When Earth Is A Pale Blue Dot

Human-Systems Integration Challenges and Opportunities in Earth Independent Operations

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The Pale Blue Dot is a photograph of Earth taken Feb. 14, 1990, by NASA's Voyager 1 at a distance of 3.7 billion miles (6 billion kilometers) from the Sun


On March 18, 2025, NASA astronauts Suni Williams and Butch Wilmore returned to Earth, after spending 286 days in space
On March 31, 2025, they participated in a news conference at the Johnson Space Center and spoke with journalists about their experience

What do heroes look like? Well, heroes put their tank on and they run into a fiery building and pull people out of it. That's a hero.

Heroes also sit in their cubicle for decades studying their systems and knowing their systems front and back. And when there is no time to assess a situation and go and talk to people and ask, 'What do you think?' they know their system so well they come up with a plan on the fly. That is a hero.

And there are several of them in Mission Control.

Barry “Butch” Wilmore, NASA astronaut

(When interviewed by Eric Berger at Ars Technica)

Apollo

Space Shuttle

Present Day (Since 2016)

"Hey, this is a very precarious situation we're in"

Suni Williams, NASA astronaut

NASA Press Release

As Starliner began its approach to the space station, five reaction control system thrusters failed off during flight. Mission teams performed a series of hot-fire tests which re-enabled four of the thrusters while the crew manually piloted the spacecraft at the station's 200-meter hold point. After re-selecting four of the thrusters, Starliner had the fault tolerance required to approach the space station for docking. At the 10-meter hold point, the mission team completed system readiness evaluations and proceeded with docking

Behind the Scene (per Ars Technica)

Heroes in MCC analyzing failures and strategizing contingencies in real time

June 5, 2024 at 14:52 UTC

"Launch was awesome"

//

Vehicle lost 1st thruster. Wilmore took manual control

Vehicle lost 2nd thruster

Vehicle lost 3rd thruster. Aborting docking was no longer an option

Vehicle lost 4th thruster. Wilmore could not fully control vehicle

2 of 4 thrusters recovered

Vehicle lost 5th thruster

All but 1 thruster recovered

Vehicle flew autonomously and docked with ISS

June 6, 2024 at 05:34 UTC

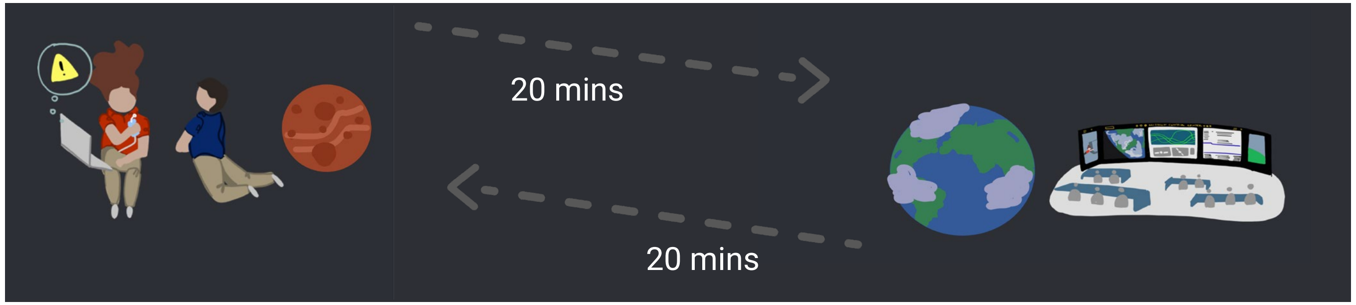
Operating close to or outside of flight rules

Earth Independent Operations

(Autonomous Mission Operations; Autonomous Crew Operations; Crew Autonomy)

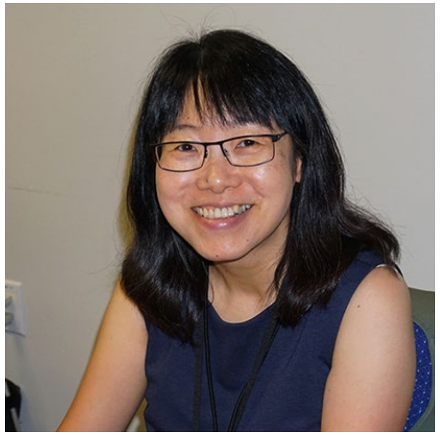
Crewed missions to destinations beyond low-Earth orbit will experience significant communication delays between the crew and mission control – on Mars surface, more than 20 minutes each way – as well as periods of communication blackouts

An integrated set of vehicle technologies are needed to support the crew to effectively respond to onboard situations in the absence of real-time ground support



Earth Independent Human-Systems Operations (EIHSO) Team

See you right here at 2pm after lunch!



