

## Human-Centric Approach for Design of Exploration Mission Habitats

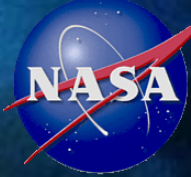
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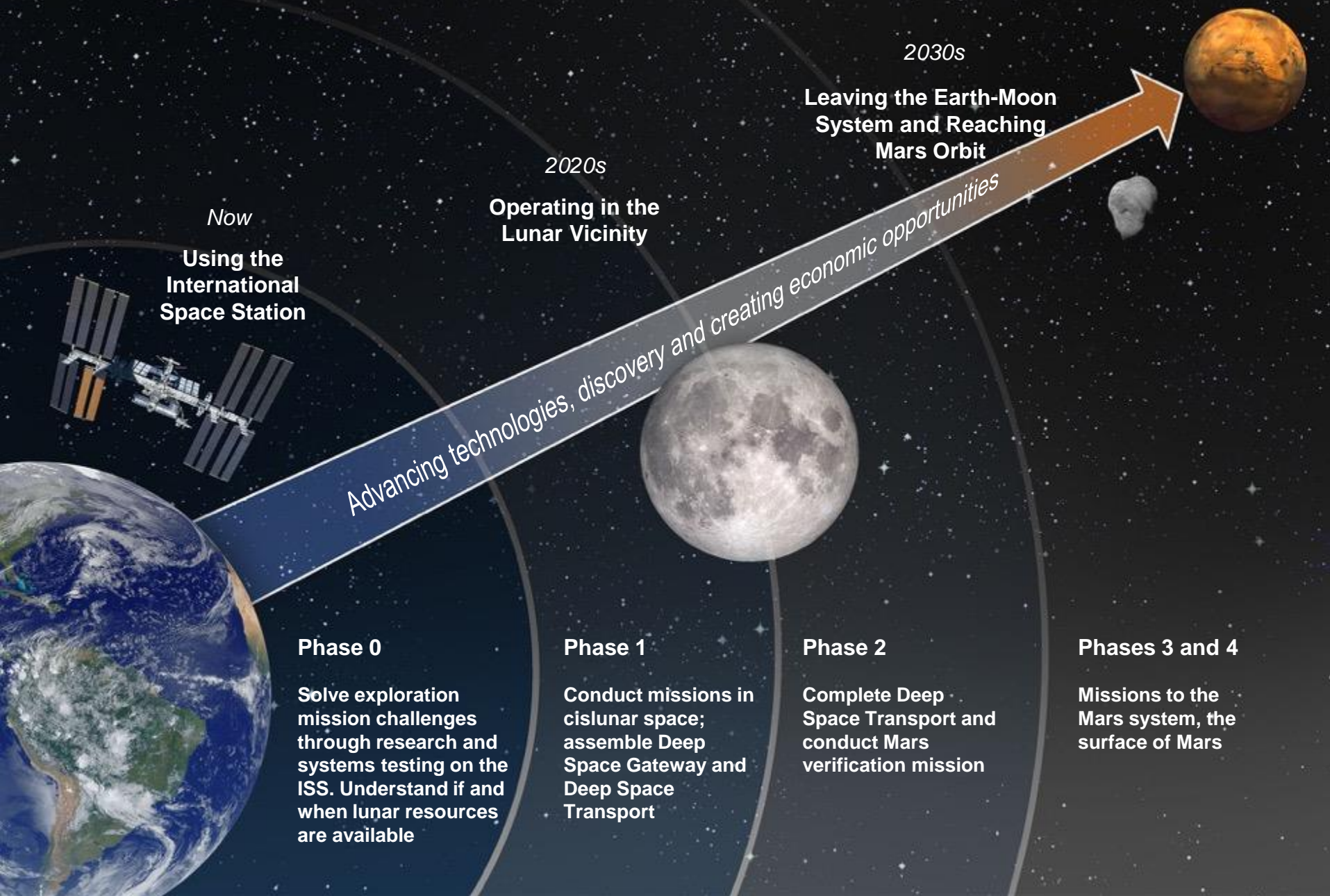
Tom Williams, Ph.D.

# Space Exploration Current Plan

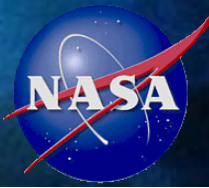


- The nation's goal for space exploration is to lead an effort that expands human presence deeper into the solar system through a sustainable human and robotic spaceflight program.
  - Maximizing utilization of the International Space Station
  - Actively promoting LEO commercialization
  - ➡ – Resolving the human health and performance challenges
  - Expanding partnerships with commercial industry
  - Enhancing international partnership
  - ➡ – Building the critical Deep Space Infrastructure
  - Enabling the capabilities to explore multiple destinations
- One of the key Human System Integration (HSI) challenges for Deep Space Missions is providing an acceptable “habitable volume” for the astronauts to live and work for an unprecedented extended period of time in a small, confined vehicle.
- **Current Human-Centered Research Focus:** Develop and validate habitability design tools and methods for use during the early conceptual design phase and mission architecture studies.
  - Enable HSI design criteria and requirements assessments
  - Determine the acceptable habitable volume and layout and assess its “goodness”

# Deep Space Gateway and Transport Plan



# Deep Space Mission Challenges



## Current ISS Operations

### Low Earth Orbit

- Real-time communication with ground operations
- Real-time comm. with family and friends
- Provision of crew care packages
- Discretionary events
- Evacuation options
- Cupola and Photography
- Exercise 2 hours/day
- High tempo workload

### Astronauts thrive on the ISS

- Large Volume
- Private Crew Quarters
- Six Month Duration (to date)

