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QUALITÀ NELL'AEROSPACE

Sfide, Risultati e Opportunità
della Qualità nella Space Economy

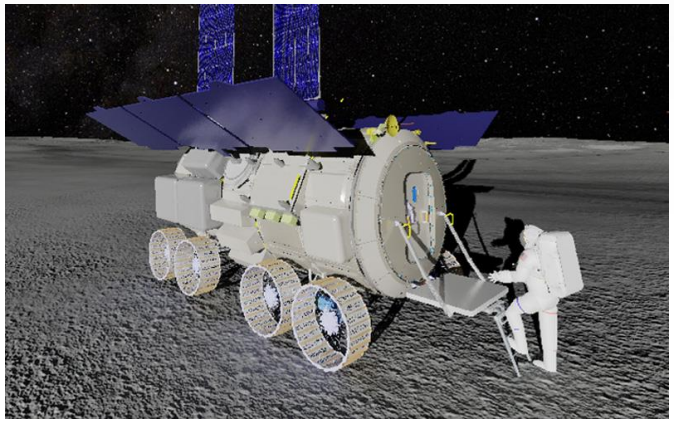
DEPENDABILITY FOR LUNAR MISSION: MAINTENANCE STRATEGIES FOR MPH EXTERNAL HABITAT SYSTEM

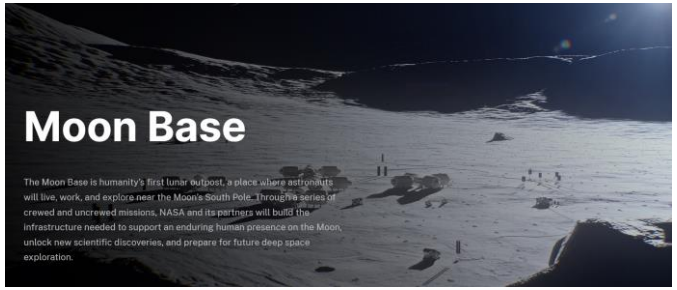
Marianna Rinaldi (ASI)
Orsola Rao (TAS-I)

11-12 NOVEMBRE 2026 TORINO

{OPEN}

OUR HOME on the MOON: MULTI-PURPOSE HABITATION (MPH)



