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Implementation of Human System Integration Workshop at NASA for Human Spaceflight

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Abstract

The human is a key element in the complex system of systems underlying space exploration missions. As a critical system, its operating bands and requirements need to be characterized and integrated with other systems. Optimal integration of the human system with hardware and software elements has an impact on multiple aspects of mission execution, including human health and performance, risk mitigation, effective design and functionality, enhanced safety, and reduced lifecycle costs. The field of Human Systems Integration (HSI) represents an interdisciplinary and comprehensive cross-cutting approach encompassing technical and management processes for integrating human as a system consideration and objective within and across all other system components and multiple domains. In addition to human activities, HSI covers training, operations and support dimensions. Moreover, HSI is an essential enabler to systems engineering practice, emphasizing human system aspects toward optimizing fully integrated system of systems performance while systematically infusing the needs of all users during the earliest stages of development. Consistent with the National Space Exploration Campaign, NASA is developing the Gateway, a lunar orbiting platform that will serve as astronaut habitat, support transit to deep space, validate new technologies and systems, and function as a science laboratory and communications hub, among other uses. It is an essential element of a phase that will extend human exploration into deep space through evolvable infrastructure and advanced technology, supporting assembly and logistics of other exploration architecture elements. In an effort to explore the current status and forward plan of HSI implementation in the mission (system of systems) lifecycle, the HSI Employee Resource Group conducted an HSI workshop using the Gateway Program as a case study. It revealed how different organizations at the Johnson Space Center incorporate HSI in their processes in preparation for the development and operation of the Gateway. The workshop focused on HSI methodology for implementation of the six NASA HSI domains: Human Factors Engineering, Operations Resources, Habitability and Environment, Maintainability and Supportability, Safety, and Training. Results from the workshop are reported on this paper, as well as some historical background of HSI at NASA, and the success in using an Employee Resource Group to promote technical knowledge. The authors hope that this information can be used to disseminate best practices for translational applications to other space exploration systems.

Keywords: Human Systems Integration, NASA, Systems Engineering, NASA HSI Domains, Employee Resource Group, System of Systems, Human as a System

Acronyms/Abbreviations

ARGOS: Active Response Gravity Offload System
CAST: Crew Autonomous Scheduling Test
CDR: Critical Design Review
ConOps: Concept of Operations
CREAM: Cognitive Reliability and Error Analysis Method
DDT&E: Design, Development, Test, and Evaluation
DoD: Department of Defense
EED: Electronic Engine Display
EMU: Extra-Mobility Unit
ERG: Employee Resource Group
FOD: Flight Operations Directorate
HCD: Human-Centered Design
HITL: Human in the Loop
HFE: Human Factors Engineering
HSI: Human Systems Integration
H/W: Hardware
ITAR: International Traffic in Arms Regulations
JSC: Johnson Space Center
NASA: National Aeronautics Space Administration
NPS: Net Promoter Score
NPR: NASA Procedural Requirements
OCE: Office of Chief Engineer
PDR: Preliminary Design Review
PFD: Primary Flight Display
SE: Systems Engineering
SEE: Systems Engineering Engine
S/W: Software
xEMU: Exploration Extra-Mobility Units

1. Purpose of the Human Systems Integration (HSI) Workshop

1.1 HSI Workshop Goals

The Human Systems Integration (HSI) Employee Resource Group (ERG) at the National Aeronautics and Space Administration (NASA) Johnson Space Center (JSC) organized its first Human Systems Integration Workshop on April 9th, 2019. The purpose of this one-day professional development event was to facilitate participants understanding of the state of HSI at JSC, and to identify how the six NASA HSI domains (1) Human Factors Engineering, (2) Operations Resources, (3) Safety, (4) Habitability and Environment, (5) Maintainability and Supportability, and (6) Training are applied to mission requirements, including verification and validation methods. The workshop hosted a speaker from NASA Headquarters who provided an update on HSI at the Agency level, and JSC presenters discussed the new Gateway program. The Gateway program serves as a proving ground for technologies that are expected to help meet lunar mission goals while testing advanced technologies, such as autonomous systems for human missions to Mars. For the Workshop, the Gateway program was selected as the case study.

1.2 The JSC HSI ERG

The HSI ERG is one of nine ERGs at JSC. ERGs are a catalyst for ensuring an inclusive and open work environment. The Office of Equal Opportunity & Diversity oversees all ERG activities on behalf of the Inclusion & Innovation Council at JSC.

In support of the Inclusion and Innovation Initiative, the JSC HSI ERG promotes HSI education and awareness. The ERG's mission is to promote cross-directorate interaction in support of establishing an HSI vision, methodology, and implementation plan. The goal of the ERG is to provide a forum where diversity of thought is acknowledged and developed into ideas supporting complex system of systems necessary for human space flight. The HSI ERG actively recruits and on boards employees offering numerous avenues, such as this workshop, for employees to develop critical skills and contribute unique insights to support JSC business challenges and NASA's missions.

2. What is Human Systems Integration?

2.1 HSI in a Nutshell

HSI is defined as the interdisciplinary technical and management processes for integrating human considerations within and across all system elements. It is a robust process in which human capabilities and limitations are effectively and affordably integrated with system design and development. HSI is also an essential enabler to systems engineering practice [1,2]. Fig. 1 shows the traditional and HSI system views. The latter shows a more accurate representation of a system as not just hardware (H/W), software (S/W), and concept of operations (ConOps), but also the human for total system capability (crew, maintenance, training, etc.). HSI treats the human as a system and considers the human throughout the lifecycle, including analysis, design, operations, and maintenance and/or disposal, and all phases in between. HSI practitioners help bridge the knowledge gap between the H/W, S/W and the human to ensure the human is treated as part of the system. Given the complexity of human spaceflight, this is translational to system of systems [3].