## Future Exploration Class Missions

### Deep Space

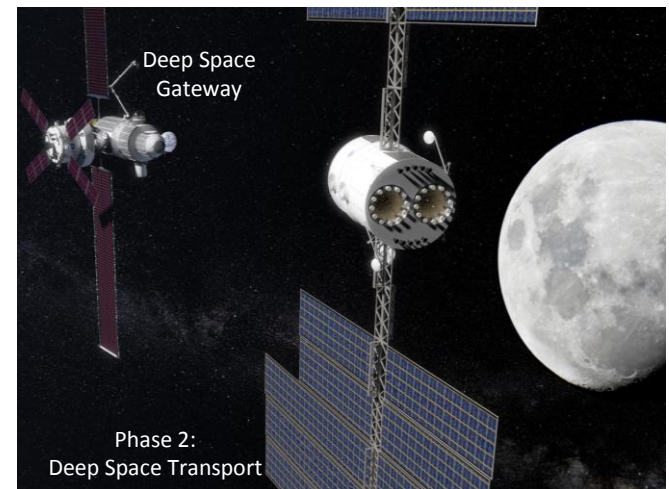
- Unprecedented duration and distance
- Loss and delay of communications with ground
- More autonomous operations
- No re-supply, no option for evacuation
- Limited volume in confinement
- Radiation exposure threats

### Major Challenges

- Selecting & Composing Crew
- Maintaining Meaningful Work, Motivation
- Enhancing Growth & Resiliency
- Ensuring Family Connectedness & Communication
- Managing Stress, Mood & Morale, Conflict
- Net Acceptable Habitable Volume, Sensory Stimulation
- Managing Sleep, Fatigue, Workload & Circadian
- Earth out of view

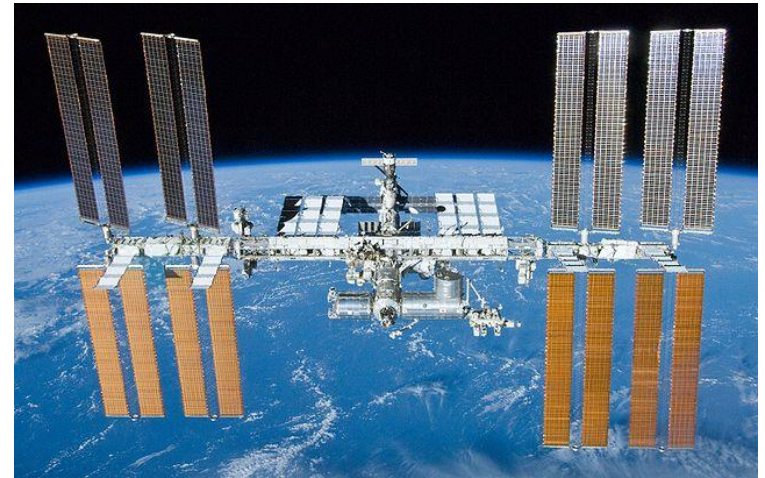
# Research Needs for Human-Centered Approach

- Our research goal: Align the habitability focused research products and outcomes with the Deep Space Gateway/ Transport Plan (the 2016–2029 time frame).
  - Allow for validating these products on the early missions (Phases 0-2)
  - Prepare for Mars transit and Mars surface (Phases 3 and 4)
- Products need for human centered approach needed :
  - Tools/ Processes to help designers
    - defining mission/program requirements that affect habitat design
    - identifying stakeholders
    - performing a critical task analysis
    - defining volume envelopes for each planned task, and assessing habitable volume and interior design
  - Standards and guidelines (NASA-STD-3001 and the Human Integration Design Handbook (HIDH)) for layout considerations
    - Need for a gap analysis for Phases 3-4



*Designs that are **effective**, **efficient**, and **acceptable** contribute to a habitat design that is livable, and one that promotes physical and psychological well-being, and high performance.*

- Habitable Volume Efforts
  - Past and Present Approaches
  - Recently Completed Work
  - Ongoing Work
- Conclusions and Next Steps



# Habitable Volume Approaches: Past and Present



## Past:

Work related to determining volume for space vehicles was primarily based on historical volumes independent of tasks and mission needs.

## Present:

Focus is on using a **human-centered design approach**

- Based on functional **task** needs
- Considerations given to **mission properties** (e.g., duration, number of crewmembers)
- Inclusion of **behavioral health considerations** as part of the task-based approach
- Emphasis on developing **tools** that give designers the ability to get past the “it depends” obstacles to estimates



# Recently Completed Work



## 2011 NHV Workshop

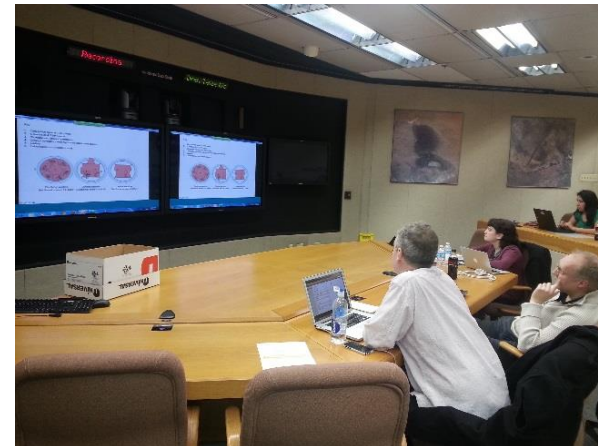
- Identified research gaps and potential mitigations to smaller volumes

## 2012 Habitable Volume Workshop

- Developed set of tools intended to assist designers (process flow, task list)

