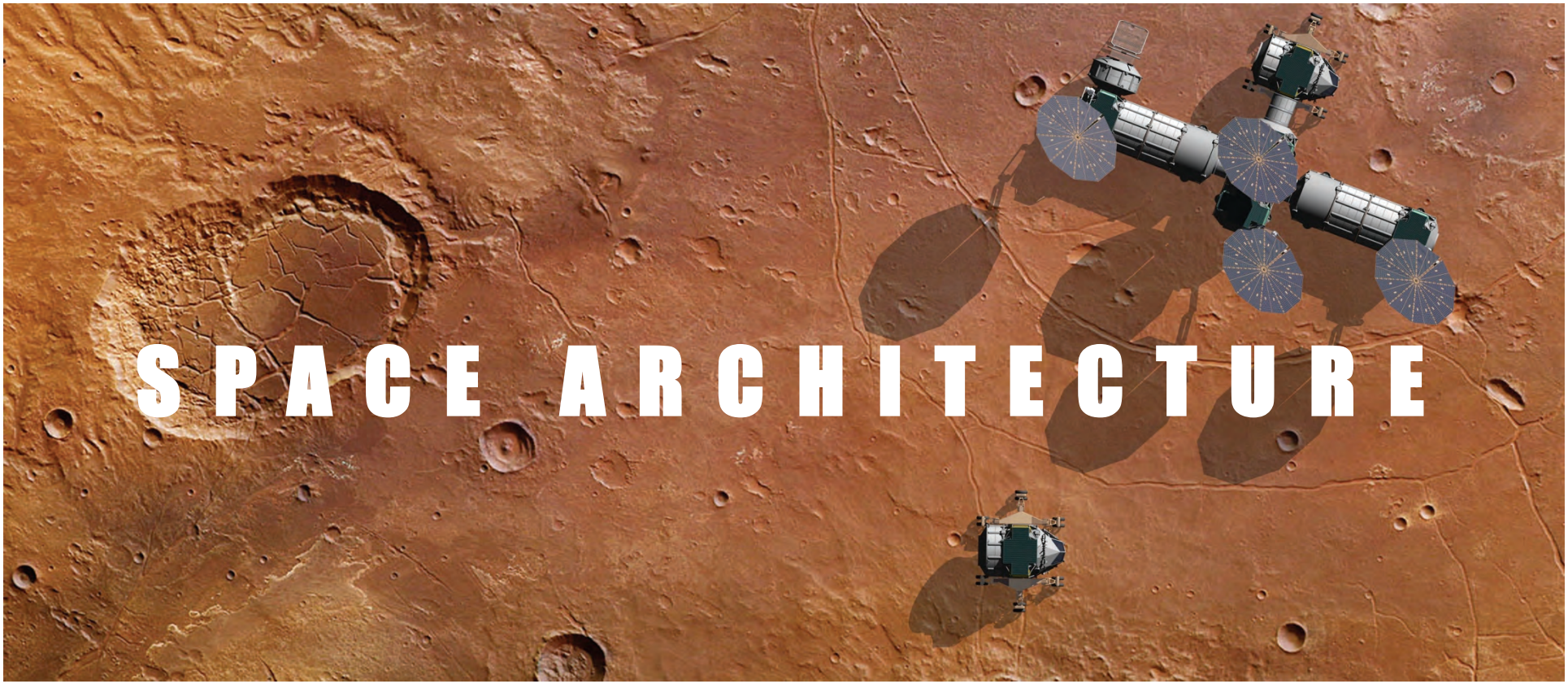


A. Scott Howe, PhD

Jet Propulsion Laboratory

24 August 2015

Space Architecture

- How can we live and work in space?

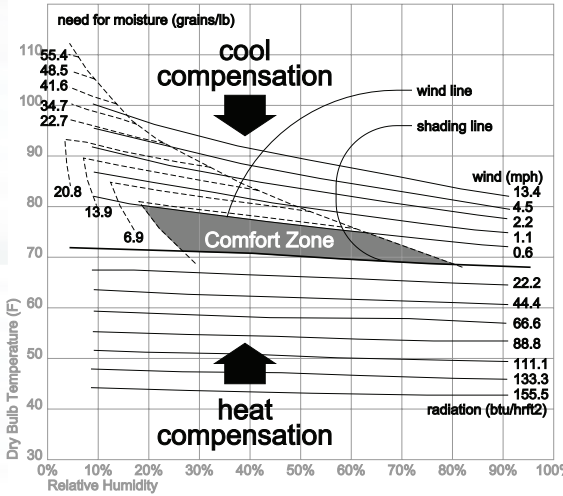
- Space Architecture definition
- Environments
  - Space environments
  - Planetary surface environments
  - Earth extreme environments
- The space architecture challenge
- Phased approach to space construction
  - Class I: Pre-integrated
  - Class II: Prefabricated
  - Class III: ISRU-derived
- Future directions

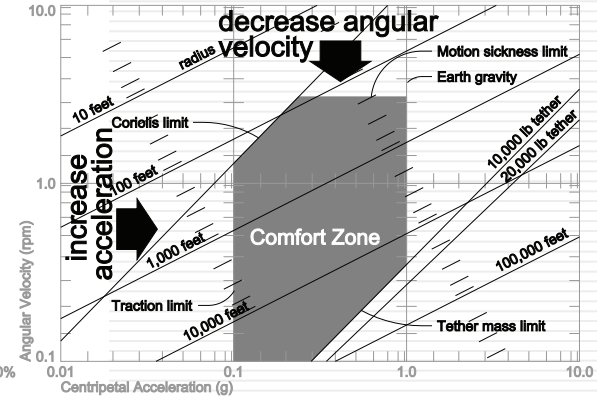
Space Architecture Definition

- spacearchitect.org defines Space Architecture as encompassing *"architectural design of living and working environments in space-related facilities, habitats, and vehicles. . . Designing these forms of architecture presents a particular challenge: to ensure and support safety, habitability, human reliability, and crew productivity in the context of extreme and unforgiving environments."*

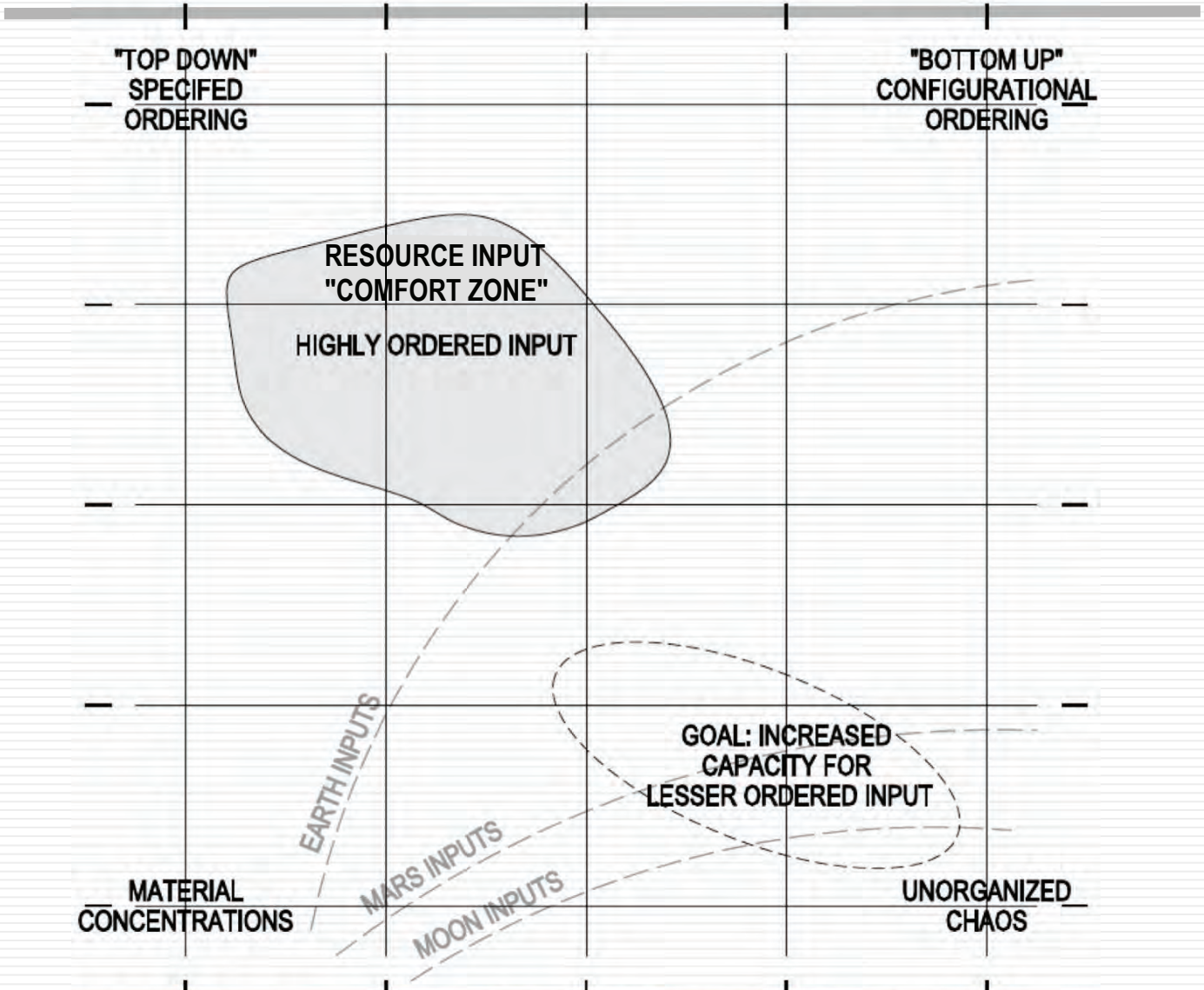
- Comfort Zones for human habitability:

	MIN	MAX
Temperature	22.5C	26.0C
Humidity	20%	80%
Light	-	300-400 lux
Sound	0dB(A)	35dB(A)
Atmosphere	Various oxygen/nitrogen mixes	
Air movement	0.1m/s	0.5 m/s
Air pressure	10psi	15psi
Gravity	0.0G	1.0G
Gravity Vector	Flat	10deg
Radiation	-	50 rads
Volume	1m^3	20-100m^3
Diurnal Cycle	20hr	28hr
Particulates	-	0.5mg/m^3
Micrometeoroid	Zero penetration	
Resource Inputs	Chaotic inputs	Ordered inputs

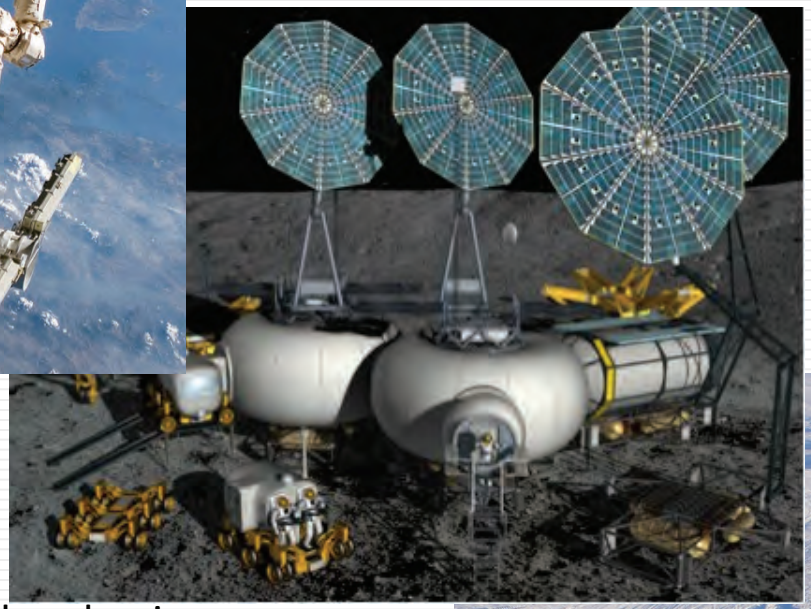


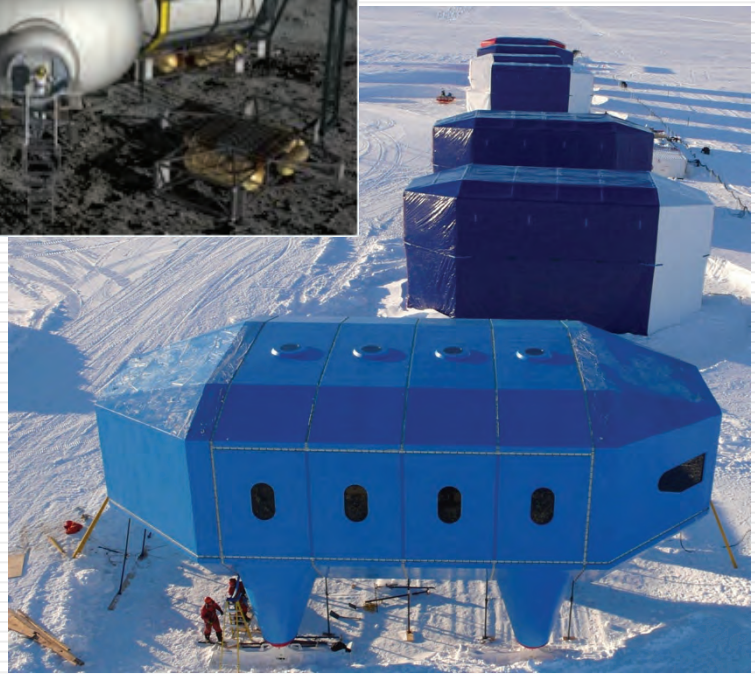


Resource Input Comfort Zone



Realms of Space Architecture

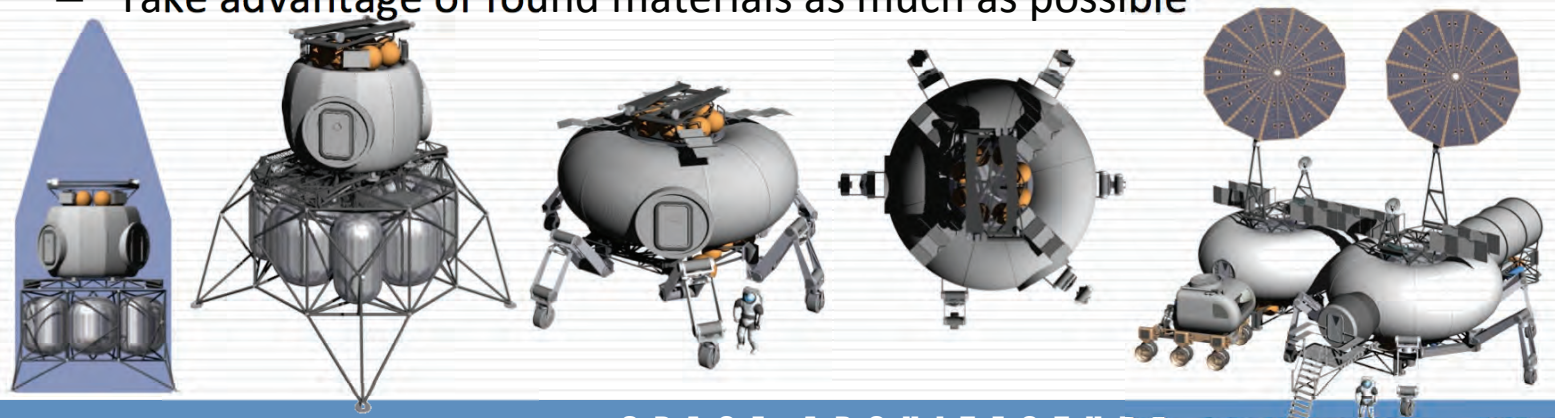




- Space Environments
  - Orbital
  - Deep space
  - Small-scale to large-scale urbanism
- Planetary Surface Environments
  - Lunar, Mars, etc
  - Outposts to colonization
- Earth Extreme Environments
  - Polar bases, under sea
  - Emergency housing, structures

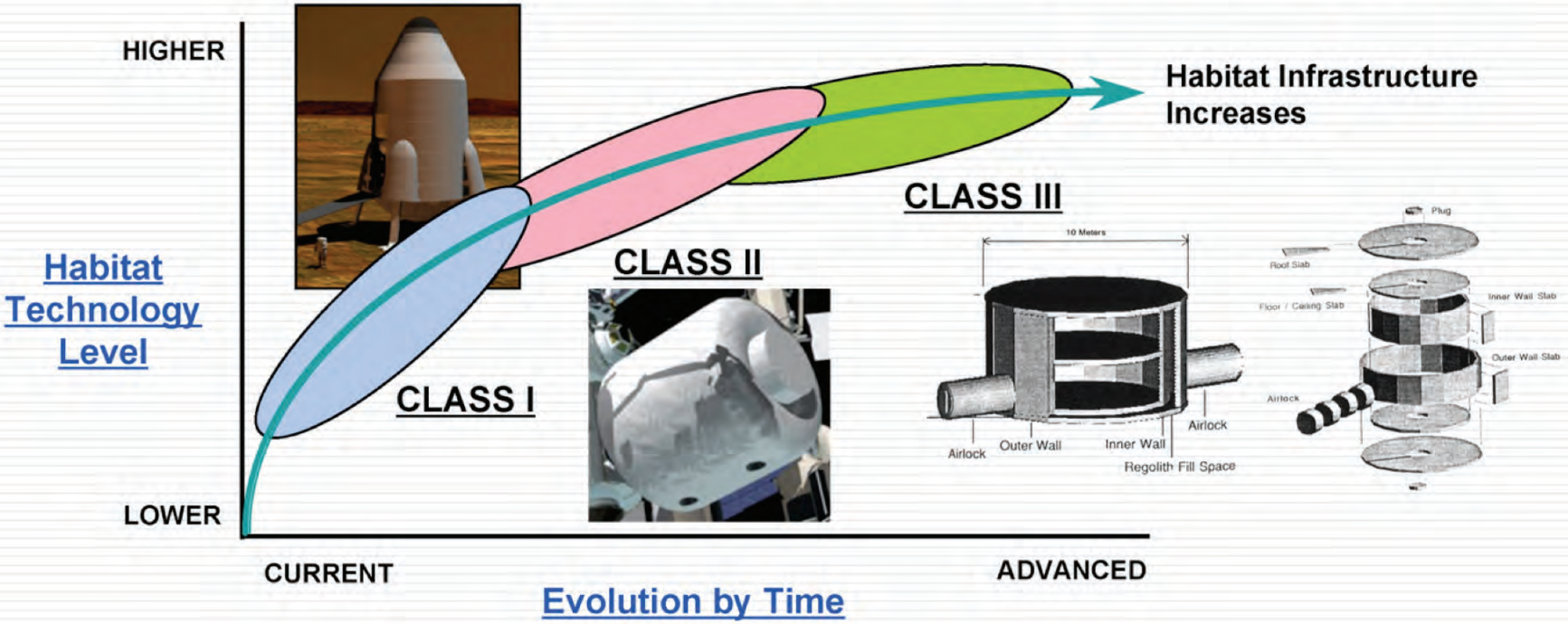
The Space Architecture Challenge

- Create an environment for human habitation that mitigates all the extremes and continually maintains the comfort zone
  - Must understand the extreme environment
  - Must design habitat, the means of construction, and how it is to be delivered
  - Work within the capacity of the transportation system
  - *It is the same as requiring all the building materials, construction equipment, power-generation capability, fuel, air to breathe, water, gases, kitchen, food, clothes, medical equipment, and workforce to all fit on only one truck*
  - Must use deployable mechanisms, kit-of-parts, and lightweight materials
  - Must use robotic labor, that has no need of pressurized environment
  - Take advantage of found materials as much as possible