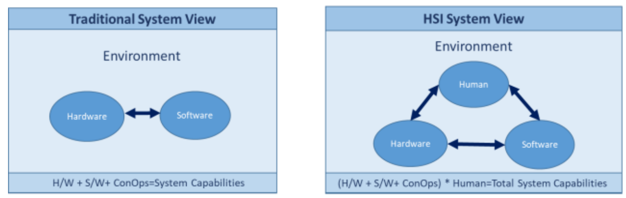

Fig. 1. Traditional and HSI System Views

One benefit of successful HSI implementation is a reduction in total system lifecycle costs. Systems are not limited to hardware or software, the human must be included as part of that system. Users of a system are tightly integrated components in a systems of systems application. For example, in an automated system, a group of people develop the software. If an issue arises, humans do the troubleshooting. Unlike hardware and software, however, humans are influenced by cognitive and biological factors that are difficult to model or analyze. Furthermore, human as a system is not limited to the end user, or the astronaut. In HSI, any human interacting within the system of systems is assessed as another system. For example, personnel supporting shipping and packaging of supplies make up a component of a complex system integrated into spaceflight missions and are important for mission success. System complexity demands an integrated design approach of multiple human factors areas. To ensure achievable mission goals and performance human factors areas of consideration often include the health and safety of astronauts and interactions between all system users in a variety of environments. The HSI Practitioner's Guide, a part of the NASA Systems Engineering Handbook, defines HSI processes across the lifecycle of a product or mission; highlighting the importance of considering human capabilities and limitations early in the mission lifecycle [1].

2.2 Rationale for HSI at NASA

Until 2013, NASA had no mandate to include HSI in programs. However, NASA has always considered the human in the safety, health, and performance of human spaceflight missions. To optimize aerospace systems and reduce human error, human in the loop (HITL) training and testing are an integral part of the development effort. In 2013, the NASA Systems Engineering Processes and Requirements, NPR 7123.1B, was updated to include a HSI definition and required all NASA programs and projects to address a HSI implementation plan as a deliverable [4]. In 2016, the NASA Systems Engineering Handbook was updated with several pages of material associated with applying HSI in a program/project. Around this time a HSI Practitioner's Guide (NASA/SP–2015-3709, 2015) was developed to support incorporation of HSI into projects [1]. Collectively, these documents provide a formal framework to implement HSI for NASA projects.

HSI objectives are consistent with NASA's need to develop and operate systems in affordable and cost effective ways, while also controlling safety and mission risks within suitable levels. Cost savings may occur through a reduction in required personnel support, the practice of Human-Centered Design (HCD), decreased reliance on specialized skills for operations, shortened training time, efficient logistics and system maintenance, and fewer safety-related risks and mishaps due to unintended human system interaction [5].

Fig. 2 shows program/project cumulative committed lifecycle costs and cost to make a design change over time [6]. Note that only a small fraction of the overall lifecycle budget is spent during Phase B of a program; however, by the time Phase B is completed, approximately 70 percent of the lifecycle cost of the program is committed. Also, note that depending on what phase the program/project is in, a design change costs grow exponentially, particularly after Phase C or Critical Design Review (CDR).

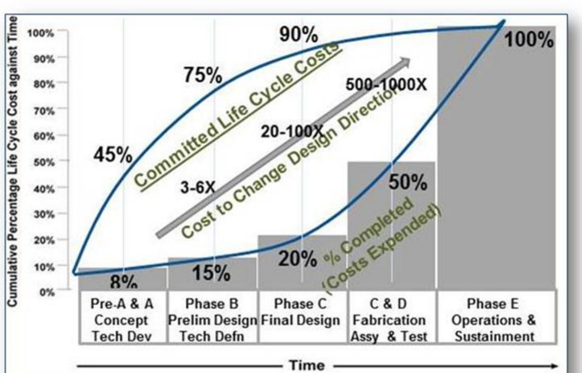

Fig. 2. Lifecycle Cost Commitment (Credit: INCOSE Handbook, 2007)

Though attention is typically focused on the Design, Development, Test, and Evaluation (DDT&E) phases, most of the total lifetime cost of ownership occurs during operations and sustainment that are critical from a mission and readiness perspective. Failure to take into consideration the operations and sustainment of the system early in the program/project can result in large operations costs. An example is the Space Shuttle Program. The Shuttle Program was proposed to Congress as a cost-effective way for low Earth orbit. Shuttle ConOps were considered similar to a commercial jetliner. As shown in Fig. 3, the actual ground processing and operations took over 25,000 workers and months to process one vehicle. The insufficient definition of operational requirements during the development phase, and concentration on performance requirements but virtually none on operational considerations, greatly contributed to a space vehicle that required intensive and costly ground processing [1]. Hence, HSI must be considered and established early in a program/project and applied iteratively throughout its lifecycle.

Fig. 3. Original Shuttle Ground Processing Concept (left) versus Actual (right)

2.3 State of HSI at JSC

The introduction of a formal HSI process in 2013 in NRP 7123.1B marked a shift in NASA's culture resulting in changes to requirements and implementation processes. Further efforts have since been made to incorporate HSI early and often to encompass the lifecycle of a project. For example, development of the HSI Practitioner's Guide in 2015 provided guidance to the day to day HSI practitioner describing the HSI needs at all stages of a project. In addition, NASA offered training courses such as the HSI Implementation Training Class, HSI Practitioner's Guide Training, and an Introduction to Human Systems Integration across various directorates to support increased knowledge of HSI at JSC. As the JSC HSI community grew, the HSI principles began to cross directorates providing increased visibility across the Center. An increasing demand for HSI related content led to the development of the April 9th, 2019 HSI Workshop.