## 2014 NHV Consensus Session

- Mapped Mars 5.0 Design Reference Mission (DRM) tasks to a conceptual habitat and provided estimate of total vehicle and per person volume for that set of assumptions



*This work has laid the foundation for the ongoing and future work focused on human-centered design with behavioral health concerns included.*

## Habitability Working Group (FY15 – FY22)

- Standing committee of internal and external subject matter experts to NASA specifically focused on NHV (including Deep Space Gateway/ Transport (used to be Future Capabilities) Teams)

## ISS Habitability Study (FY13 – FY17) – *ongoing flight study*

- Ongoing flight study; Focused on habitability and habitable volume based on near real-time observations from crewmembers (text, audio, video)

## Space Utilization Data Collection Tools (FY14 – FY18) – *ongoing ground-based research*

- Unobtrusive data capture (Kinect, RFID, IMU) of crewmember location and posture, to be used in work flow analysis critical in assessing layouts

## Task Volume Dataset Development (FY13 – FY22) – *ongoing internal work*

- Includes SME coordination, digital human modeling; intended as inputs to SOLV

## Spacecraft Optimization Layout and Volume (SOLV) Model (FY14 – FY18) – *ongoing ground-based research*

- Tool for designers to use in pre-Phase A to help intuit the design in terms of layout and volume

*This work will all contribute to the development and validation of tools and processes for designers to use to address habitable volume needs.*

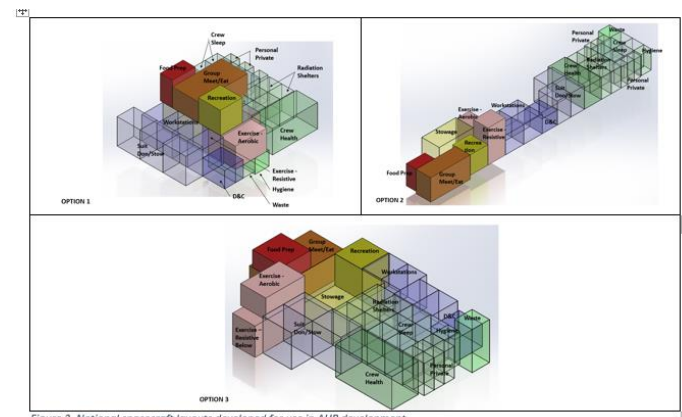


Figure 2. Notional spacecraft layouts developed for use in AHP development.

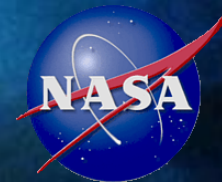
# Habitable Volume: Current Need



- Early estimates of volume needs to determine whether concepts are feasible
  - Work closely with the CisLunar Internal Architecture Team to address these types of concerns
    - Serve as core team members to provide inputs to habitability assessments and design criteria
    - Ensure that research products are made available
    - Provide early estimates of volume needs based on CisLunar (now Deep Space Gateway/ Transit) DRM assumptions
- Requirements Document development for future missions
  - Participate in Habitat Technical Team's assessment of the standards applicability to the Deep Space missions and identifying gaps
- Interim guidance based on the past experience and current research status for use in the Deep Space mission planning



# Conclusions and Next Steps



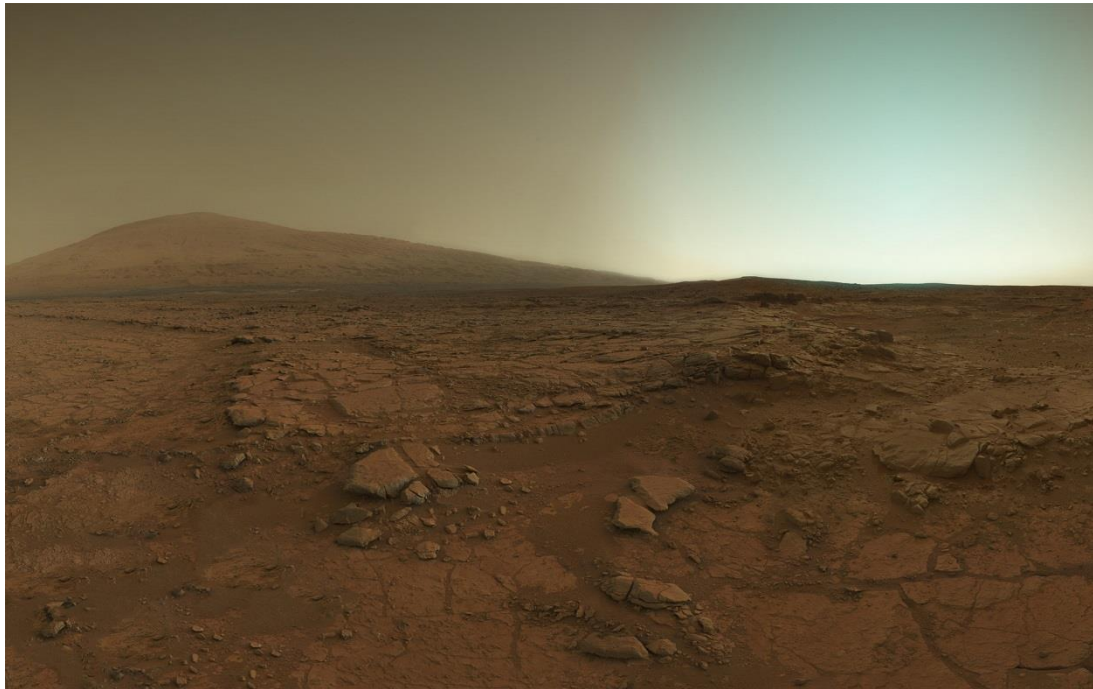
- Consider current products as a starting point since there are a number of assumptions and caveat due to unknowns in the very early stages of the Deep Space mission planning
- Continue working toward validation approaches and solutions through the analogs and the early phases of Deep Space Gateway/ Transport mission plan