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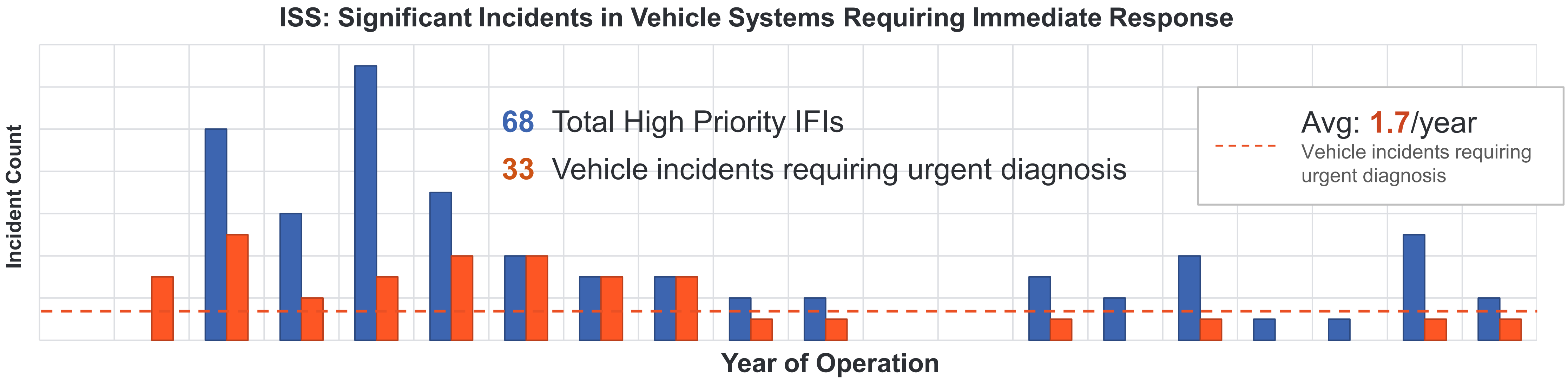
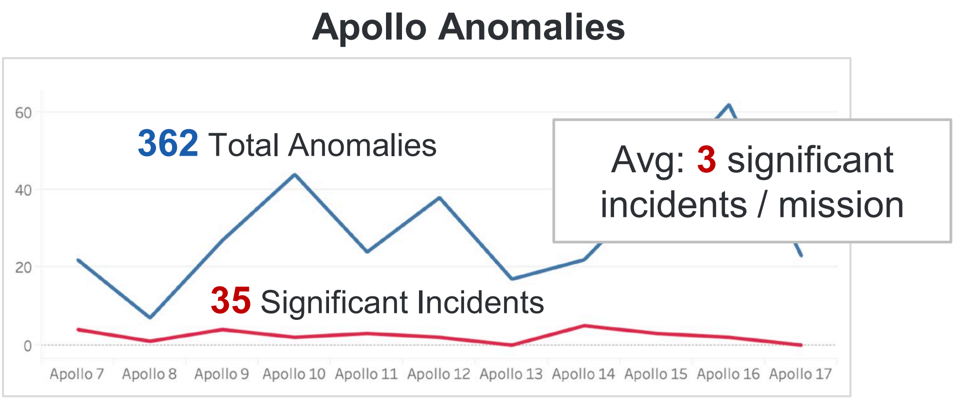
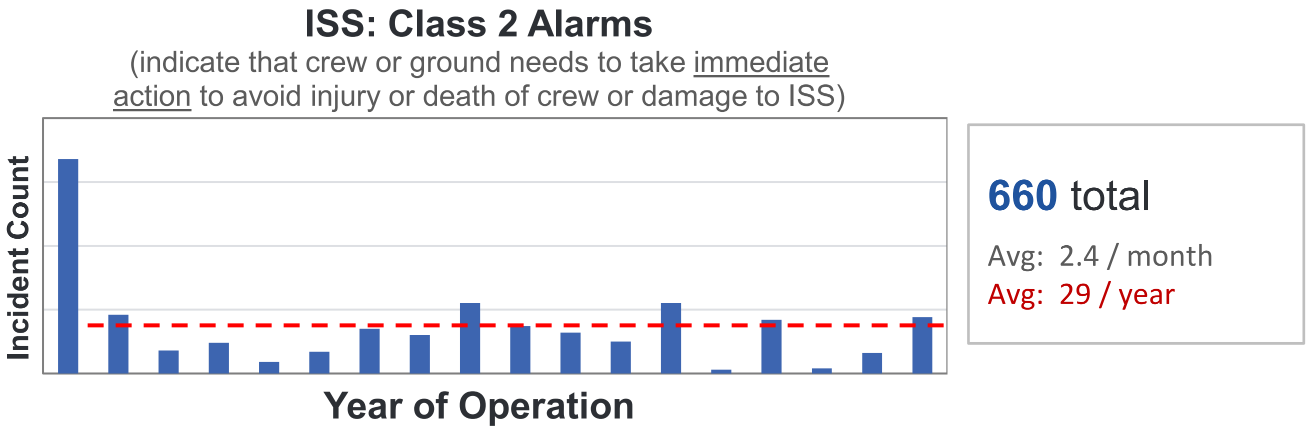
Across human spaceflight missions, unanticipated events requiring urgent responses occur frequently