3. HSI Workshop Planning and Implementation

3.1 Planning Process

Planning the HSI Workshop was a collaborative process. The bulk of the organization fell to the executive board of the HSI ERG. Representatives from the Office of Equal Opportunity and Diversity also helped with procurement and logistics. Weekly face to face meetings allowed the planning team to pool resources and ensure consistent effort for all workshop needs, and provided structured time for using organizational tools such as a logistical tracker spreadsheet. This tracker became a centralized location for all event information and was an excellent tool to ensure efficient and consistent progress was made on each action.

The planning team utilized the HSI SharePoint site that allowed all members to store, edit, and track all Workshop documentation as it was created. Logistically this was helpful when creating the material to be used on the day of the event. In preparation for the day of the event, each presenter uploaded their presentation to the HSI SharePoint site. This allowed a single computer to be used during presentations leading to a decease the setup time between presenters and minimized the chance of technical difficulties.

Workshop advertisement was a significant consideration in the planning process. The planning team used a top-down and bottom-up approach. Invitations to senior leadership were sent out requesting the attendance of management representatives of each JSC organization, and to encourage their employees to attend the Workshop. A flyer was created to advertise the Workshop and then uploaded to the SharePoint. Once on the HSI SharePoint, all members assisted in the distribution of flyers. JSC's high traffic areas were identified and larger posters were created and posted in these areas. Additional advertisements were sent to all employees in JSC's daily electronic digest. These efforts resulted in a full workshop registration list with a waitlist.

3.2 Technical Program

From a technical standpoint, it was important to address technical diversity and create a high level of engagement. The planning team identified presenters from different projects and disciplines allowing participants a holistic view of HSI and all of its domains. Impacts of HSI are far reaching, so it was understood that the content of the workshop should be as well. Everything from software methods, real-life experiences, and how to implement HSI thinking from management. This intentional effort allowed the HSI ERG to illustrate the broad range of HSI impact across disciplines via tangible examples of the implementation in various projects and programs.

The day opened with a keynote speaker providing an overview of the Gateway program and HSI domains. Eight JSC organizations then presented 15 minute status presentations of HSI in their organization in either the "where we are" or "where we are going" sections. This equipped the participants with the knowledge and tools they needed for the afternoon working group session.

Working groups played a key role in the structure of the workshop to reach a high level of participant engagement. Working groups design ensured all members of the group felt heard, stayed on time, and had quality content to share at the end of the day. Members of the HSI community served as facilitators and attended training prior to the event. Facilitators learned the basics of managing a group discussion and mitigating potential issues which helped working groups run smoothly. The workshop agenda is provided in Appendix A.

3.3 Use of HSI Domains and Verification and Validation Exercise

One workshop objective was to increase discussion and experience with HSI verification and validation practices. To this end, participants were divided into one of six HSI domain working groups. Each working group used a fast paced process to derive conclusions on verification and validation methods for HSI requirements based on given assumptions for the Gateway Program. Facilitators first ran through requirements brainstorming session, then narrowed it down to a few requirements to focus on for verification and validation methodology discussions. After each of the working groups completed the exercise, everyone came together to present their results to the whole group of workshop participants, resulting in cross-domain discussions. The presentations highlighted the interconnectivity of domains, as well as, increasing the understanding of different verification and validation methods.

4. Outcome of the HSI Workshop

4.1 Presenters and Presentation Summaries

Dr. Vincent Michaud, Deputy Chief Health and Medical Officer at NASA HQ, who is also the Agency Champion of HSI, served as one of two keynote speakers. In his overview of HSI at NASA, he explained that given the unprecedented period of development and design with various hardware and vehicles for future space missions, there is a push for HSI across the Agency. However, he stressed the need for a culture change before HSI is fully embraced, citing two reasons behind the current hesitancy: (1) Unclear, varied, or lengthy definitions of HSI, and (2) HSI as an unfunded mandate. To address these concerns, NASA Headquarters formed an HSI Tiger Team, charged with re-defining HSI, developing goals and a vision for HSI, and overseeing the implementation of HSI across the Agency. Dr. Michaud emphasized the need for "top-down advocacy and leadership emphasizing the human in design, training, and operations." The benefits of HSI and risks associated with a lack of HSI need to be communicated across the Agency. After all, HSI is embraced in various industries because it saves money by avoiding changes made later in the design cycle, avoiding human-centered mishaps, and reducing risks and schedule delays due to redesign.

Dr. Jennifer Rochlis, Chief of Human Systems Engineering & Development Division, presented the origins of the HSI ERG. Dr. Rochlis, along with George Salazar, Dr. Deborah Neubek, and Dave Fitts, co-founded the ERG in 2012. The primary motivation stemmed from the perception that no one at NASA seemed to be doing HSI. Dr. Rochlis acknowledged that, in reality, people may have been doing HSI work, but may not have known what to call it. JSC Employee Resource Groups traditionally encompass underrepresented groups and are not technical in nature. However, the co-founders proposed the idea of an HSI ERG since HSI practitioners are underrepresented, and they wanted to identify individuals who were practicing HSI to pool their resources together. The ERG turned out to be a fantastic platform; however, some constraints came along with having a non-traditional ERG. For example, the co-founders were required to form a separate group to develop the NASA's HSI Practitioner's Guide. The co-founders' goal for the ERG was to put themselves out of business after five years because they hoped HSI would gain enough traction, and would no longer require an ERG. However, that is not yet the case at NASA.

Mr. Mychal Miller, Systems Engineer, provided an overview of NASA's HSI Practitioner's Guide. The Guide created a framework for Practitioners to do HSI more quickly, while offering guidance for managers and others involved with the process. The Guide attempts to cover all points where humans and systems interact and offers phase by phase guidance and HSI best practices. Each design phase was developed as a practitioner's starting point because they may be pulled into a project at any time, not just at the beginning. For example, a practitioner may walk into a project where requirements have already been developed. The Guide includes a checklist and an annotated outline to help a variety of HSI users and practitioners.

