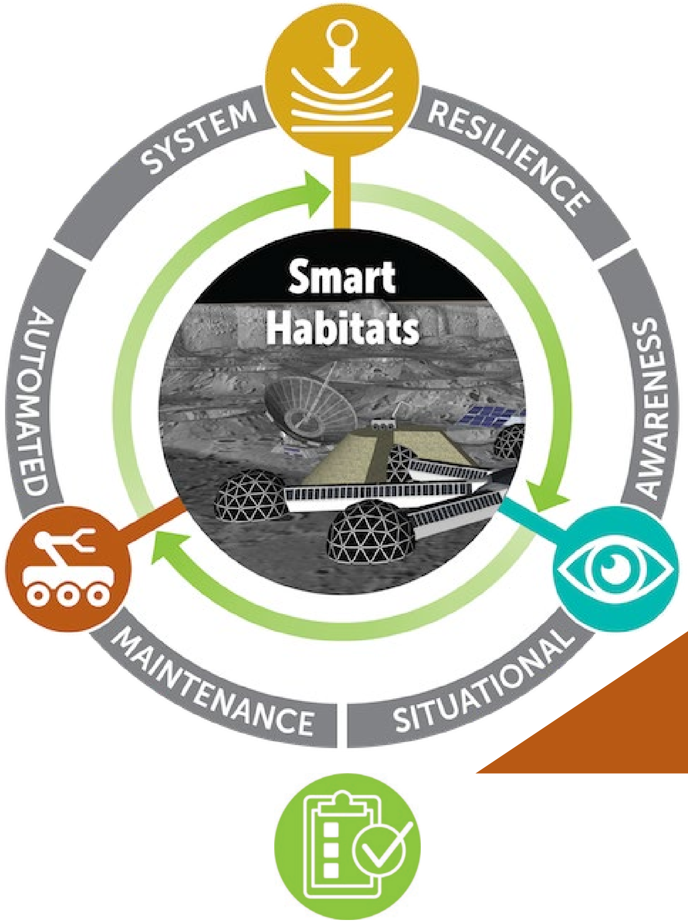


Resilient Design of Extraterrestrial Habitats

EDSE Workshop and Grantees Meeting

October 7, 2019

Shirley Dyke

Purdue University, RETH Institute

Outline

- What is resilience?
- How does this apply to deep space habitats?
- Challenges in a system of systems
- What is RETH Institute?
- How can we design for resilience?
- What are the specific challenges in this approach?

Funded by the *National Aeronautics and Space Administration*

Previous Projects

- NSF MRI
- NSF NEESR
- NSF CISE
- NSF RCN

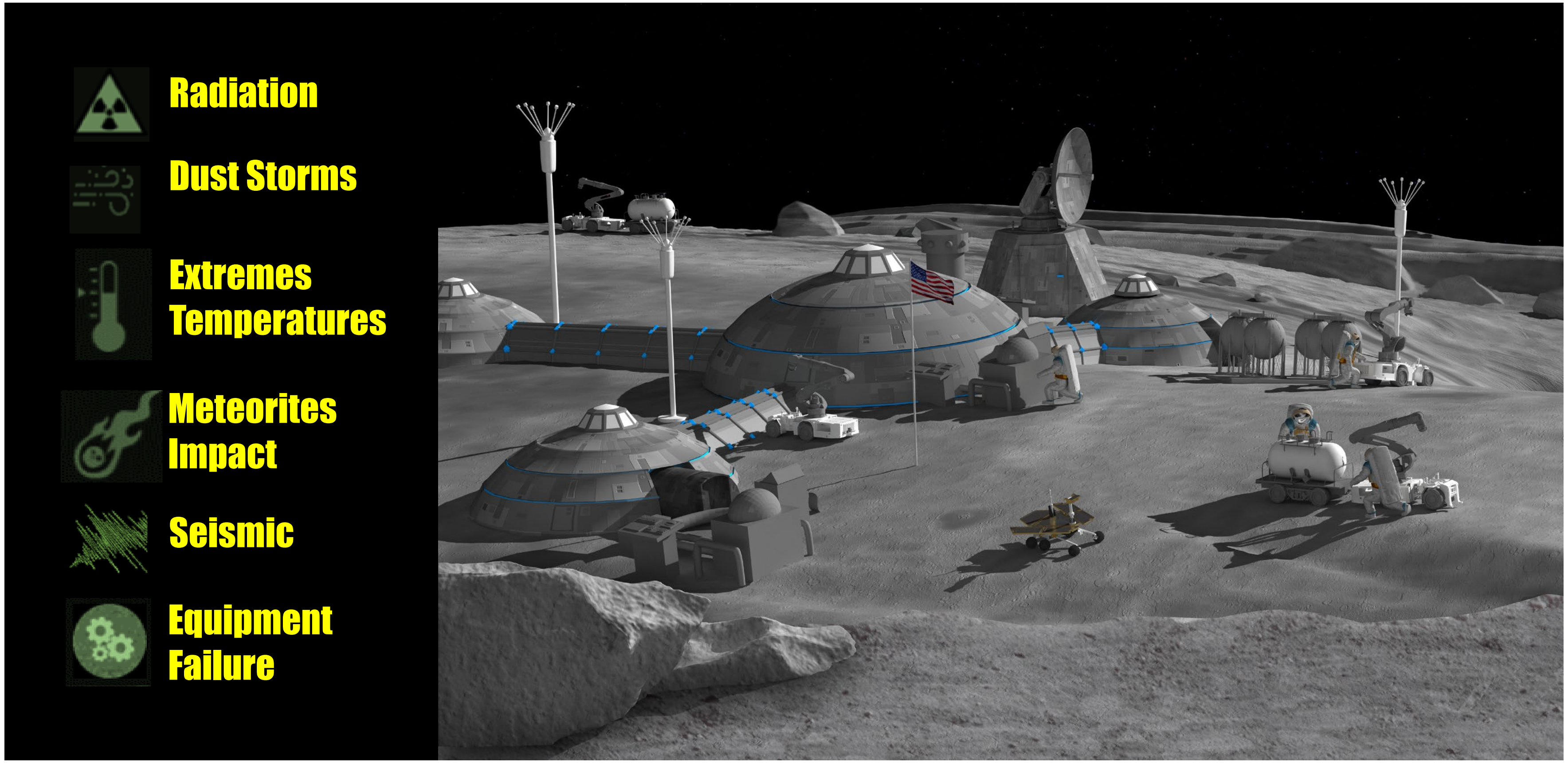
Funded by the *National Aeronautics and Space Administration*