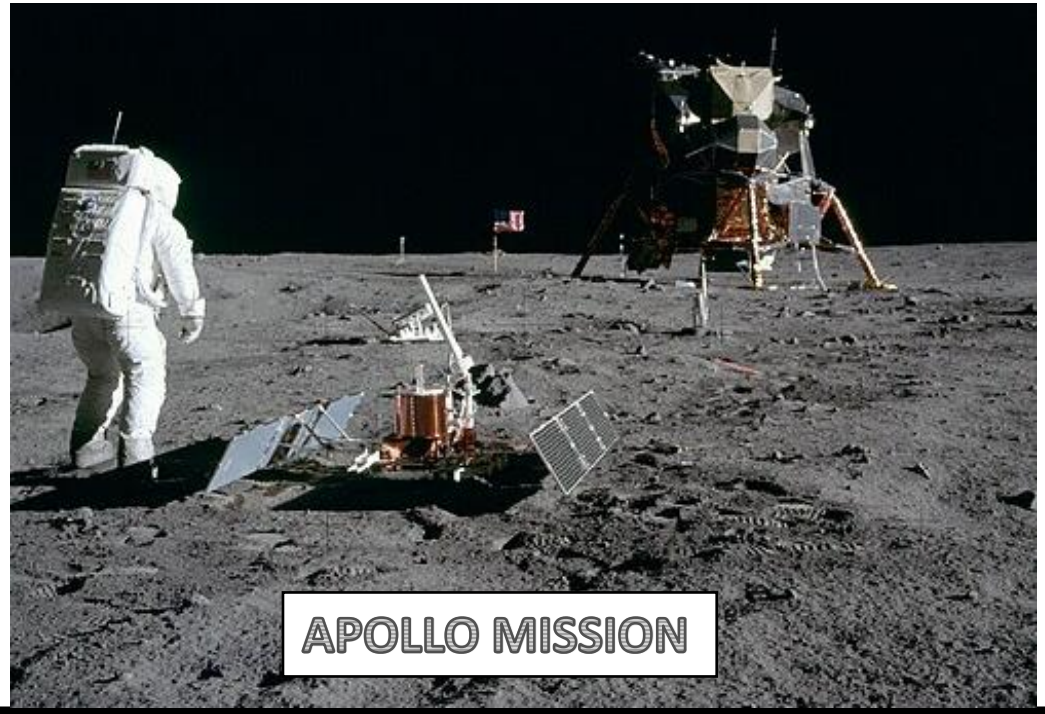




FROM **SURVIVABLE**
Short duration missions

A PARADIGM SHIFT

TO **DEPENDABLE** Systems FOR AN ENDURING PRESENCE





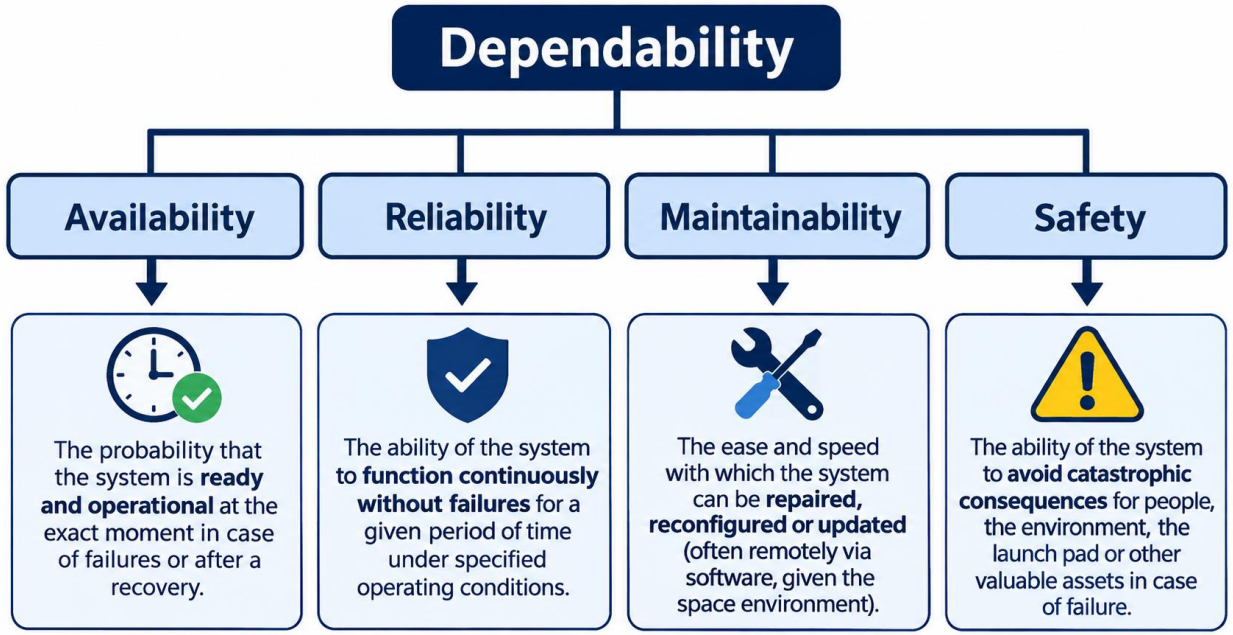
Apollo Era
Short Duration,
YEAR 1960s-1970s, Mission Success Focus, Minimal Repair



