Lunar Surface Contributions to Addressing NASA's Human System Risks

National Academies of Science

July 9 2025

Daniel M. Buckland MD PhD [1,2]

Mary Van Baalen[1]

1 NASA Johnson Space Center, Houston, TX, USA

2 University of Wisconsin - Madison, USA

Overall Problem

Which Human System Risks are informed or mitigated by (non-polar) mission sites which can or must be done by human explorers on the lunar surface:

1) To *prepare* for a Mars mission

2) To *support* Lunar missions

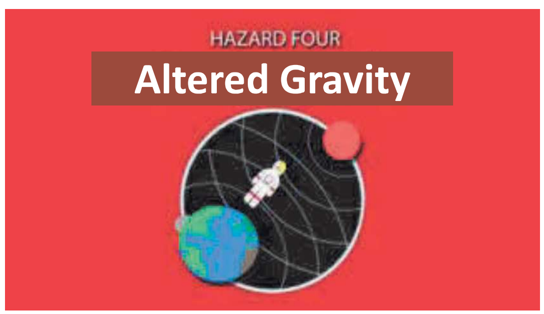
3) Due *to inability of automation* to reliably perform mission critical operations.

The NASA Human System Risk Board (HSRB)

- Tracks the evolution of the top ~30 human system risks identified to be associated with human spaceflight
- Characterize the risk by likelihood and consequence
- Crew as a Vehicle System:
  - Risk to the fitness of a crew when the mission requires their performance.

Challenges for Human Spaceflight Beyond Low-Earth Orbit

NASA has organized hazards astronauts will encounter on a continual basis into five classifications:



Human Spaceflight Operations in Low-Earth Orbit

❖ **ISS Mission ops rely on:**

- Real-time communication
- Frequent resupply
- Evacuation opportunity

Experts on the ground constantly manages the state of the vehicle

- **85+** specialists available
- **~660** years combined on-console experience
- **22** unique console disciplines

The ISS relies on frequent resupply of spare parts and other resources from visiting vehicles to maintain the vehicle

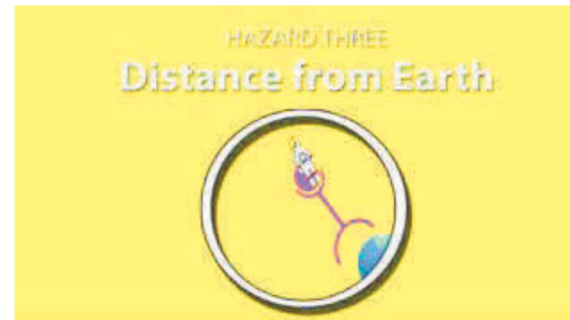
An example Orbital Replacement Unit (ORU)

Mission Control provides crew with real-time direction and oversight for complex task execution

Human Spaceflight Beyond Low-Earth Orbit

❖ **Challenges beyond LEO:**

- Limited communication
- Limited resupply
- Limited evacuation opportunities



Increasing Earth-independence and crew autonomy

Lunar delay ~15 sec round trip (>than Apollo)
Mars delay up to 40 min round trip

From 85+ to 4 people available to respond

MCC + MER

- 85 system experts
- 660 years combined specific systems experience
- ~2 years to operator cert
- Additional years to specialist cert
- In-depth understanding of a single system
- Training builds academic engineering background
- Constantly using skills and studying flight rules