What is resilience?

- Resilience is *not* simply robustness, reliability or redundancy….
- Resilience is a comprehensive approach that accounts for *disruptions* through the design process and adapts to them in operation
- We currently lack the innovative design frameworks and technologies needed for deep space habitats to successfully achieve this level of resilience and function autonomously under (and transition between) a variety of unmanned and manned operating modes.

Funded by the *National Aeronautics and Space Administration*

RETH Institute



In a world of **finite resources**, **irreducible uncertainty**, and **extreme hazards**, safety is created through **proactive resilient processes** rather than through reactive barriers and defenses.

Funded by the *National Aeronautics and Space Administration*

Vision: Enable the design and realization of smart and resilient space habitats.

Mission: To propel space exploration forward by developing new knowledge, technologies and techniques and collaborating with other NASA centers and industry to establish the knowhow to create smart and resilient extraterrestrial habitats.

RETH INSTITUTE

NASA | PURDUE UNIVERSITY | UCONN UNIVERSITY OF CONNECTICUT | HARVARD UNIVERSITY | UTSA The University of Texas at San Antonio | PURDUE UNIVERSITY Discovery Park

This material is based upon work supported by NASA under grant or cooperative agreement award number 80NSSC19K1076.

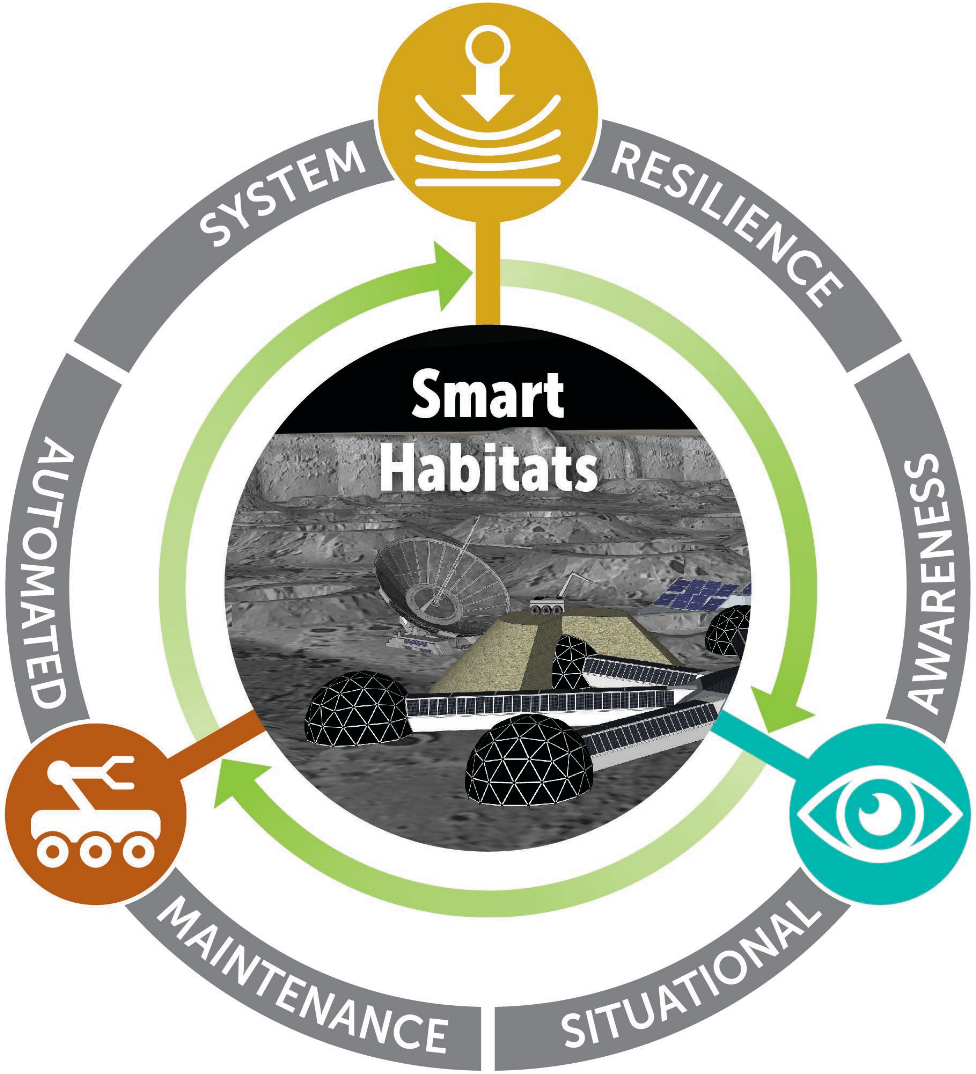
RETH Institute (2019/09)

