



COSMIC Capstone Challenge: Final Briefing

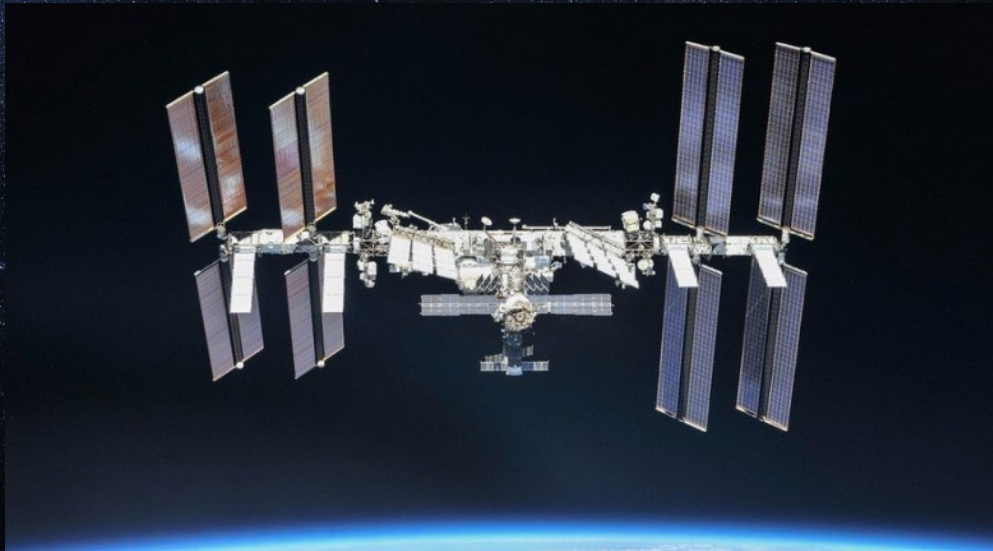
Bearcat Assembly, University of Cincinnati Self-Assembled Science Station

Students: Diego Quevedo, James Talavage, Sarah Hudson,
Conrad Kent, Gerardo Martinez-Avila, John Radey, Sophia Yu
Advisor: Benjamin Rupp
Mentor: Dr. Ou Ma

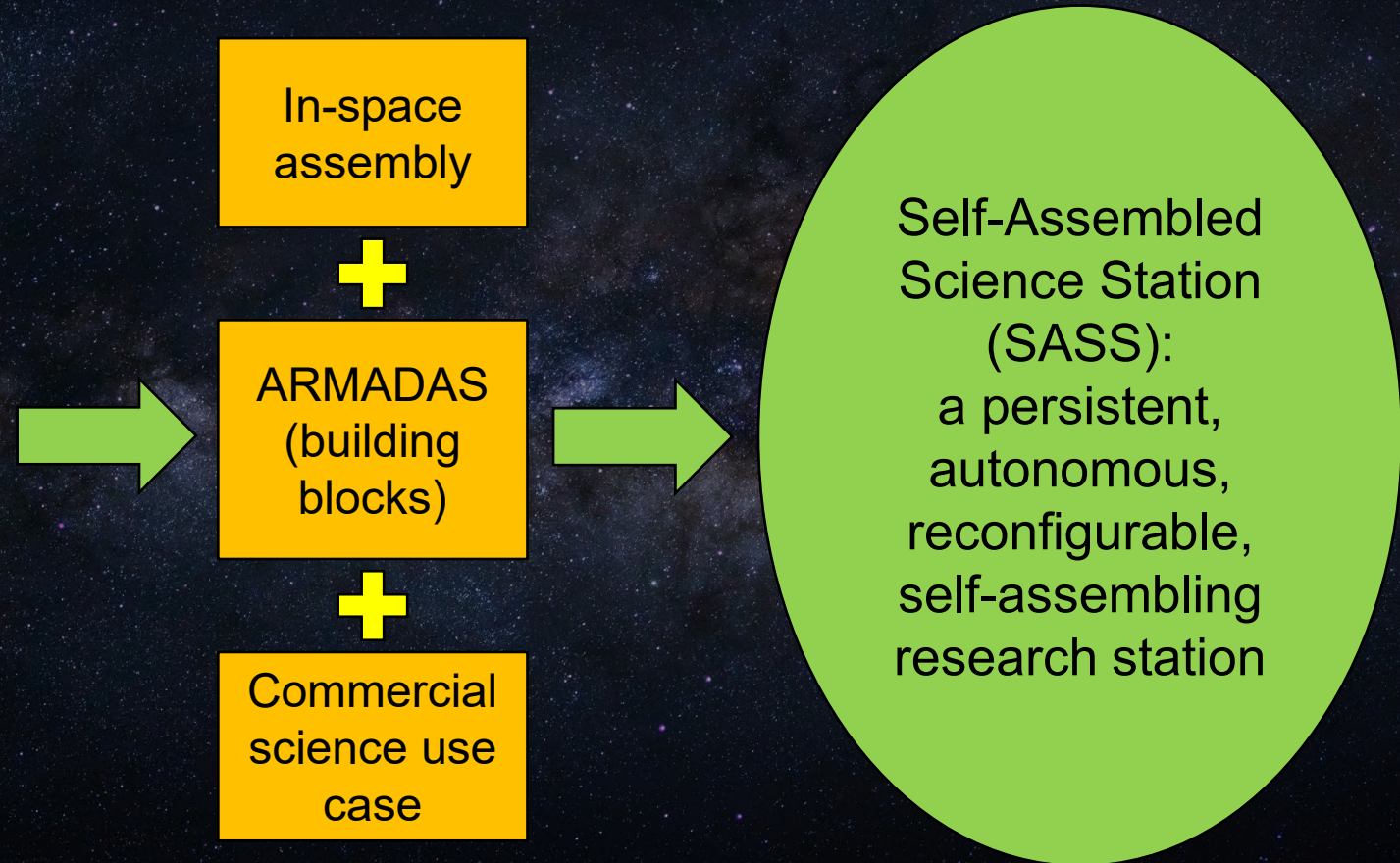
April 16, 2026

Executive Summary

What comes after the ISS is gone?
Where can scientists do space research?
How can we increase the TRL of ISAM?