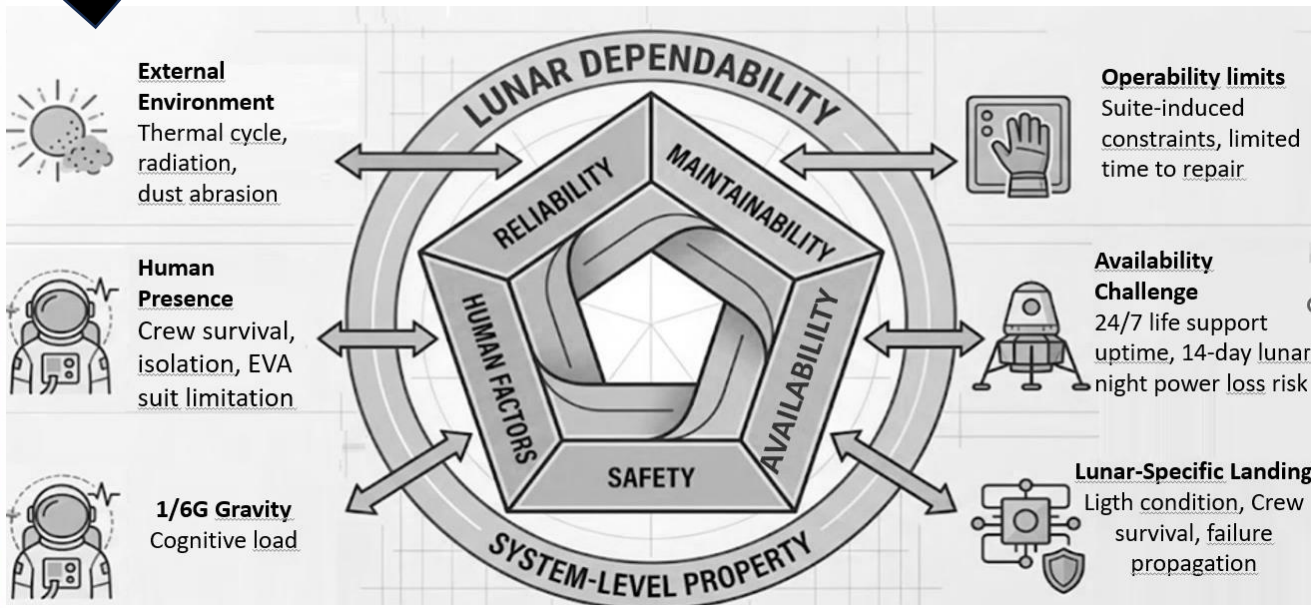
Future Lunar Base
Extended Duration
YEAR 2030s+, Sustainability focus, Maintainable Systems

DEPENDABILITY FRAMEWORK FOR LUNAR HABITAT

Dependability(RAM+Safety)



System Lunar-Specific Challenge



ENVIRONMENTAL

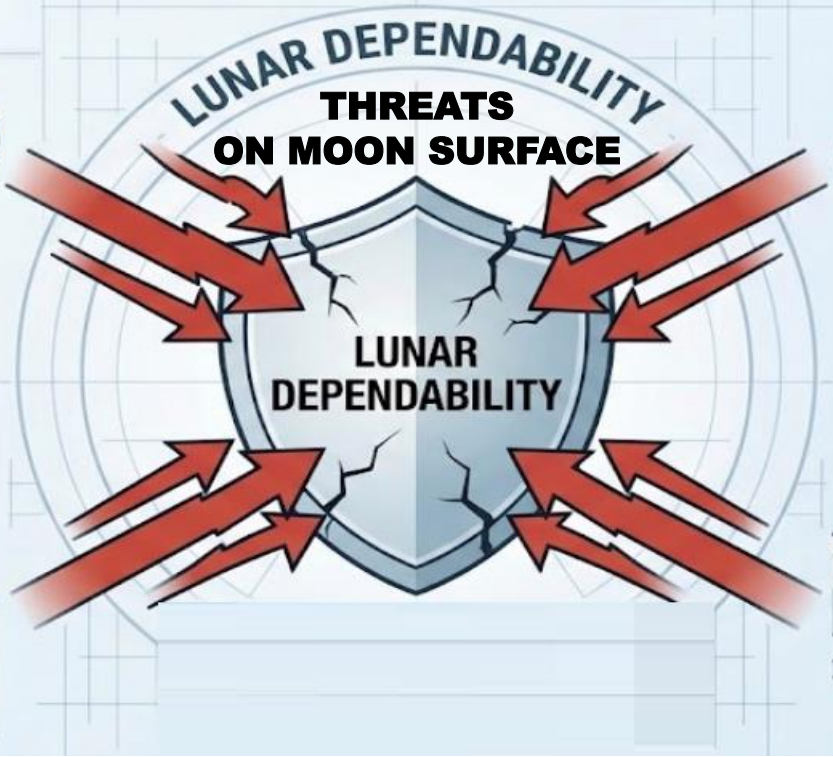
- Thermal cycling
- Radiation
- Dust



OPERATIONAL



- Accessibility
- Dust intrusion
- Limited EVA time



LOGISTICS

- Maintenance depends on onboard resources and resupply opportunitiess

- Spares strategy early definition;
- maintenance intervals VS crewed mission cadence