Partner Institutions:

- Purdue University (HQ)
- University of Connecticut
- Harvard University
- University of Texas-San Antonio

Corporate Partners

- Collins Aerospace
- ILC Dover



Funded by the *National Aeronautics and Space Administration*

Civil Engineering

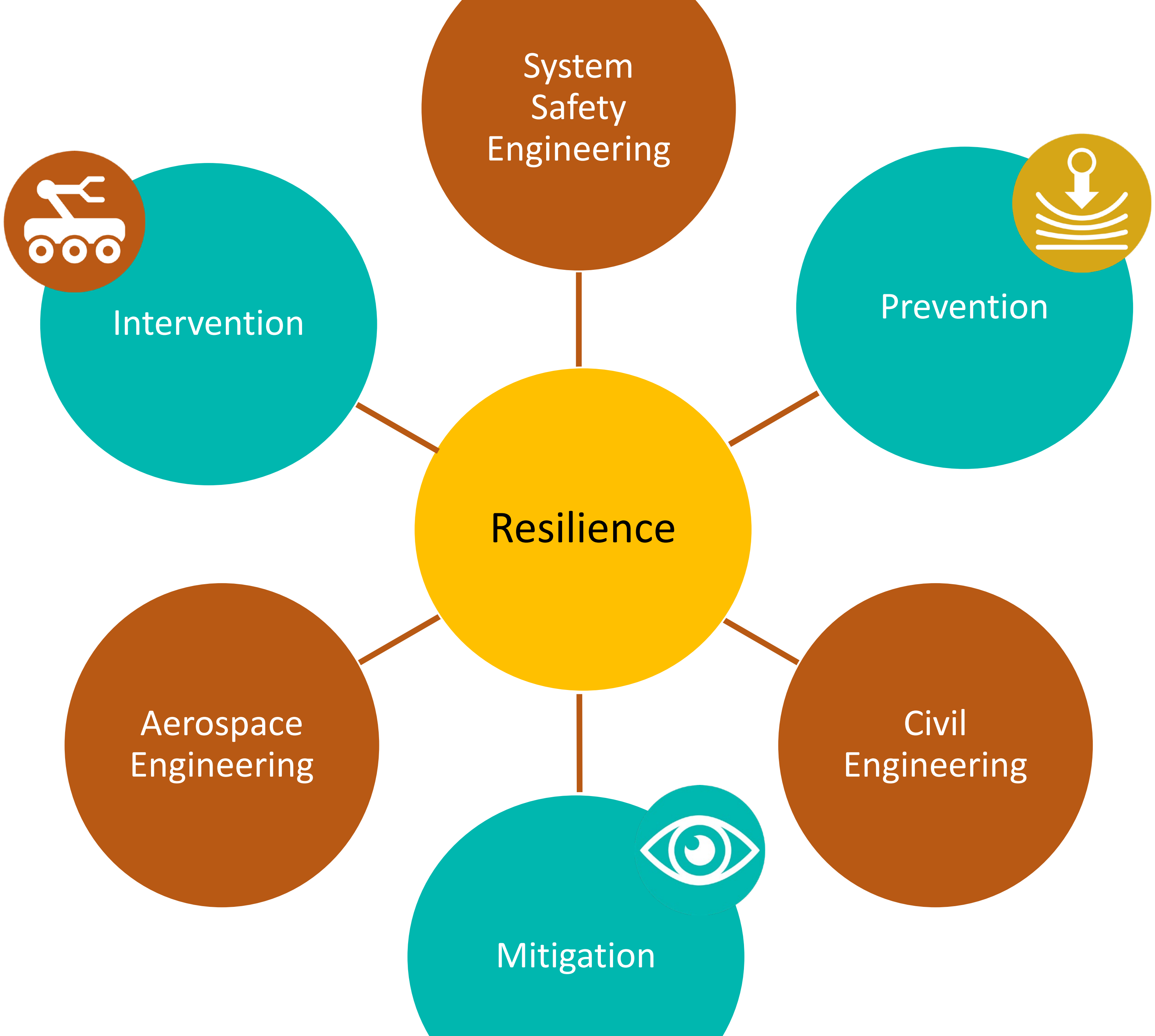

Mechanical Engineering


Aero... Engineering


Resilient Design of System-of-Systems

- Multi-hazard / Unknown hazards
- Numerous failure modes / vulnerabilities / cascading failures
- Emergent behaviors / complex systems
- Limited resources
- Numerous configurations / modes of operation
- Long periods of dormancy