## Next Steps

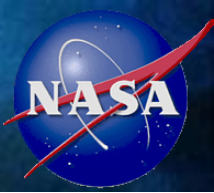
- Validation of SOLV and integration with other research products
  - Potential integration with data from space utilization tool currently in development
- Planned validation studies
  - Analog and flight studies planned for Fiscal Years 2017-2020 to validate tool outputs
- Establishing a plan for mechanisms to transition tools and processes to operations
  - Capture research results in the Agency Standards
  - Provide research outcomes and products to the Mission Architecture teams to influence new vehicle/habitat design



# Thank You!



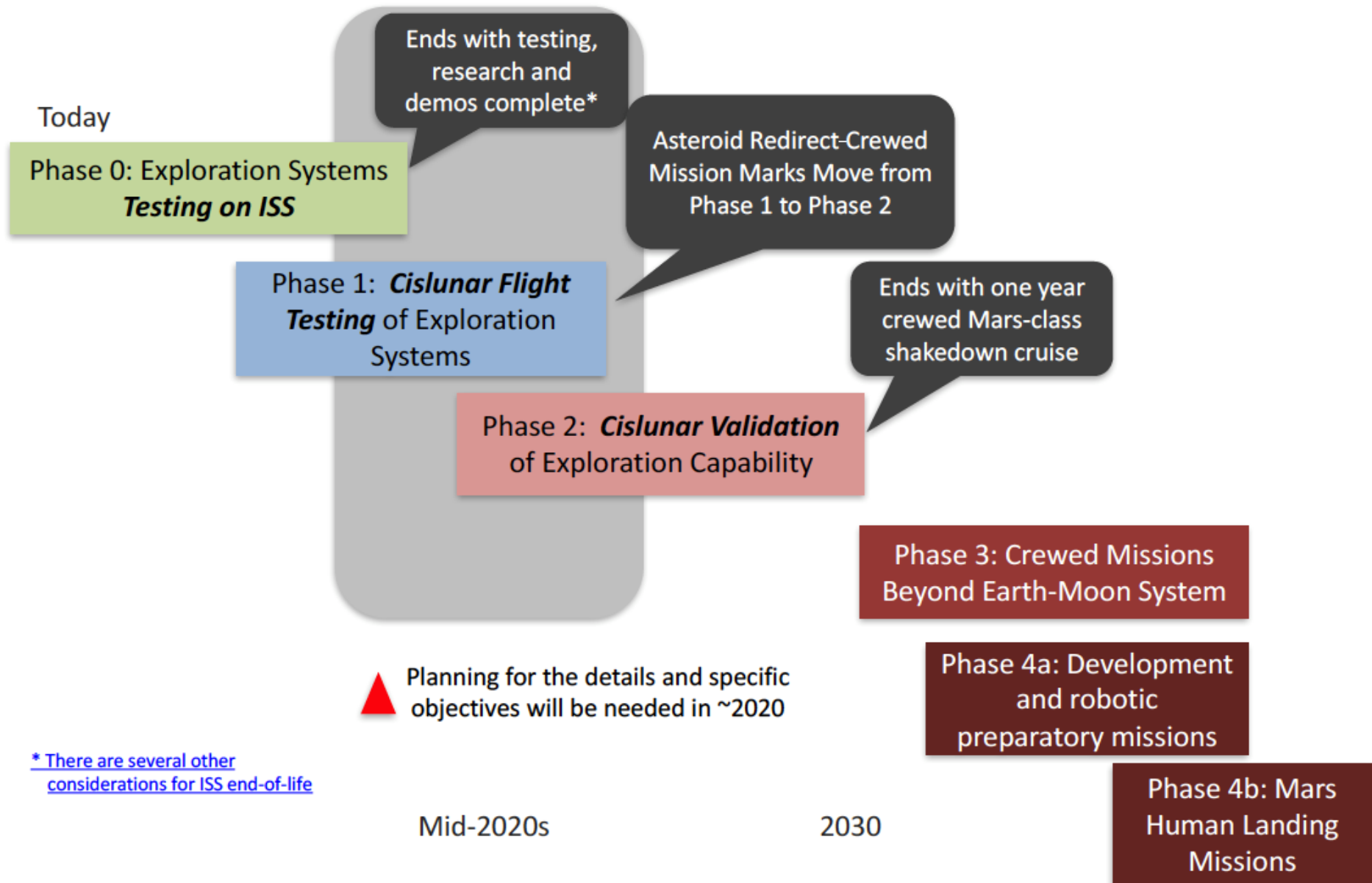
HRP Link:  
<http://humanresearchroadmap.nasa.gov/explore/>



# Backup Material



# Human Space Exploration Phases From ISS to the Surface of Mars as of November 2016



# Risk-Standard-Requirement Flow



## Risk

Inadequate Human-System  
Interaction Design

## Handbook

NASA Handbook  
NASA/SP-2010-3407, Human Integration Design Handbook  
June 2014

## Standard(s)

3.0 Program Implementation Standards (all)

5.0 Perception and Cognition (all)

6.0 Natural and Induced Environments (all)

7.0 Habitability Functions:

7.1.2 Food Prep, Consumption, and Cleanup

7.2 Personal Hygiene

7.3.1 Body Waste Management Facilities (all)

7.4.2 Volume Accommodations [V2 7039]

7.5 Medical (all)

7.6 Stowage (all)

7.7 Inventory Management System (all)

Space Flight Health Standard  
NASA-STD-3001, VOLUME 2, HUMAN FACTORS...  
January 2011