Mr. Dennis Pate, Human Factors Engineer with Safety & Mission Assurance, explained that JSC's Safety & Mission Assurance office keeps a record of significant incidents and close calls. This office maintains a lessons learned database that can be utilized by the NASA community. However, challenges include (1) Gathering the information (e.g., not every event or incident may be reported); (2) Sharing the information (e.g., International Traffic in Arms Regulations (ITAR) restrictions); and (3) Communicating the information (e.g., difficult to capture peoples' attention, and to create visualizations that do not skew or bias the data). Mr. Pate discussed how the lack of HSI may have contributed to significant incidents in human space flight, highlighting the need for NASA to capture corporate knowledge and lessons learned for future use.

Ms. Ginger Kerrick, Chief of the Flight Integration Division, explained how the Flight Operations Directorate (FOD) practice HSI throughout the design process. FOD stresses the importance of following HSI principles to ensure a smooth transition from the design and development stages of a project to the operations stage in which the end user directly interfaces with the new systems. To that end, HSI should be considered early in the design phase and include end-users in the conceptual stages. As FOD personnel (crew and ground controllers) are often the end-users of these systems, they have a particular interest in ensuring the design is easy to operate. Ms. Kerrick encourages her team to "get involved early in the design process, because that is where you can affect the most change." For example, the Gateway vehicle is now planned to have a window, which was not always the case. Ms. Kerrick explained that a window is not only beneficial from a crew psyche perspective, but also from a payload perspective considering the number of payloads that make use of windows on the International Space Station (ISS).

Mr. Bill Othon, Associate Chief of the Aerosciences and Flight Mechanics Division, and Gateway Test Lead, echoed Dr. Vincent Michaud's sentiments during his discussion on an upcoming fleet of new vehicles and the importance of HSI early in the design process. He stated the importance of ensuring the interoperability of different vehicles and building realistic testing environments. For example, because NASA and its partners do not have access to the intended operational environments (e.g., Moon's orbit and surface), teams need to "build [realistic] mockups, and deal with the fact we're not in zero-g." Mr. Othon discussed specifics on NASA's NextSTEP program, a multi-disciplinary effort across NASA centers and industry, to prepare and evaluate Gateway habitat design concepts. This process involves creating mockups and crewed simulations on the ground to ensure habitats work as designed. Autonomy and establishing trust in automation will be a major challenge with Gateway due to long periods of time when the vehicle will be uncrewed. The levels of autonomy include: (1) Uncrewed, (2) Vehicle and Mission Control, (3) Vehicle, mission control, and crew, and (4) Vehicle and crew.

Ms. Angela Bauer, Branch Chief of Aircraft Engineering and Ms. Taylor McCanna, Aerospace Engineer, discussed HSI in aircraft operations. Specifically, aircraft that support spaceflight readiness training and other aircraft operations (space-bearing cargo). NASA utilizes T-38 jets to train crewmembers before space missions. These are old jets, but avionics upgrades have been done over time. Some crewmembers have never flown an aircraft, let alone a high-performance jet. However, NASA wants to ensure crewmembers' first time flying is not on a spacecraft. When flying, crewmembers need to make quicks decisions. To aid in immediate decision-making aircraft cockpits communicate the best information in the best way. For example, the fire warning, which is one of the most important and worst warnings an operator can get, is indicated by four lightbulbs and two warnings displayed at eye level for attention-grabbing purposes. Design intuitiveness is a key factor. For example, the landing gear switch is shaped like a wheel. Redundancy is also important. For example, the Electronic Engine Display (EED) can be turned into the Primary Flight Display (PFD) if there is a failure with the EED. Displays should also protect against inadvertent activation. For example, there are red guard-switches, which force an extra decision and protect against human error.

Mr. Jason Hutt, Orion Crew Systems Integration Lead, described the current push for Orion design completion. Orion is designed to hold four crewmembers, with the first crewed mission planned to occur in about two or three years. HSI is relevant to all human interfaces planned for Orion, including crew module, launch abort vehicle, and service module. For example, the general cabin layout was designed for seat pads to be stowed once crews reach orbit to increase the habitable volume for a mission of up to 21 days. This configuration has been tested on the ground. Orion also has three landing orientations with ground teams testing each to ensure crews egress the vehicle safely and as expected. An operational walkthrough performed with 14 participants (13 flown and non-flown crewmembers and 1 Flight Director) allowed for the identification of several usability studies. These identified HSI issues not detectible in isolated tests. For example, the hygiene bay door hinge was found to block the exercise device from being used at the same time.

Dr. Matt Healy, ISS flight controller, discussed the Crew Autonomous Scheduling Test (CAST) technology demonstration on the ISS. Current standard practice is for the ground to use the ISS Planning Flowchart to develop a schedule that is logical and efficient. This schedule is built generically and not customized to crews' personal preference. For example, some crews may want to exercise after eating. The purpose of the CAST investigation was to give the crew a limited degree of control over their schedule for the day, rather than the ground dictating the schedule. Giving crews control of their schedule could be beneficial in multiple ways for missions on the ISS and future missions beyond low-Earth orbit (e.g., Moon and Mars). Crew control could (1) Mitigate communication latency, intermittent communication, and limited bandwidth; (2) Enable crews to contribute to best manage their schedule; and (3) Minimize idle time waiting for Mission Control responses. The investigation used an experimental design format and revealed crew-planned days were planned and executed successfully. Also, the crew scheduled what the investigators thought they would schedule (i.e., crew scheduled tasks based on priority and duration.) However, this investigation and its potential use in the future may require a paradigm shift in ConOps. Also, the ground does not want to burden crews who have limited mission planning experience, and the ground still needs to ensure constraints are retained.