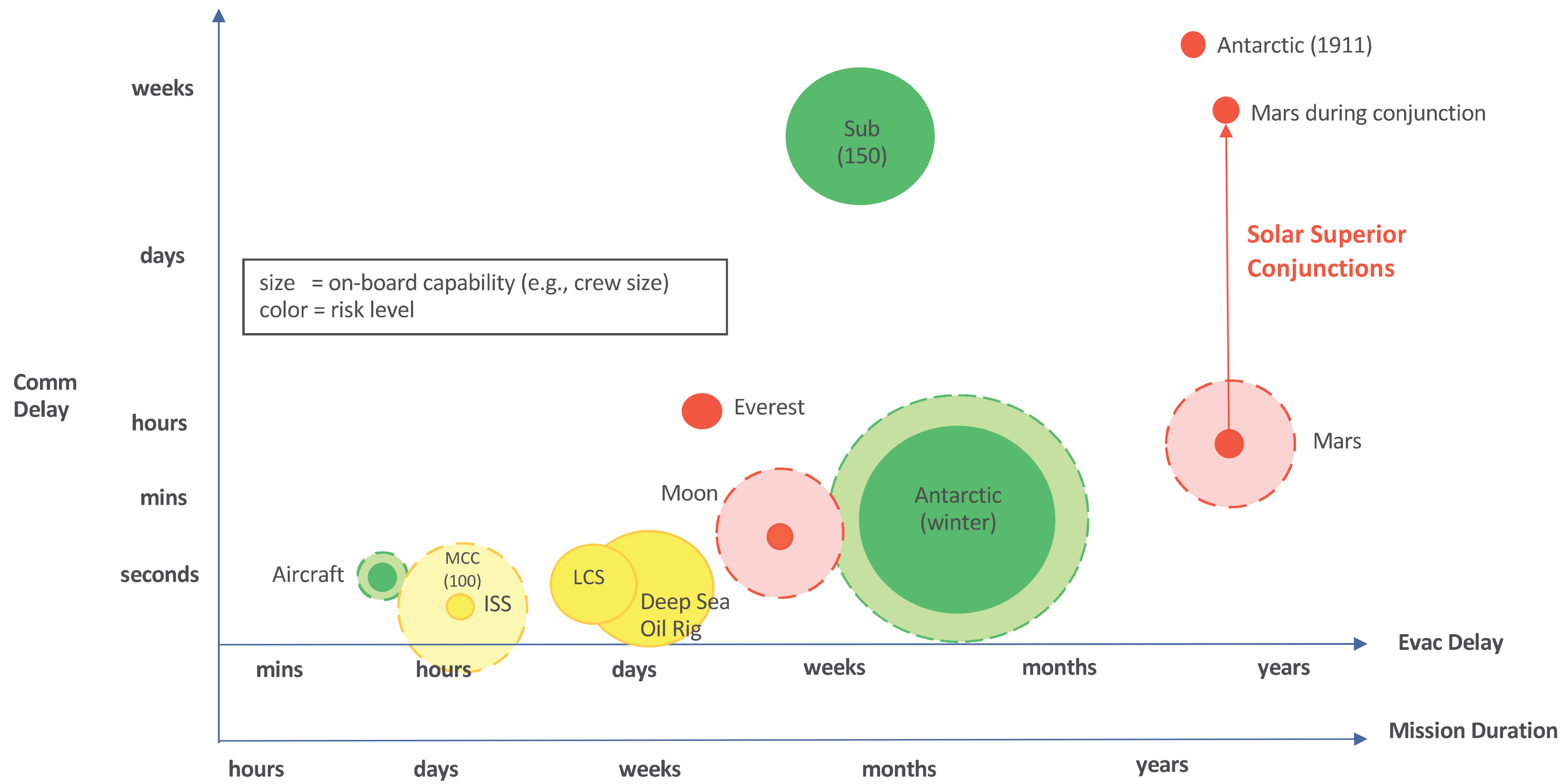
Astronauts

- 4 crew members
- 91 years combined relevant work experience**
- 2 years ASCAN training
- ~2 years flight-assigned training
- *I&S, C&T, EPS, ETCS, ECLSS, ITCS, Emergency, MCS, OOM, Struc & Mech, Crew Systems, VV, Orb Mech, CMO, Med Ops, EVA, ROBO, Ops LAN, Photo/TV
- Time gap between training and flight; degradation of knowledge may be significant

**Calculated based on all active astronauts who are eligible to be assigned a flight as of January 2021

> ***"4 people with 25 years experience each on 4 console positions cannot replace 10 people with 10 years of experience on 10 console positions even though both groups have 100 years total experience. It's not just the experience, it's the experience in unique console positions."***
>
> -D. Dempsey, Training Expert

State of Knowledge: What do analogues tell us?