7.0 Habitability Functions (Continued):

7.8 Trash Management System (all)

7.9 Sleep (all)

7.10 Clothing

7.11 Housekeeping (all)

7.12 Recreational Capabilities [V2 7084]

8.0 Architecture (all)

9.0 Hardware & Equipment (all)

10.0 Crew Interfaces (all)

11.1 Suit Design and Operations (all)

12.0 Operations [reserved]

## Requirements

### ISS

SSP 50005: International Space Station  
Flight Crew Integration Standard

SSP 50313: Display Graphics and  
Commonality Standard (DGCS)

### MPCV

MPCV 70024: MPCV Human System Integration  
Requirements

MPCV 72242: Orion Program Display Format  
Standards

MPCV 70152: Orion Program Crew Interface  
Labeling Standard

### Commercial Crew

CCT-REQ-1130 ISS Crew  
Transportation Requirements  
Document

### Deep Space Gateway/ Transport Vehicles

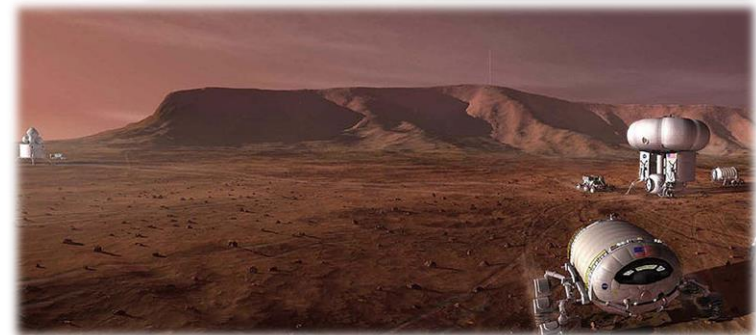
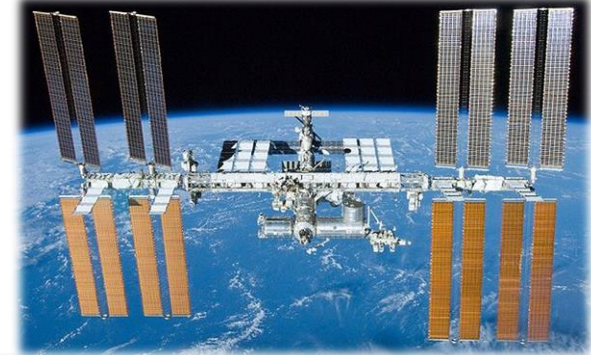
Deep Space Habitat Requirements  
Document (TBD)

## Risk Statement

Given the criticality of human-systems interaction during long-duration spaceflight operations with increasing autonomy and time delay, there is a possibility of reduced crew performance due to inadequate human-system interaction design that may result in-flight and ground errors, impacts to timeline, failure to accomplish critical tasks, failed mission objectives, and an increase in crew injuries.

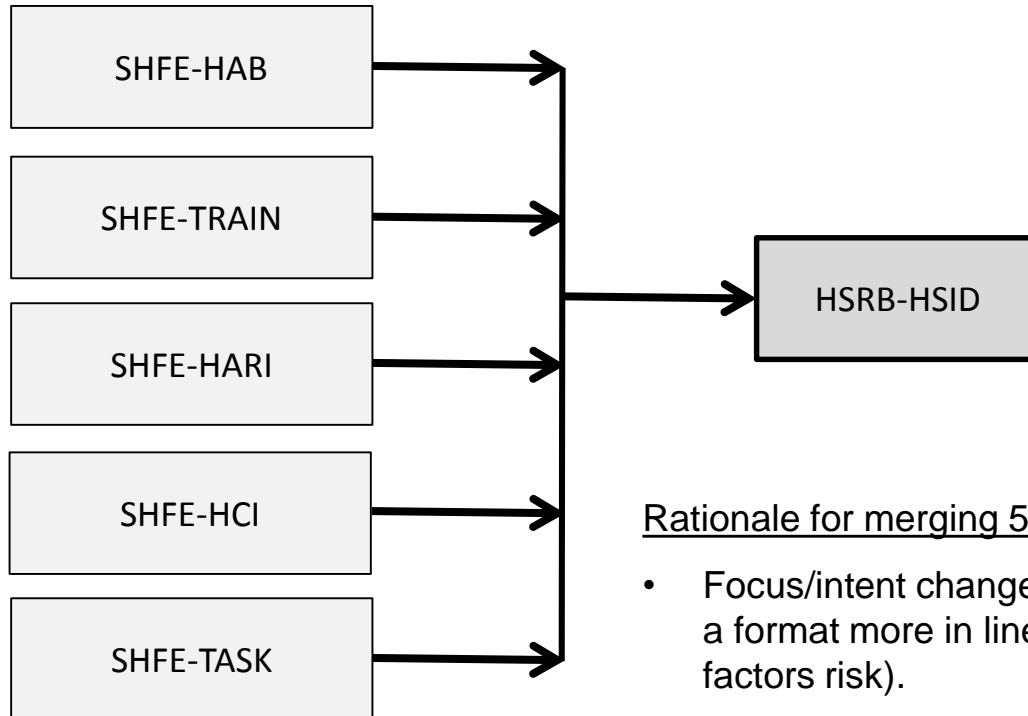
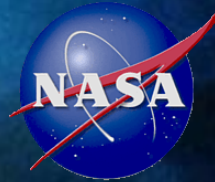
## Contributing Factors

- Physical/Technological Environment
- Perceptual Factors
- Physical/Mental Limitations
- Cognitive Factors
- Organization Process and Climate
- Resource Acquisition Management



- What environmental and habitability factors impact crew health and performance?
- What human-interface design characteristics support adequate crew health and performance?