Ms. Megan Haught, Risk Analyst, developed the CREAM HRA Calculator (CHRAC), where CREAM stands for Cognitive Reliability and Error Analysis Method and HRA stands for Human Reliability Analysis. This tool was designed to estimate human failure probabilities in events. The CREAM process breaks down a specific event and calculates a failure probability for each piece. There are five steps, including: (1) Failures and recovery actions,(2) Cognitive activity matrix, (3) Cognitive demand failures, (4) Weighting factors for common performance conditions, and (5) Cognitive failure probabilities. Ms. Haught explained human failure probabilities in space can be evaluated using CHRAC. She demonstrated its potential using a seemingly simple event (making a cup of coffee with a specific coffee maker). She found that while the coffee maker never experienced a hardware failure, that the operation failed a number of times due to human error.

Mr. Ben Greene is the Systems Engineering & Integration Lead for the new Exploration Extravehicular Mobility Unit (xEMU), a suit designed for future missions to the Moon. During the design process thus far, the xEMU team has used lessons learned from the original EMU design from 40 years ago, performed HITL testing, implemented space medical standards, collaborated with experts, and developed a systems engineering team. xEMU was initially demoed on the ISS. Although this enabled ground teams to collect useful data, the ISS is not a perfect analog since there is not much dust onboard (in contrast to the amount of dust on the Moon.) Different teams are working on different parts of the suit. For example, there is a team building a life support system, and a team working on informatics. Mobility is a major focus of the xEMU for lunar surface operations. Compared to the EMU, the xEMU has reduced bulk and hardware obstruction. The xEMU helmet also enables better visibility because of improved visor design and the bubble shape of the helmet. Task efficiency and situational awareness are also improved via informatics (navigation and displays controls.) Although HSI was not a requirement, the team chose to embed and embrace it throughout the design process. For example, there are domain experts on the team, including co-authors of NASA's HSI Practitioner's Guide and HSI-trained personnel. The team also has significant engagement with stakeholders and experts in a wide range of technical areas, and uses the Practitioner's Guide as a checklist and product maturity matrix.

Ms. Debra Ludban, Deputy Manager of Gateway Vehicle Systems Integration, served as the workshop's second keynote speaker. Gateway, which is being designed for a 15-year life, should accommodate four crew members at a time. Like the ISS, the Gateway Program is an international effort, meaning that there are ground teams and crews from the United States and other countries. The Gateway Program is incorporating lessons learned from the ISS Program as the vehicle is being developed. Gateway is currently planned to start with 30-day missions including science and technology demonstrations. The ISS Program is transforming into a future capability team, and there is a need to consider how NASA and its partners can develop a smaller station concept (Gateway) to get back on the Moon. Since the ISS in low-Earth orbit, crews can get back to Earth in a few hours if needed. It is also known how humans respond to low-Earth orbit environmental conditions, and capabilities exist to launch mass to the ISS. However, missions beyond low-Earth orbit will differ. A mission to or from the Moon could take days, and entry velocities will be much higher. This will multiply for Mars missions. Ms. Ludban emphasized that NASA and its partners will need to get back to the Moon in a way that is innovative and sustainable. They will also have to think about a gradual buildup of capabilities (e.g., technologies that will be needed.) Sustainability will also call for some reusability. For example, NASA and its partners plan to re-fuel the Lunar Surface Lander in lunar orbit to minimize costs.

Dr. Sherry Thaxton, Systems Engineering and Integration (SE&I) and HSI Lead for Gateway, discussed collaborative relationships as a requirement for HSI practitioners. Dr. Thaxton helps coordinate Gateway working groups based on NASA's HSI Practitioner's Guide allowing integration and contributions of subject matter experts. The HSI plan for Gateway is currently in draft, but the team is working to capture deliverables and key milestones while taking a lean approach similar to the commercial sector that minimizes requirements and formal verifications.

Dr. Gordon Vos, Discipline Scientist & HSI Subject Matter Expert, gave an overview of HSI and NASA's HSI domains. At NASA, organizations tend to be vertically siloed. However, HSI domains, which tie in at every single interaction cycle, try to break down those silos. Fig. 4 highlights the purpose of each domain.

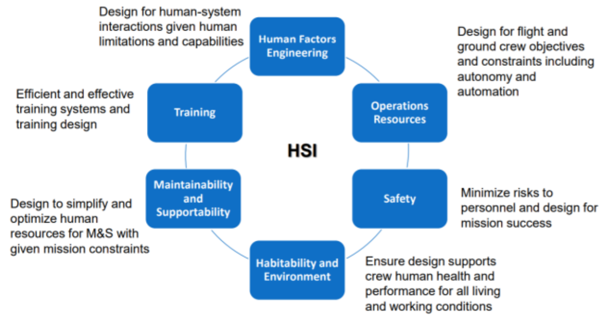

Fig. 4 NASA HSI Domains (Credit: Dr. Gordon Vos)

4.2 HSI ERG Going Forward Discussions

Mr. George Salazar, Chief Engineer of the Human Interface Systems Branch, facilitated an open discussion with workshop participants on the role of the HSI ERG promoting HSI at JSC and NASA in general. Topics included updates to NASA's HSI Practitioner's Guide, retention, training, and the facilitation of an HSI Community of Practice. Dr. Jennifer Rochlis proposed that attendees consider the benefits and limitations of an HSI ERG. "What do we form outside of the ERG to do good work?" Every technical directorate interprets how to do HSI in a slightly different way. She thought we need to allow for that, assuming the framework is the same. Dr. Rochlis also discussed the importance of HSI advocacy from the headquarters level. Mr. Salazar said that there is a hope that NASA will get to the point where an HSI ERG is not needed. Perhaps instead of an ERG, NASA could create a Community of Practice. Dr. Eileen Stansbery, Chief Scientist and Deputy Director of the Exploration Integration and Science Directorate and the HSI ERG co-executive sponsor, discussed the advantages and limitations of ERGs and Communities of Practice. "A Community of Practice can have broader inclusion within a community, which includes both employees and mid-level managers, which have an interest in or are stakeholders in a field. ERGs can take interested individuals that may not be practitioners of that discipline, but Communities of Practice typically only encompass practitioners. ERGs have broader reach ability. To have both at JSC is a value. We need to take advantage of the differences."

