload modeling ("what if" predictions), a telepresence test bed, automated data acquisition & analysis tools, remote usability testing, and context aware usability (e.g., smart habitat) testing. 2. How can NASA determine which evaluation methods (or combinations of methods) are the most efficient? A tool or decision-aid needs to be developed to help designers select the	

		appropriate test(s) for human-system interfaces. An example is a decision aid using a simple wizard or check-list to determine the best and most efficient method for evaluating a design. 3. When should a heuristic evaluation be conducted versus a usability test or subject matter expert review? 4. When should a fast-time simulation be used versus a real-time, human-in-the-loop simulation? 5. How can we develop standardized usability methods of evaluating commercial off the shelf (COTS) products? Need to develop guidelines that incorporate usability COTS tradeoff considerations for spacecraft operations, reduced-g, medical devices, user capability level (novice to expert), and other specified options. Product: A collaborative testing and evaluation environment be established between JSC & ARC to provide human factors impromptu services (e.g., consulting on design and evaluation, usability testing, etc.) for internal and external customers. Collaborative and standardized evaluation tools and decision aids will need to be developed for the testing /evaluation environment.

33	Human Reliability and Risk Management	Human risk analysis tools can provide preliminary estimates of human error as well as red flags for situations that need further investigation to determine actual risk to humans or missions:
		1. How can NASA make more informed decisions about system-level risk that include elements of human reliability?
		2. How to design a robust and reliable system free from human errors?
		   a. How to evaluate the design, anticipate those errors and design a system that recovers from those errors?
		   b. What is the reliability of the human for different tasks and in various operating modes?
		3. A database of performance shaping factors (PSF) (factors that are known to degrade or improve human performance) specific for NASA exploration-specific tasks is required.
		4. Risk assessment tools are required that utilize the PSF database to generate predictions of human error and human reliability and

identify situations that may challenge humans to perform optimally.

a. The data would be a set of numbers (similar to hardware reliability numbers) which would predict the chance of human failure. The data would be specific to tasks and working environments. These data would allow engineering to incorporate the human into their analyses and develop a realistic safety assessment that includes human error.

b. In addition, there may be a set of procedures for estimating human reliability in unique task situations. Quantification of human performance reliability would help strengthen HFE input to design

Product: (1) Tool that provides human error/system analyses, (2) quantified human reliability data, and (3) a "work effectiveness" metric similar to that being developed by the EVA group.

Appendix E
Results of Stakeholder Review

Gap Topic	Score			Weighted Score
	High	Med	Low	
Display Information Content	4	1	0	14
Display Sizes	3	2	0	13
Displays and Controls Ergonomics	3	2	0	13
Behavioral Health and Performance - Cognition	3	1	1	12
Acoustics - Modeling	2	3	0	12
Teleoperations	2	2	1	11
Communications	2	2	1	11
Crew scheduling tools	2	2	1	11
Training	2	2	1	11
Alarms (Displays & Controls)	2	2	1	11
Anthropometry – Space Suits	3	0	2	11
Automation Evaluation Tools Development	3	0	2	11
Labeling	2	2	1	11
Stowage	3	0	2	11
Human Performance Models for Display Evaluation	2	1	2	10
Procedures	1	3	1	10
Function Allocation	2	1	2	10
Acoustics – Requirements Development	1	3	1	10
Lighting Design Aid	1	3	1	10
Inventory Management	2	1	2	10
Medical Procedures	1	2	2	9
Extra-Vehicular Activity (EVA)	1	2	2	9
Anthropometry – General Design Guidelines	1	2	2	9
Robotics	1	2	2	9
Lighting Tool Development	0	4	1	9
Maintainability	1	2	2	9
Human Factors Engineering Tools	1	2	2	9
Human Reliability and Risk Management	2	0	3	9
Non-traditional Multi-modal Displays	1	1	3	8
Usability Evaluation Center and Tools	1	1	3	8
Procedure Development	0	2	3	7
Design Capture	1	0	4	7
Anthropometry – Human Models	0	0	5	5