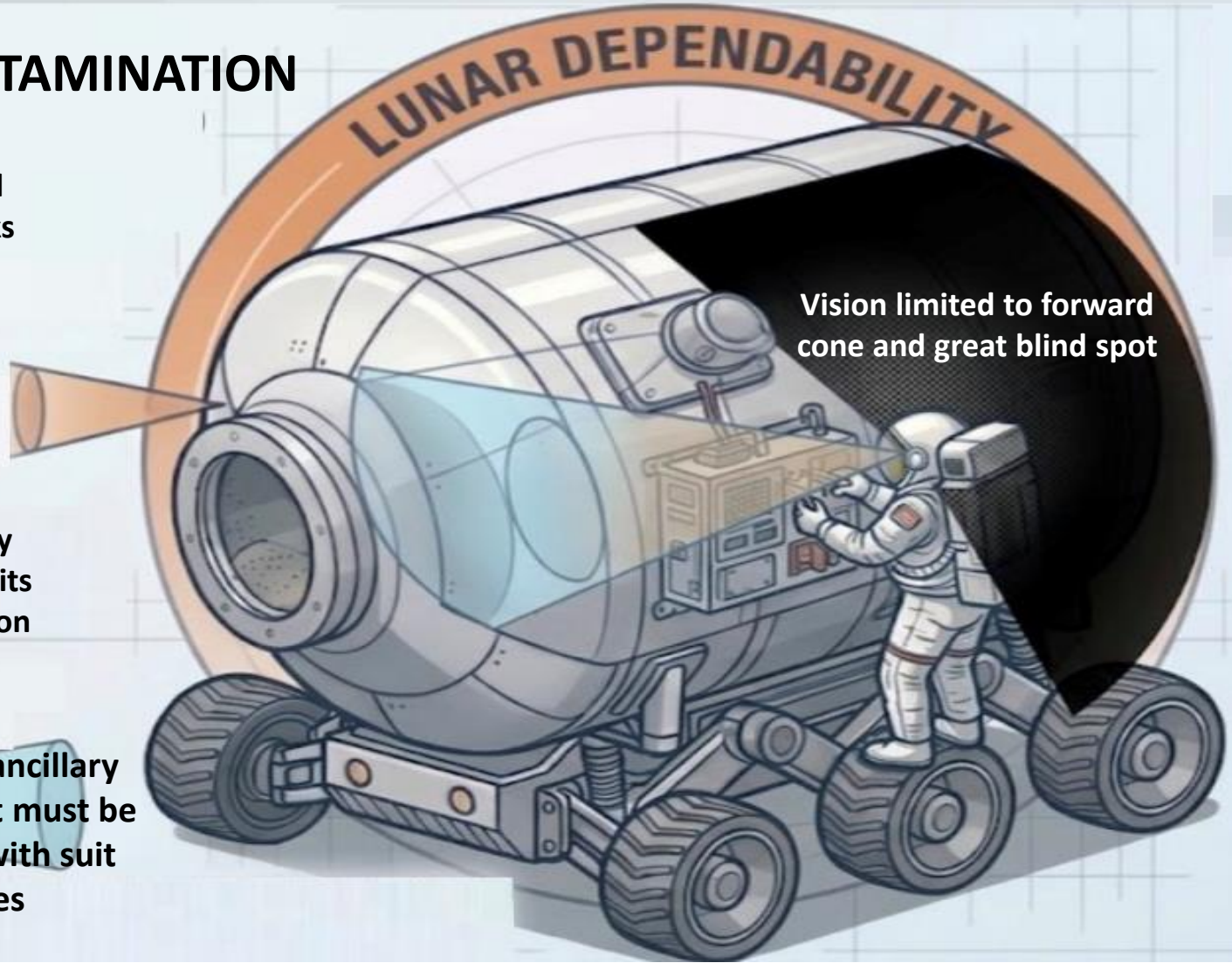
HUMAN FACTORS



- Suit constrains
- Reduced Tactile feedback and fine manipulation
- Crew workload Fatigue, stress
- Limited field of view