Ms. Christie Sauers, Deputy of the Orion Cockpit Working Group, facilitated an open discussion with workshop participants about the future of HSI at NASA. A key focus of NASA's HSI Practitioner's Guide is having an HSI plan and a team to execute a plan. However, she asked how one would evaluate if the right people are in those roles. Dr. Jennifer Rochlis explained that this can take years to cultivate. She thinks it helps to have a little perspective and subject matter expertise from everywhere. Those in leadership positions have to figure out how to staff and train the workforce. Ms.

Sauers emphasized the need to seek the right people. HSI needs to be there from beginning to end of the project, not for a phase here and there. One participant discussed problems of implementing HSI, and asked how much time should be dedicated to HSI planning and implementation. Another participant answered there is no magic number or formula. They suggested looking at the breakdown of tasks based on NASA's HSI Practitioner's Guide, and do a best estimate from bottom-up. They also suggested planning for iterative HITL testing. Ideally, HSI will become embedded in every phase and not called out specifically. Ms. Sauers added that there are case studies in NASA's HSI Practitioner's Guide and the HSI ERG SharePoint that show trade studies.

4.3 Working Group Summaries on Gateway Program Case Study

Prior to splitting up into Working Groups, Ms. Tiffany Swarmer, Aerospace Human Factors Specialist and Crew Systems Instructor, led all participants through a high level overview of Working Group expectations, and a quick ice breaker exercise, where participants brainstormed system requirements and validation and verification methods for a new drip coffee maker.

Each working group proceeded to run a learning exercise to formulate big picture requirements and possible verification and validation methods given some Gateway assumptions to present their findings at the day's conclusion.

Human Factors Engineering Working Group developed many requirements, including range of motion and anthropometry, performance capability, human error, usability of the system that controls the displays, systems monitoring, and the environment. While developing the requirements, the group noticed some overlap with other domains, such as safety, and training. The group focused their discussion on three high-level aspects: performance, usability, and systems monitoring; and narrowed them down to two specific requirements, for which they developed verification and validation methods:

(1) The crew shall be able to respond to an emergency within X number of seconds to safely complete X task.
   a. Verification method: Demonstration
   b. Validation methods: HITL, simulation, table top exercises (crew evaluation)

(2) The system shall comply with international standards.
   a. Verification method: Inspection by checklist
   b. Validation method: Reference documents

Operations Resources Working Group discussed autonomous data logging for Gateway and settled on two requirements, each with the same verification and validations methods:

(1) The system shall log data while the vehicle is untended such that crew can utilize data to make operational decisions.
(2) The system shall allow a search of the recorded data. Guidelines: Search results should be returned in X period of time, and search results should have X degree of accuracy.
   a. Verification methods: Test data logging capability, the test response time of the query system, demonstration of the search capability, analysis of the usability of the search results
   b. Validation method: Operational test in an analog to validate the capability

Maintainability and Supportability Working Group emphasized that critical elements of Gateway must have common interfaces and maintainability requirements. This group developed three requirements, each with the same verification and validation methods:

(1) Define what Gateway systems shall be maintainable by crew or robotics.
(2) Define common interfaces for all maintainable systems.
(3) Critical hardware shall have robotics interfaces.
   a. Verification methods: Review drawings to verify sizing/shape of tool interfaces; perform software testing, human/robotic interface testing, hardware interface testing (place tool on the interface); demonstration with hardware to show robot can grab the hardware.
   b. Validation methods: Perform fit checks, virtual reality demonstration, maintenance as crew or robotically. For example, demonstrating robot can access and perform maintenance on hardware, which could be difficult in 1g. Perform test in parabolic flight, low Earth Orbit, or ISS.

Safety Working Group had over a dozen ideas, but narrowed it down to four requirements, and verification and validation methods for each where applicable:

(1) The Gateway shall have redundant, dissimilar critical flight systems.
   a. Verification methods: Analysis and test
   b. Validation methods: Test

(2) The Gateway shall have vehicle reliability of 0.99 or greater over one year
   a. Verification methods: Analysis and test
   b. Validation methods: Test

(3) The Gateway shall have emergency egress path illumination of X lumens.
   a. Verification methods: Analysis and test
   b. Validation methods: None provided

(4) The Gateway end items shall have appropriate levels of containment based on the toxicity/biological rating
a. Verification methods: Analysis and test
b. Validation methods: Test

Training Working Group assumed that there would be a one year crew training flow that requires minimal travel to different training centers. Their goals were to build a list of approved objectives, and to avoid giving crews more details than needed. This group decided what should be trained (requirements/objectives), how and where (verification), and when (validation) the training should be executed:

(1) Determine frequent and urgent tasks
(2) Develop procedures to scope the tasks that the crew needs to do
(3) Attain agreement of rules that everyone will be operating by across NASA organizations and international partners
   a. Verification methods (how): approval of objectives from partners, providers, and disciplines; verify the objectives were met in the lesson or event; verify the objectives were achieved on orbit.
   b. Verification methods (where): determine the facility or format of the content; level of fidelity required; availability of technology and content (e.g. Video conference, Virtual reality, Augmented reality, Computer based training, Remote training, Online content, NASA's Neutral Buoyancy Lab (NBL), and NASA's Active Response Gravity Offload System (ARGOS).
   c. Validation methods (when): determine when the training occurs in the flow (no training, on-board training, ground training required, early-on to introduce generic skills); determine the roles of the crew and the team members.