Credit: NASA



Team Overview



Diego Quevedo



Conrad Kent



Sarah Hudson



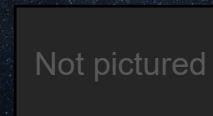
James Talavage



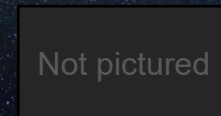
Gerardo Martinez-Avila



Sophia Yu



Dylan Roach

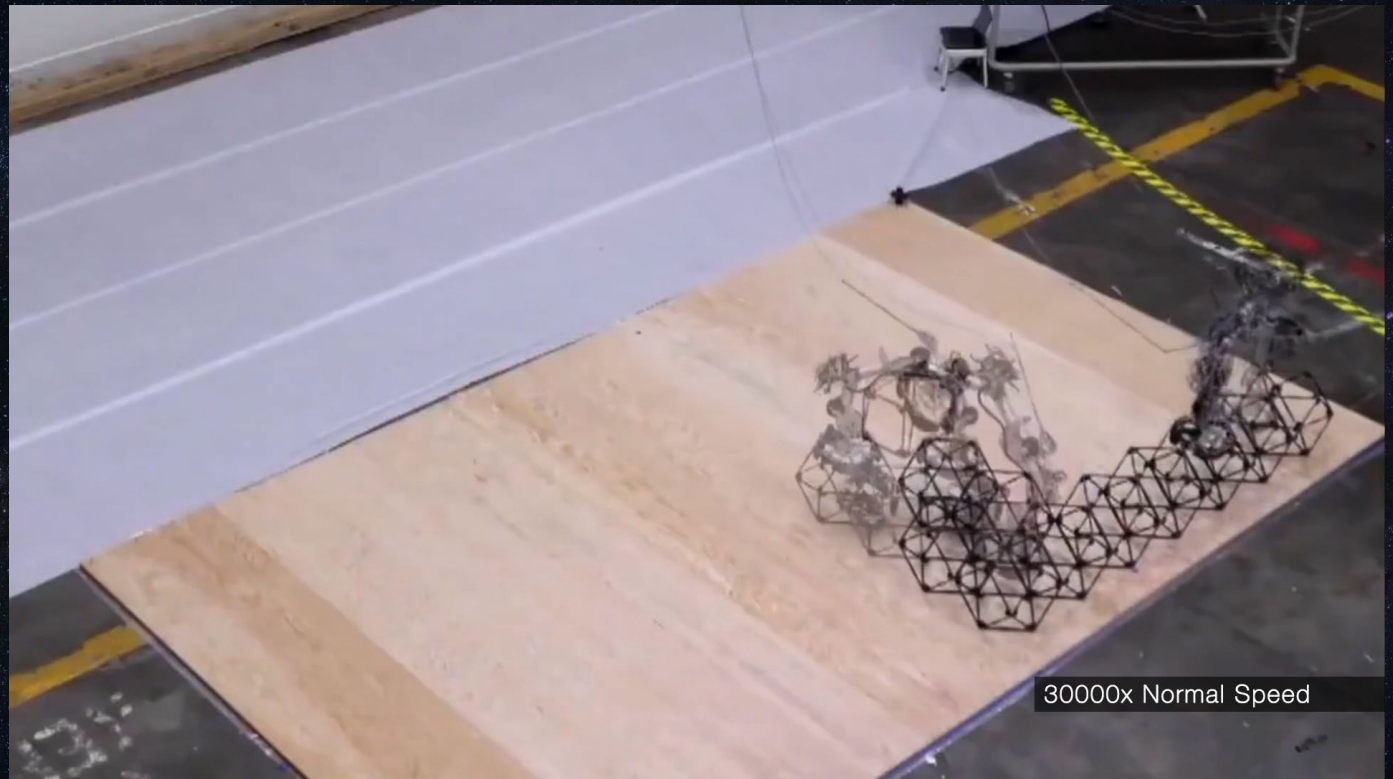
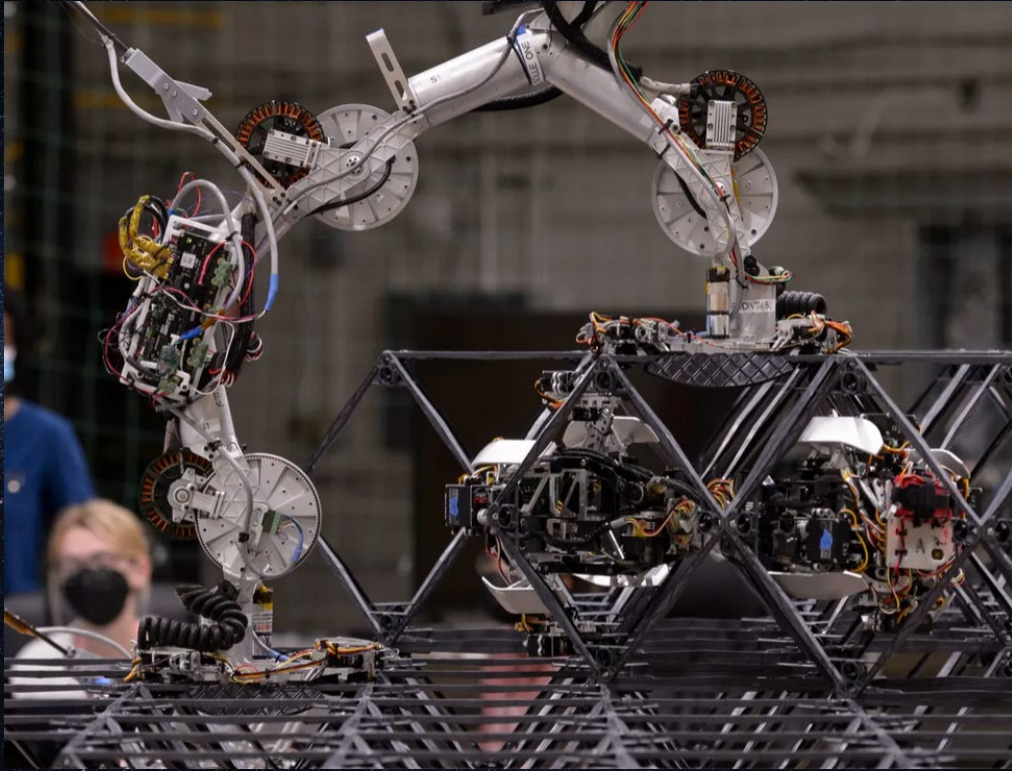


John Radey

2.4 Program Management Milestones

Milestone	Completion Date
Select program manager	August 2025
Chose capabilities	November 2025
Defined system requirements	January 2026
Completed trade studies	In progress
Finalized conceptual design	In progress
Developed a path to PDR	In progress

ARMADAS Concept

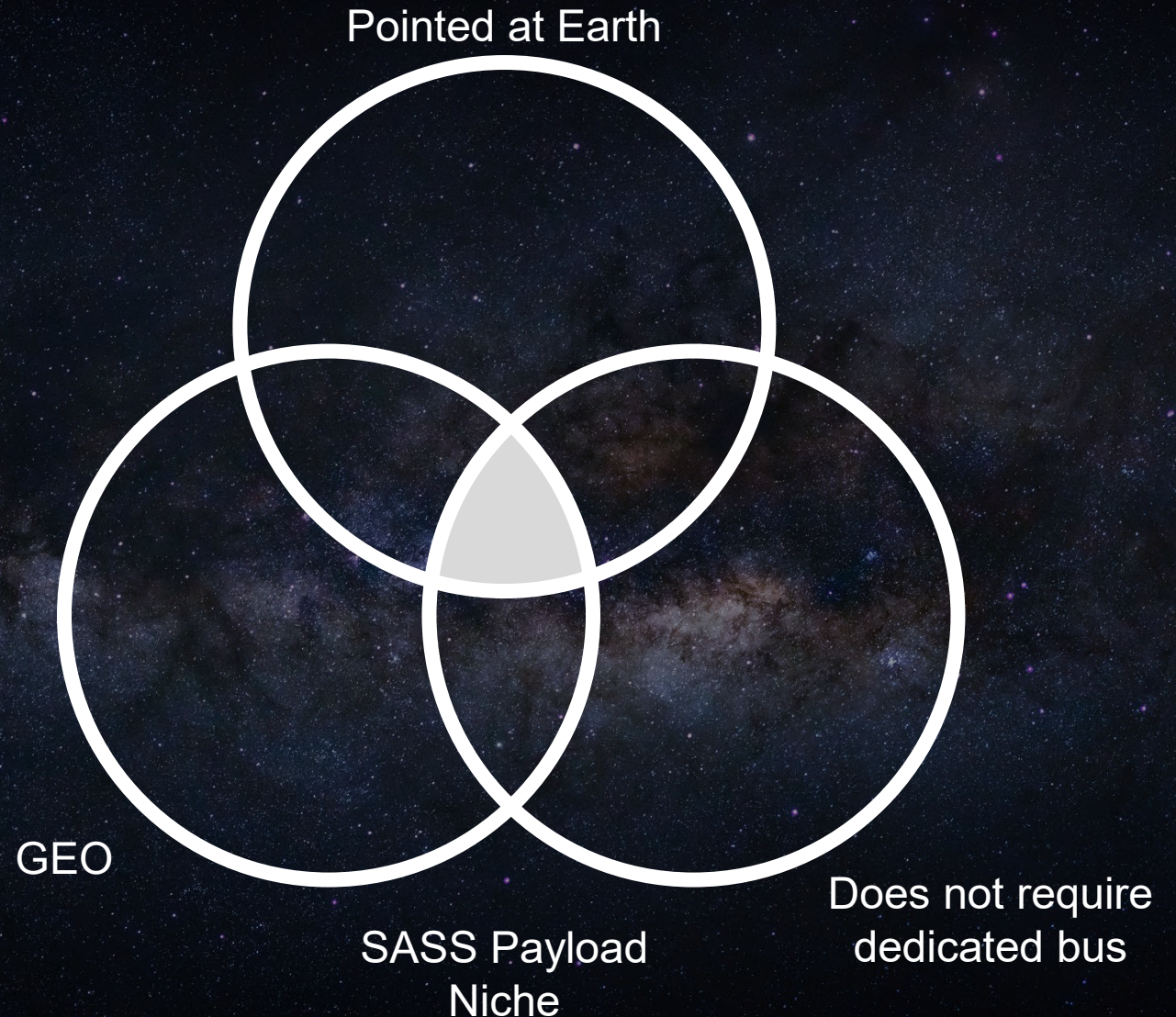


Credit to NASA

Self-Assembled Science Station

Persistent Payload Station Concept

- Experimental and Earth Observation payloads make up billions of dollars of the space market
 - >\$1.5 billion in CubeSat market by the mid 2030s
 - >\$7 billion in Earth Observation market by mid 2030s
 - Billions spent on ISS every year
- The SASS Concept is aimed at a specific niche of these markets and would be on the order of hundreds of millions of dollars.