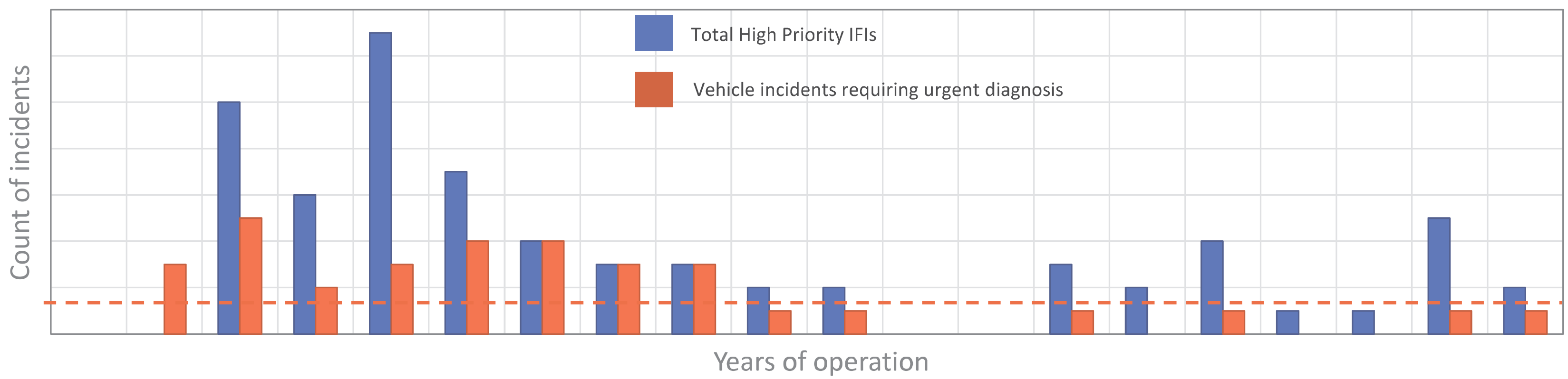


Characterizing the Earth Independent Operations Risk

Anomaly Rates for Human Spaceflight

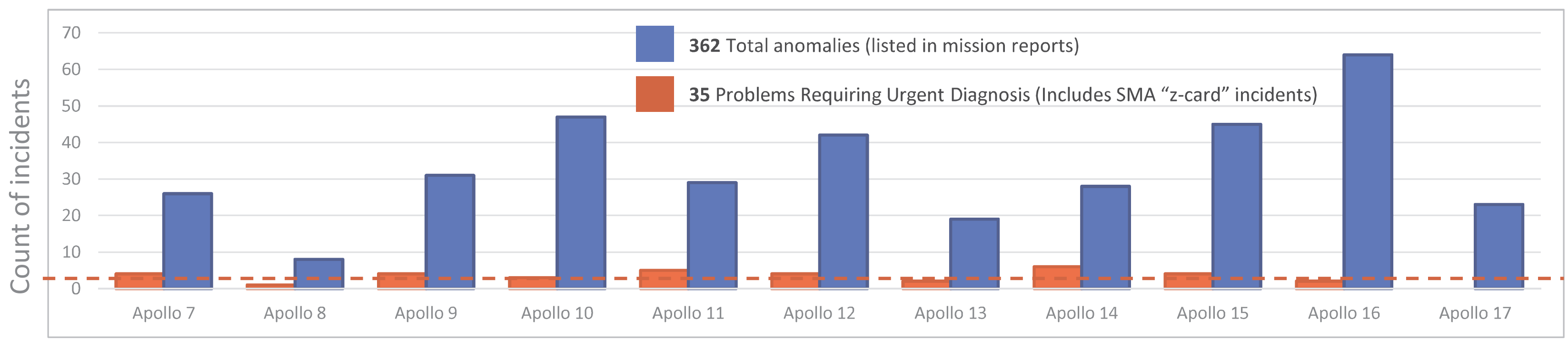
ISS

Avg: 1.7/year
Vehicle incidents requiring urgent diagnosis



Apollo

Avg: 3/mission
Vehicle incidents requiring urgent diagnosis



State of Knowledge: Problems during crewed space flight

HRP Funded

Apollo Mission Reports Analysis:

Anomalies per Mission* (Rounded Average):

33

Anomalies per Mission Day (Rounded Average):

3

Incidents Requiring Urgent Diagnosis per Mission (Rounded Average):

3

*Anomaly count pulled from Apollo Mission Reports

Increased complexity of mission leads to increased likelihood of adverse events

Greatest Risks per Mission Categories

Lunar Surface Missions less than 30 days

- EVA
- Dynamic Loads on Planetary Surface Landing
- Earth Independent Human-Systems Operations
- Food and Nutrition Needs
- Medical Events Impacting Performance of Mission Duties
- Sensorimotor Degradation
- Altered Sleep Environment
- Crew Team Dynamics
- Crew Egress Ability

Lunar Surface Missions up to 1 year

- EVA
- Dynamic Loads on Planetary Surface Landing
- Earth Independent Human-Systems Operations
- Food and Nutrition Needs
- Medical Events Impacting Performance of Mission Duties
- Sensorimotor Degradation
- Altered Sleep Environment
- Crew Team Dynamics
- **Aerobic and Muscle Deconditioning**
- **SANS**

Mars Preparatory Missions up to 1 year

- Earth Independent Human-Systems Operations
- Food and Nutrition Needs
- Medical Events Impacting Performance of Mission Duties
- Altered Sleep Environment
- Crew Team Dynamics
- SANS
- **Behavioral Health**
- **Blood Flow Changes**

Mars Surface Missions

- Earth Independent Human-Systems Operations
- Food and Nutrition Needs
- Medical Conditions
- Crew Team Dynamics
- Aerobic and Muscle
- EVA
- Sensorimotor
- **Bone Fracture**
- Blood Flow Changes
- Crew Egress on Landing
- **Dust Injury**
- Dynamic Loads on Landing
- **Renal Stone Symptoms**
- SANS
- Behavioral Health
- **Pharmaceutical Effectiveness**
- Altered Sleep Environment

High Value Risk Mitigation Targets

EVA

- Increased physical & cognitive workload at differing suit pressures
  - Understanding workloads, demands, and implications/decrements associated with operating exploration suits, tools, and procedures in high-fidelity analog environments.
  - Ensure exploration spacesuits can accommodate necessary workloads.
- Monitoring and maintenance of crew health and performance in real-time
- Increased quantity and density of EVA
  - Characterization of health and performance outcomes as a function of EVA duration and frequency.
  - Development of operational fitness for duty requirements and work-rest intervals during exploration operations.
- Functional performance effects of hypoxia research can decrease DCS risk

Planetary Surface Landing

- Passive foot forces during extraterrestrial surface landings
- Crew occupational surveillance
- Accurate quantification of deconditioning effects on human tolerance
- Validated/updated tools that accurately predict injury risk in spaceflight
- Interaction of the seat and suit in dynamic phases of flight
- Differing landing and thermal environments of landing locations.
- Crew fatigue and fitness levels relative to egress tasks on landing day.
- The effect of partial-gravity (either Lunar or Mars) over an extended time needs to be applied to contributing risks to determine mitigating effects of partial-gravity.