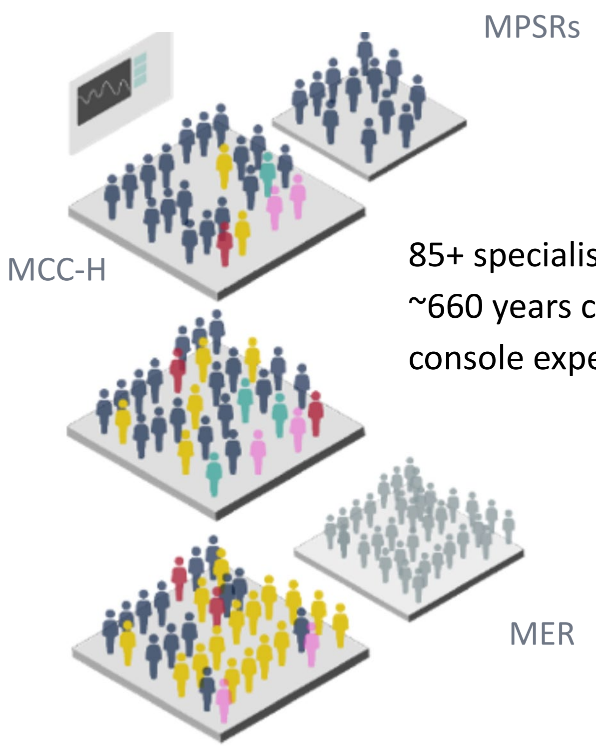






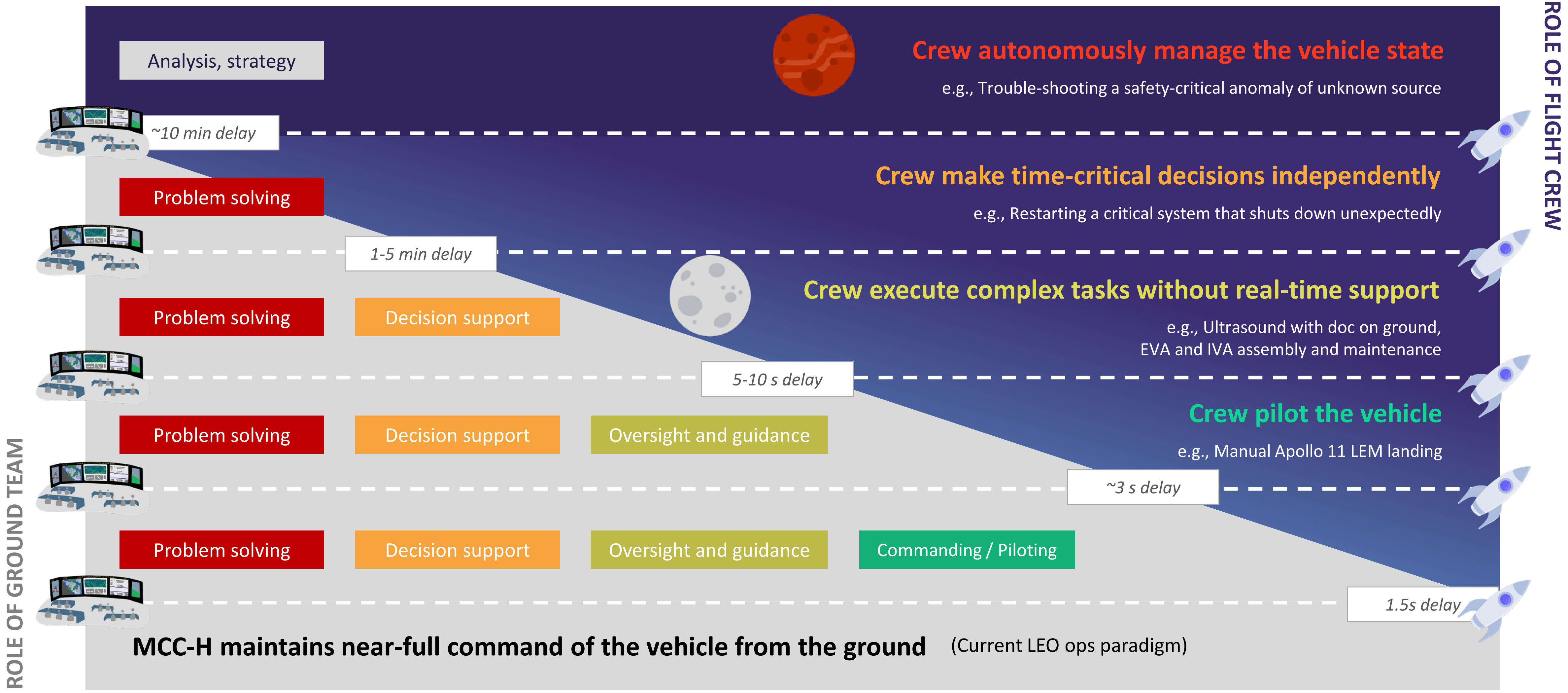
In the current mission operations paradigm, nearly all aspects of safety-critical operations are managed from the ground