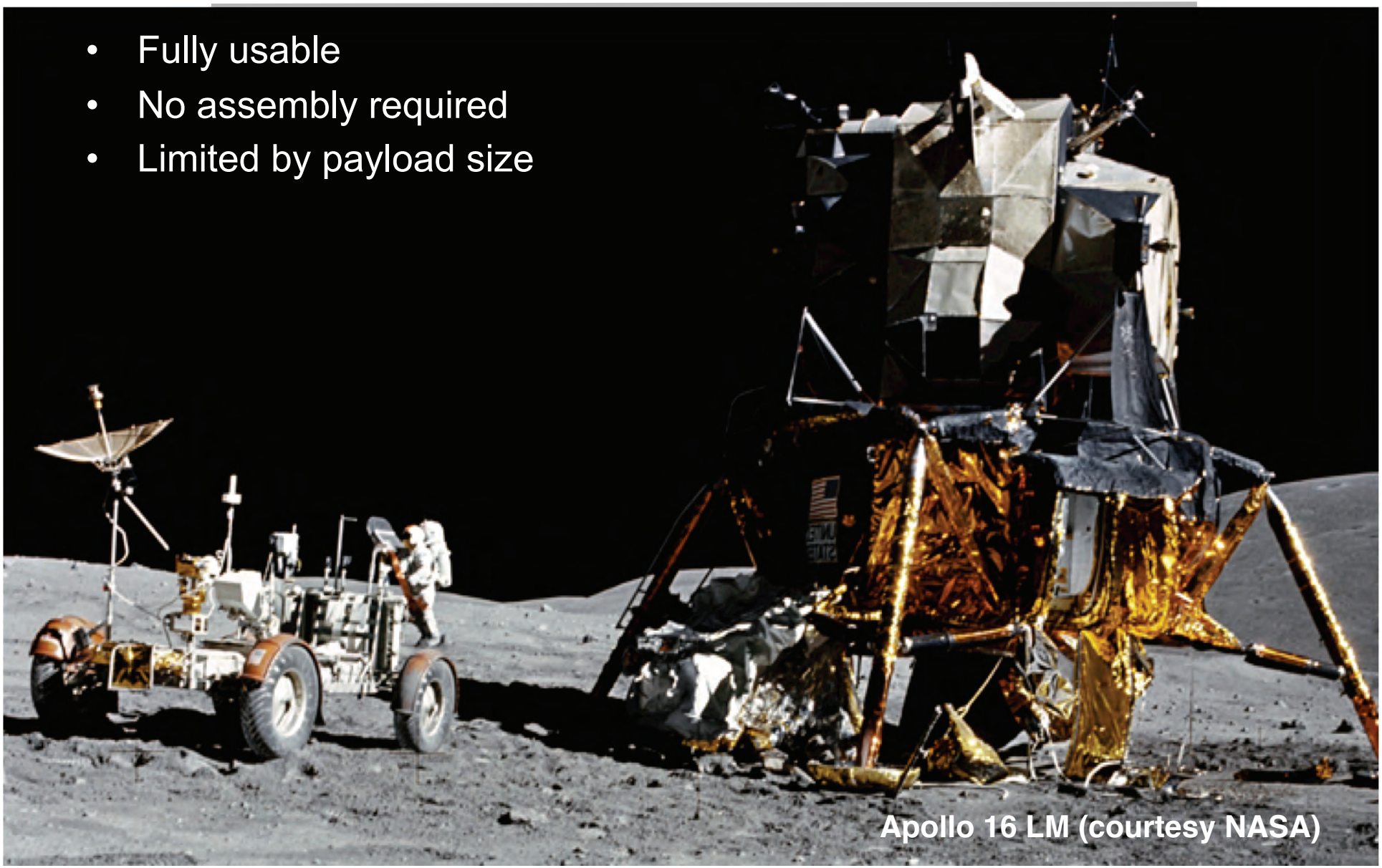
Phased Approach to Space Construction

- CLASS I:
  - Preintegrated, Hard Shell Module
- CLASS II:
  - Prefabricated, Surface Assembled
- CLASS III:
  - ISRU Derived Structure w/ Integrated Earth components



Class I: Pre-integrated Construction

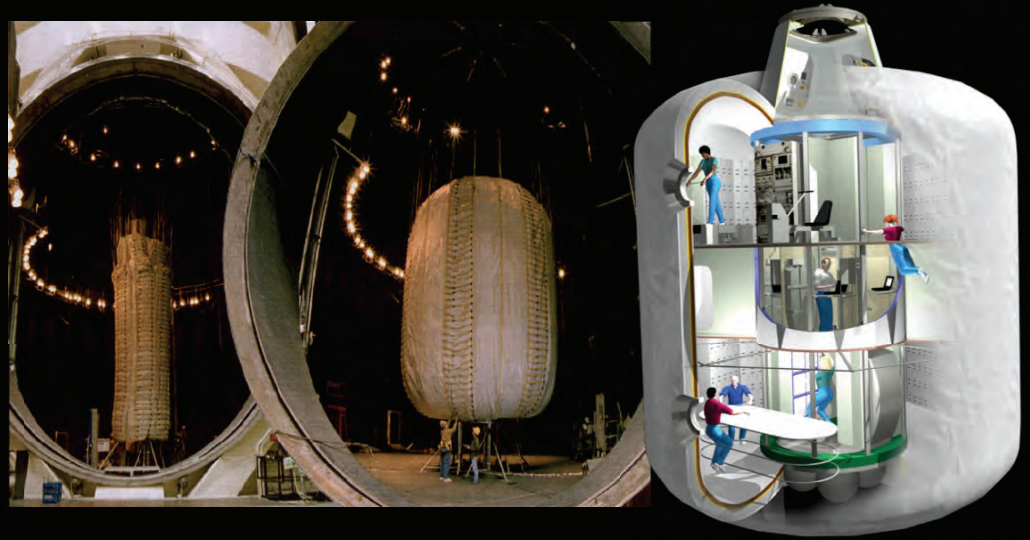
- Fully usable
- No assembly required
- Limited by payload size



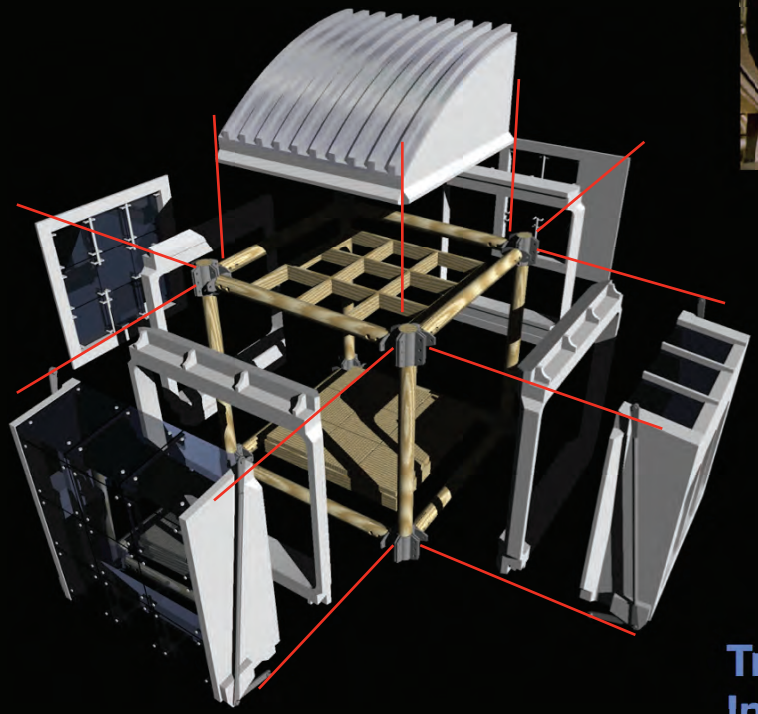
Apollo 16 LM (courtesy NASA)

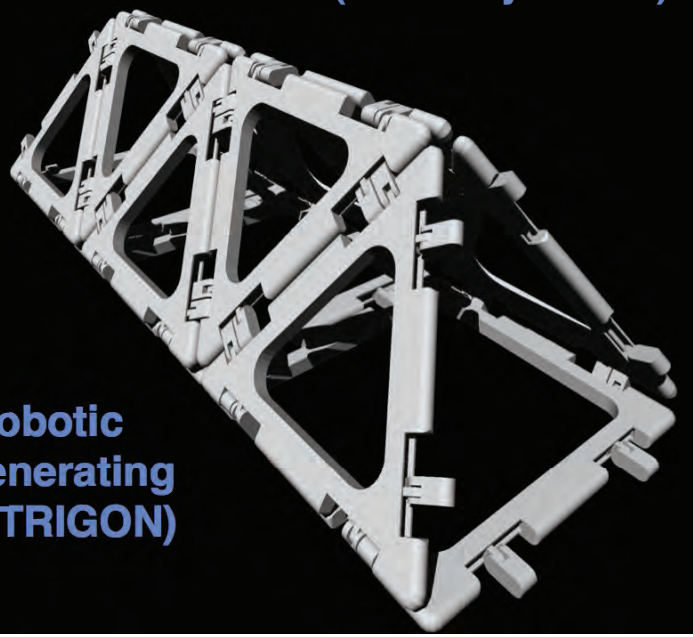
Class II: Pre-fabricated Construction

- Assembled onsite
- Robust joints
- Replacable
- No size limit



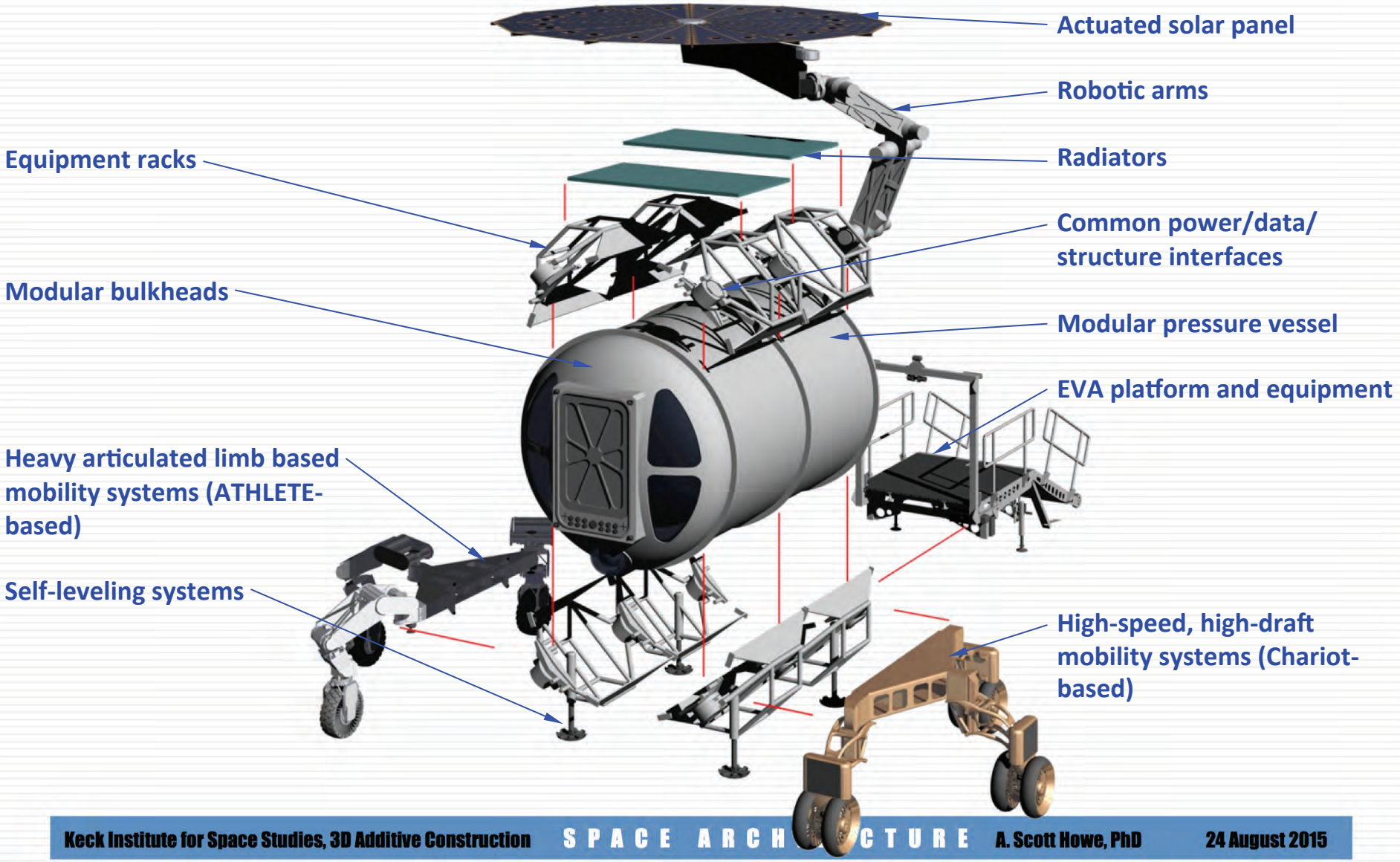
TransHab (courtesy NASA)



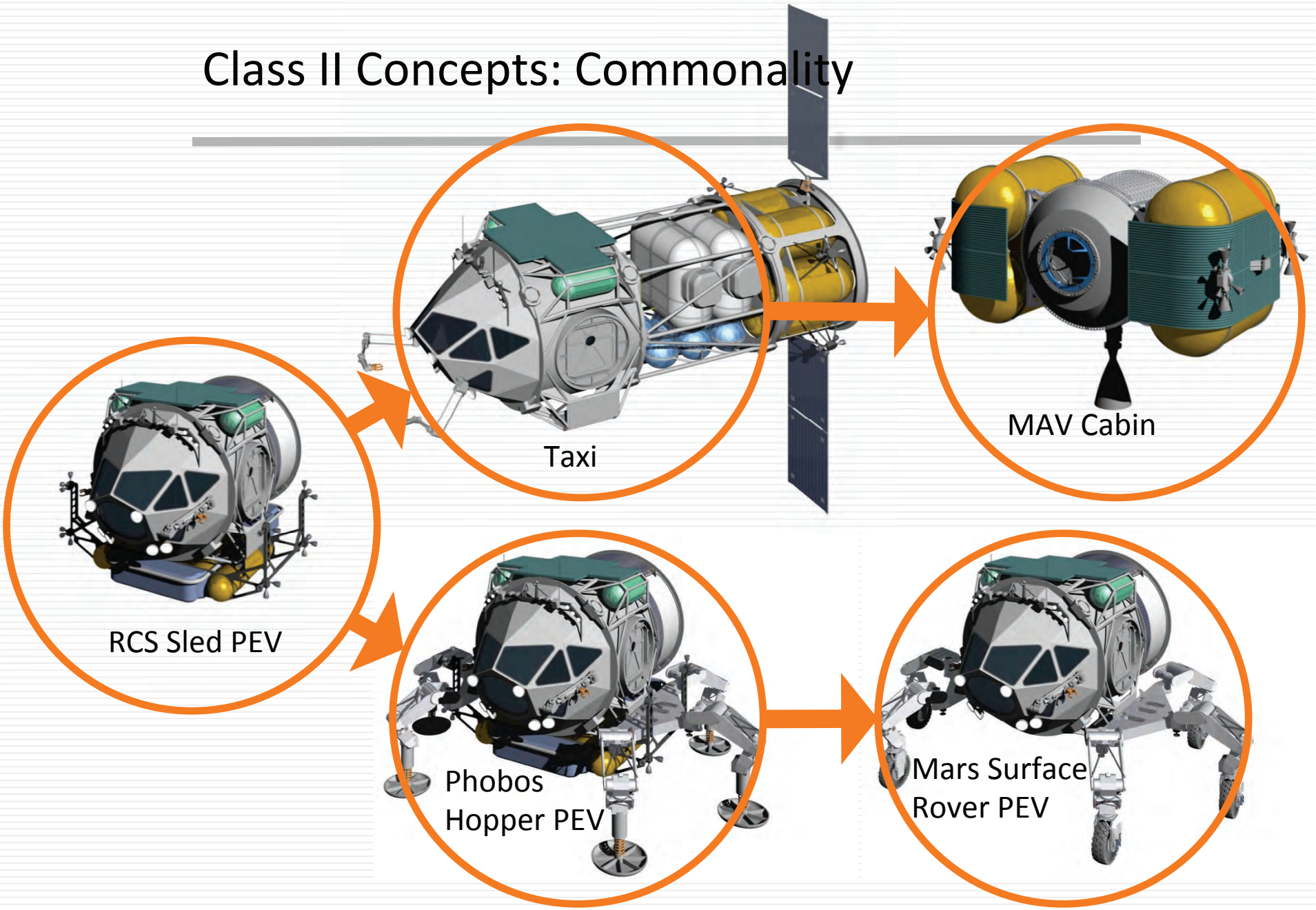


Transformable Robotic Infrastructure-Generating Object Network (TRIGON)