Lunar Independent Operations

- Develop metrics framework assessing resiliency of crew-system integration toward Earth-independent operations
- Characterize and develop necessary human-in-the-loop simulation capabilities
- Establish standards development approach for rapidly evolving on-board technologies for data systems, decision support, autonomous systems

Food and Nutrition Needs

- Determine the interaction of food and nutrition with other human health risks
- Determine the impacts of food system restrictions on food intake, mission objectives, health, and performance
- Determine the requirements, methods, and technologies that can provide a food system that is safe, nutritious, and acceptable for at least five years, within resource limitations.
- Sustainable Dietary Tracking

Medical Conditions

- A Crew Health and Performance integrated data system architecture
- Identify, develop, and integrate appropriate medical training modalities reduced real-time communication
- Better integrate Medical Infrastructure/Capability with Vehicle and Mission Design.
- Correlate In-mission environmental exposures with long term health outcomes
- Validate the efficacy of an inflight medical capability
- Continue to characterize new medical events

Sensorimotor

- Develop and validate countermeasures that target motion sickness, spatial orientation, manual/fine motor control, and postural control and locomotion
- Characterize operational manual control and EVA abilities during and soon after G-transition
- Characterize the effects of Lunar partial gravity on EVA performance
- Better understand the underlying mechanisms such as changes to the g-receptors and central nervous system

Altered Sleep Environment

- Develop, evaluate, or validate objective measures of sleep quality and quantity
- Understand the impact of Artemis and Mars scheduling constraints on crew alertness, performance, and countermeasure use
- Develop, evaluate, or validate objective measures of circadian phase
- Develop, evaluate, or validate individualized biomathematical models of performance impairment due to sleep loss and circadian misalignment
- Evaluate, develop, assess, or validate the impact and applicability of active technologies that reduce impairment
- Lighting as a countermeasure

Crew Team Dynamics

- Integrated team training and countermeasure validation.
- Training, procedures, and countermeasures for multi-team systems under communication delays.
- Maintain lunar-focused analogs and Mars-focused analogs

Aerobic and Muscle Risk

- Understand the influence of <u>long-duration</u> 1/6g and 0g exposure on adaptations to aerobic fitness & muscle strength and functional performance
- Individual trajectories for in-mission deconditioning, determine exercise efficacy
  - Determine contribution of EVA to fitness
- Updated standards to meet planetary surface EVA demands
- Effective exploration exercise countermeasures and performance monitoring systems

SANS

- Determine underlying mechanism(s) of SANS
- Determine role of mission duration in the development of SANS findings
- Test and validate countermeasure efficacy during spaceflight
- Mechanical countermeasure development and operational deployment
- Miniaturize ocular assessment hardware

Behavioral Health

- Characterize in-mission prevalence of sub-clinical behavioral and cognitive changes
- Key indicators and thresholds that lead to meaningful change.
- Establish onboard capabilities for in-mission monitoring
- Develop and validate inflight capability to support early risk detection and countermeasure deployment that does not rely on re-supply or real-time communication with ground

Blood Flow Changes

- ❖ Identification of biomarkers to initiate treatment
- ❖ Characterize the risk of venous thrombus and implementation of countermeasures
- ❖ Characterization of risk of orthostatic hypotension during sustained exposures to G_z acceleration after weightlessness and partial gravity
  - Acquisition of biomedical and acceleration data and crew symptoms during Artemis missions
- ❖ Understanding of the contributions of weightlessness, radiation, and isolation to cardiovascular disease risk

Dust Injury

- "Mars Leaning" Surface Mission Experience
- Incorporating/Encouraging Lunar Dust Monitoring
- Assessment of Lunar Volatiles
  - Chemical reactivity and behavior
  - Containment Strategies
  - Volatile mapping and further exposure characterization
- Allergen Assessment of Lunar Dust

Bone Fracture

- Characterization of the anti-resorptive countermeasures in the astronaut population.
- Capability to monitor for changes in trabecular bone architecture of deeply embedded bones (i.e., hip and spine) <u>during</u> spaceflight.