Funded by the *National Aeronautics and Space Administration*

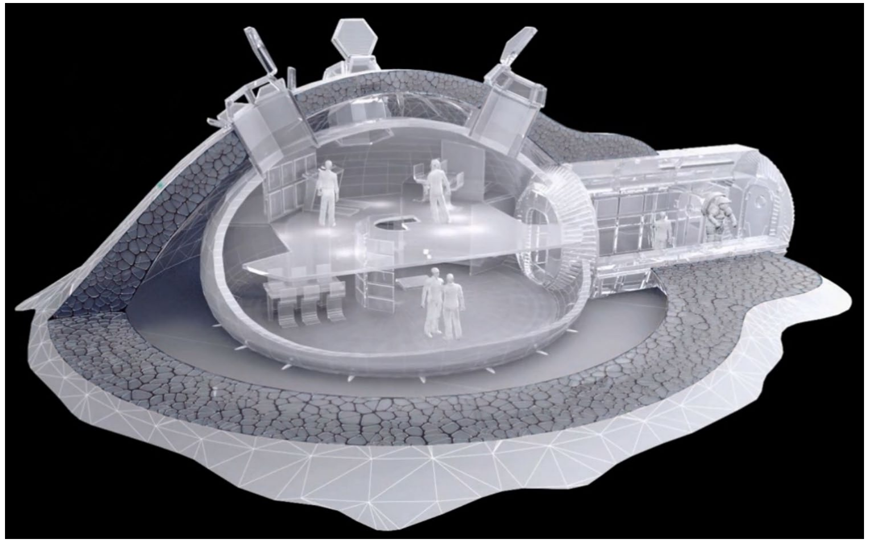

System Safety Engineering
Intervention
Prevention
Resilience
Aerospace Engineering
Civil Engineering
Mitigation

Resilience is not robustness, reliability or redundancy …

- Risk analysis, risk management and health management are widely used to support system performance and reliability

- Existing approaches are driven by avoiding or minimizing the occurrence of known/anticipated faults.

- For long term space habitat system this is inadequate:
  - high reliability is inefficient and costly
  - disruptions are inevitable, yet difficult to predict
  - humans will not always be present



European Space Agency

Funded by the *National Aeronautics and Space Administration*

Our Approach to Resilience

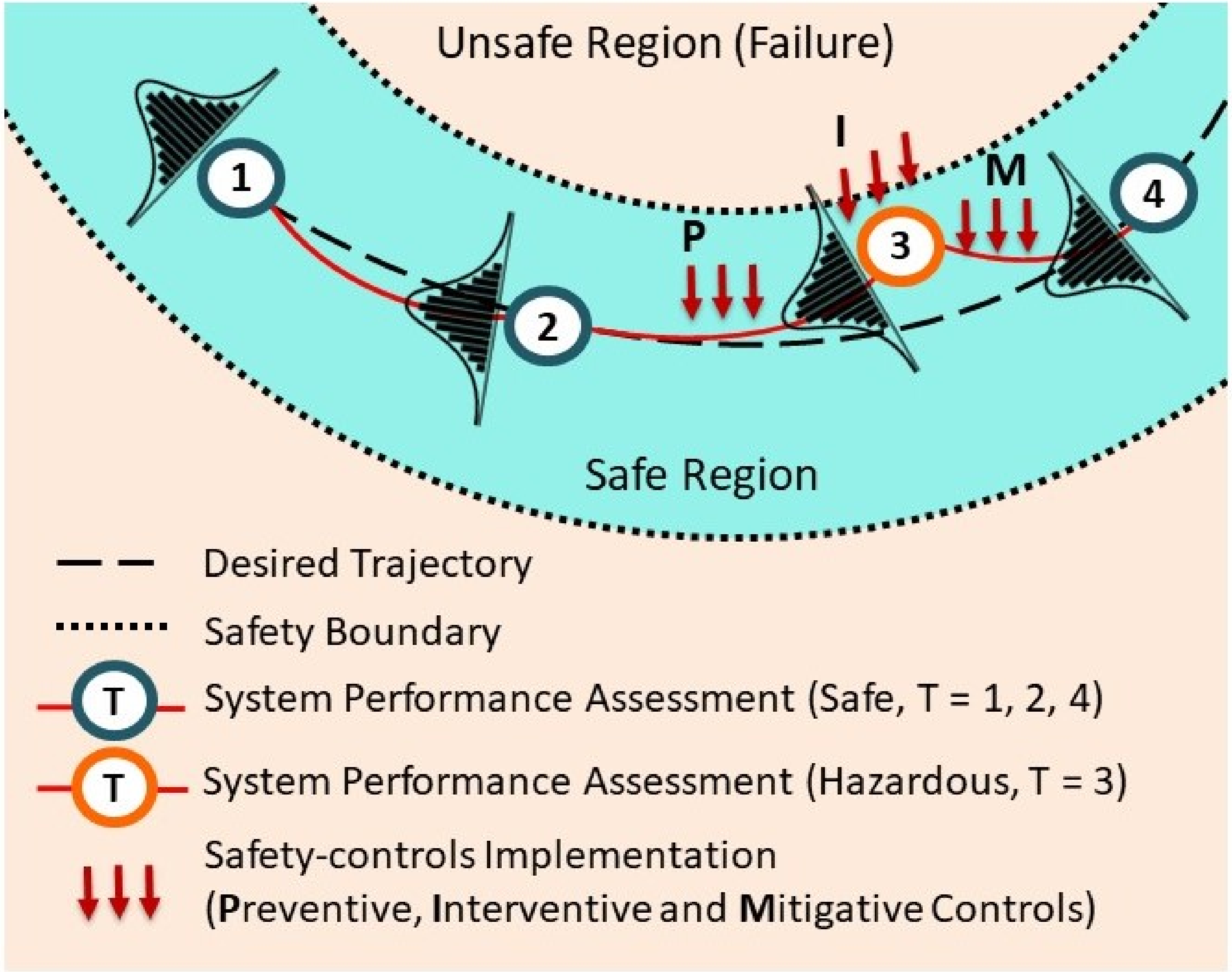
1 State estimation, assessment of performance or function.
2 Within boundary.