Habitability and Environment Working Group developed two requirements with examples for each and separate verification and validation methods:

(1) Provide a breathable atmosphere (PP02 range, PPCO2 range, total pressure, trace contaminants)
   a. Verification methods:
      i. System: Test and analysis of major constituents
      ii. Human: Measure blood gas, pulse ox, and cognition
   b. Validation methods: Chamber test with the simulator and/or human
(2) Provide an acceptable acoustic environment (noise level max, max level sustained)
   a. Verification methods:
      i. System: Measure decibel (total), acoustic dose from each piece of hardware
      ii. Human: Cognitive performance test
   b. Validation methods: Within acceptable limits (OSHA)

4.4 Workshop Closing

The HSI Workshop ended with a reflection of the day. Ms. Alicia Baturoni-Cortez, Education Program Specialist at JSC, cautioned that participants may leave with a "professional development halo effect." This occurs when people pause from their daily responsibilities to focus on a topic in-depth and rediscover its value. However, returning to daily responsibilities can cause us to lose focus on the importance of a topic. She asked participants to reflect on their big takeaways from the day's events and how they might keep them in focus or put them into practice going forward. One participant shared how they were trained in school to design for requirements, but not do anything past that. The problem people face was that this kind of work is actually not in requirements. For example, the participant referenced Mr. Ben Greene's presentation about xEMU. Even though HSI was not part of the xEMU requirements, they did it anyway because it was the right thing to do and would save them in the long run.

Another participant thought that HSI was kind of isolated at NASA, but by coming to this workshop they found out that HSI was across all disciplines. That was an eye opener for them. A third participant discussed how HSI and human factors are commonly thought to be interchangeable, but human factors is actually a domain of HSI (which was explained throughout the Workshop.) It is important to know about other domains that specialize in certain areas, and for different groups to work together to achieve goals of a project/program. The workshop was also an important reminder to involve stakeholders from the beginning. They also learned that NASA's HSI Practitioner's Guide had many principles that need to be identified throughout the design process. At the same time, users of the Guide should provide feedback to improve it so that the HSI community can continue to grow.

The HSI Workshop culminated with HSI Chair, Jackelynne Silva-Martinez, playing a closing video featuring photos taken throughout the day. Then, she encouraged all participants to join the HSI ERG and to utilize resources available through the HSI ERG SharePoint website.

4.5 HSI Distance Learning Lesson

The various presentations during the workshop were tangible examples of how HSI is applied in different projects within JSC, with more emphasis on their contributions for the upcoming Gateway mission. The planning team thought these would make for good training material, and arranged to have some video clips recorded from the presenters and subject matter experts as a side bar during the workshop. This in an effort to compile their direct HSI applications on current and future projects to the theoretical training material the ERG had already developed. The distance learning lab at the Flight Operations Directorate used that material to create an online lesson that will be available to the entire Agency. The objectives include: (1) Define Human Systems Integration within the context of NASA's lifecycle phases, (2) Interpret how "system of systems capability" influences HSI, (3) Explain the 6 NASA HSI domains through examples, (4) Identify HSI domains within selected significant incidents and close calls in human spaceflight.

Other post workshop plans include the dissemination of recorded videos from the workshop presentations through the NASA Engineering and Safety Center Academy. This will make the available to any employee at NASA. Furthermore, the HSI ERG will continue offering events with professional development purpose within the Center.

4.6 Metrics

The HSI ERG executive board developed several metrics to measure workshop success. This section summarizes the outcome of those metrics.

4.6.1 Demographics of the Participants

Out of 72 workshop participants, 25% were at the management level, 30% were project leads, and 45% were at the individual contributor level. At JSC, many ERG events are attended mainly by individual contributor employees. Thus, having management and project/program leads participation was above average. In addition, the workshop attracted participants from outside of JSC, such as, NASA Headquarters, Langley Research Center, and Ames Research Center; and over 10 contractor companies were represented. Diversity was also noticed in cultural backgrounds and professional fields. Participants had different levels of experience, including interns, early career, and experienced professionals, from across many directorates of JSC including non-engineering fields such as legal, education, external relations, and procurement.

4.6.2 Workshop Survey

31 participants out of 50 registered completed a post-event survey. 25 out of 31 respondents stated that this workshop met their expectations. Four did not respond to this question, and two expected a more general talk for those who were new to the HSI community. The net promoter score (NPS) was used to identify whether attendees will recommend this workshop to others. An NPS of +50 is an excellent score [7]. Respondents gave an overall score of 48.38. Ratings indicated that most participants were very enthusiastic and would like to continue this kind of events.

Respondents stated that they would like to have more HSI community engagement. They would like (1) Program manager talks about the challenges of funding and implementing HSI; (2) Cross-center interactions such as representatives or presentations from other NASA Centers to share information and promote collaboration; (3) Show employees how to work with commercial providers on HSI; and (4) More visibility of HSI work to help individuals gain credibility in the broader JSC and NASA communities.

Employees would also like to learn more about HSI in general and its implementation. Some of the topics suggested were:

(1) Working outside of silos. For example, some employees stated they often feel their individual components are deprioritized (e.g., Operations feels they do not need human factors, or human factors does not reflect an adequate understanding of operations in their research.)

(2) Enhance awareness of the 'how' in HSI. Some individuals stated that they know why it is important, but they would like more information on how to implement HSI inside and outside of NASA, outside of JSC, and on International approaches to HSI.

(3) More formal training on requirements, implementation, and decomposition.