Pharmaceutical Effectiveness

- Pharmaceutical use and effectiveness from all Mars precursor missions to enable characterization of this risk for a Mars mission.
- Determine medication stability
- Characterize the potential magnitude of physiologic changes that influence Pharmacokinetics and Pharmacodynamics

In Need of Solutions

Lack of comprehensive evidence results in limited perspectives that often focus in a singular area and lead to four erroneous assumptions about possible solutions:

1. Engineering can design more reliable/robust systems so that anomalies do not occur
2. Artificial Intelligence will address anomalies
3. MCC can continue to address anomalies, even with delayed comm
4. Training can be amplified to prepare crew to address anomalies

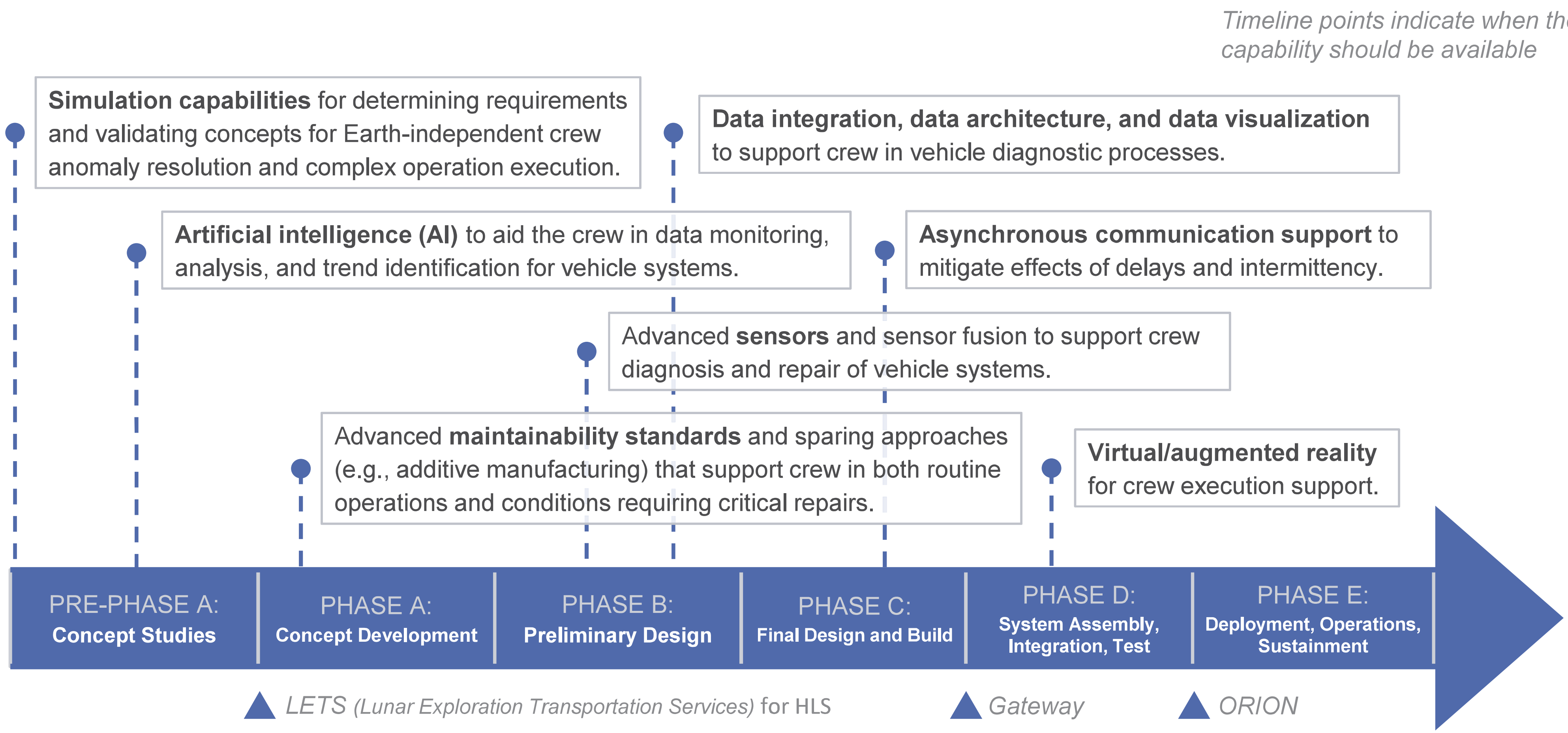
Earth-independent operations are not viable without advances in all four of these areas.