# Rationale for an Integrated SHFE Risk for HSRB



## Risk of Incompatible Vehicle/Habitat Design (HAB)

- Designing vehicles and habitats that allow crew to live and work in this space environment.

## Risk of Performance Errors due to Training Deficiencies (TRAIN)

- Providing a wide-range of training approaches that will result in crew effectively performing work.

## Risk of Inadequate Human-Computer Interaction (HCI)

- Providing computer interfaces that allow crew to effectively perform work.

## Risk of Inadequate Human and Automation/Robotic Integration (HARI)

- Designing integrated human-systems for automation and robotics that allow crew to effectively perform work.

## Risk of Inadequate Critical Task Design (TASK)

- Designing tasks, schedules, and procedures that consider human capabilities and limitations.

## Rationale for merging 5 SHFE risks into 1 HSID risk:

- Focus/intent changed from a research-specific breakout of risks, to a format more in line with programmatic concerns (1 human factors risk).
- More efficient and effective way to track the risk and report to management since the 5 SHFE risks have similar metrics, tools and approaches.
  - However, since the 5 research risk areas require very different expertise, we will retain these individual SHFE risk domains within HRP.

# Crew Comments Database

Example Comments from Each Domain\*



## Habitability (HAB)

"It is difficult doing tasks without adequate lighting."

"Looking out the window helps. Having the Cupola is a huge plus in terms of habitability"

"Many tools are difficult to find because lockers are full – need labeling and reorganization."

## Human-Automation/Robotic Integration (HARI)

"Flying the real arm with the real day/typical lighting conditions is really important before the actual track and capture."

"Crew's skills can atrophy while onboard so allowing them extra time to fly the arm increased their confidence and resulted in success."

## Training (TRAIN)

"You do not remember something you were trained on 2 years ago."

"In a training session, when everything is laid out nicely on the table and the tools are there, it does not simulate on orbit conditions."

## Critical Task Design (TASK)

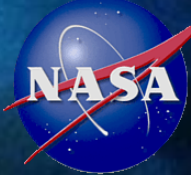
"Scheduling two crewmembers for EMU activities is more efficient with one crewmember reading and one crewmember doing to avoid missed procedure steps rather than going back and forth with an EMU to the SSC with the procedure."

## Human-Computer Interaction (HCI)

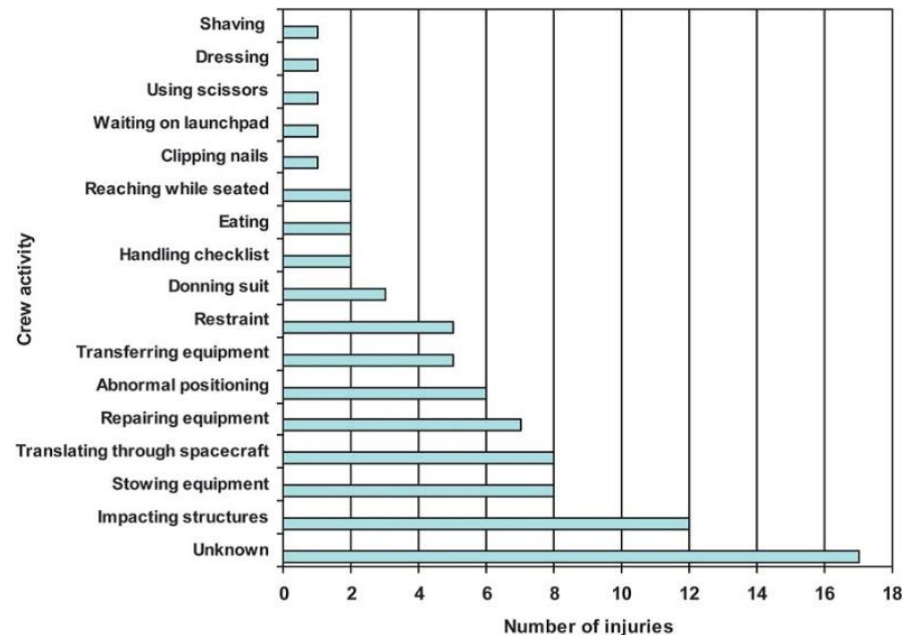
"The one crewmember noted that procedures are more complicated than they need to be."

"Some crewmembers disliked having to hit the Edit button to write a Crew Note."

# Previous Related Work



- **Scheuring et al. (2009)** cataloged documented injuries during the entire United States space program.
  - Found that many injuries were related to layout and habitability:
    - Impacting structures
    - Stowing equipment
    - Translating through spacecraft
- **Better habitat design (in terms of habitable volume and layout) could reduce these types of injuries.**



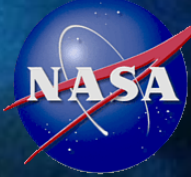
Types of crew activity causing in-flight musculoskeletal injuries throughout the U.S. space program.