Safety-controls act (passive)

3 State estimation, identification of undesirable trajectory. Action must be taken. *Decision* made.

Safety-controls act (adaptive)

4 State estimation, assessment of performance or function. Within boundary.



Thrust 1 will develop the techniques needed to establish a control-theoretic paradigm for resilience, and the computational capabilities needed to capture complex behaviors and perform trade studies to weigh different choices regarding habitat architecture and onboard decisions.

Thrust 2 will develop and validate generic, robust, and scalable methods for detection and diagnosis of anticipated and unanticipated faults that incorporates an automated active learning framework with robots- and humans-in-the-loop.

Thrust 3 will develop and demonstrate the technologies needed to realize teams of independent autonomous robots, built using soft materials, that navigate through dynamic environments, select the appropriate modular sensors and end-effectors for specific needs, and collaboratively replace damaged structural elements using deployable modules.

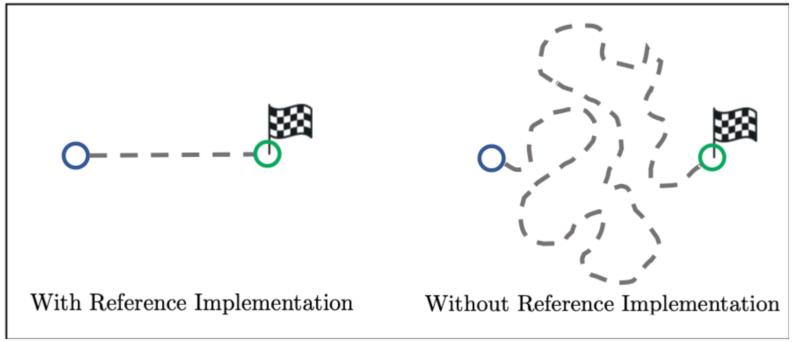
Reference Implementation

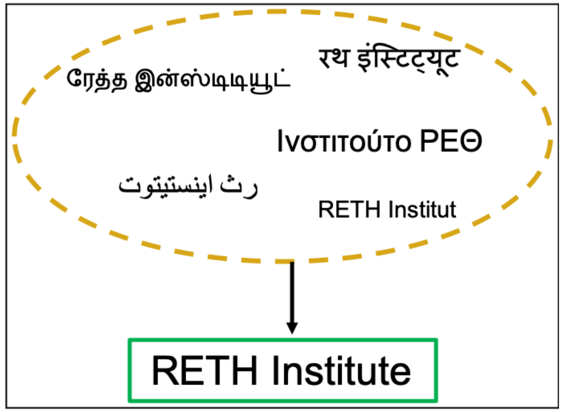
- End-to-end representative example that is used to establish the steps and tool chain that must be developed

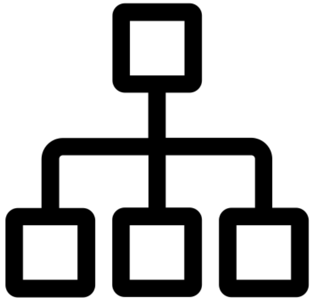
Demonstrate the process (end-to-end)