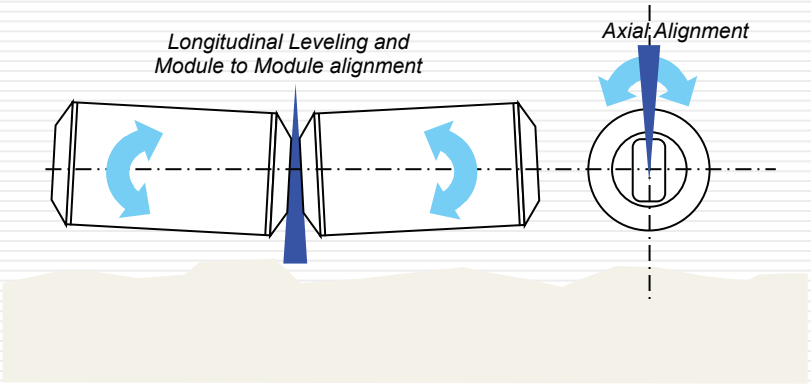
Class II Concepts: Plug-in Accessories

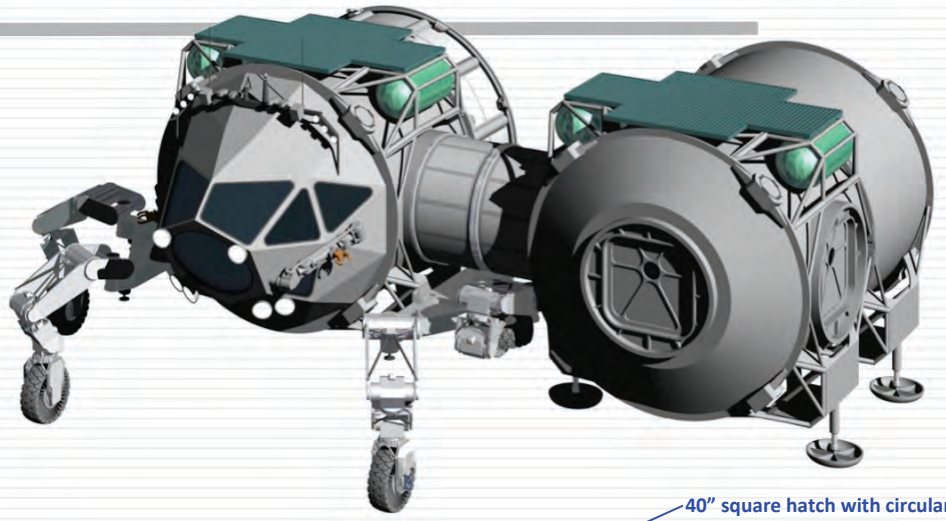


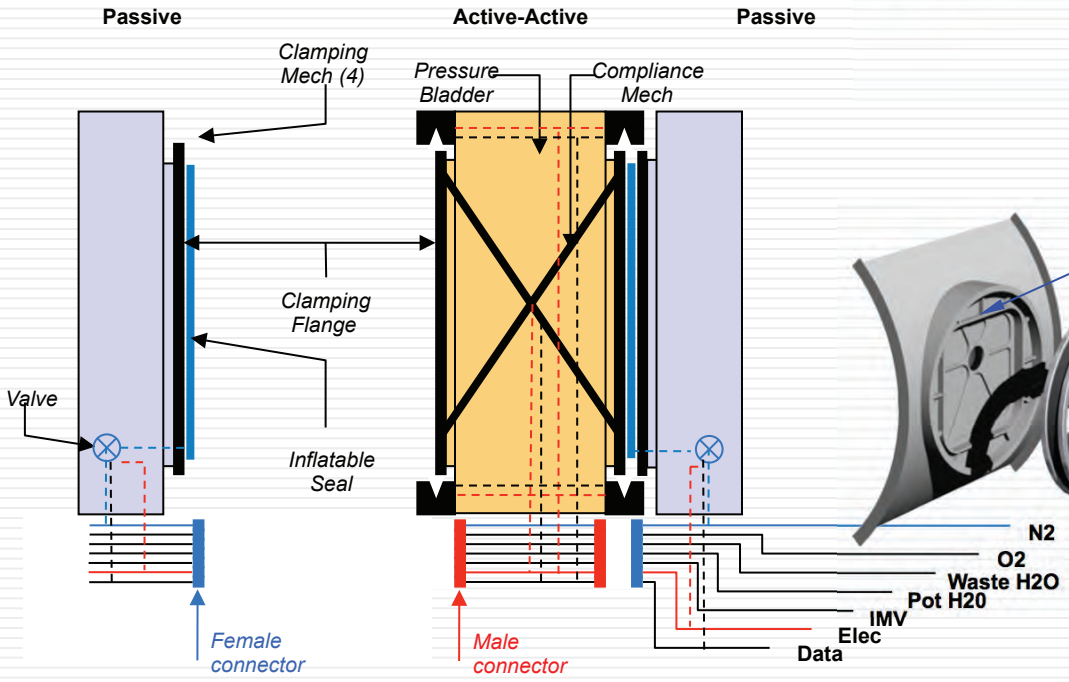
Class II Concepts: Commonality

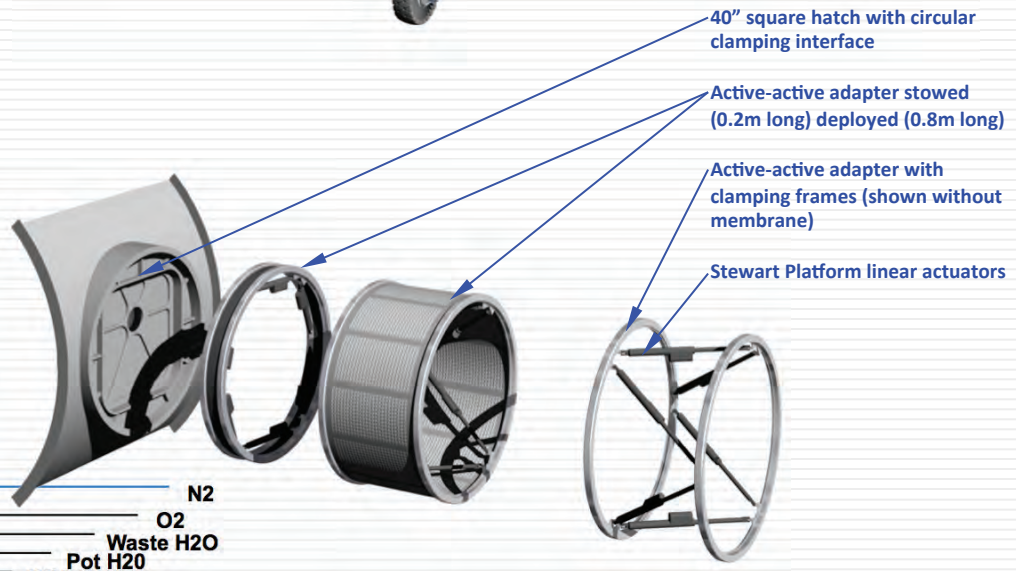


Class II Concepts: Docking and Connections

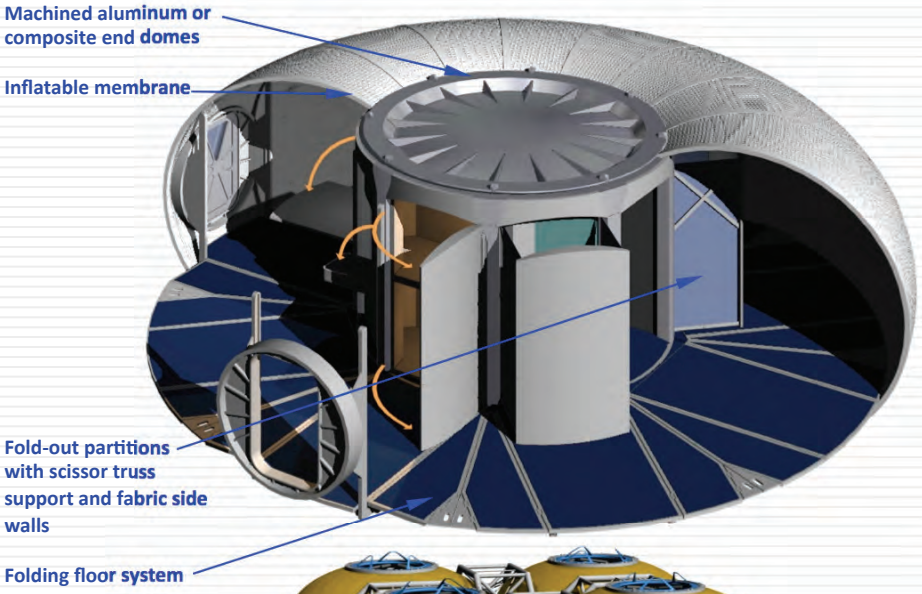


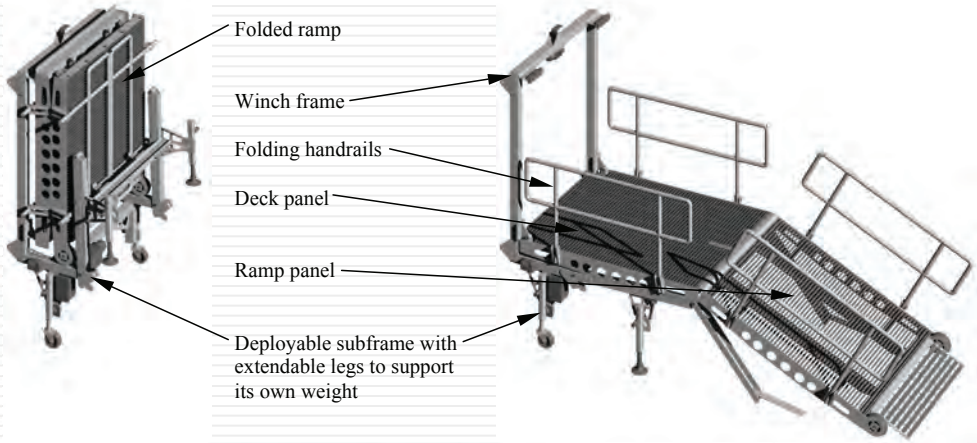


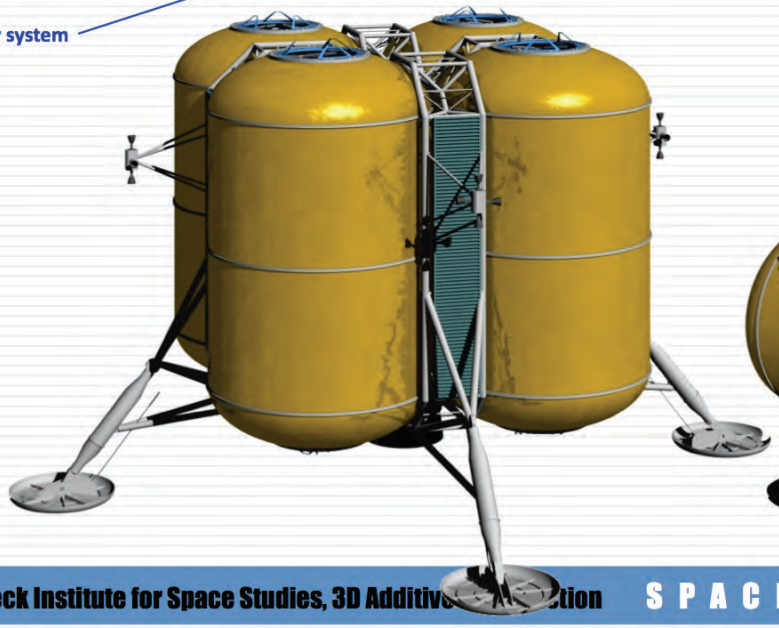


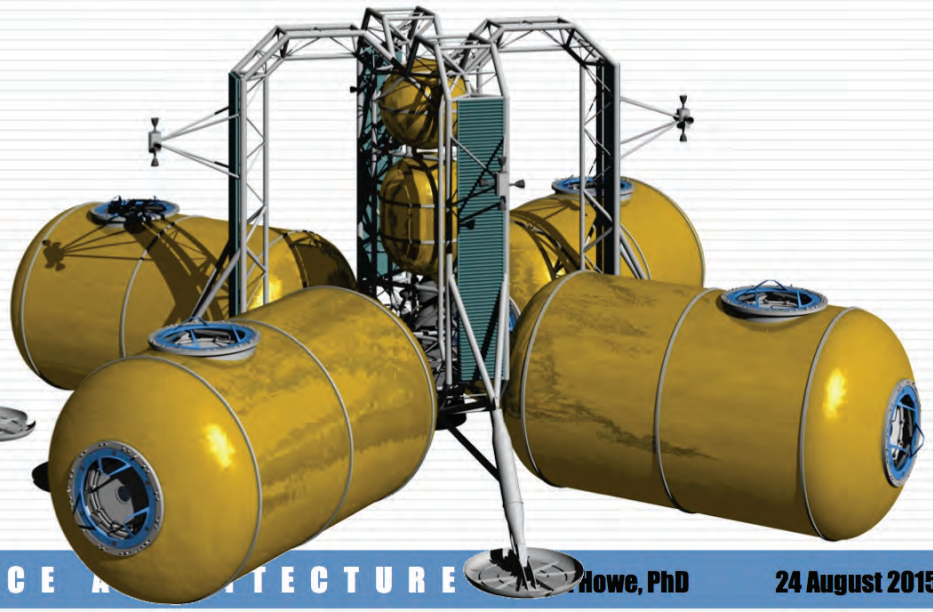


Class II Concepts: Deployable Systems

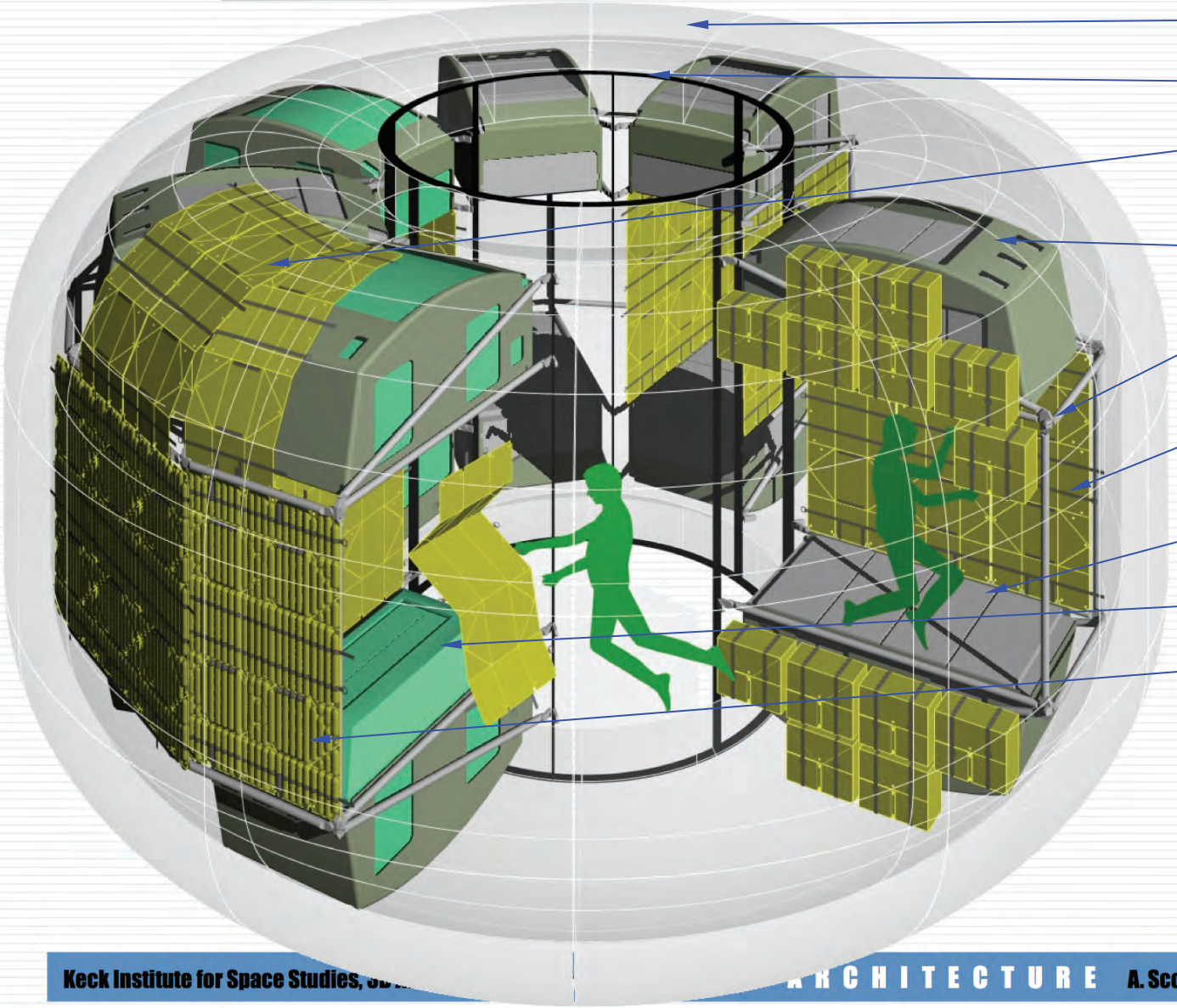






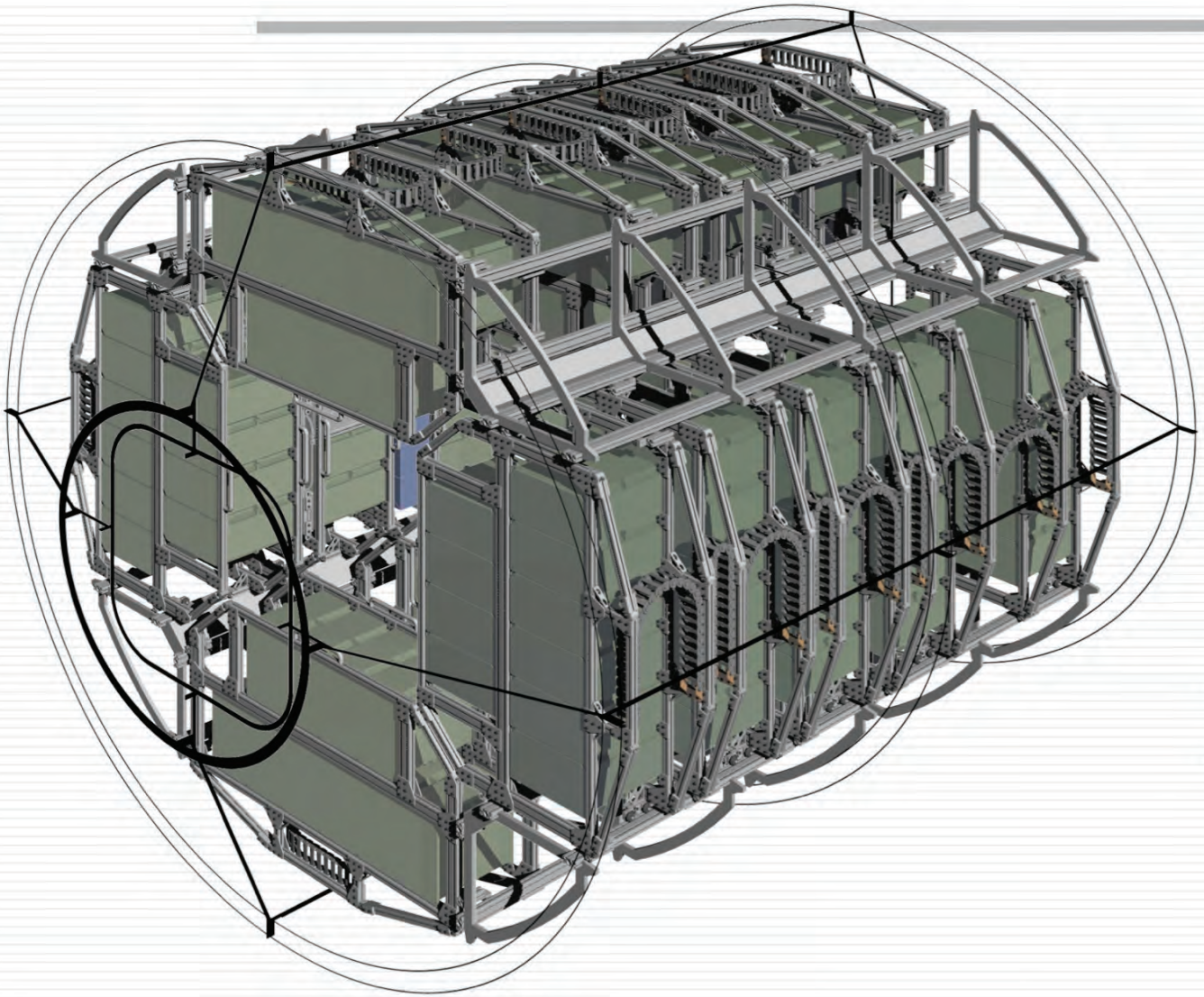


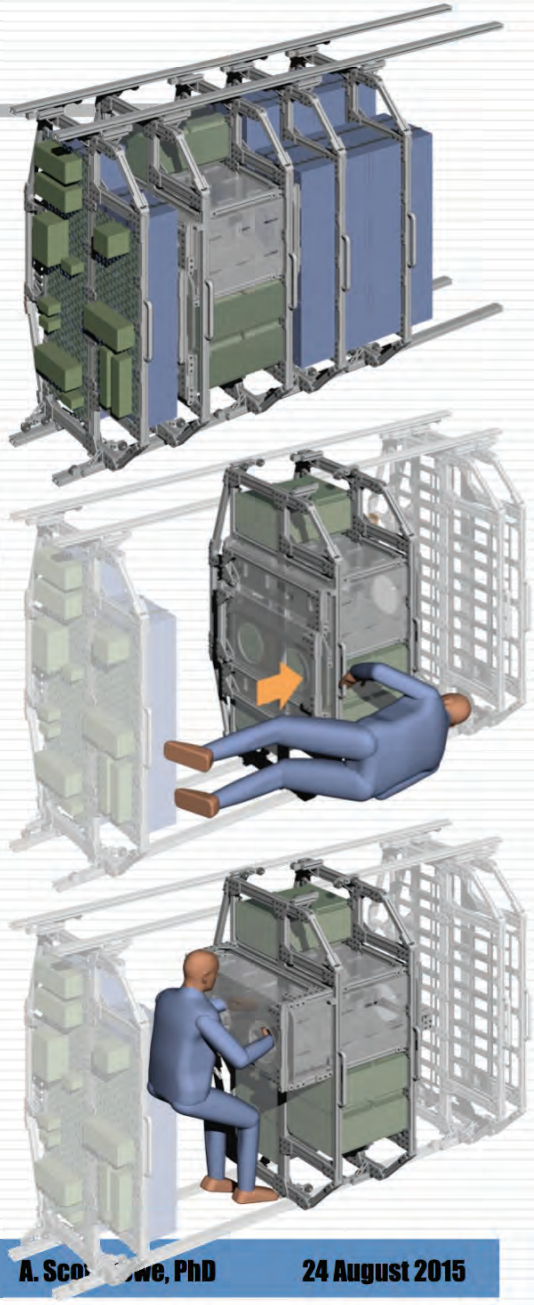
Class II Concepts: Logistics-2-Living



- Inflatable habitat walls
- Hard core
- Hydrogen-impregnated CTBE material draped against wall
- ISS rack – total capacity 16 racks
- Lightweight snap-together kit-of-parts frame system