- There is evidence that the crewmembers may place varying levels of importance on habitability throughout the course of a long mission:
  - Stuster's Journals study (2000) included an analysis of journals maintained by 11 crewmembers over the course of their ISS missions (which lasted up to a maximum of 215 days). The highlights of the results related to HSID were:
    - "Habitability" was discussed most frequently in the first quarter, the least frequently in the second quarter, and the frequency in the last quarter returned to the levels in the first.
    - Out of 24 categories, "Equipment" represented the 6<sup>th</sup> most frequently discussed category (mentioned by each crewmember an average of almost 50 times per mission).
    - "Stow/Restow" sub-category was the most frequently mentioned topic in the "Logistics/Storage" category.
  - Feedback from experts with Antarctic experience indicate that missions in excess of 6 months may result in different habitability needs.



ISS Service Module configuration with galley, treadmill, crew quarters, and waste and hygiene facilities co-located. (from HRP Evidence Report)

# Aerospace Accident Related to Poor HSID

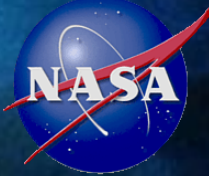


- Virgin Galactic's suborbital space plane SpaceShipTwo was destroyed in a tragic accident during a test flight on Friday (Oct. 31, 2014). The crash left one pilot dead and the other seriously injured.
- \*NTSB's investigation briefing described the following stressors contributing to the Co-pilots error:
  - Memorization of tasks – data card not referenced
  - Time pressure – complete tasks within 26 sec
  - Operational environment – no recent experience with vibe and loads
  - Lack of consideration for human error
    - No safeguards in design to prevent error
    - No warning in manuals/procedures
    - Sim training did not replicate operational environment
    - Hazard analysis did not consider pilot-induced hazards

*The challenge is identifying these HSID issues and resolving them before they result in a catastrophic accident!*



# HSID For Exploration Missions



- Spaceflight Operations are **changing**
  - New vehicles with “glass cockpits”
  - Crew access to more information and new technologies that are unproven in space
  - Crew operating with time delays or no comm, and decreased ground support
  - New robotic exploration agents, beyond robotic arms and Earth-controlled rovers
  - Highly autonomous systems, beyond current experience with limited maturation
  - Planetary exploration in the 21<sup>st</sup> Century with harsher environment
- New **standards and guidelines** for HSI are required for future exploration missions.
- Given all the evidence, HSID is currently a “red” risk for Exploration Planetary Missions.



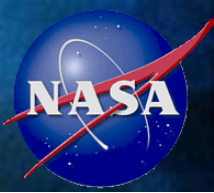
SpaceX Dragon Vehicle



Planetary Surface Operations



*“New technology does not remove human error. It changes it. Dekker (2006)”*



# **Current/ Planned Research Highlights**

# HISD Risk-related Research Domains



## **Incompatible Vehicle/Habitat Design (HAB)**

- Designing vehicles and habitats that allow crew to live and work in this space environment.



## **Performance Errors due to Training Deficiencies (TRAIN)**

- Providing a wide-range of training approaches that will result in crew effectively performing work.



## **Inadequate Human-Computer Interaction (HCI)**

- Providing computer interfaces that allow crew to effectively perform work.

## **Inadequate Human and Automation/Robotic Integration (HARI)**

- Designing integrated human-systems for automation and robotics that allow crew to effectively perform work.

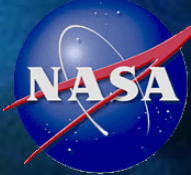


## **Inadequate Mission, Planning, and Task Design (MPTASK)**

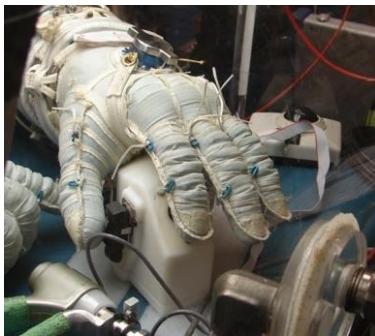
- Designing tasks, schedules, and procedures that consider human capabilities and limitations.



# Current Research Priorities

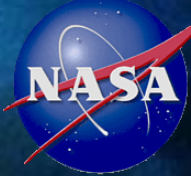


- Net Habitable Volume (NHV) and vehicle/habitat layout – 3-D space utilization
- Level of automation, task/ function allocation
- New training approach including just-in-time training and procedures
- Human-system interaction/interface design including teleoperations, and human-robot teaming



# Habitability and Net Habitable Volume

S. Thaxton, M. Greene, T. Williams, R. Archer, S. Schuh, K. Vasser



## • Background

- Data related to spaceflight habitability is currently limited to operational data (which is unsystematic or captured months after the mission), short-duration spaceflight, and analog missions that do not incorporate microgravity.
- The impacts of long-duration missions in microgravity on habitat design are significant.
- Of particular interest is data to define an acceptable minimum net habitable volume (NHV) for long-duration missions.

## • Research Objectives

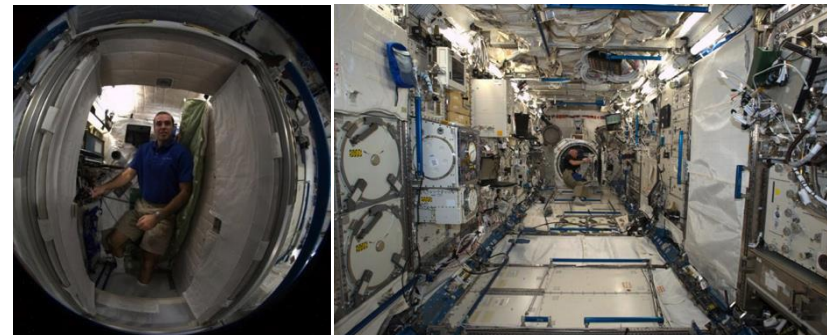
- Characterize the current state of ISS habitability
- Document/ characterize details about how crewmembers currently utilize the space on ISS
  - Specific focus areas include: Private personal areas, group activities, suit donning and doffing, crew health and medical procedures, stowage
- Determine how it relates to long duration spacecraft/ habitat design