A DEPENDABILITY CHALLENGE FAR BEYOND APOLLO & ISS

EVA-SUIT INDUCED CONSTRAINTS:THE HUMAN FACTOR DEPENDABILITY



DUST CONTAMINATION



Can increase torque required for manual tasks up to 40-60%



TASK TIME



~8hours
Suit battery budget limits EVA duration

GRIP ABILITY



Tools and ancillary equipement must be operable with suit gloves

Vision limited to forward cone and great blind spot



ACCESSIBILITY

Maintenable components should be positioned within reach, in accessible area and accounting for 1/6 G reduced gravity

Preventive Maintenance:
Scheduled actions to prevent failure
Predictive Maintenance (Condition-Based) :
sensor-based monitoring to forecast and identify failure and to inform maintenance timing
Corrective Maintenance:
Replacement of failed ORUs, with in-situ repair where feasible

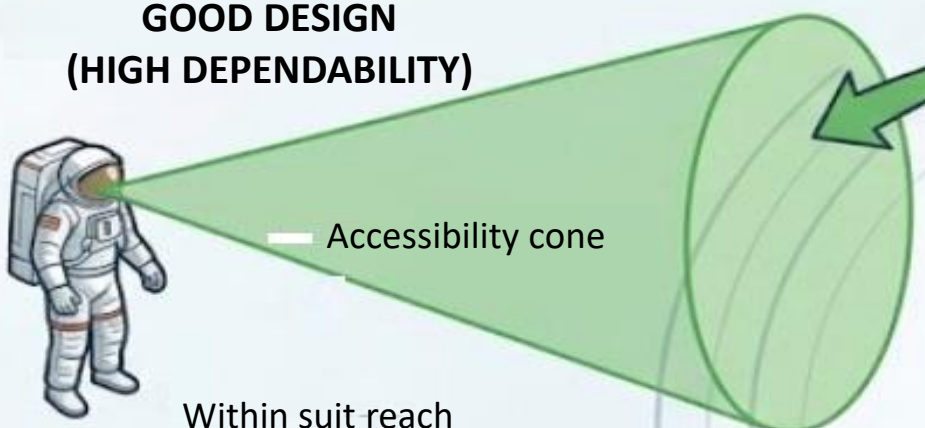
MAINTENANCE IS A DESIGN DRIVER- NOT JUST A CONTINGENCY
Lunar-habitat maintenance must be tailored to the mission context: limited resupply, constrained crew time and EVA operations affected by spacesuit constraints.

AVAILABILITY Limitation: resupply ARE LIMITED
(every 1-3 years VS 2-3 months on ISS),
crew time is limited (7-day crewed periods),
and external maintenance requires EVA with severe suit-induced constraints.

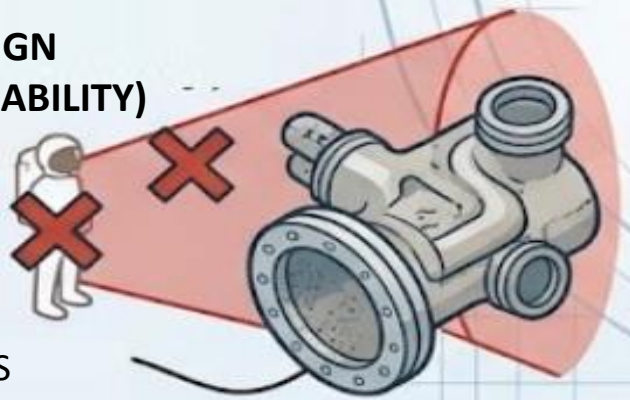


DEPENDABILITY OVER EXTERNAL LUNAR HABITATION

GOOD DESIGN (HIGH DEPENDABILITY)



BAD DESIGN (LOW DEPENDABILITY)



Many small, difficult-to-grip fastners (e.g. Legacy ECLSS manifold)