- Unfolded CTBEs used as partitions
- ECLSS racks
- Rack-based crew quarters
- Membrane Forward Osmosis (FO) filter water wall derived from used CTBEs

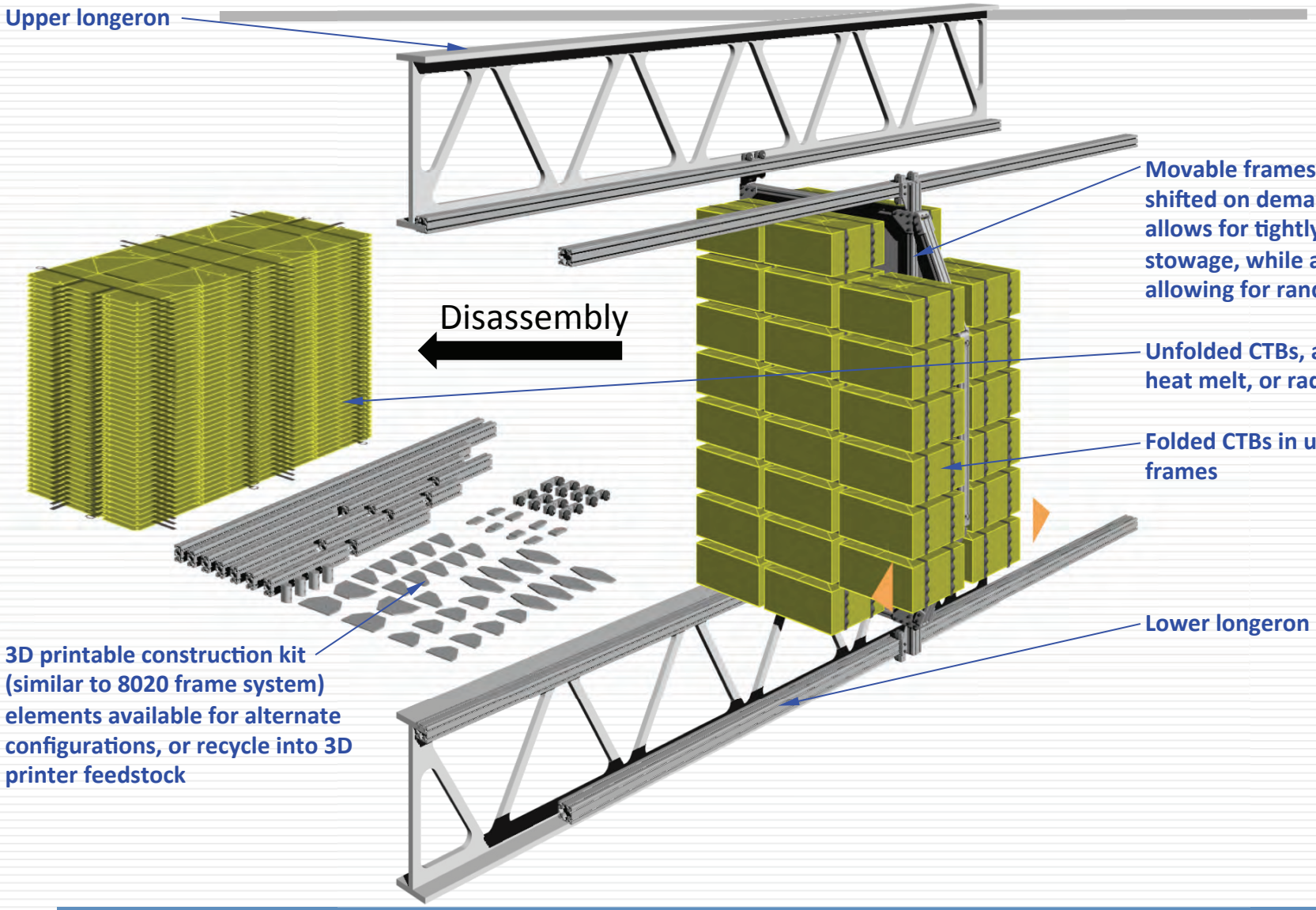
Class II Concepts: Flexible Outfitting



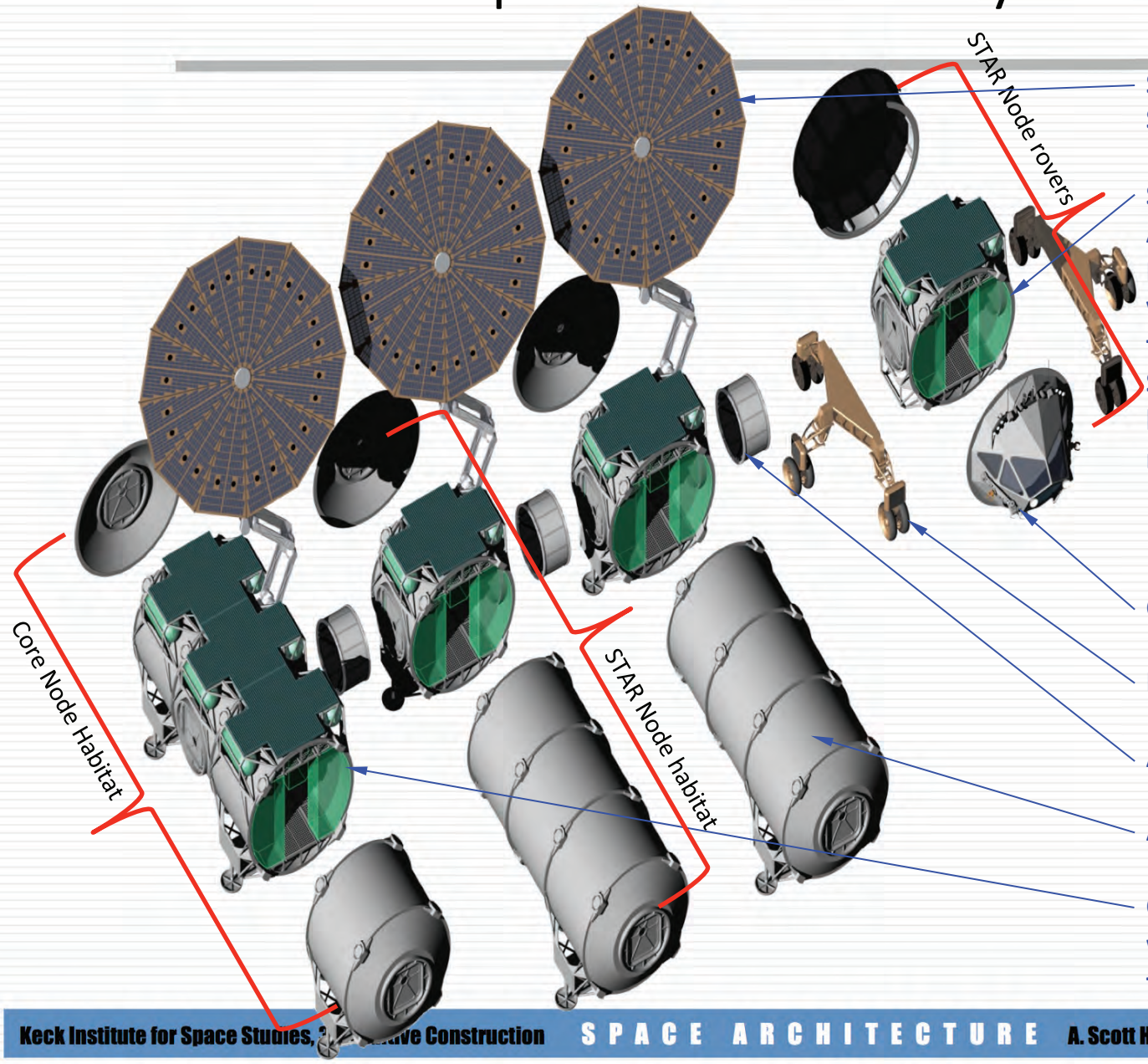


Random Access Frame (RAF) concept

Class II Concepts: Repurposing



Class II Concepts: In-situ Assembly



Solar arrays optional each STAR Node

Space Technology & Advanced Readiness (STAR) Node (open loop ECLSS, air ventilation, fire suppressant, thermal, limited PMAD): STAR Node is central open loop ECLSS module for rovers as well

Cockpits or end cones

Modular mobility systems

Active-active adapter

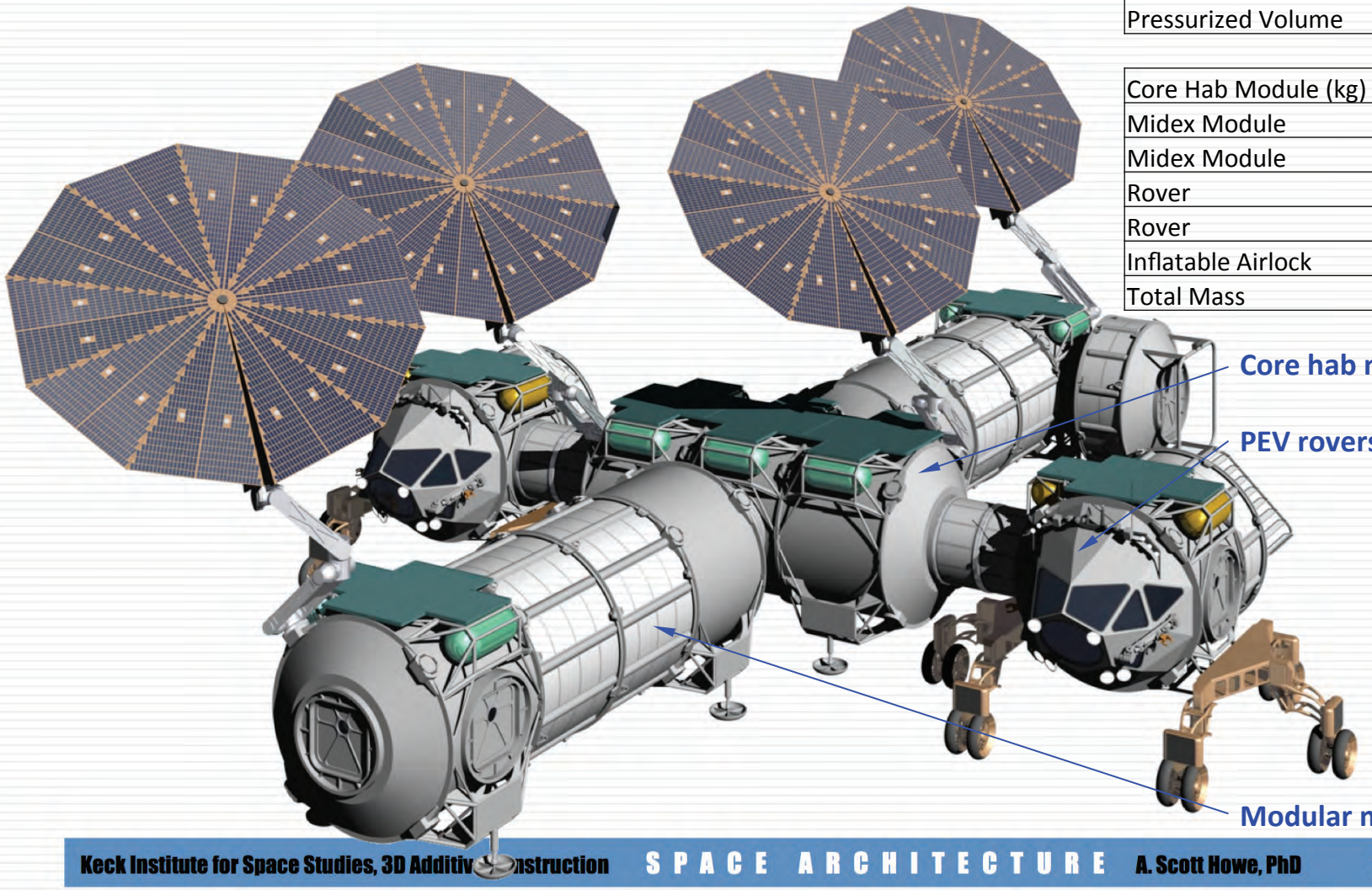
Additional volume

Core Hab (closed ECLSS, air / water revitalization, thermal, PMAD, avionics)