<https://www.grandviewresearch.com/industry-analysis/cubesat-market-report>

<https://oig.nasa.gov/wp-content/uploads/2024/02/IG-22-005.pdf>

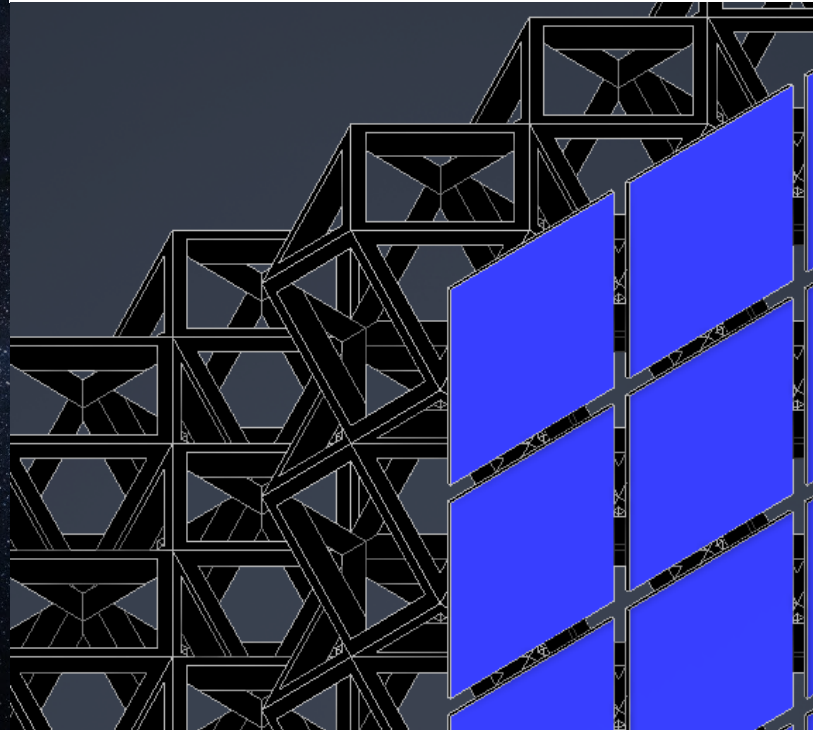
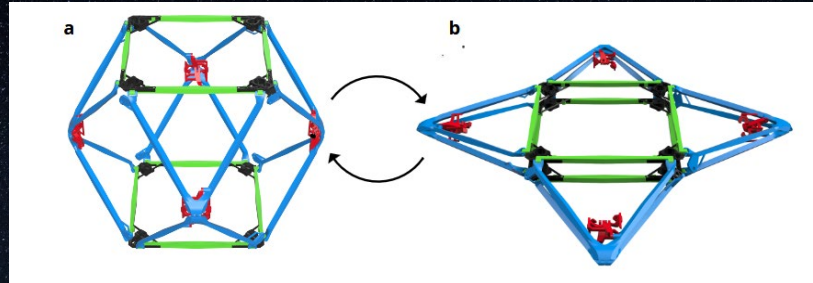
<https://www.grandviewresearch.com/industry-analysis/earth-observation-market-report>

Self-Assembled Science Station

Concept of Operations

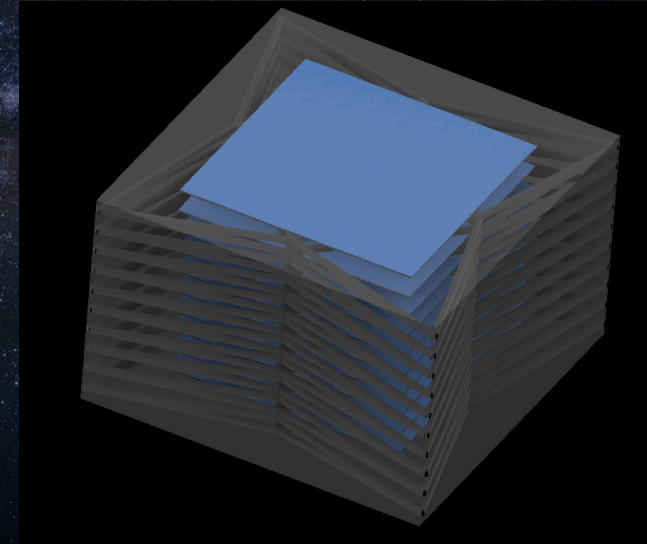
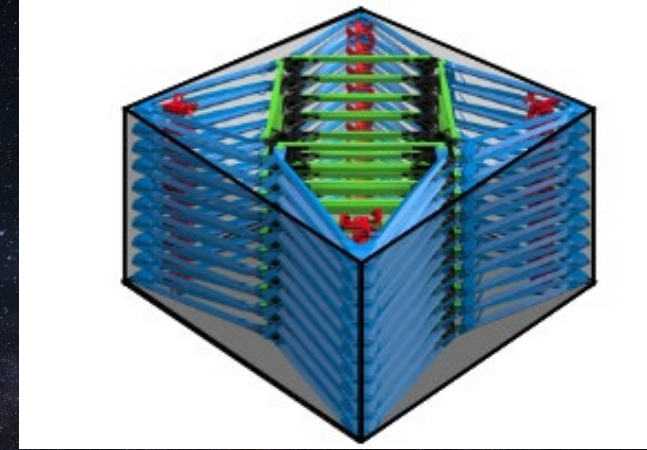
Components 1

Credit: NASA



Voxels: Structural, Routing, or Solar

Credit: NASA

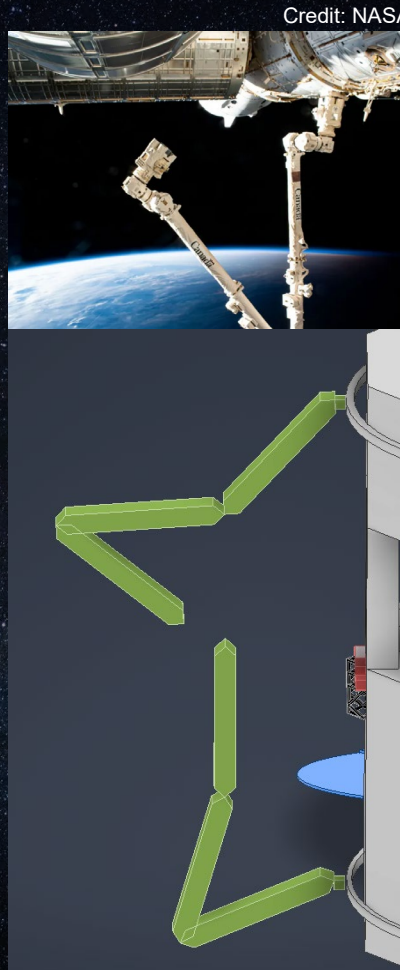


Cassettes

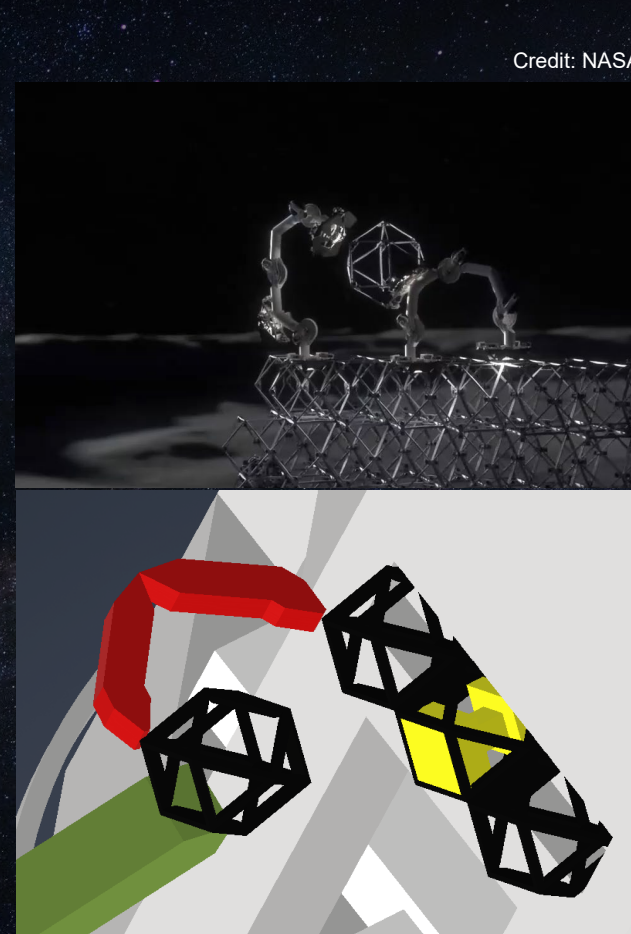
Self-Assembled Science Station

Concept of Operations

Components 2

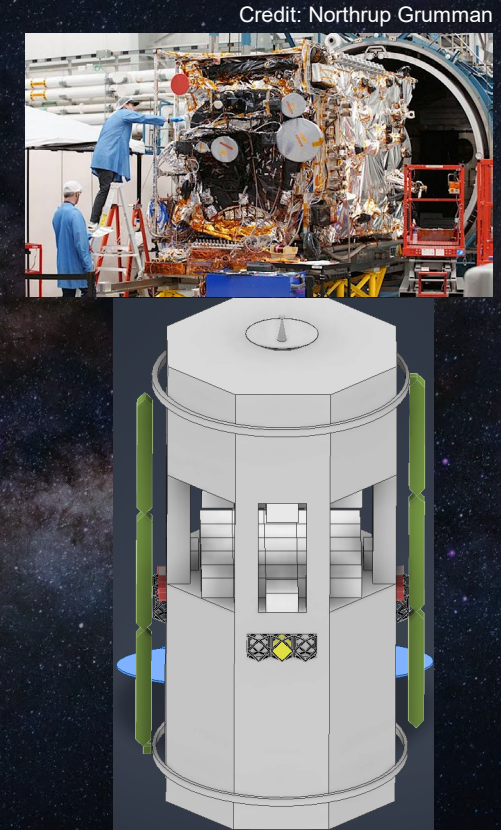


Logistics Arms
(Dual-arm
manipulator)