1. Accessibility

2. Tactile coding

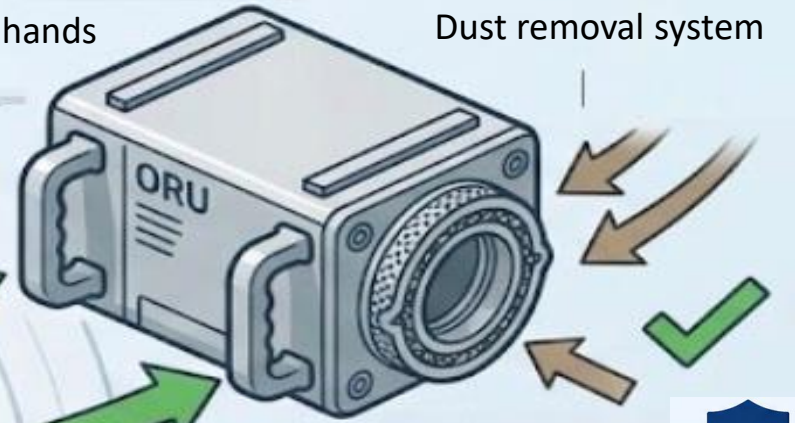
3. Single crew operations

4. Dust rejection

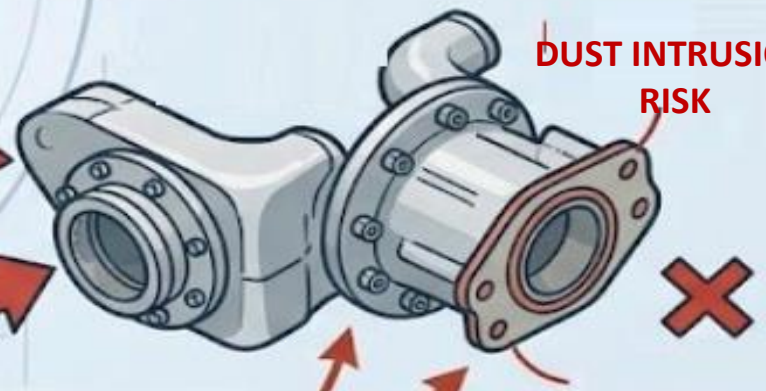
5. Low Torque

>50mm gloved hands

Dust removal system







DUST INTRUSION RISK

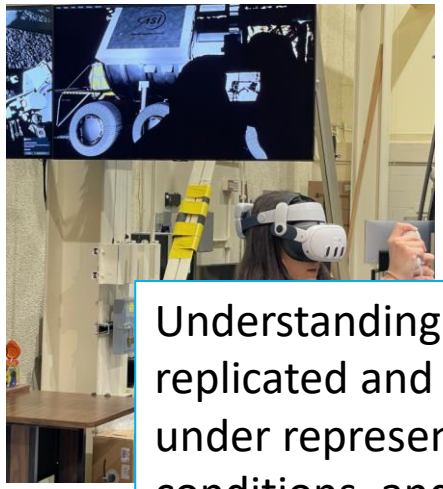
Complex: high torque interface

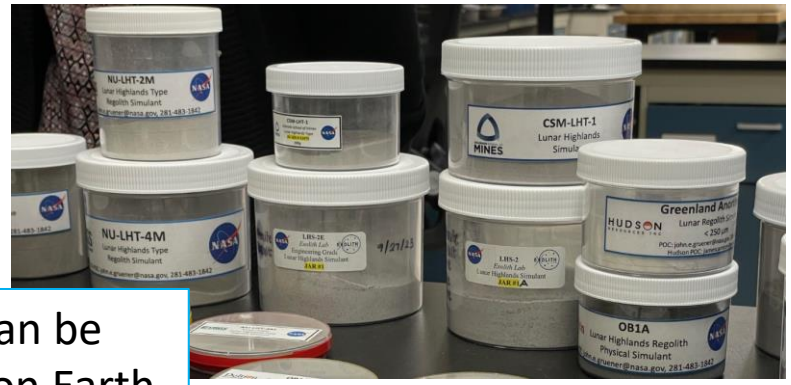
DUST INTRUSION RISK

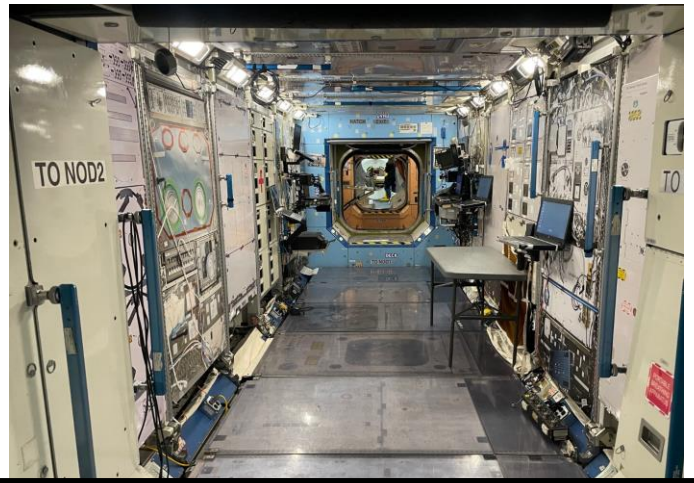
TESTs and OTHER «COMFORT ZONES»...