(4) A deeper understanding of all the different domains under HSI through practical examples.

(5) Program based HSI case studies (e.g. Shuttle, ISS, lunar landers, and space-based CREAM) and tools are available to improve their HSI knowledge and interactions.

5. Conclusion

This first Human Systems Integration Workshop at NASA JSC achieved its goals to disseminate the importance of incorporating HSI on human spaceflight missions and projects to reduce lifecycle costs. Addressing the current status and forward plan for the HSI implementation at each of the JSC's directorates allow the participants to see tangible examples of where in the mission's lifecycle HSI can be implemented. Workshop participants also exercised their systems engineering verification and validation methodologies to demonstrate understanding of NASA HSI Domains. This was done using the workshop presentations as background with given assumptions for the Gateway Program, which was used as a case study. Participants realized the interdependency across the different domains, which was the purpose of the exercise.

Additionally, the workshop served to promote the HSI ERG across the various NASA centers, and its mission for encouraging the diversity of thought, generating interdisciplinary collaboration opportunities.

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- Inclusion & Innovation Advisers: Peggy Wooten and Tu-Quynh Bui
- Keynote Speakers: Dr. Vincent Michaud and Ms. Debra Ludban
- Presenters: Dr. Jennifer Rochlis, Mychal Miller, Dennis Pate, Ginger Kerrick, William Othon, Angela Bauer, Taylor McCanna, Jason Hutt, Dr. Matthew Healy, Megan Haught, Ben Greene, Dr. Gordon Vos, and Dr. Sherry Thaxton
- Facilitators: George Salazar, John Love, Christie Sauers, Tiffany Swarmer, Debbie Musgrove, Douglas Wong, Nicole Schoenstein, Diane Koons, Herbert Silva, Jason Hutt, Lucia Mccullough, Alicia Baturoni-Cortez, and Kristopher Field
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- The Organizing Committee: The 2019 HSI ERG Executive Board, Jackelynne Silva-Martinez, John Love, Alicia Baturoni-Cortez, Nicole Schoenstein, Natalia Russi-Vigoya, Tiffany Swarmer, Herbert Silva, Douglas Wong, Rachel Walker, Rudy Balciunas, and George Salazar.

Appendix A - Workshop Agenda

NASA JSC Human Systems Integration Workshop
April 9th, 2019 Agenda

When		Duration	What	Who	Where
7:40	8:10	0:30	Registration	Alicia Baturoni Nicole Schoenstein Natalia Russi Rachel Walker	B12
8:10	8:20	0:10	Welcome Remarks	Jackelynne Silva-Martinez	B12/200
8:20	8:50	0:30	**Keynote Speaker: Overview of HSI at NASA** **NASA HQ Deputy Chief Health and Medical Officer** **NASA HSI Champion, Dr. Vincent Michaud**	Introduced by HSI Executive Sponsor: Eileen Stansbery	B12/200
			Where are we?		
8:50	9:20	0:30	Topic 1: HSI ERG How did the ERG started? - Jennifer Rochlis HSI Practitioner's Guide - Mychal Miller	Facilitator: George Salazar	B12/200
9:20	10:20	1:00	Topic 2: JSC Organizations Significant Incidents in HSF - Dennis Pate (NA) HSI in FOD - Ginger Kerrick (CA) Vehicle Integration and Test - Bill Othon (EA) HSI in Aircraft Operations - Angela Bauer, Taylor McCanna (CC)	Facilitator: John Love	B12/200
10:20	10:30	0:10	*Coffee Break*		
			Where are we going?		
10:30	10:50	0:20	Topic 3: HSI ERG Open discussion: updates to the Practitioner's Guide, retention, training, facilitation of CoP	Facilitator: George Salazar	B12/200
10:50	11:50	1:00	Topic 4: JSC organizations HSI in Orion - Jason Hutt (GV) Crew Autonomous Scheduling Test - Matthew Healy (CO) Human Reliability Analysis for Gateway - Megan Haught (OP) xEMU and HSI - Ben Greene (EC)	Facilitator: John Love	B12/200
11:50	12:00	0:10	**Discussion: Future Projections/Visions**	Facilitator: Christie Sauers	B12/200
12:00	13:00	1:00	*Lunch and Networking*		
13:00	13:30	0:30	**Keynote Speaker: Overview of Gateway Program** **Gateway Vehicle Systems Integration Deputy Manager, Debra Ludban**	Introduced by HSI Executive Sponsor: Annette Hasbrook	B12/200
13:30	13:45	0:15	HSI on Gateway	Sherry Thaxton	B12/200
13:45	14:15	0:30	Overview of NASA HSI Domains	Gordon Vos	B12/200
14:15	14:35	0:20	Overview of Working Groups and Transfer to Different Rooms	Tiffany Swarmer	B12/200
14:35	15:35	1:00	**Working Groups: NASA HSI Domains**	Facilitators:	
			Human Factors Engineering	Doug Wong (NA)	B12/134
			Habitability and Environment	Nicole Schoenstein (SF)	B12/136
			Safety	Diane Koons (NE)	B12/146
			Maintainability and Supportability	Herbert Silva (ES) Kristopher Field (CX)	B12/150
			Operations Resources	Jason Hutt (GV)	B12/253
			Training	Lucia Mccullough (CK)	B12/255
15:35	15:45	0:10	*Coffee Break and Transition back to Main Room*		
15:45	16:45	1:00	**Working Groups Presentations**	Facilitator: Tiffany Swarmer	B12/200
16:45	16:55	0:10	**Discussion: What now? What are our actions and opportunities?**	Facilitator: Alicia Baturoni	B12/200
16:55	17:00	0:05	Closing Remarks and Recognitions	Jackelynne Silva-Martinez	B12/200
17:00	19:00	2:00	*Happy Hour - Optional*		

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