External
Assembly
Arms

Internal
Assembly
Arms

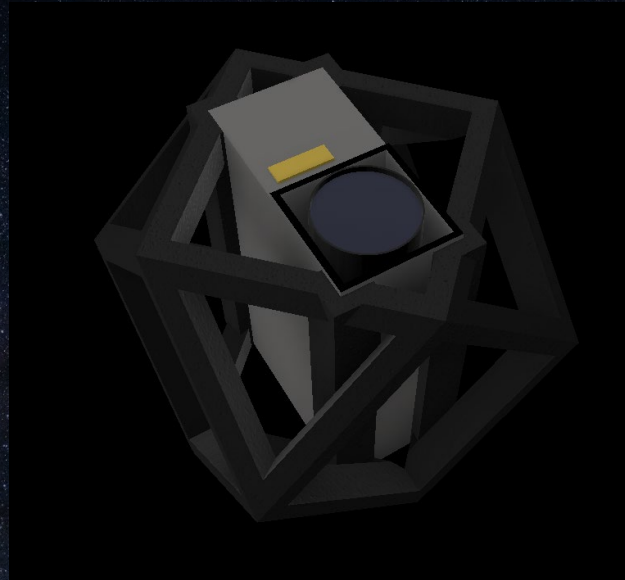


Station Core

Self-Assembled Science Station

Concept of Operations

Components 3



Small Experiments
6U CubeSat sized
6 kg payload
<30 W



Shielded Experiments
12U CubeSat sized
20 kg payload
<60 W

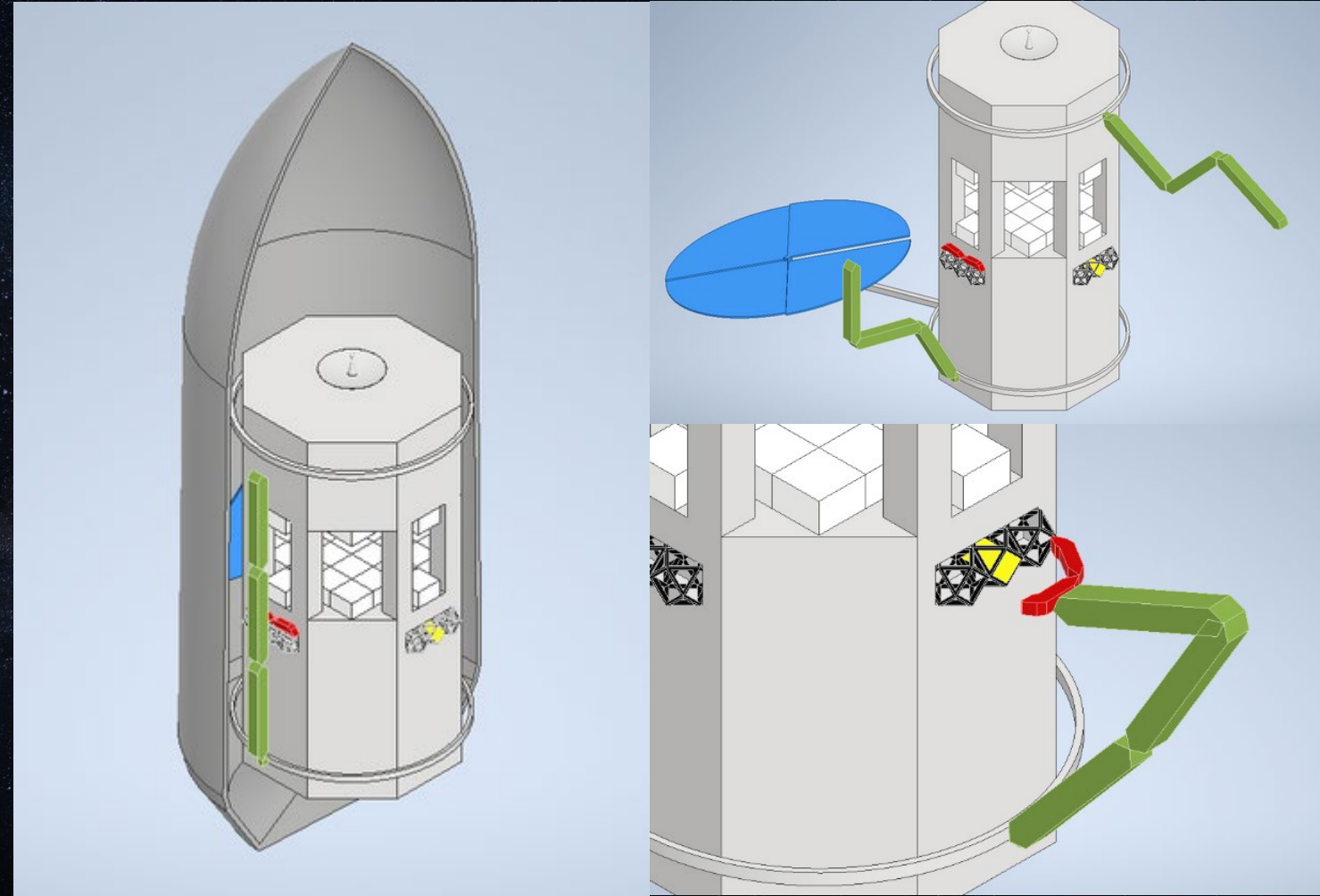


Large Experiments
Arkisys Bosun Locker
(Medium) sized
100 kg payload
<100 W

Concept of Operations

Initial Construction 1

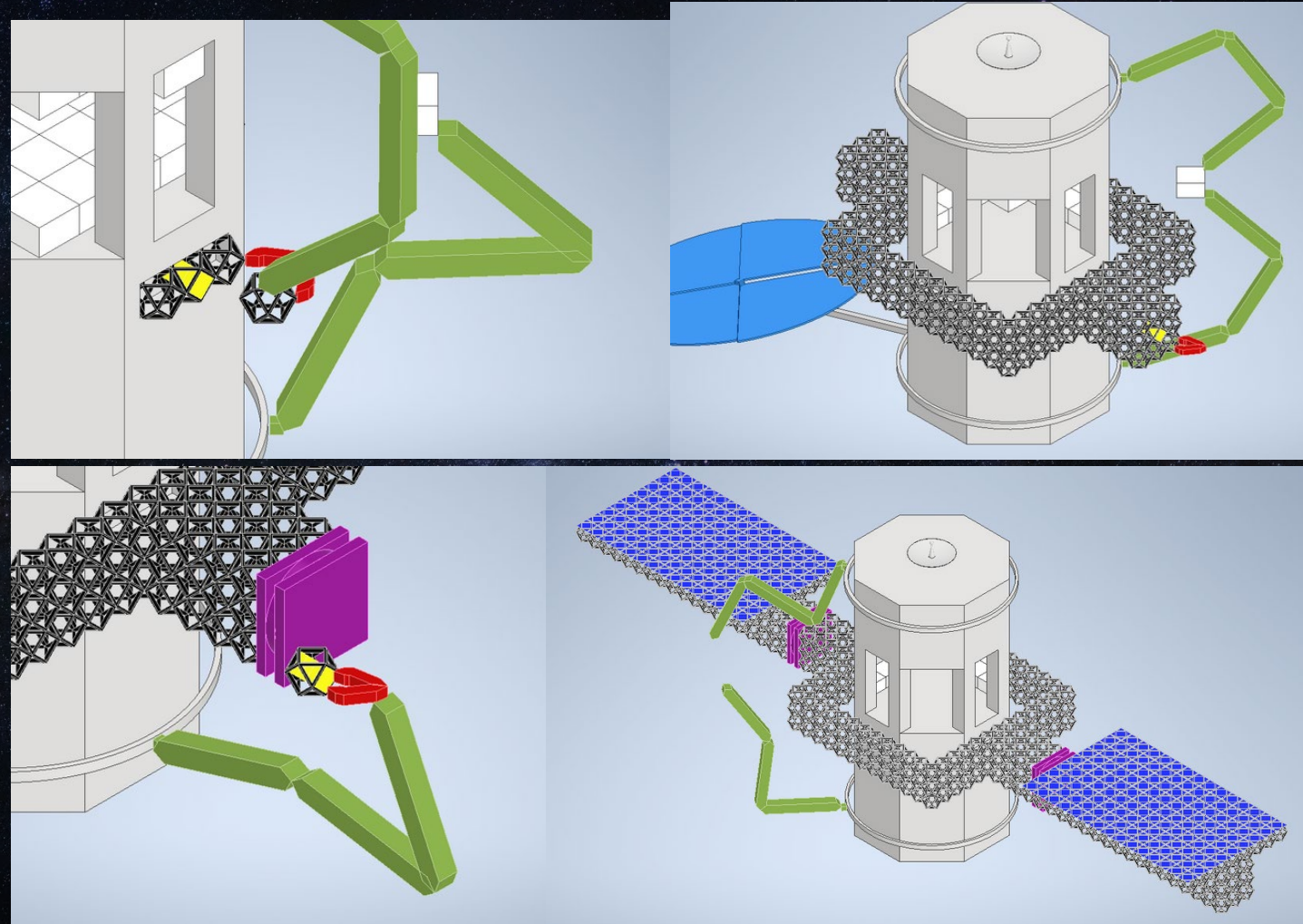
- Initial launch includes all components for the first set of experiments
 - Assume launch aboard reusable Falcon 9 (<4 ton mass)
 - Voxels are folded and packed into "cassettes"
- Temporary solar panel, communications equipment, and dual arm manipulator are deployed (MET 1 hour)
- System reaches GEO, dual arm manipulator deploys first SOLL-E arm (MET 1 week)