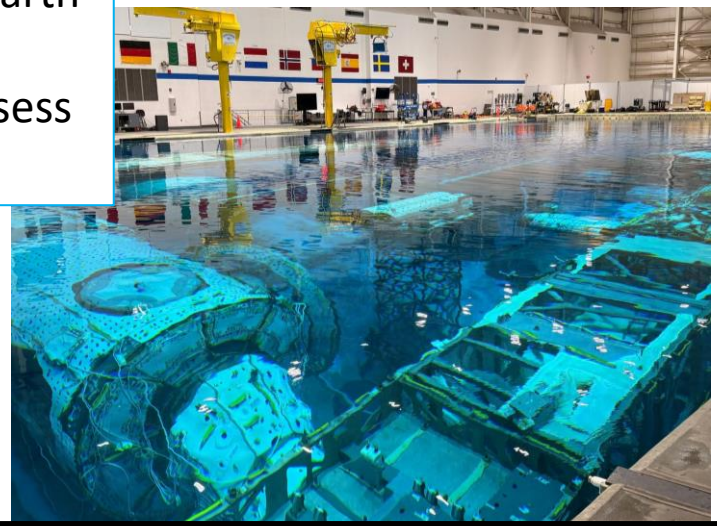






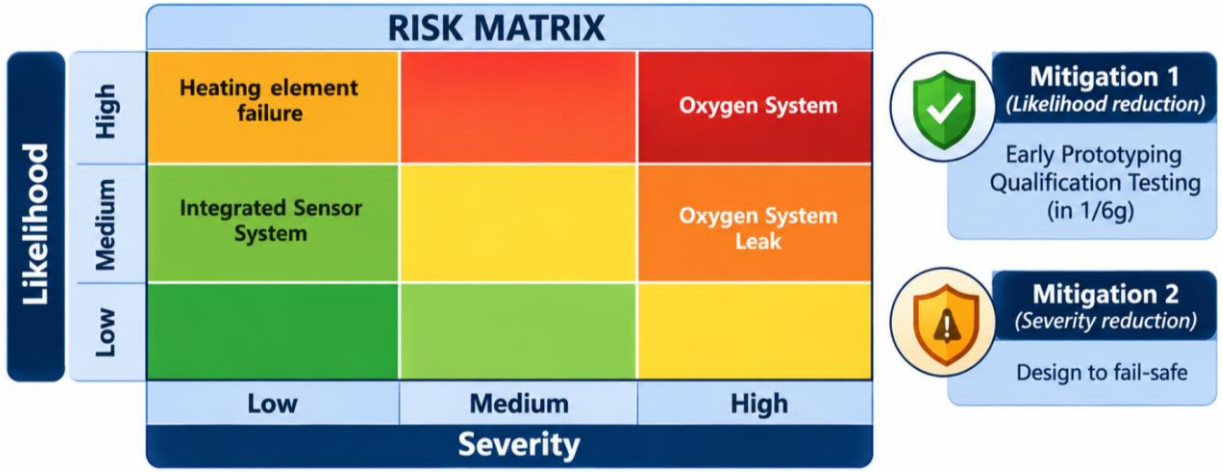




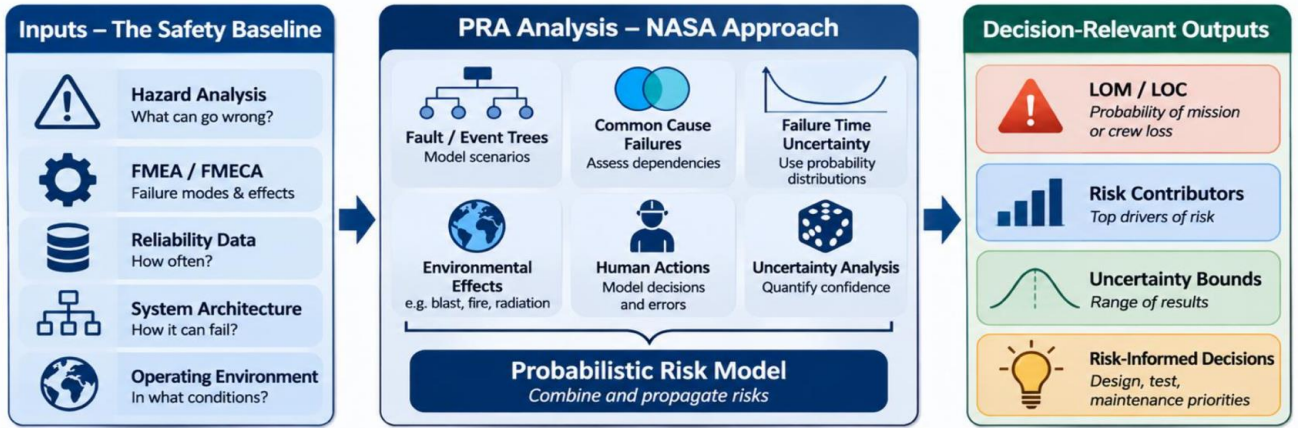


Understanding what can be replicated and tested on Earth under representative conditions, and how to assess the remaining risks

RISK-BASED MAINTENANCE PRIORITIZATION



PROBABILISTIC RISK ASSESSMENT (PRA)



SAFETY FIRST and RISK BASED PRIORITIZATION

Within the MPH project, identified risks are assessed for their implications for mission safety and operational health and safety (HSE)