Class II Concepts: Expandable Outpost

Modular Horizontal Midex Outpost	
Habitable Volume (m3)	121.8
Non-habitable Volume	78.7
Pressurized Volume	200.5

Core Hab Module (kg)	9827.0
Midex Module	11280.0
Midex Module	11280.0
Rover	6809.0
Rover	6809.0
Inflatable Airlock	3464.0
Total Mass	49469.0

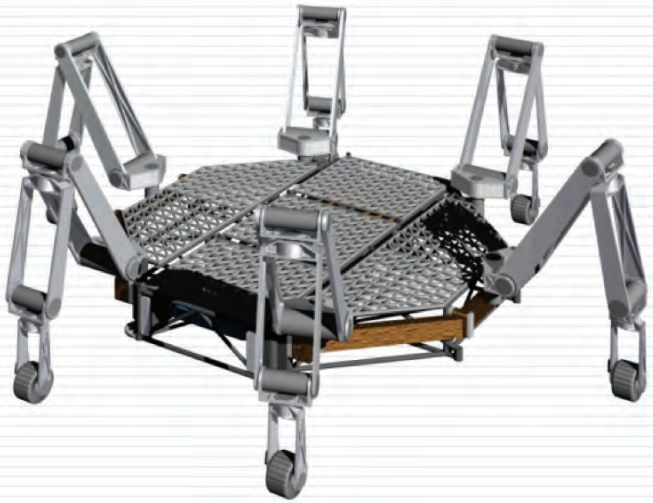


Class II Execution: Robotic Construction

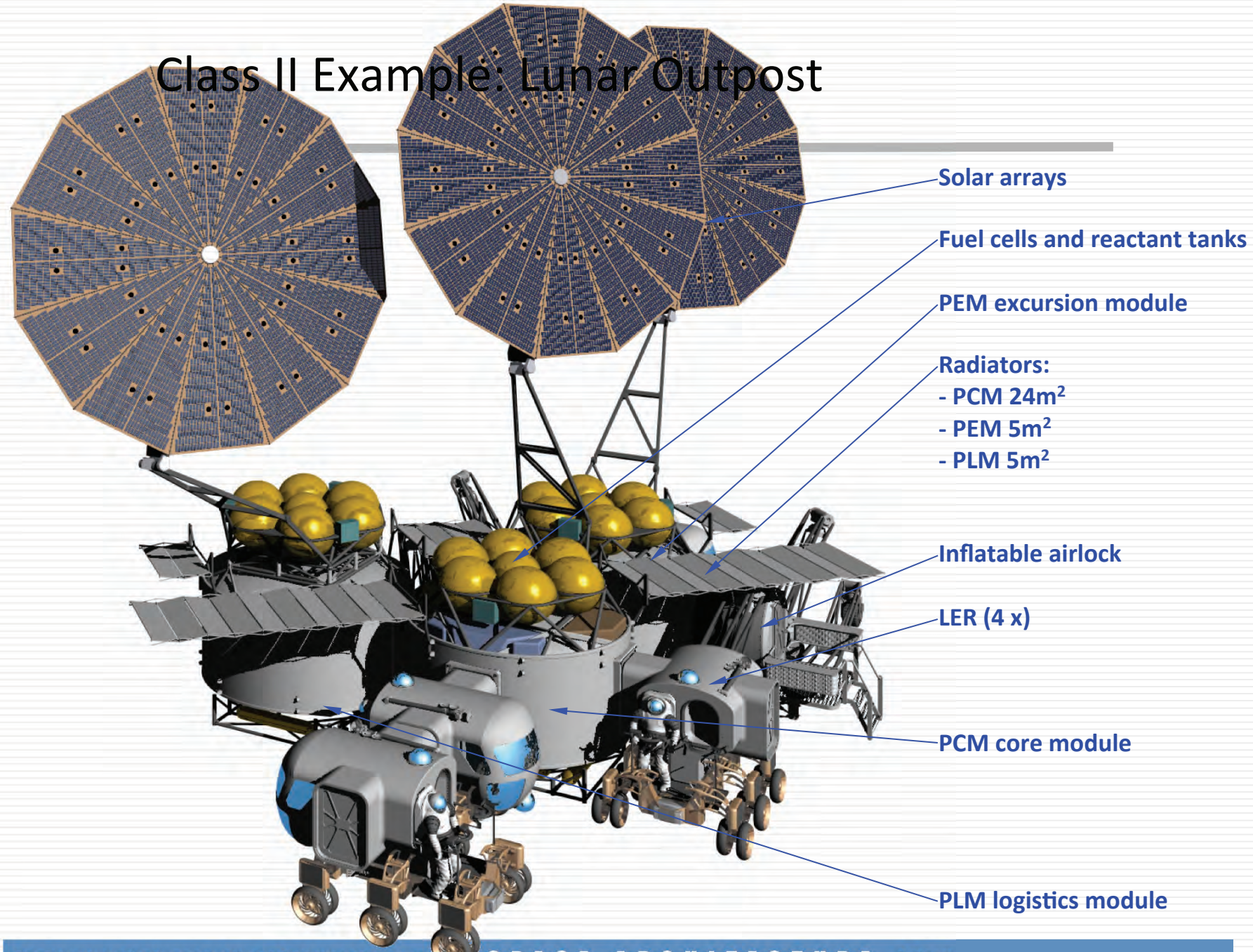
- Encapsulate infrastructure where none is available
  - Materials, Power, transportation, labor, material handling
- Encapsulate complexity into simply manageable units
- The devil is in the details
  - Understand material handling of even the smallest parts

- Smart constructor, dumb parts
  - Constructor is high cost
  - Parts are low cost
  - Constructor is bottleneck
- Smart parts without constructor
  - Self-construct
  - Parts are high cost
  - Faulty parts can be ignored
  - No bottlenecks
- Smart constructor, smart parts
  - Parts assist with their assembly
  - Constructor is medium cost
  - Parts are medium cost

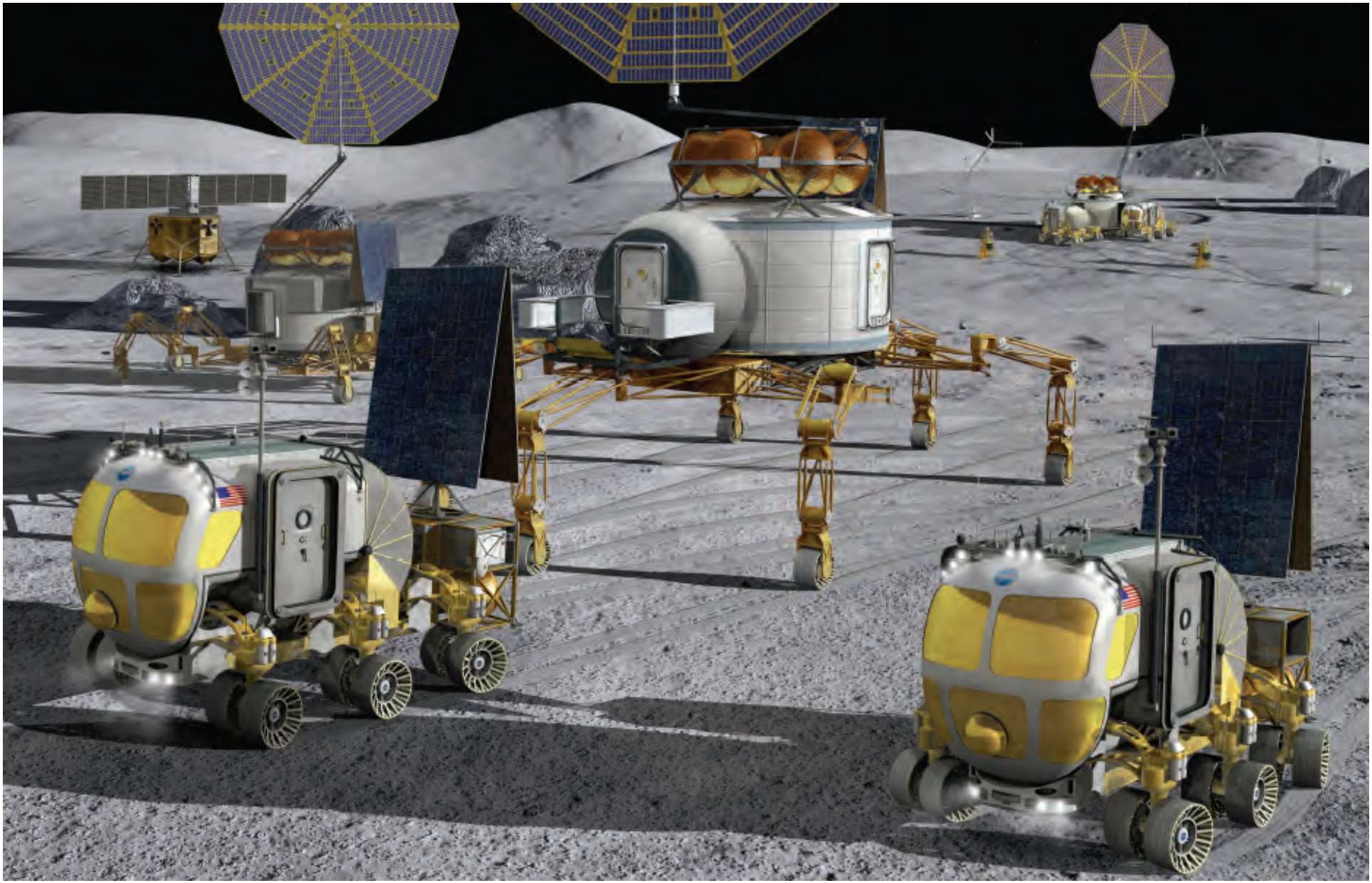
Class II Execution: Robotic Assembly



Class II Example: Lunar Outpost

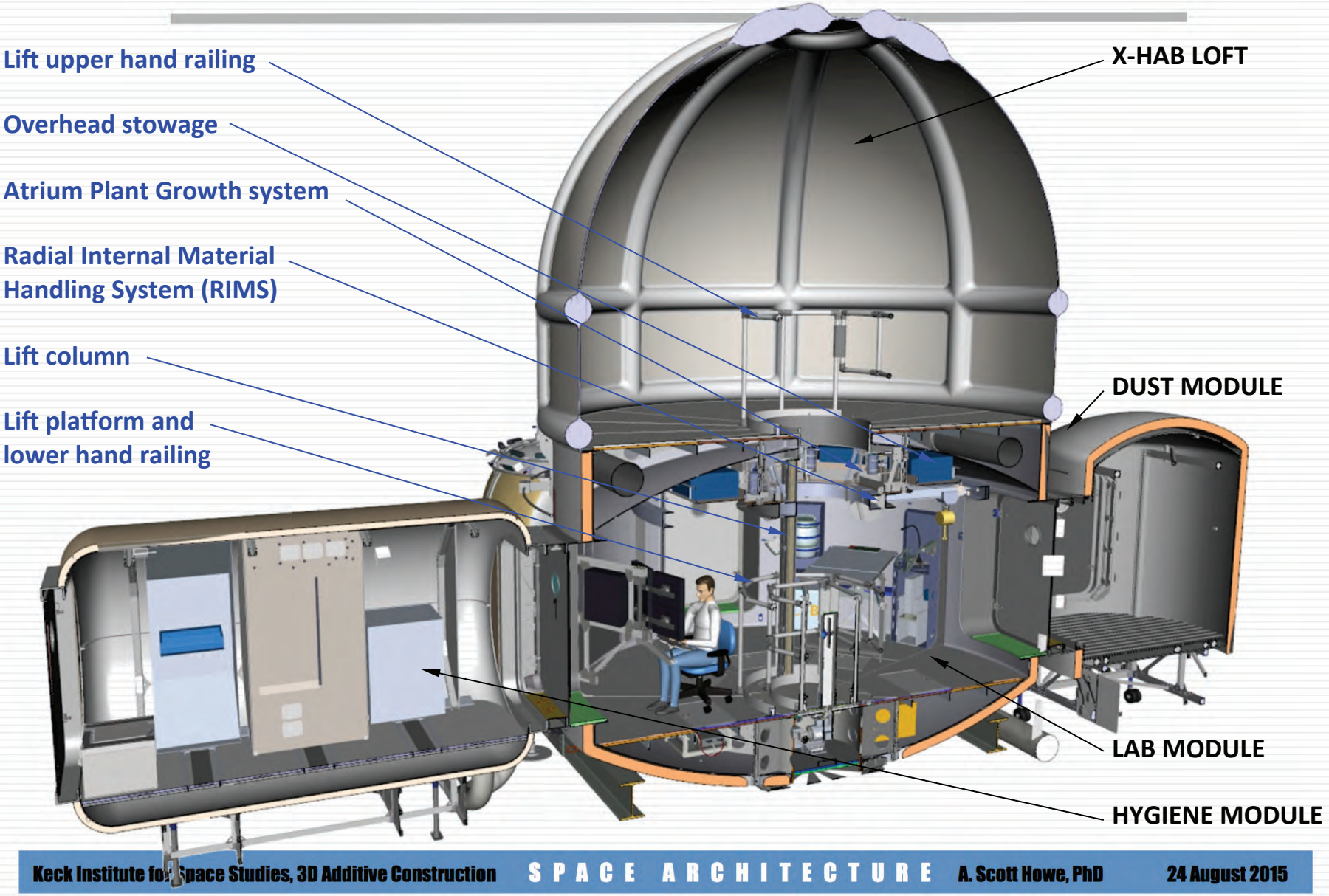


Class II Example: Mobile Outpost



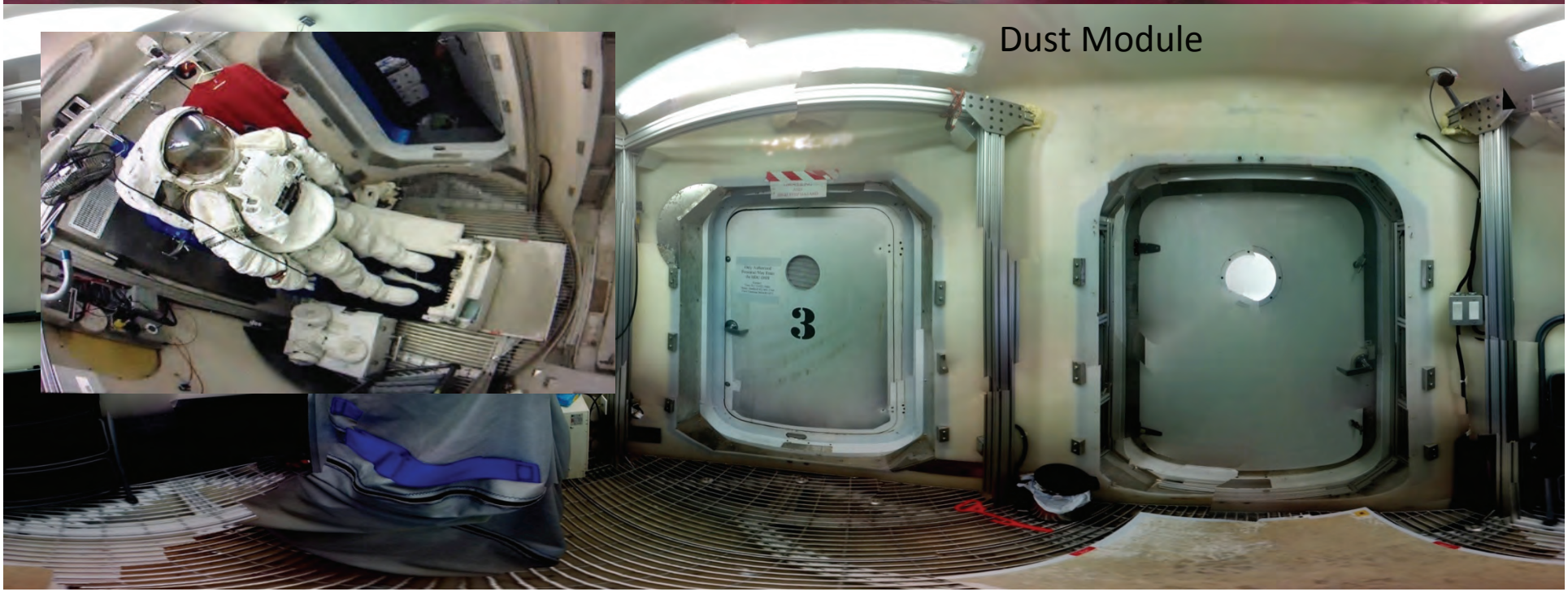
Class II Prototype: Habitat Demonstration Unit