## • Subjects:

- 1-yr crewmembers (1) completed
- 6-mth crewmembers (5) **in progress**
  - Data collection includes observations captured using audio, video, photo, and/or text on a custom iPad application; PI Conferences using 2-way audio; and habitability questionnaires

The screenshot shows the iSHORT application interface on an iPad. At the top, it says "New Observation" with a timestamp of 11:26 AM and a battery level of 100%. Below this, the "Observation Date" is set to "Dec 27 2013, 11:25 AM" with a "Change Date" button. The "Observation" field contains the text "This is just a test." There is a "Tags" section with a tag labeled "Interface Design". Below the observation field is a "Priority" section with three buttons: "Must be addressed" (highlighted in blue), "Nice to have", and "No change needed". At the bottom left is a "Photos/Video" section with a camera icon. At the bottom right is an "Audio" section showing a microphone icon and "Recorded: 4.41s". At the very bottom are "Save and Submit" and "Reset" buttons.

iSHORT – iOS-based observation recording tool



# Fine Motor Skills Study on ISS

K. Holden, A. Sandor, E. Cross, M. Greene



- **Background**

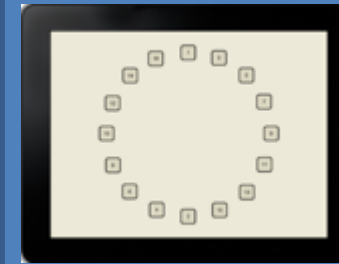
- Future long-duration crewmembers will depend on fine motor skills to complete their computer-based mission objectives.
- Data on fine motor performance in long-duration spaceflight are incomplete/inconclusive.

- **Research Questions**

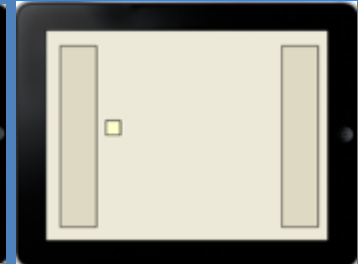
- How does fine motor performance in microgravity vary over the duration of a 6-mth or 1-yr space mission, and how does it differ from a closely-matched participant on Earth?
- How does performance vary before and after gravitational transitions, including the periods of early flight adaptation, and very early/near immediate post-flight periods?

- **Subjects:**

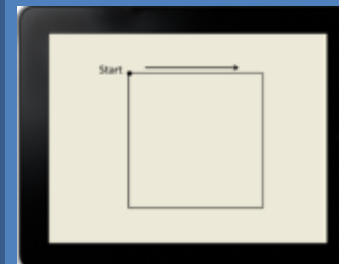
- 1-yr crewmembers (2) completed
- 6-mth crewmembers (6) in progress
- Ground-matched subjects (7) in progress
- Pre-, Post-, and In-flight sessions (every 1-2 weeks)
- Crew uses finger and stylus to complete tasks
- Sessions are 15 minutes or less



Multidirectional  
Pointing



Unidirectional  
Dragging



Tracing

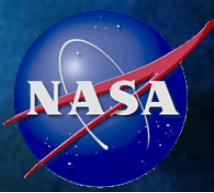


Pinch-Rotate



# Effects of Long-Duration Spaceflight on Training Retention and Transfer

I. Barshi, D. Dempsey, K. McGuire, L. Landon



- **Background**

- There has not been a complete, systematic study of the effects of spaceflight on retention and transfer.
- This ground study probes retention and transfer of cognitive processes underlying all operational tasks, including: Memory, Perception, Motor Control, Decision Making

- **Research Question**

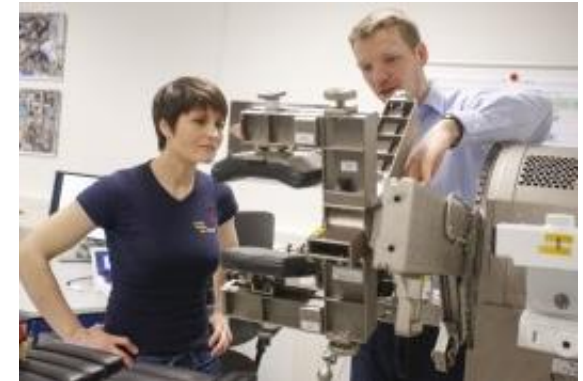
- Do the Power Law of Forgetting and the Universal Law of Generalization that have been established in university-based studies hold for astronauts following the schedule of a long-duration (6mth) space mission?

- **Subjects:**

- 25 University students in progress
- 5 crew and crew-like (ground) in progress

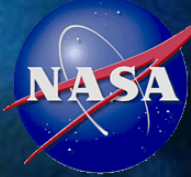
- **Tasks:** Data entry and memory/mapping

- **Schedule:** Train task “pre-flight”, retention quiz at FD90 and FD150 and R+30



Crew report they do not retain things learned many months pre-flight.

# Forward Work



- Increase joint research opportunities with other HRP elements, International Partners (IP), other agencies, and industry, both in analog and space
- Systematically reassess research priorities to ensure the HSID risk is adequately addressed – *Need for macro-level metrics to demonstrate risk burn-down*
- Establish infrastructure for structured capture of operational performance data that can help with research prioritization

Research results will be captured in the Agency Standards, and provided to the Mission Architecture teams to influence new vehicle/habitat design.