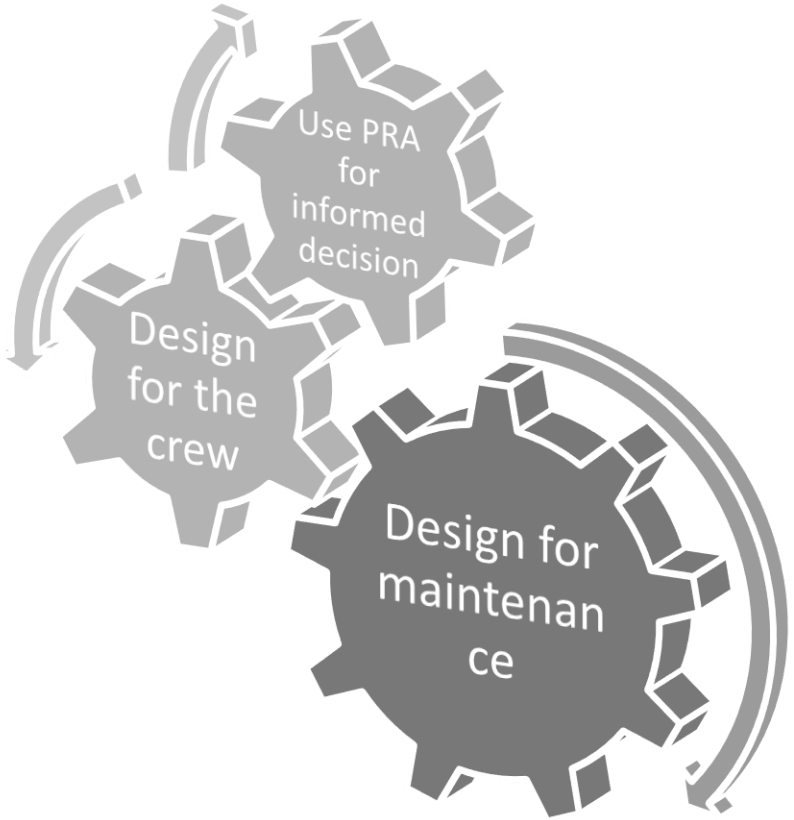
PRA can complement the risk register with quantitative, scenario-based analysis of system-level risk, including uncertainty and dominant risk contributors.

DEPENDABLE DESIGN

- EVIDENCE FROM TESTING (Mock-up, Pre-developments test, regolith)
- EVIDENCE FROM ANALYSIS (FMEA,FTA,PRA)

CONCLUSIONS





A dependable lunar habitat is not simply a system that works: it is a system designed to remain safe, functional and maintainable throughout its intended mission lifetime.

Thank you for your attention