Direct control | Oversight and guidance | Decision making | Problem solving



85+ specialists available with ~660 years combined on-console experience

As communication delay increases, responsibilities for safety-critical operations need to be shifted to the flight crew



Comm delay: times are notional, and reflect round-trip delay

NASA Engineering and Safety Center (NESC)

NESC's mission is to perform value-added independent testing, analysis, and assessments of NASA's high-risk projects to ensure safety and mission success

Mars Campaign Office (MCO)

MCO is responsible for maturing and demonstrating exploration capabilities necessary to enable human missions to Mars

Human Research Program (HRP)

HRP uses research to develop methods to protect the health and performance of astronauts in space

CURRENT PROJECT

Assessment of human-systems integration risks on missions beyond LEO; design for maintainability on long duration missions

Development and demonstration of technologies that support crew-led anomaly response and procedure execution

Onboard crew data needs; effects of communication delays; data representation; simulation fidelity

Human-Systems Integration Challenges and Opportunities

Three Example Topic Areas

1. Onboard Anomaly Response

Anomalies will occur throughout the duration of a mission, even with the best engineering processes in place

Onboard support systems will be needed to compensate for reduced ground support

Existing Knowledge

Safe Human Expeditions Beyond Low Earth Orbit

Valinia et al. (February 2022)

A critical challenge for deep space exploration is developing onboard data systems that will integrate sensor telemetry and engineering data to support anomaly resolution by the crew

Intelligent, adaptive systems may help with early detection of anomalous events, though previous research has shown that autonomous and automated systems can increase workload and complexity of tasks for humans, especially in off-nominal situations when human systems integration was not considered

HRP Directed Tasks on Anomaly Response Analysis and Crew Onboard Data Needs

Panontin et al. (2021)

To develop requirements for onboard anomaly-resolution support systems and to validate their design and development, it is critical to accurately simulate off-nominal events and conditions in human-in-the-loop (HITL) facilities and labs. This research identified characteristics necessary to make such simulations realistic and challenging:

- Impact to a critical system
- Causal relationship not immediately understood
- Time pressure
- Imperfect information during initial stages

Opportunities

Long Pole Challenge

- Intelligent adaptive systems capable of solving unanticipated novel problems

Other Challenge

- Onboard data systems that integrate sensor telemetry and engineering data to support anomaly resolution

Collaboration

- Realistic anomaly scenarios and HITL testing capabilities

2. Exploration System Maintainability

Throughout much of NASA's history of human spaceflight, maintenance was performed by trained mechanics at depot facilities on the ground after vehicles returned from missions. The launch of the ISS brought space vehicle maintenance into a new era of in-mission maintenance using orbital replacement units (ORUs) by astronauts under the instruction and supervision of flight controllers at mission control

Attempting to use the paradigm exemplified by ISS operations with the communication and resupply delays anticipated for missions beyond low-Earth orbit will pose great risks for crew health and safety

Existing Knowledge

Opportunities

Maintainability of Manned Spacecraft for Long-Duration Flights

Prepared by Boeing for ***Ames Research Center*** *(August 1968)*

Increases in reliabilities in parts and assemblies, although mandatory, will not be sufficient in themselves to achieve the overall level of assurance that are sought.