Concept of Operations

Initial Construction 2

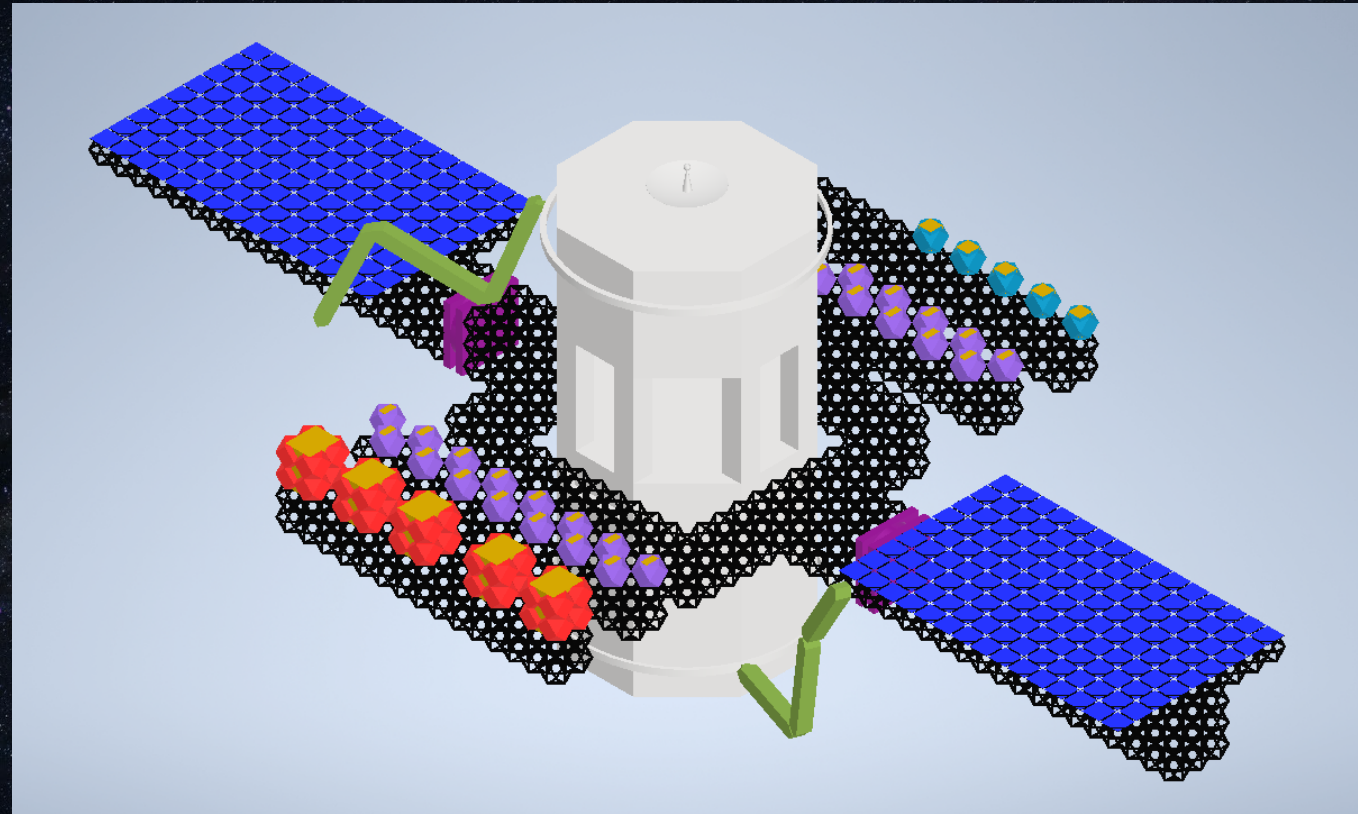
- Dual-arm manipulator removes voxels from cassettes, hands them to SOLL-E arms
 - MMIC-I bots bolt voxels to structure built into core
- The central structure is finished, work begins on solar panels (MET 2 weeks)
 - Rotator joints (purple) for tracking sun
 - Dual-arms move assembly bots
- The solar panels are completed (MET 4 months)
 - Electrical routing will be pre-built into some of the voxels, allowing modular DC and data busses



Concept of Operations

Initial Construction 3

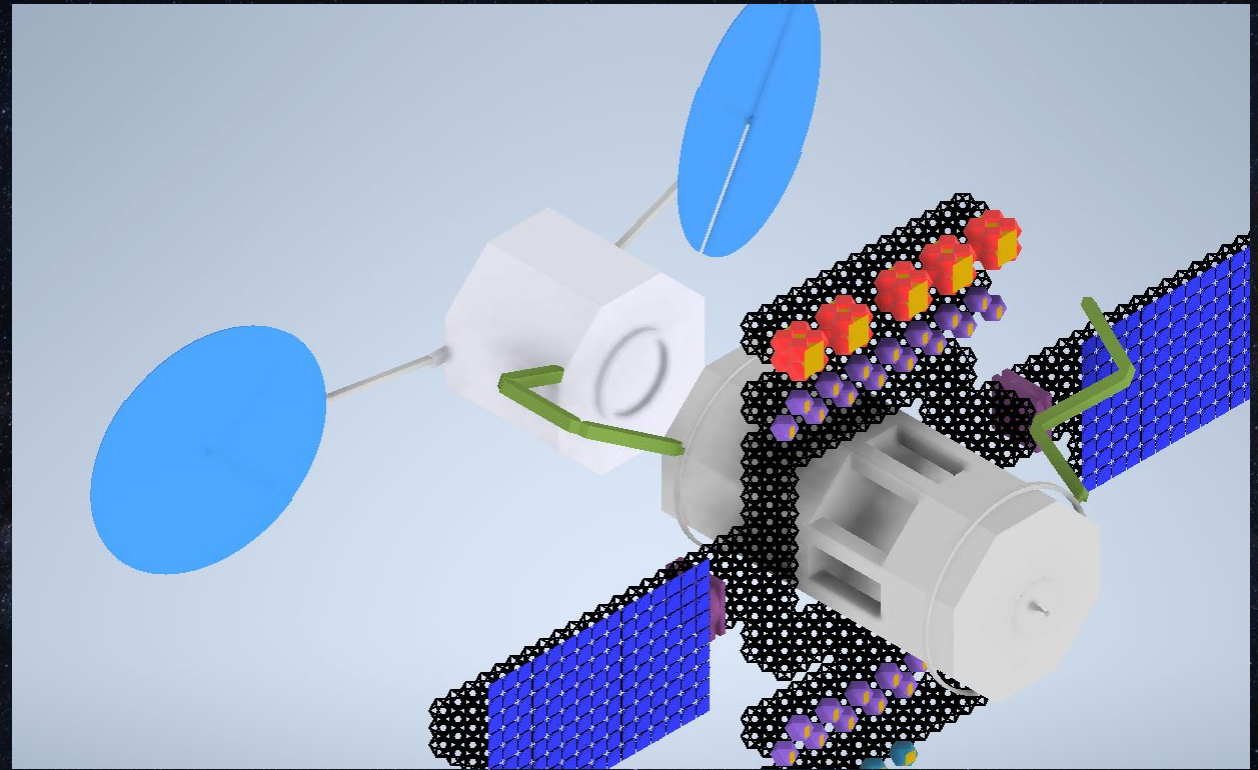
- The structure is finished, experiments are placed on the earth-facing side of the station (MET 5 months)
- After assembly arms are inactive, freeing up power for high-bandwidth communications
- Experiments can be used for radiation studies, Earth observation, or anything else that requires a high-orbit but does not necessitate a free-flying payload.