Class II Prototype: HDU Configuration



Class II Comfort Zones: Working in Space

HDU Lab deck



Dust Module

Class II Comfort Zones: Working in Space

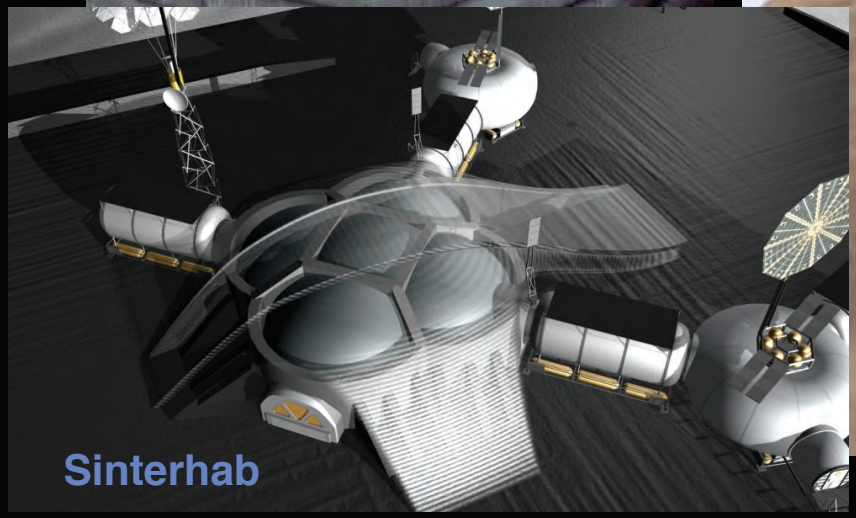
X-Hab Inflatable Loft

Photo: James W. Young

Class III: In-situ Construction

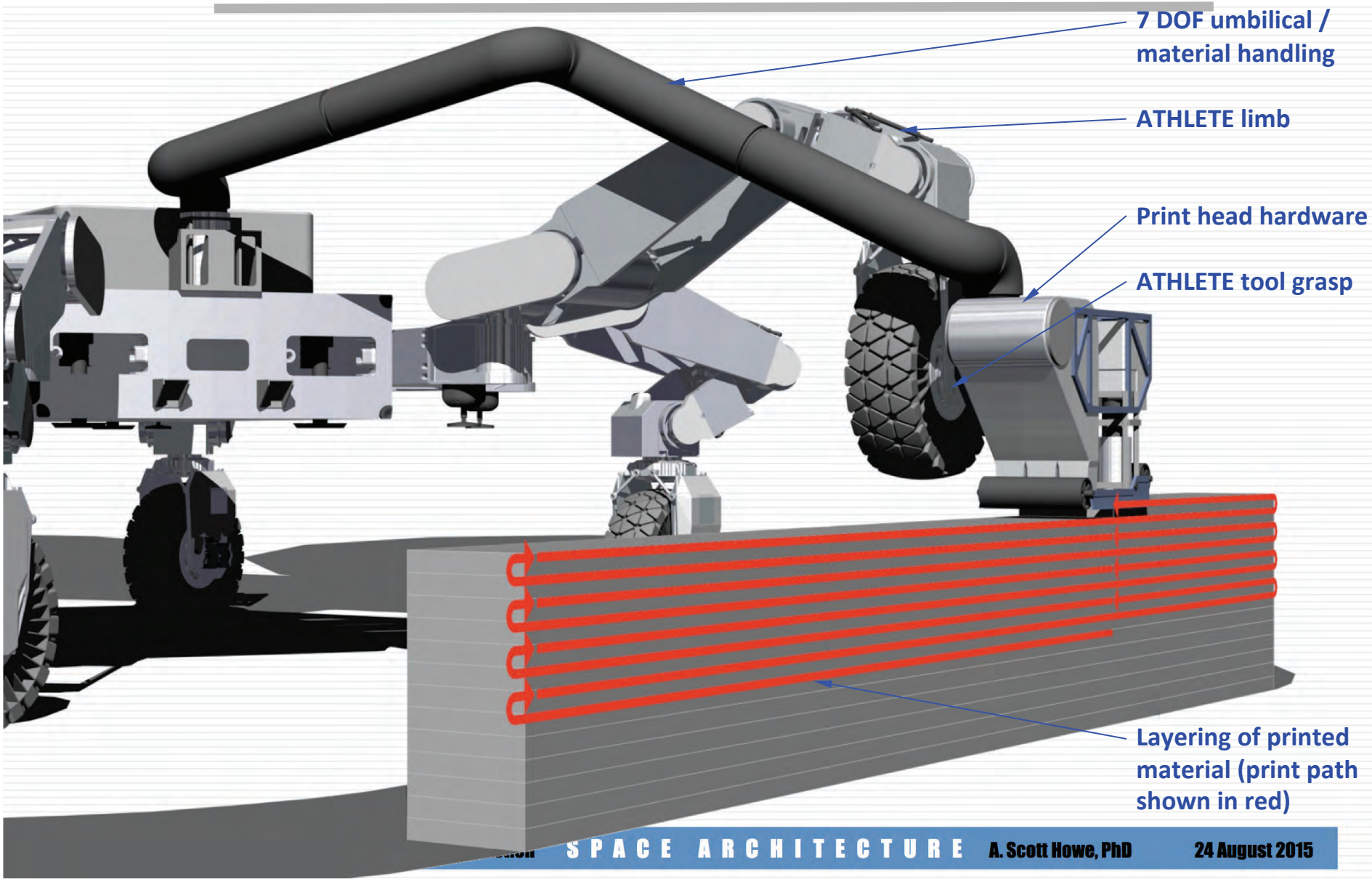
- Need up-front technology
- Onsite effort
- Unlimited resources
- Sustainable

Sandbag domes (courtesy CalEarth)



Sinterhab

Class III Concepts: 3D Additive Construction



Class III Concepts: 3D Additive Construction

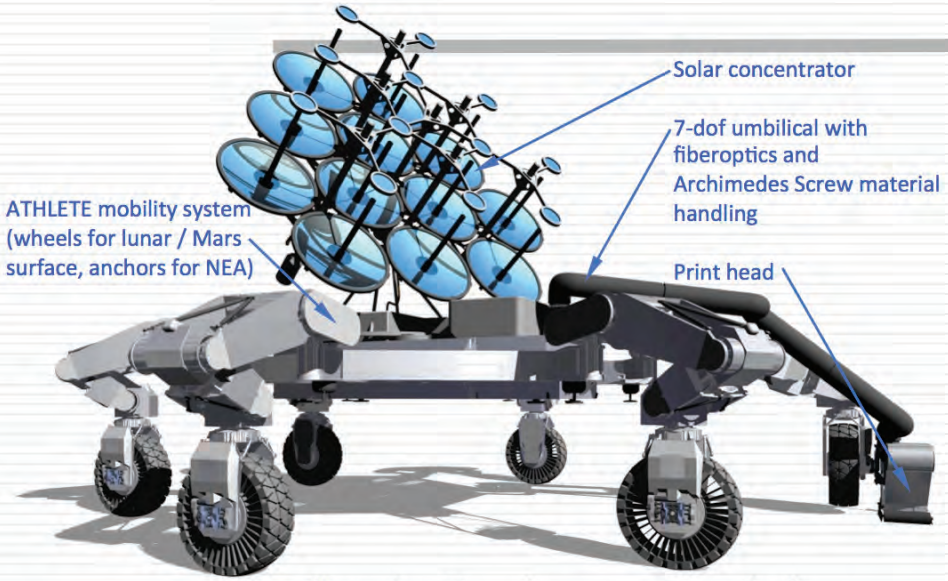


Illustration: Mars solar concentrator technology

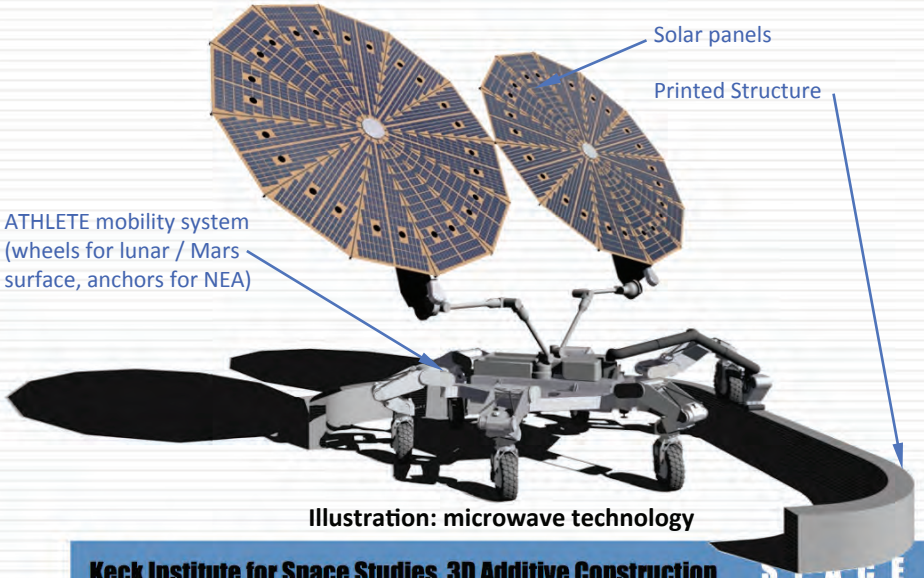


Illustration: microwave technology

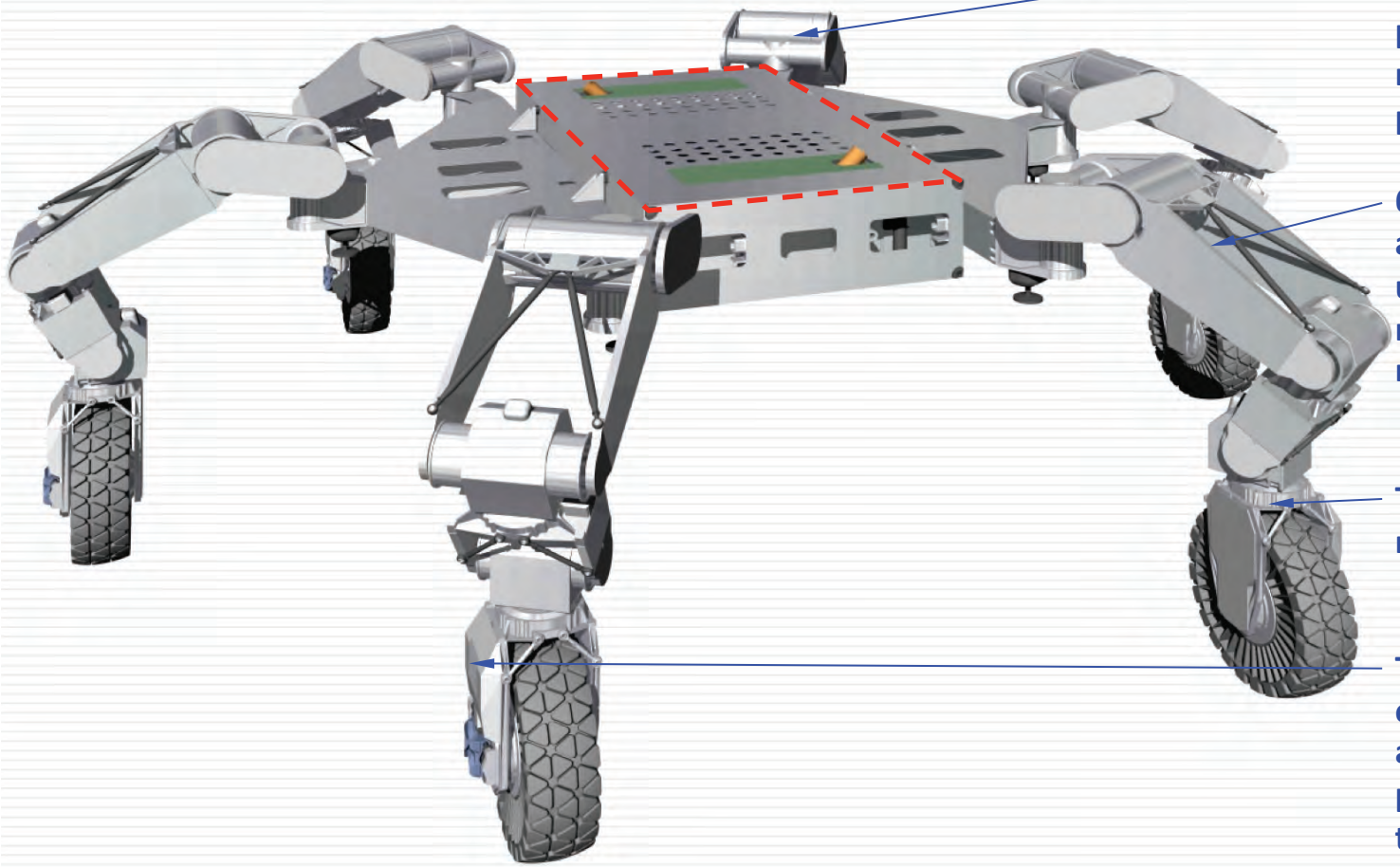
Technical Approach / Expected Accomplishment: **Using ATHLETE's precision positioning capability, four technologies can be used to make a print head and material handling system to adapt/utilize large-scale 3D printer technologies consisting of: fiberoptic solar concentrator, microwave sintering, foam hardening, and in-situ concrete. The FACS system is expected to be capable of printing modular 'bricks', panels, or in-situ structures out of native regolith.**

Task Objectives: **Develop a large-scale 3D additive printing capability and build upon ATHLETE precision mobility system. The 3D print head becomes a modular tool for ATHLETE that can be autonomously mounted on one of its limbs for the purpose of paving and stabilizing native surfaces by sintering or melting regolith.**

Infusion Path: **Proposals for capturing a small NEA are currently being considered for both science and human spaceflight as part of the NASA Asteroid Redirect Mission. This technology can be used to enhance ATHLETE's ability to anchor to an NEA. The technology can also be used to pave surfaces, print domes, vaults, and other structures for Lunar or Mars surface human missions.**

Primary Technical Hurdles: **Fiberoptic solar concentrators are currently at TRL 6 and can be quickly integrated with ATHLETE for a demonstration. Additional effort will be needed to integrate microwave sintering and foam hardening systems. In-situ concrete can only be worked out conceptually, because hardening agents are currently not well understood. However, partners/collaborators (KSC, USC, etc) have been working on potential technologies in this area.**

Class III Concepts: Precision Positioning



Customizable pallet: can be used as a platform for power plants, reservoirs, mixing, filtering, and other processing

6-DOF or 7-DOF articulated limb: can be used primarily for mobility, but also as a robotic arm

Tweel: allows for wheeled mobility

Tool adapter: available on each limb, can grasp tools and provide mechanical power through the power take-off, borrowing the motor in the wheel

Class III Concepts: Precision Positioning

ATHLETE limb grasping a tool -- drilling into a rock cliff -- tools can be lifted well above main body

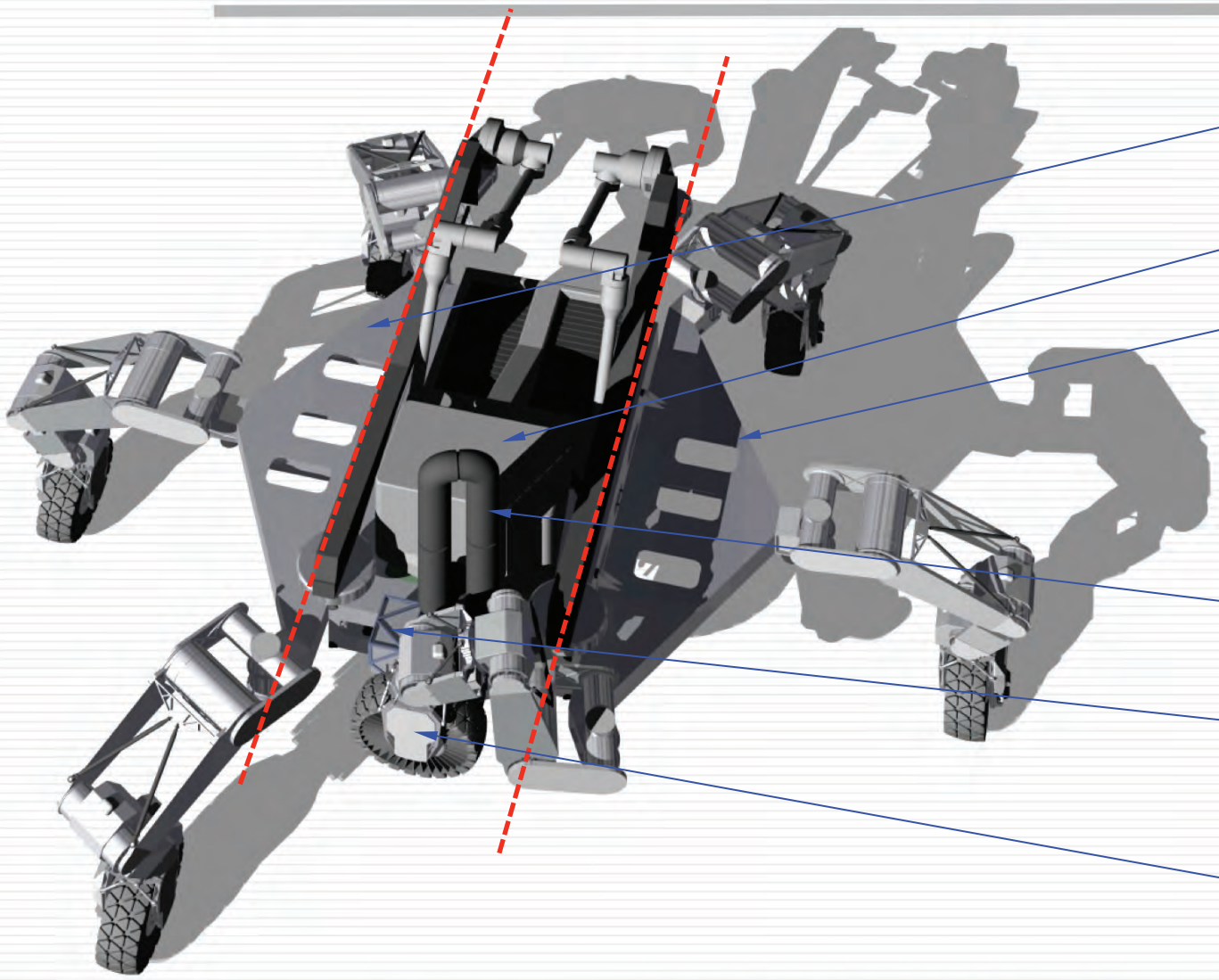
Payload on modular pallet (showing a mockup habitat with 60” high door)