Develop a common language

Establish framework for more accurate models

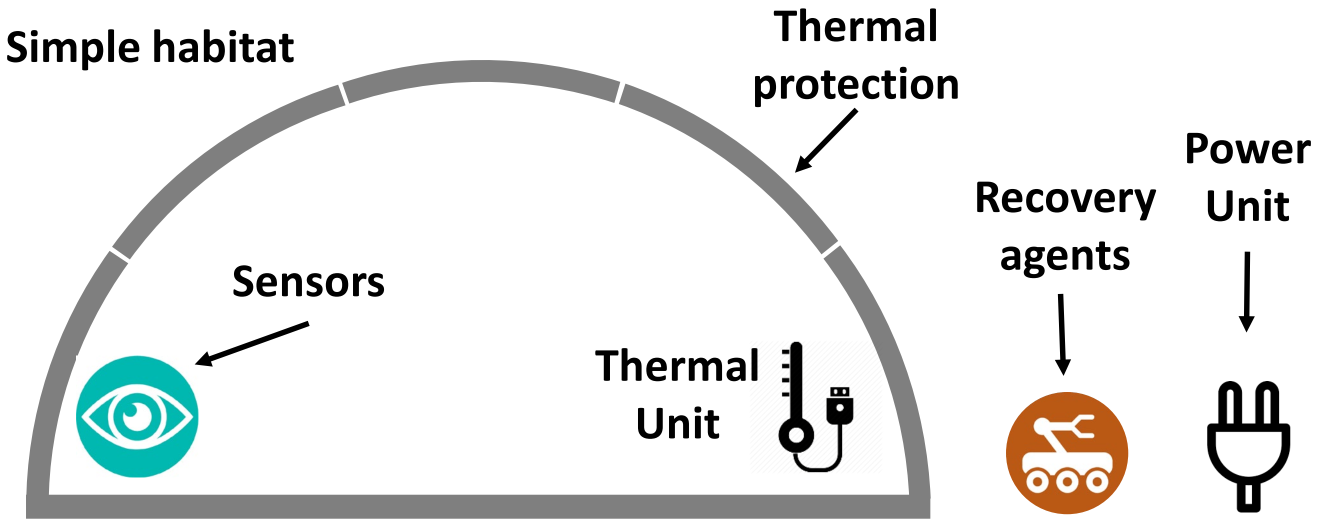






Funded by the *National Aeronautics and Space Administration*

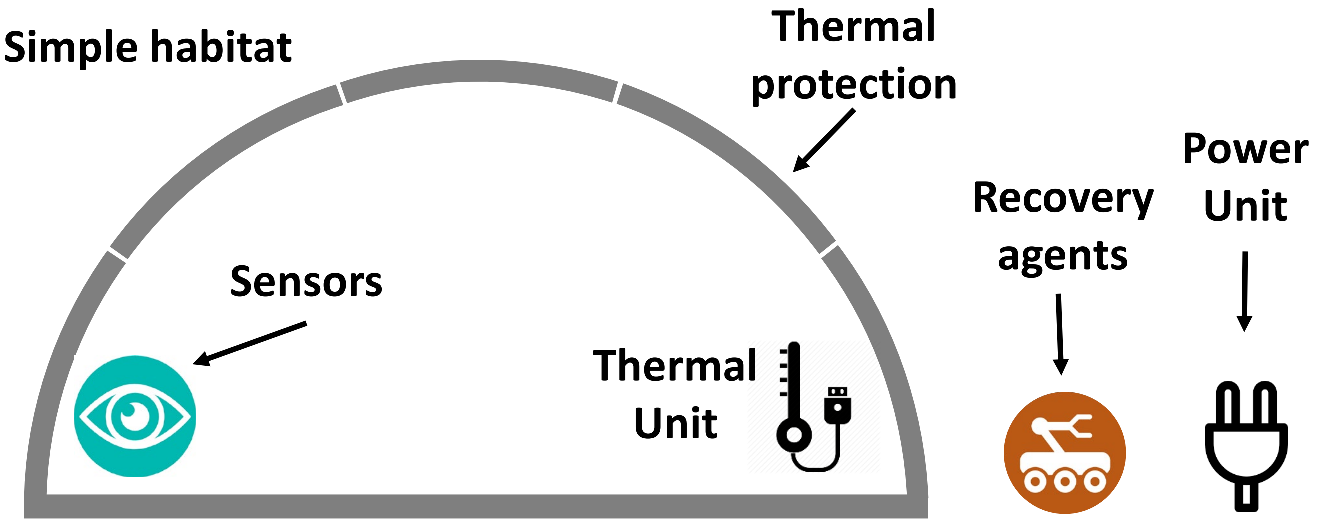
Thermal Management



Environmental Model	Structural Subsystem	Thermal Subsystem	Power Subsystem
External temperature	Damage state	Conductivity	Limitations
Radiative heating		Damage influence	
Meteoroids		Management	