Concept of Operations

Resupply

- Resupply missions bring station-keeping fuel and new experiments to swap out with old ones
- This allows new customers to use the station while launching a minimal amount to GEO
- Replacement robots and solar panel sections are brought up as needed



Concept of Operations

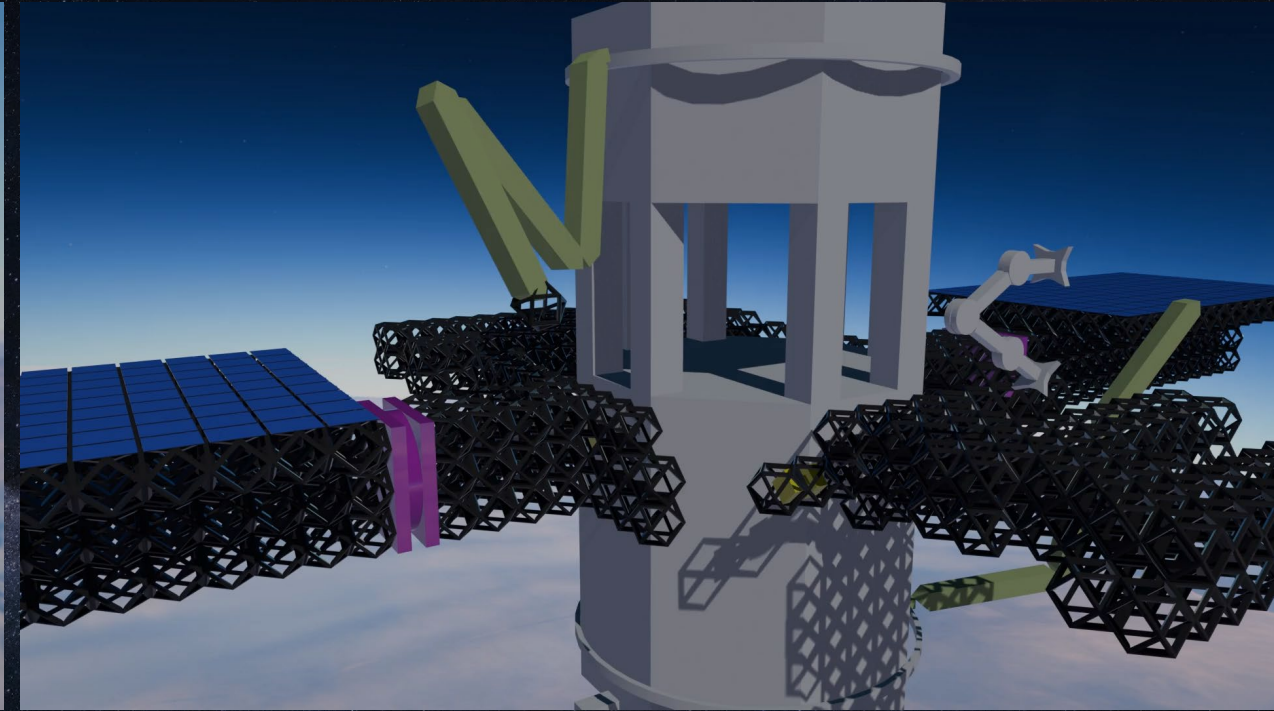
Why Assembly?

- Swapping customer payloads and degraded solar panel sections is built-in to the system architecture
- Potential volume savings, modularity, and risk mitigation strategies vs. deployables
 - More points of failure, but also more options to address failures
- Prepares technology for larger assembly missions which could not be done without assembly

Animation of Assembly and Operation



Animation of assembly



Animation of operation

Impact

Overall Impact

ISAM Impact

Space Research Impact

Autonomous assembly
TRL increases

Directly supports NIIP 2.2.1

Flight qualify ARAMDAS to be a
standard in-space assembly standard
interface (NIIP 2.1.3, 3.1.1, NS 4)

Provides an in-space service to
commercial, academic, and
government clients (NIIP 3.2)

Cost reduction for future
payloads (standard
modularity)

Space infrastructure assembly
standard established for future
facilities

Test bed for rapid technology
validation

Collaboration between commercial,
academic, government, and international
stakeholders for the advancement of
space science

Market replacement for ISS
research facilities

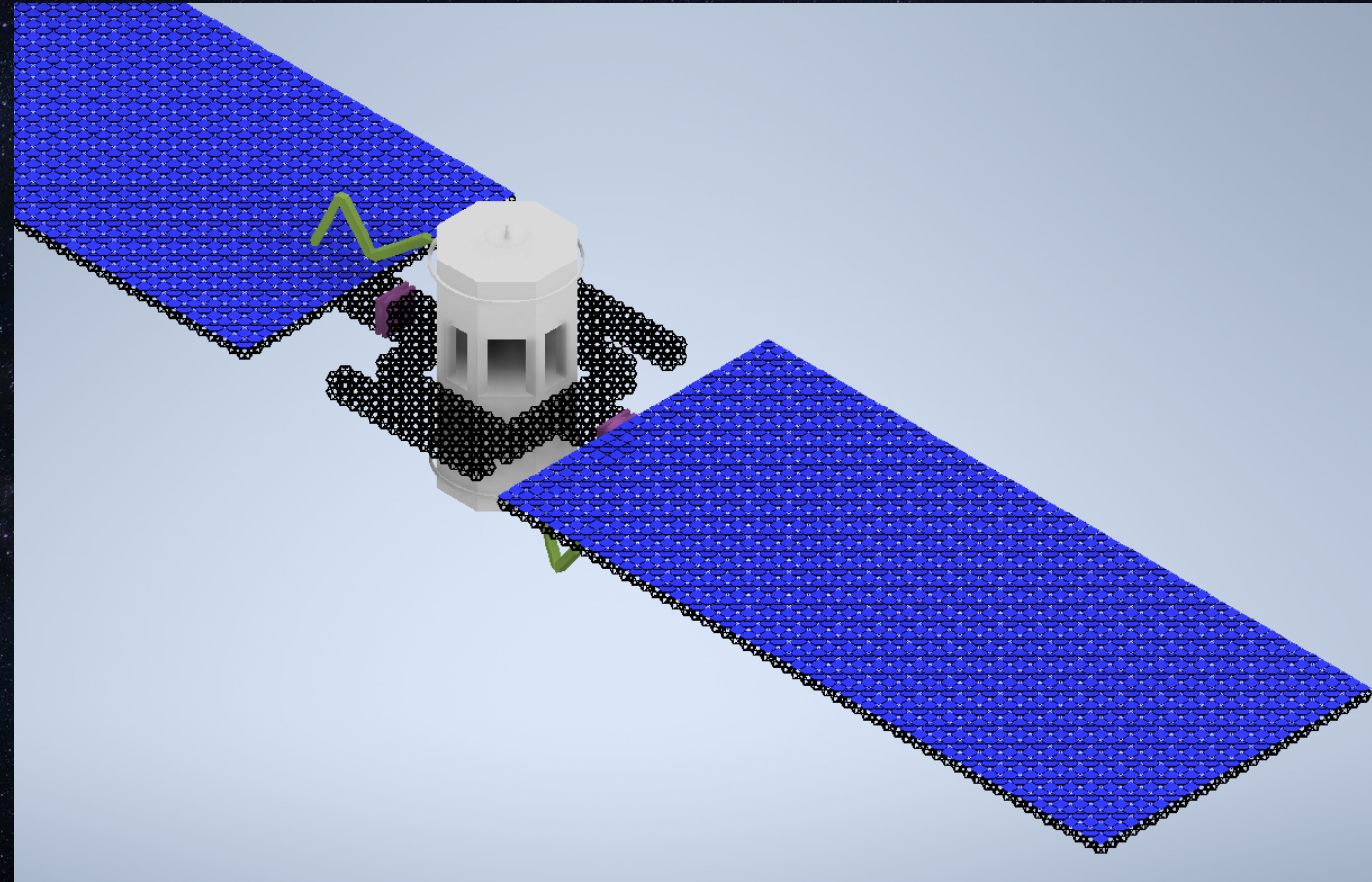
Proposes a use case which fully
characterizes the first
autonomously built persistent
platform (NS 4)

Improve scientific output
(NS 3)