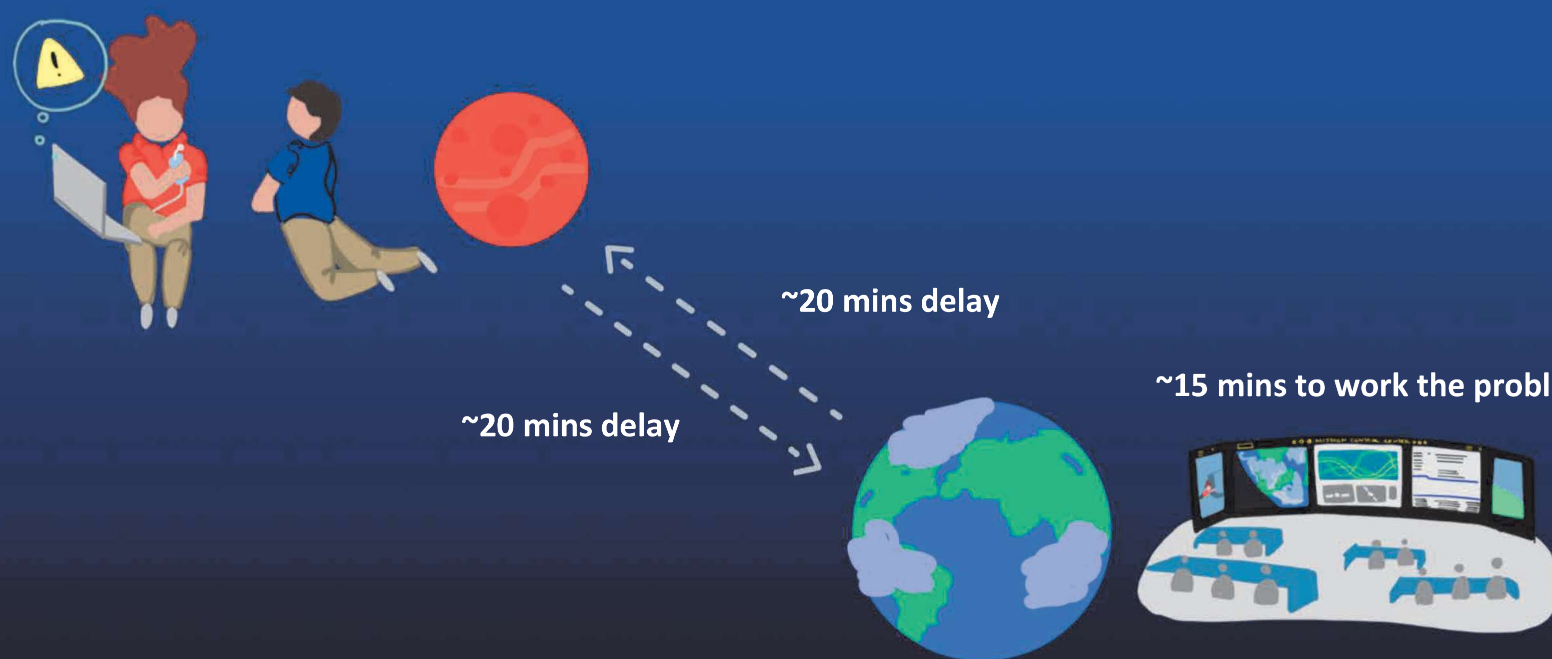
Backup slides

Reimagining Mission Systems, Tools, and Roles for Beyond LEO

- Onboard data systems that support monitoring, analysis, and trend identification for vehicle systems via sensors
- Diagnostic tools such as data visualization and decision aids
- AR/VR and other supportive technologies to help crew characterize and assess impacts of problems in complex, interconnected systems
- In-space manufacturing technologies
- Standards and requirements for advanced maintainability, reliability, and diagnosability must be established early

Research and technology capabilities to focus on





Advice from ground will be up to 1 hour outdated

Anomaly Response Procedures

Designed For This

Performed In This