Funded by the *National Aeronautics and Space Administration*

Thermal Management



<u>Sensing</u>
Temperature
Accelerometers

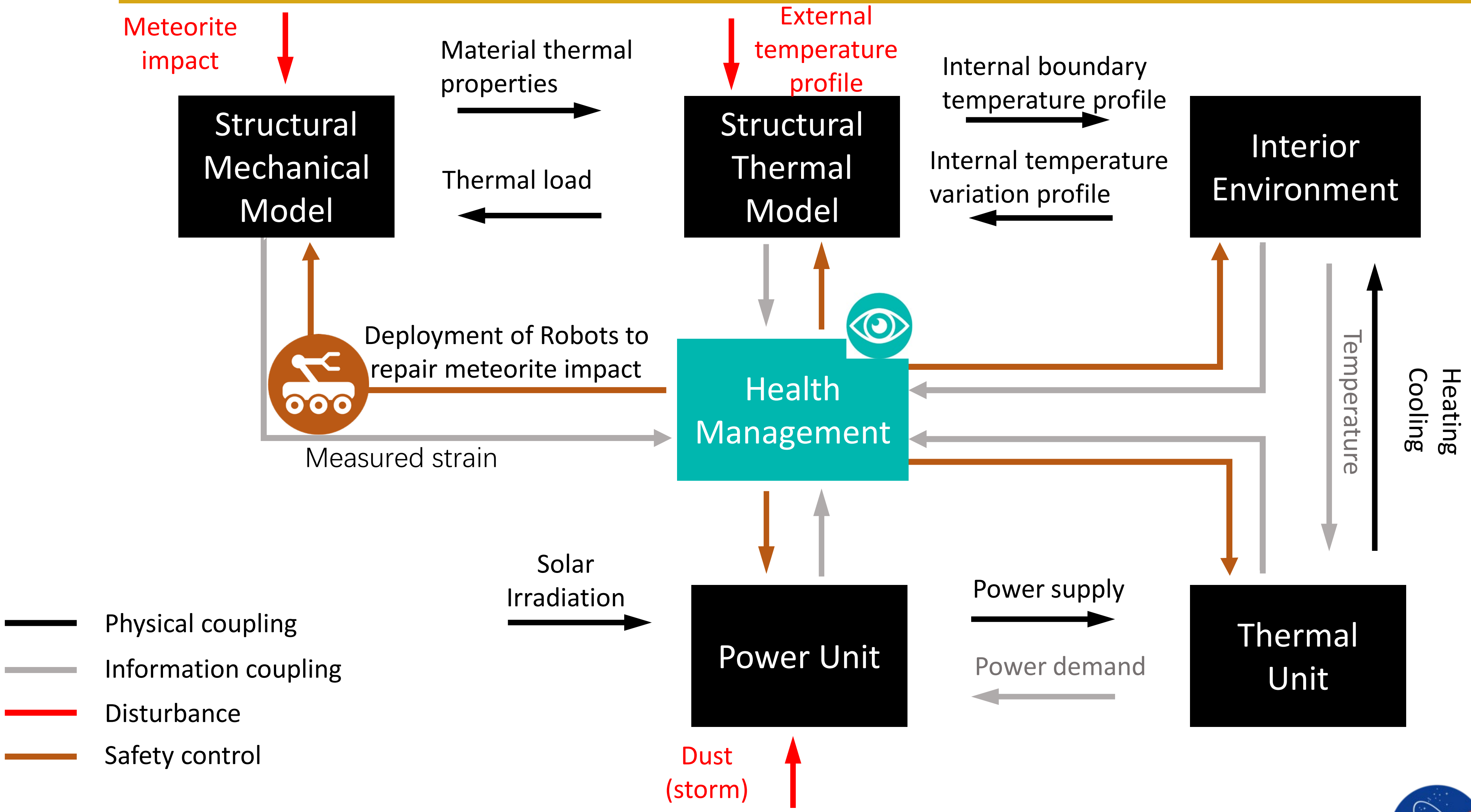
<u>Interventions</u>
Repair
Data Gathering

Sample Research Questions

- *What are the safety controls?*
- *How to model the interdependencies between subsystems?*
- *How to determine the number/location of sensors needed?*
- *How do we quantify the resilience power of safety controls?*
- *What is the impact of a sensor failure?*
- *What partitioning of the system is appropriate for cyber-physical testing?*

Funded by the *National Aeronautics and Space Administration*

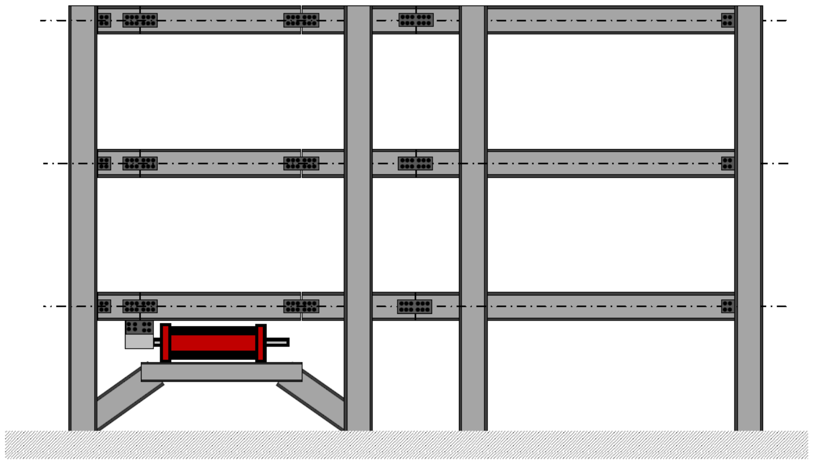
Thermal Management



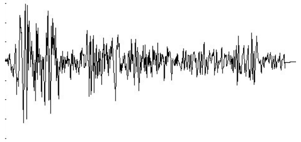
Funded by the *National Aeronautics and Space Administration*