The solution lies in the inclusion of appropriate on-board resources to augment or maintain, through the mission, the high reliability level that a spacecraft initially possesses

NASA Exploration Systems Maintainability Standards for Artemis and Beyond

Valinia et al. (August 2023)

Study produced a set of 24 technical requirement candidates (18 new candidates and 6 revisions to NASA STD-3001 Volume 2 Revision C)

Those candidate requirements were designed to provide the crew with appropriate on-board resources (access, tools, training, decision aids, information management) and address environmental factors that can significantly impact maintenance activities (e.g., dust on lunar surface)

Long Pole Challenge

- Methods to improve reliability prediction of complex systems in extreme environments

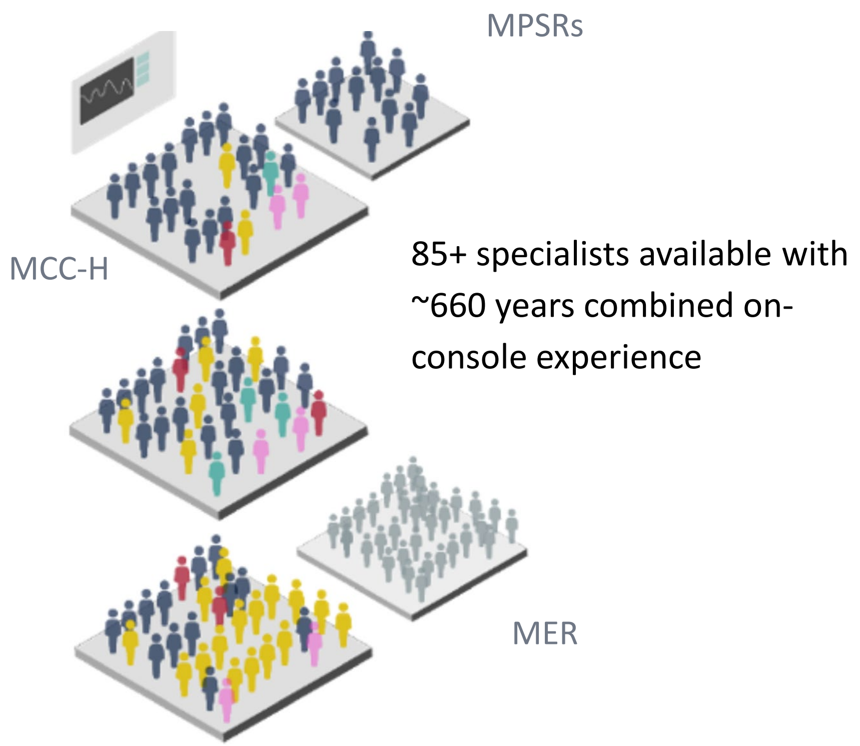
Other Challenge

- In-space manufacturing technology capabilities to support space logistics

3. Crew Complement and Training

Current missions like ISS are supported by 80+ experts on the ground at any given time, with a combined 600+ years of system-specific experience across 22 unique console disciplines

Current crew training ratio is 10 to 1 (10 months of training to 1 month of mission). Flight operation experts believe 2 years is the max duration that should be considered for a Mars pre-mission, flight-assigned training flow



Existing Knowledge

Humans to Mars, But How Many? A Historical Review of Crew Size Determination for Mars Missions

Chaikin (December 2024)

Wernher von Braun, modeling after Antarctica explorers who were largely cut off from the world and needed experts and technicians on hand to contend with any situation, proposed no less than 70 people would make the 260-day journey to Mars, with 50 of them setting foot on the Mars surface

Any decision should consider the roles and tasks of astronauts, and the need for cross-training to provide backup in case of contingencies, as critical factors

Trade Space Analyses: Balancing Crew and Mission Design Parameters

Dempsey et al. (August 2024)

Methodology for conducting a systematic trade space analysis of crew size using quantitative data from human performance modeling of crew workload and expertise

Opportunities

Long Pole Challenge / Collaboration

- An accessible crew complement trade space analysis tool with built-in knowledge of crew expertise and skill requirements given architectural and mission design parameters and constraints of human capabilities

Other Challenge

- Effective onboard training approaches and technologies on long duration flights

For more information:

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