Tri-ATHLETE vehicle with three limbs x2 = six limbs total

Limbs

Wheels on limbs for mobility

Class III Concepts: Modular ISRU Processing



Tri-ATHLETE vehicle

Dedicated FACS pallet

Tri-ATHLETE vehicle

Stowed umbilical

Print head holster on end of pallet

ATHLETE limb reaches up to grasp print head with tool adapter

Class III Concepts: Material Handling

7-DOF Umbilical facilitates printing in multiple degrees of freedom

3-DOF Umbilical facilitates printing only in the vertical orientation

Articulated archimedes screw

Core of Archimedes screw can function as conduit for cables, fiberoptics

Tri-ATHLETE vehicle

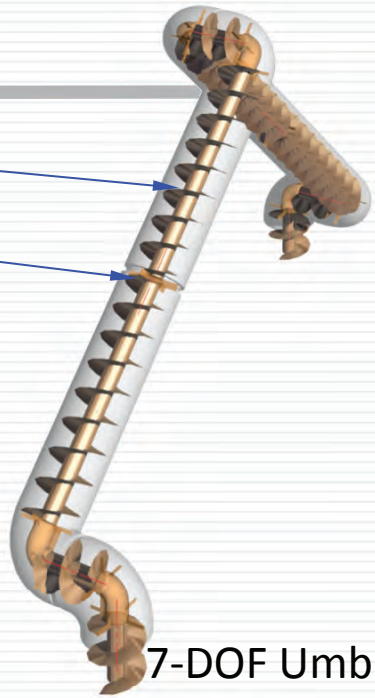
Dedicated FACS pallet

ATHLETE limb

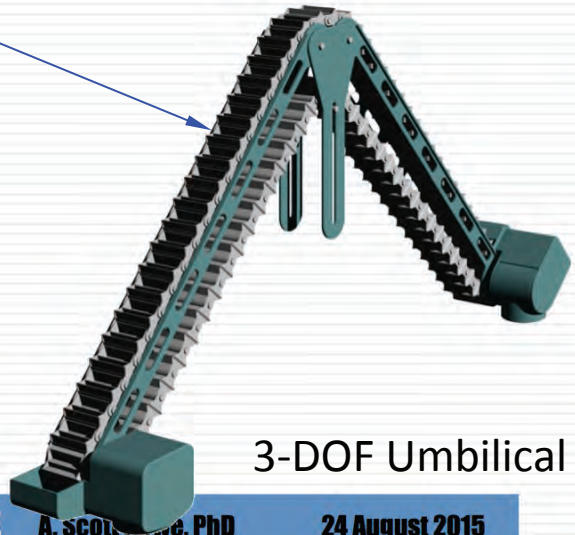
Conveyor belt with deep bucket pockets

Print head

Material handling umbilical

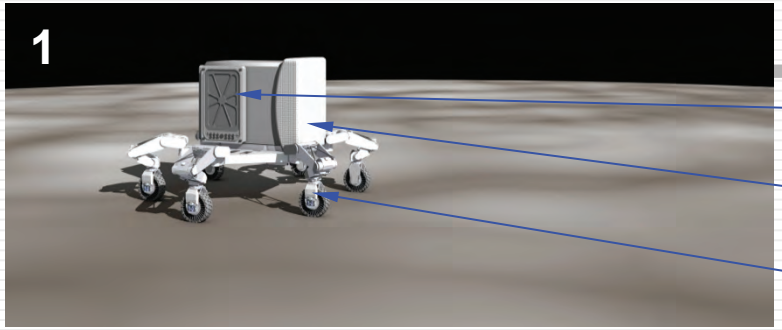


7-DOF Umbilical



3-DOF Umbilical

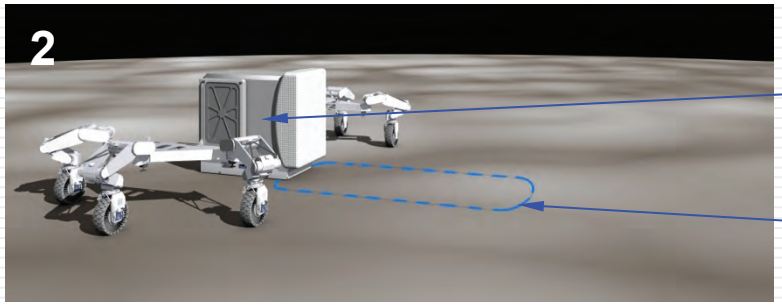
Class III Execution: Printed Shells



Airlock module with docking ports

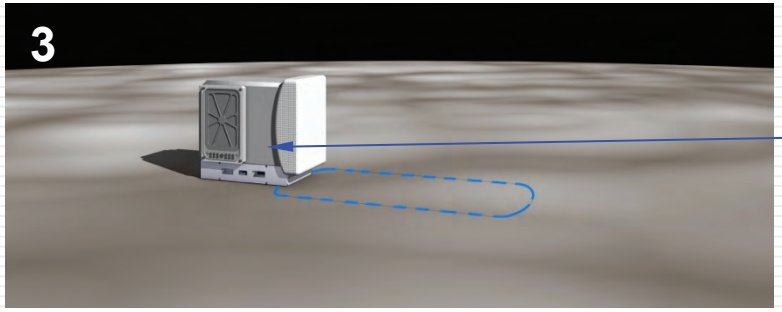
Inflatable liner stowed

ATHLETE mobility system

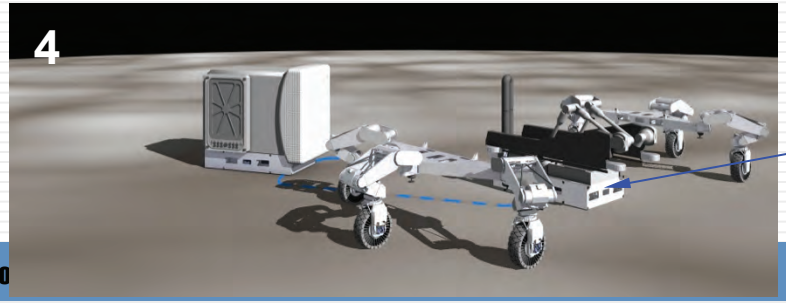


Tri-ATHLETE vehicles set Airlock module and pallet in target location

Proposed habitat location (blue dashed)