Past work … Real-time Hybrid Simulation

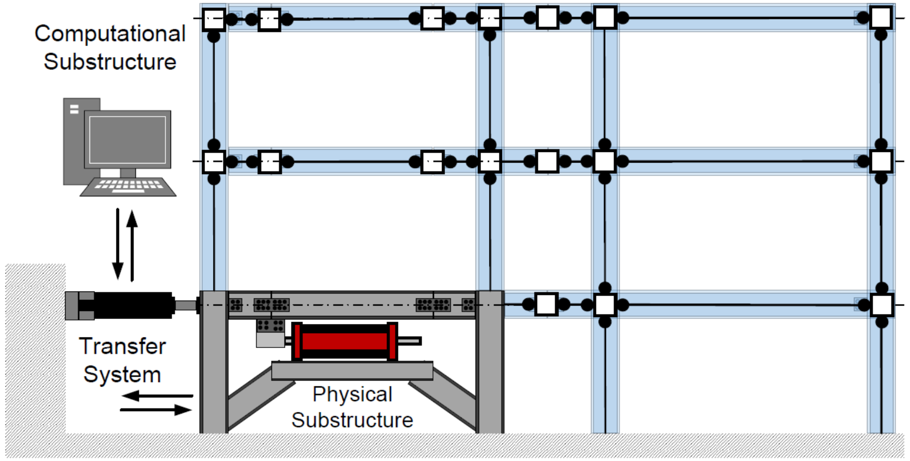
Full-physical



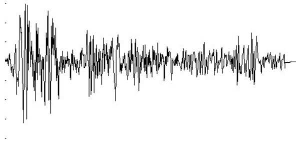
Seismic
Excitation



Cyber-physical

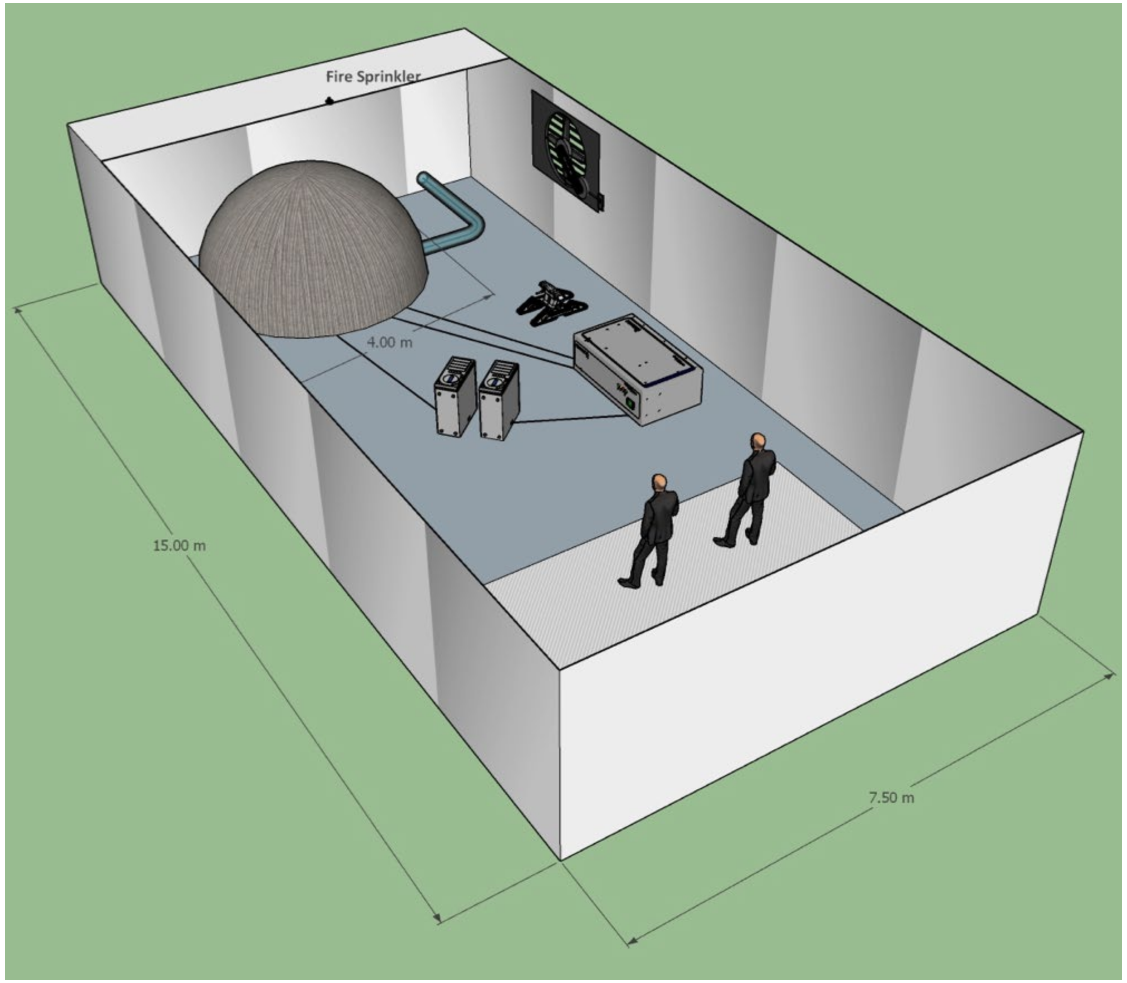


Seismic
Excitation



Funded by the *National Aeronautics and Space Administration*

Cyber-Physical Testbed



The “**reconfigurable habitat**” will initially consist of one dome-type structure, with removable panels and several subsystems.

We can emulate various conditions, operating modes, configurations – sometimes physically and sometimes virtually.

We can examine resilience under various faults, deterioration, etc. Growth of the habitat system can also be investigated.

Funded by the *National Aeronautics and Space Administration*

Cyber-Physical Testbed Characteristics

- Includes Cyber Components
- Includes Physical Components
- Can be configured in <u>multiple</u> ways
  - to represent different *reference systems*
  - to examine different aspects of a *single reference system*
- Leverages the control-oriented dynamic computational modeling platform (CDCM) for real time execution
- Leverages our models, codes/software, etc

Funded by the *National Aeronautics and Space Administration*

Acknowledgements

- Purdue University's Provost Office provided early funding for this effort through the New Horizons program.

https://www.purdue.edu/reth/

@Purdue_RETH

- NASA, Space Technology Mission Directorate Grant: 80NSSC19K1076.

- Discovery Park at Purdue University