Alternative ConOps

Datacenter Concept

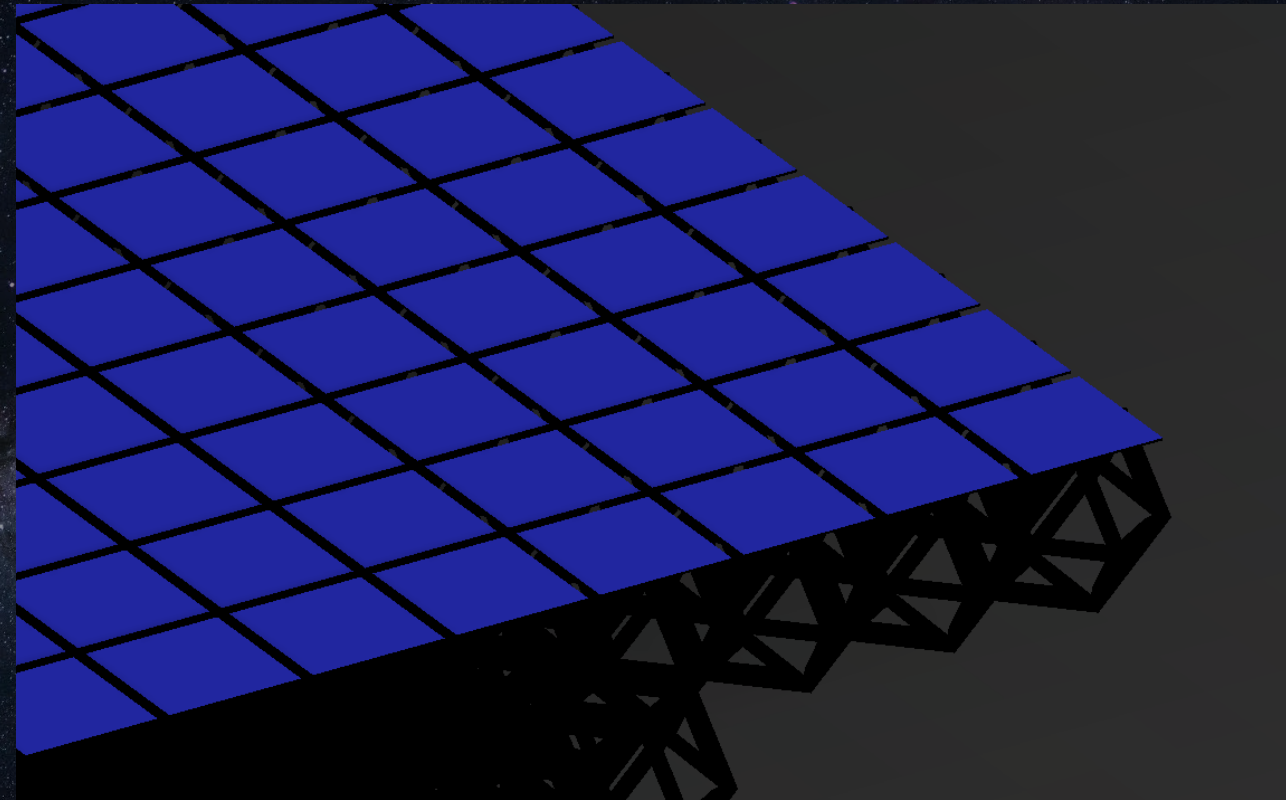
- Google's Project Suncatcher and other studies have proposed datacenters in space. SASS hardware could be directly applied to this application
- Not extensively studied for this project, but a basic analysis done on cost
 - Assume sun-synchronous orbit, industry standard rack power consumption, and high electricity price on the ground
 - At \$400/kg, launching only the solar panel voxels in a configuration like SASS would be more cost effective than paying for ground electricity in 5 years
 - Number of panel voxels needed for one rack pictured



Feasibility

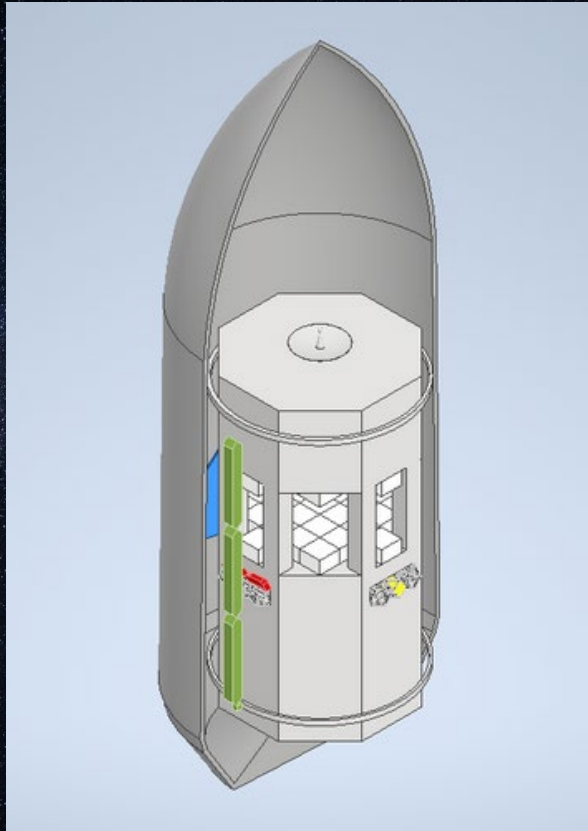
Power and Thermals

- Number of experiments was the driving requirement, number was iterated multiple times to find a workable payload configuration
- Continuous power requirement of 2250 W, drives solar panel requirement of ~3000 W
- Panel voxel requirement of ~140 for direct sunlight, assume ~500 for mass calculations
 - Trim down during path to PDR
- Thermal Calculations use emissivity and absorptivity of white epoxy and have requirement of 16.5 m²
 - Easily accounted for with experiment side panels and core structure surface