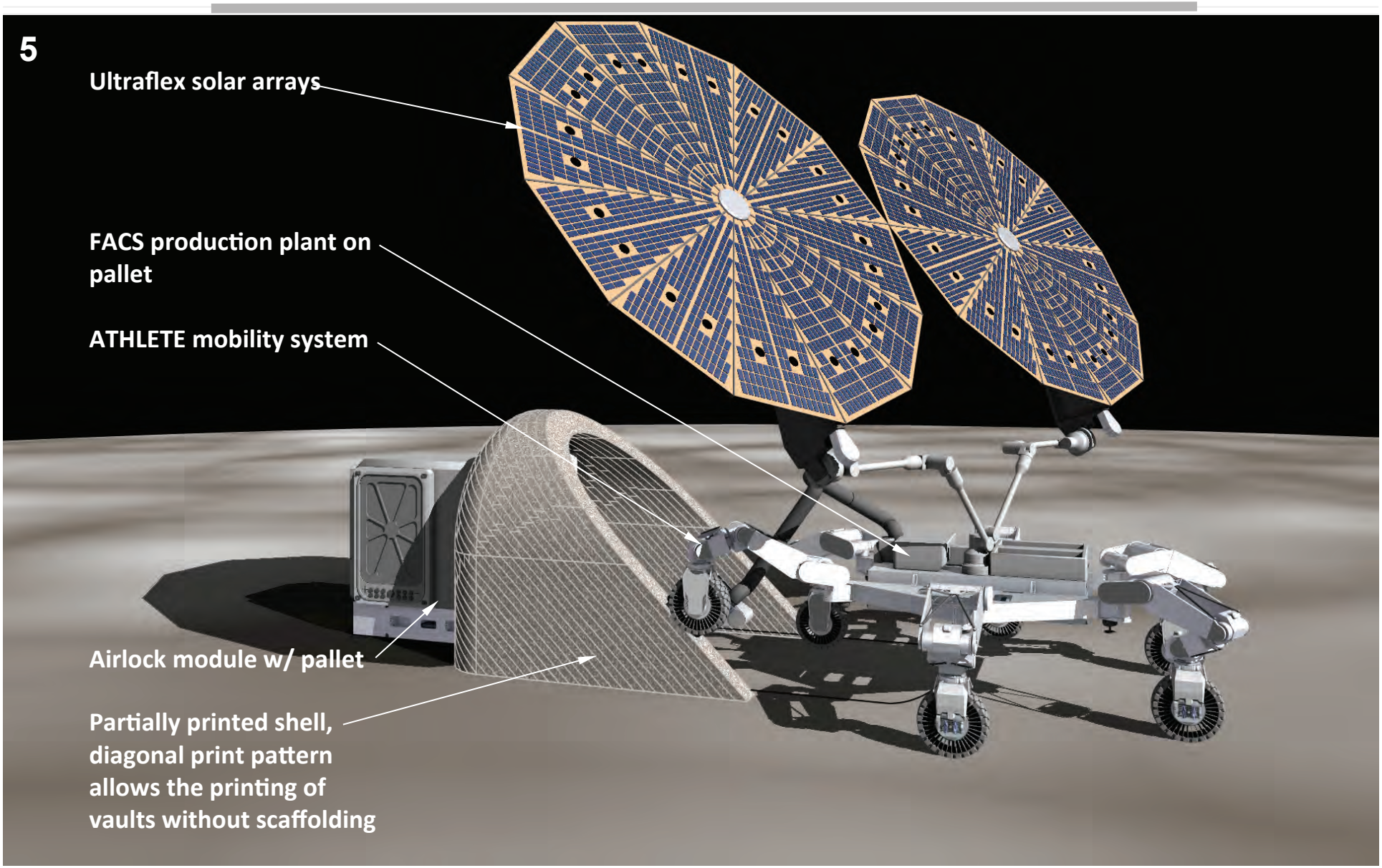


Airlock module and pallet in permanent location

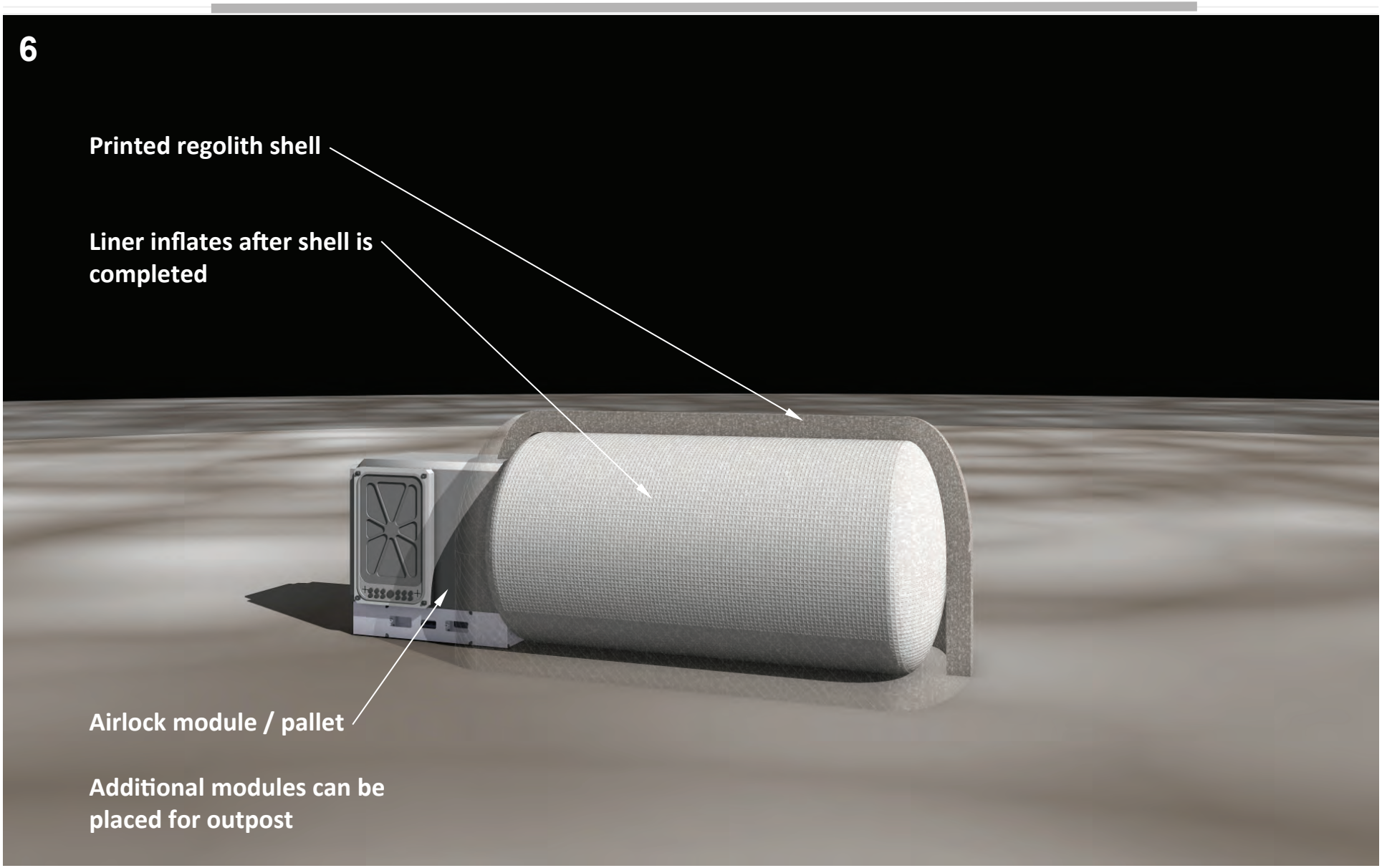


Tri-ATHLETE vehicles pick up FACS pallet to begin printing of habitat shell

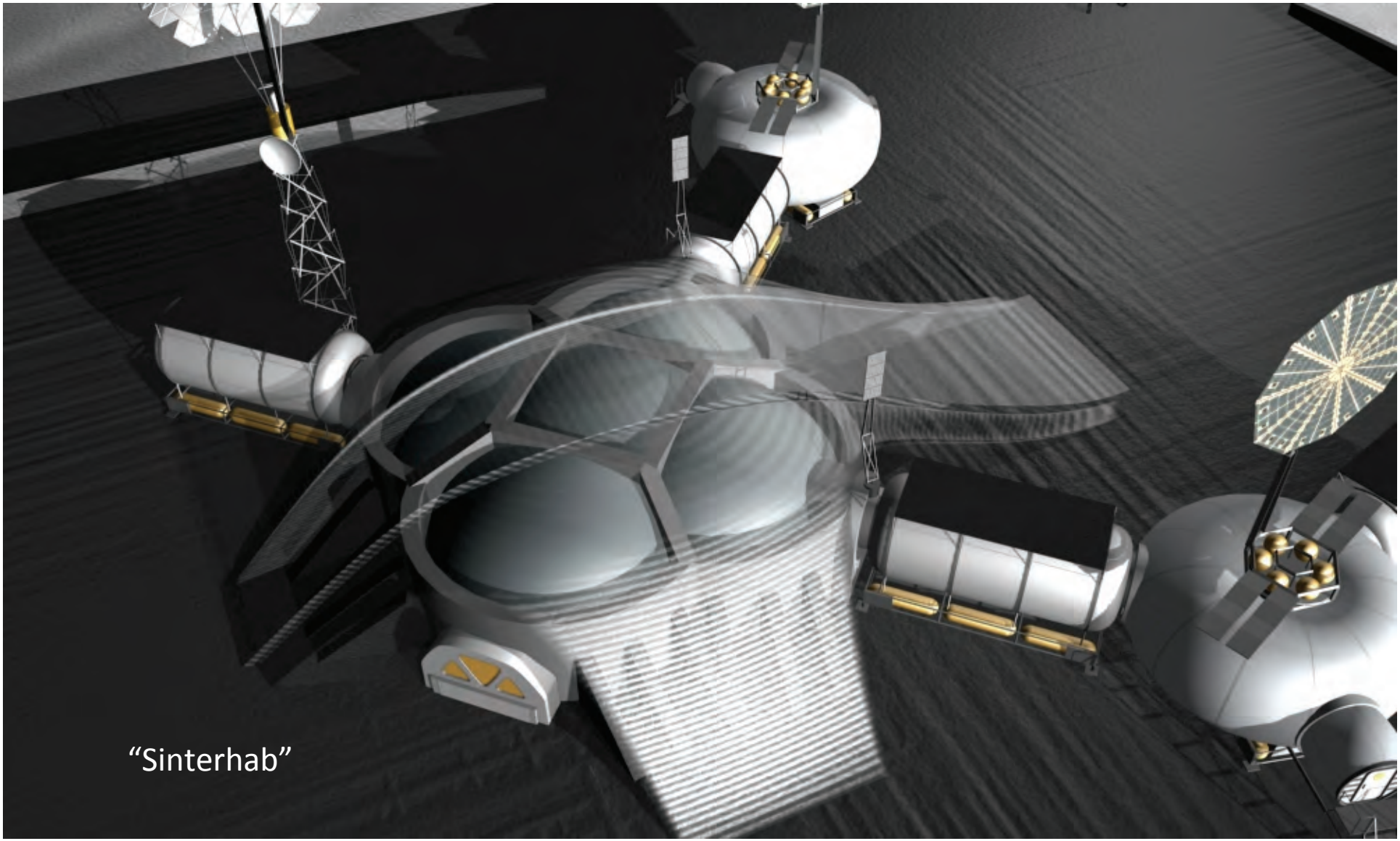
Class III Execution: Printed Shells



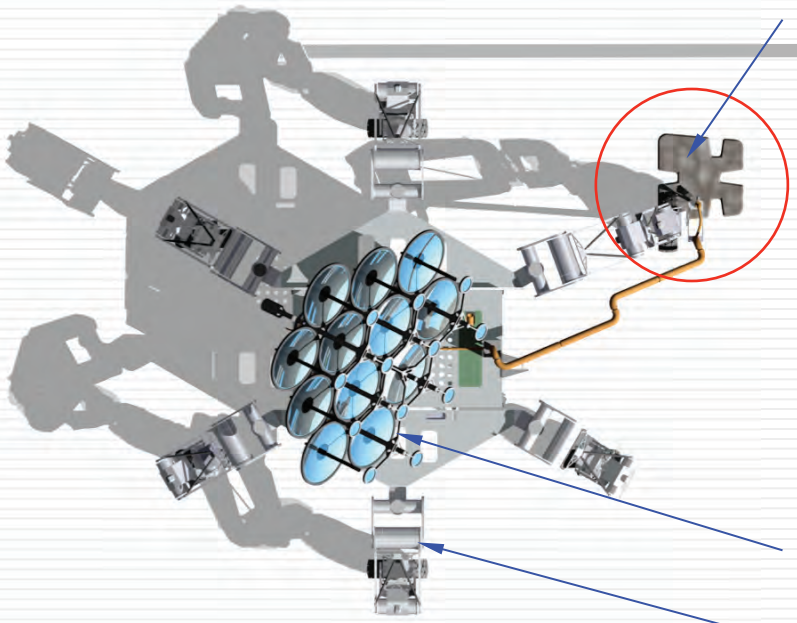
Class III Execution: Printed Shells



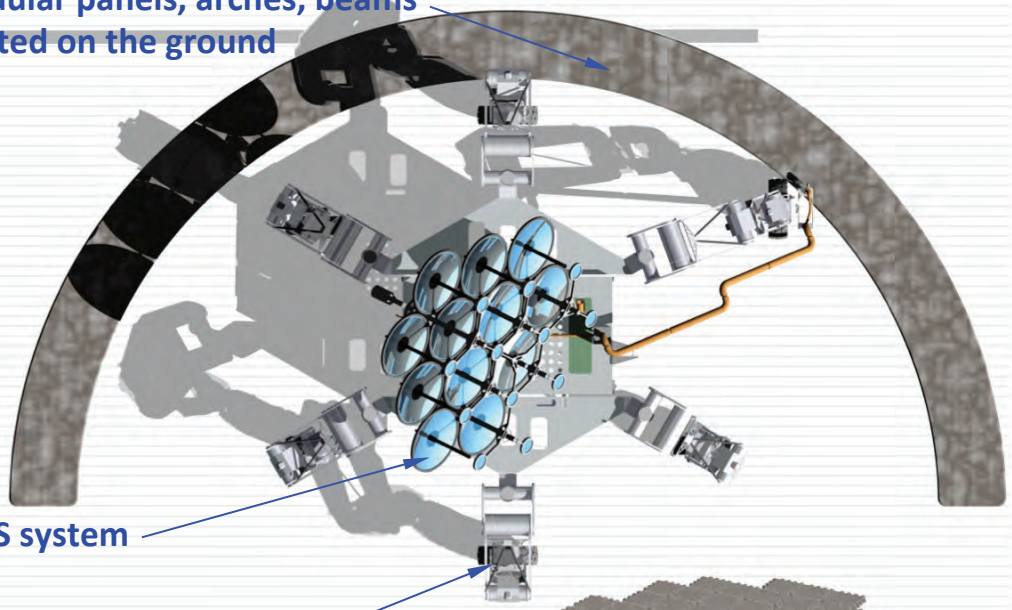
Class III Execution: Printed Shells



Class III Execution: Prefab Panels

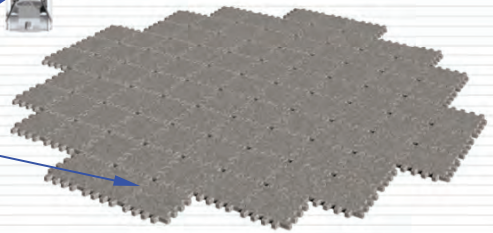


Modular panels, arches, beams printed on the ground

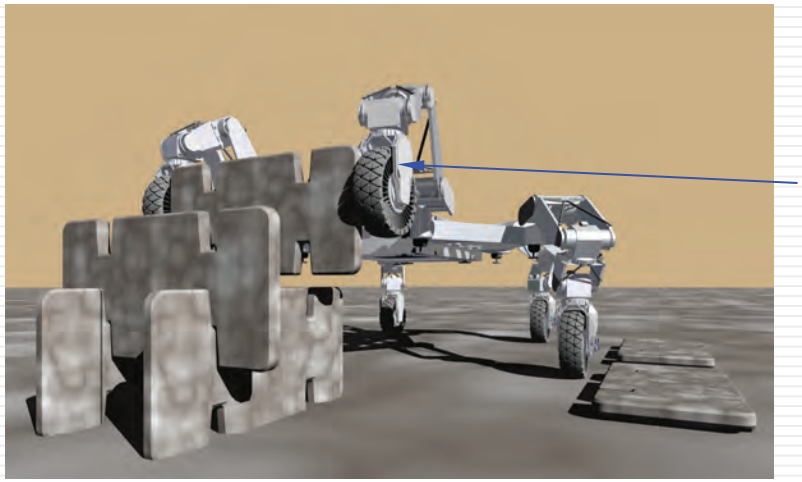


FACS system

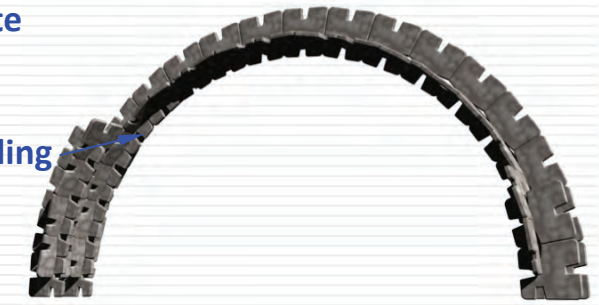
ATHLETE mobility system



In-situ printed paving blocks for lander pads

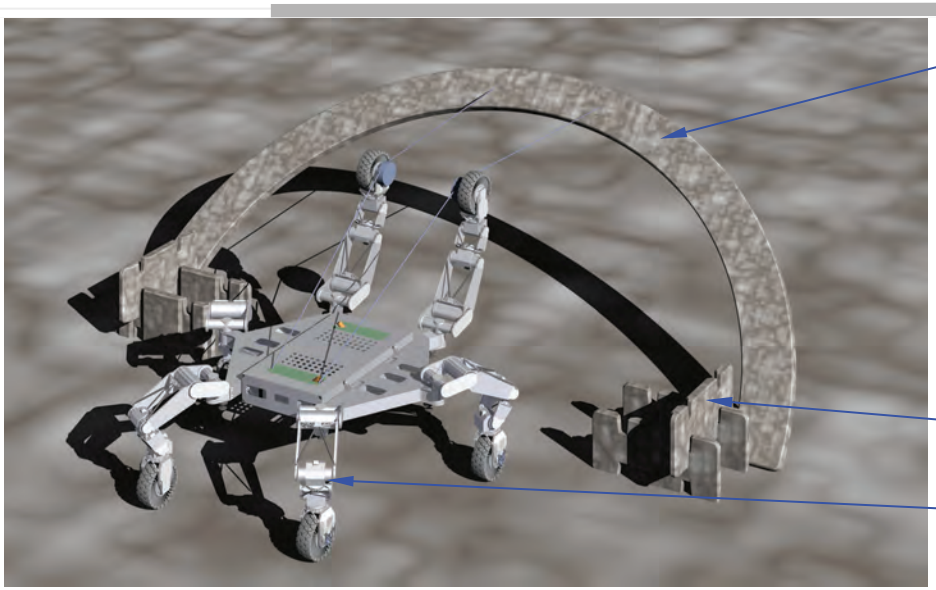


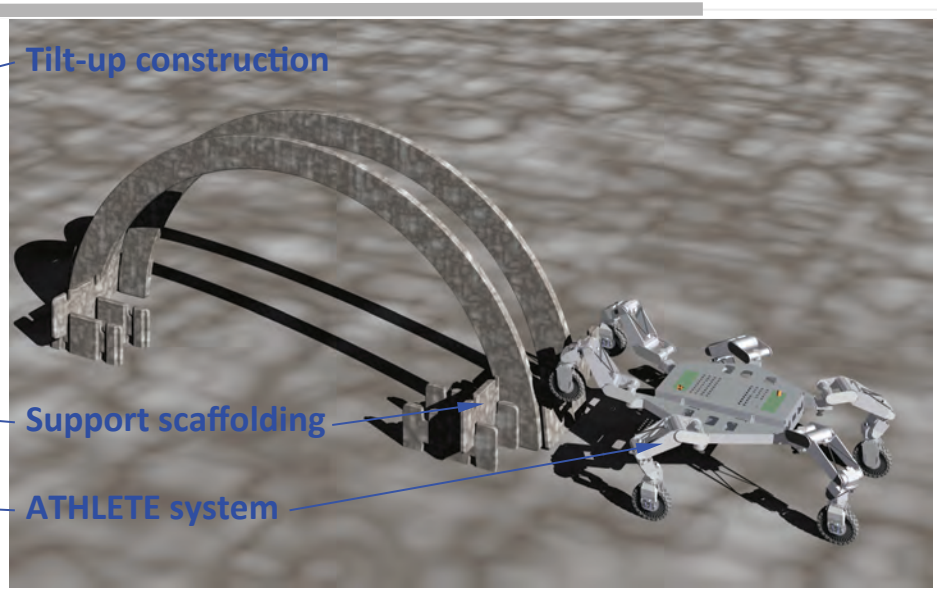
ATHLETE can lift and manipulate panels into in-situ structure

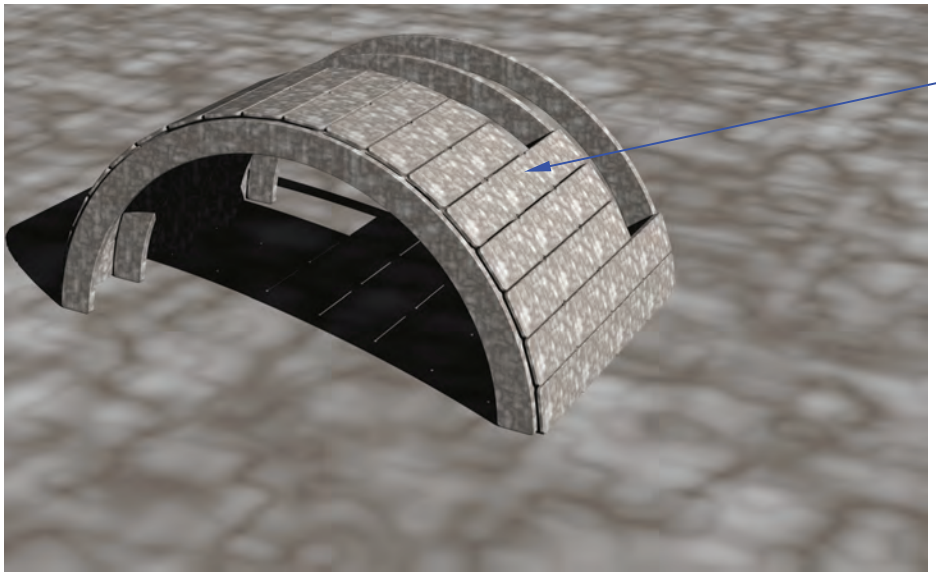


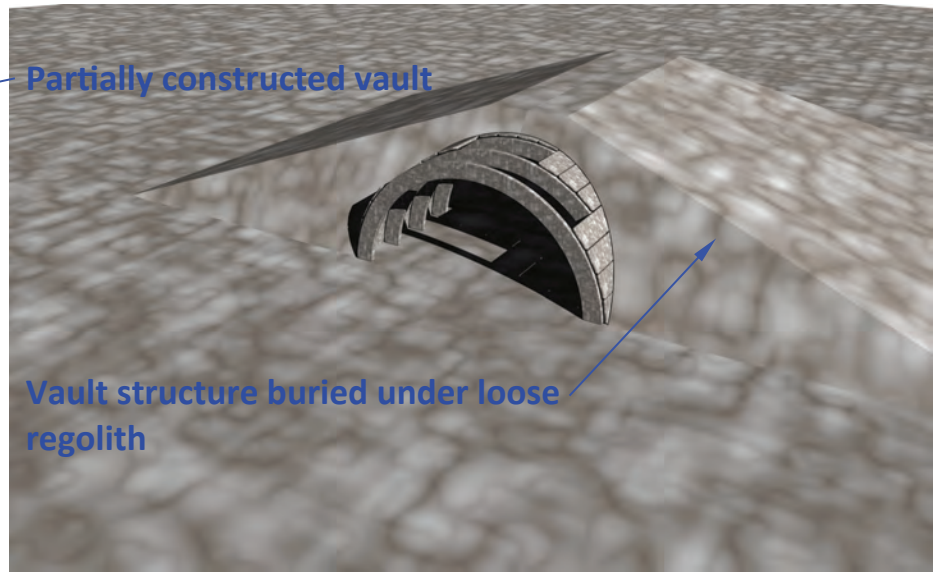
Modular archways and scaffolding assembled from in-situ printed panels

Class III Execution: Prefab Panels

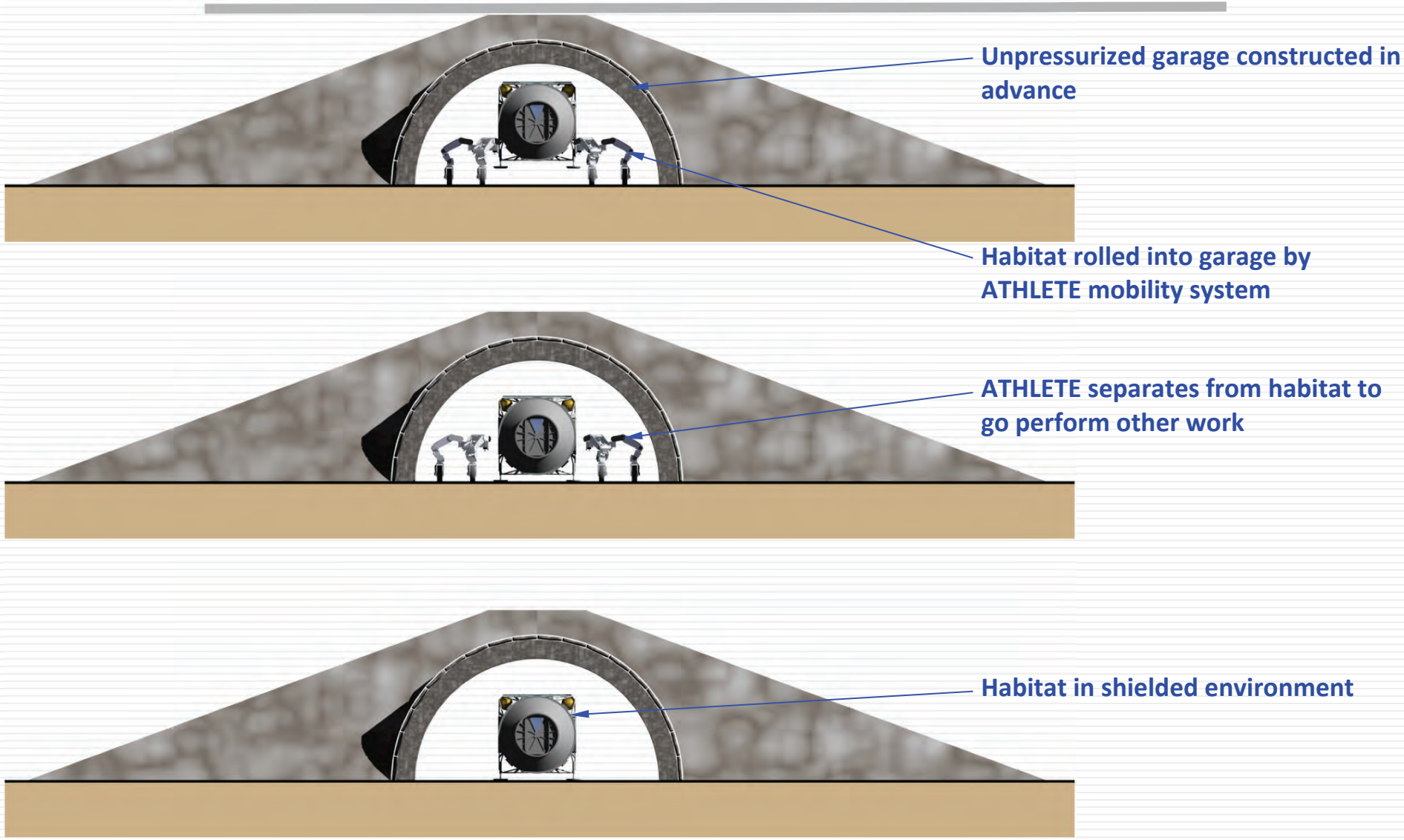








Class III Execution: Prefab Panels



Questions?

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  - 818-684-4442

- Concepts and Discussions are based on material from AIAA publication:
  - "Out of This World: The New Field of Space Architecture"