Feasibility

Bill of Materials & CAD



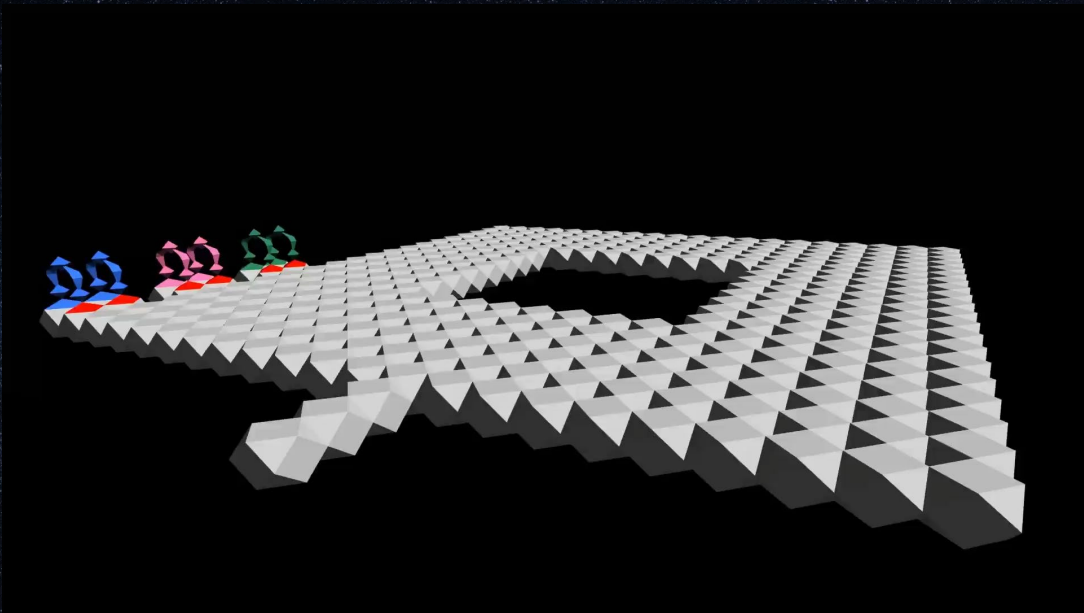
Falcon 9 Payload



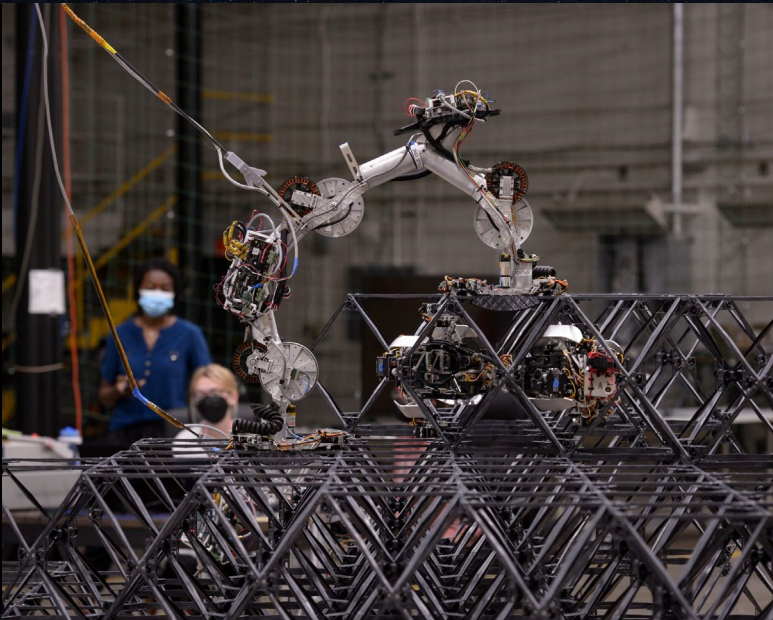
Component # and Description	Mass (kg)	Power (W)	Number
1a. Standard Voxel	0.38	0	200
1b. Power Routing Voxel	0.5	0	100
1c. Solar Panel Voxel	0.55	0	500
2a. Small Experiment Bay	1	0	25
2b. Large Experiment Bay	4.5	0	5
2c. Shielded Experiment Bay	4	0	3
3a. Small Experiment	6	30	25
3b. Large Experiment	100	100	5
3c. Shielded Experiment	20	60	3
4. Voxel Cassettes	5	0	80
5. Logistics Arms (Dual Arm Manipulator)	300	250	2
6. External Assembly Arms	5	20	2
7. Internal Assembly Arms	3.5	5	2
8. Prop and Avionics (and docking) Module	1000	100	1
9. Comms and Power Module	300	150	1
10. Solar Panel Joints	30	10	2
	Mass (kg)	Power (W)	
Total for Mission 1	3547.5	2250	

Feasibility

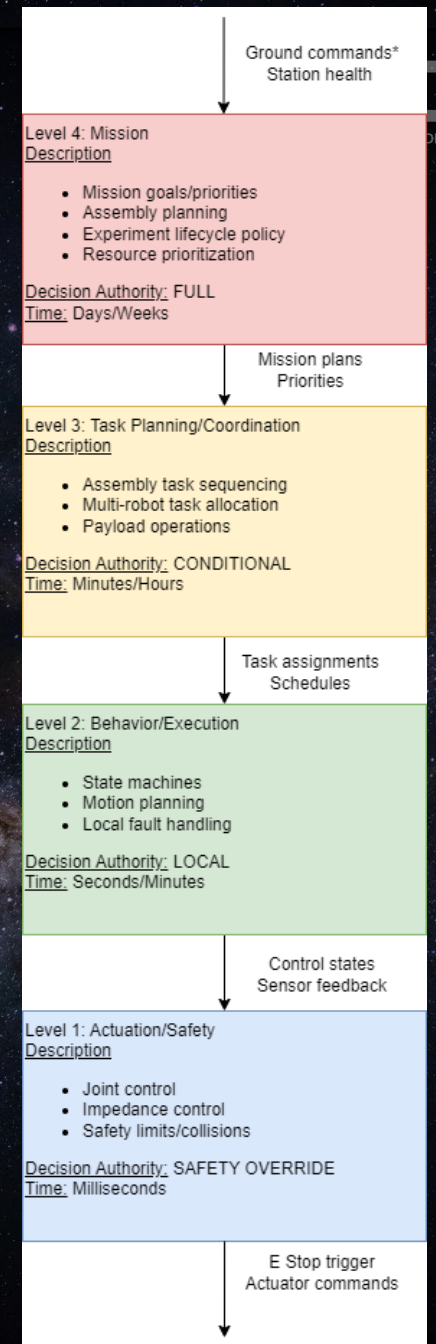
Autonomy



Credit: <https://doi.org/10.1126/scirobotics.adi2746>



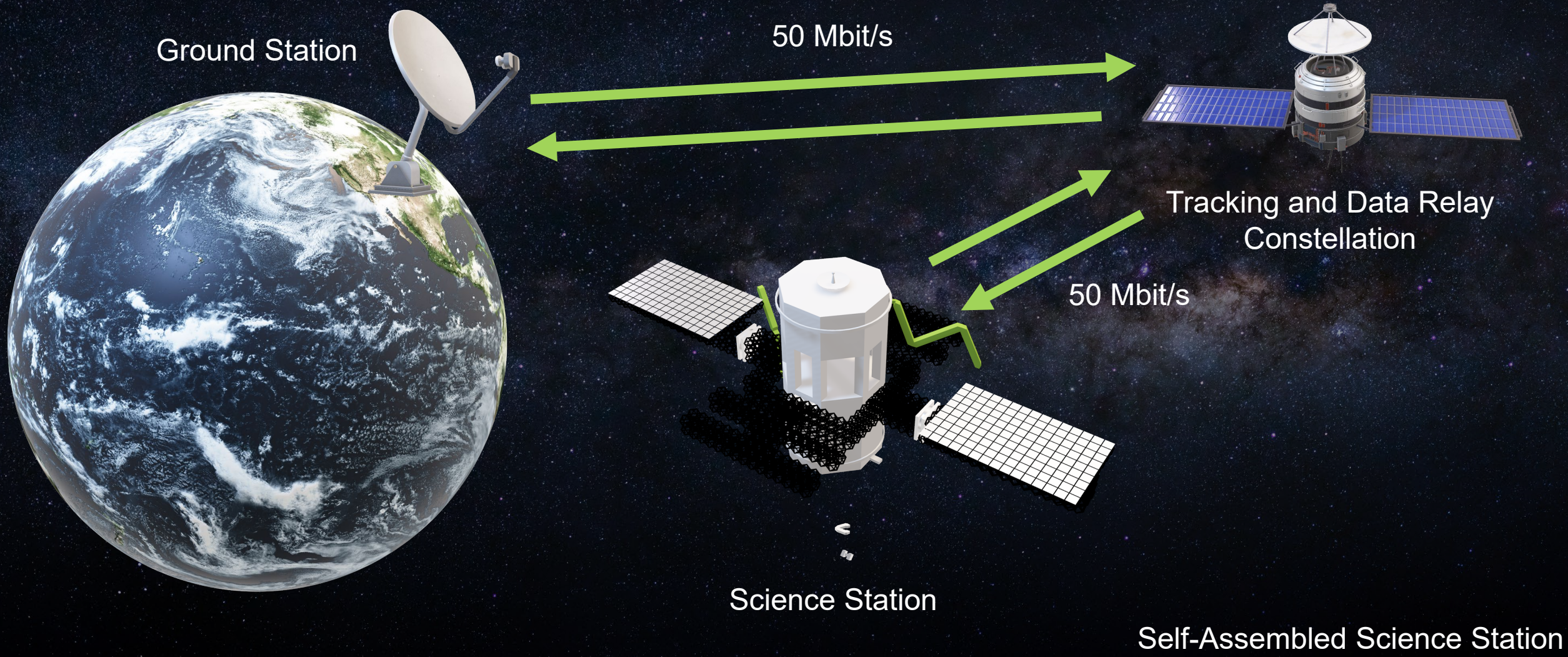
Credit: NASA/Dominic Hart



SASS is an exciting use-case for ARMADAS

Self-Assembled Science Station

Data Handling and Comms



Risks

5	9d.1, 9e.1				
4		<u>S1.3</u> , <u>S3.1</u>	<u>S1.2</u>	9b.1	
3	7d.1, 7e.1		7a.2, 7b.2, 8b.1	<u>S1.1</u> , <u>S4.1</u> , <u>S6.1</u> , <u>S7.1</u> , 6a.2, 6b.2, 7a.1, 7b.1	
2	7c.1, 8a.1	<u>S2.1</u> , <u>S5.1</u>	9b.2, 9c.1	<u>S4.2</u>	
1		<u>S5.2</u> , <u>S10.1</u>	<u>S10.2</u> , 6a.1, 6b.1		2.1, 3.1
	1	2	3	4	5

Consequence

Before Mitigation

- Schedule/cost risks (S...) and technical risks.
- Schedule risk mitigation strategies:
 - 1: Analysis prior to PDR design
 - 2: Prototyping prior to PDR design
- Technical risk mitigation strategies:
 - 3: Latch detection (joint/latch level)
 - 4: Runtime evaluation/replace early
 - 5: Robot deployables assistance

5					
4	<u>S1.3</u> , <u>S3.1</u>	<u>S1.2</u> , 9b.2			
3	6a.1, 6b.1, 7d.1, 7e.1, 9d.1, 9e.1	<u>S4.1</u> , <u>S6.1</u> , <u>S7.1</u>	<u>S1.1</u>		
2	7c.1, 8a.1	<u>S2.1</u> , <u>S4.2</u> , <u>S5.1</u>	7a.2, 7b.2, 8b.1, 9c.1	9b.1	
1		<u>S5.2</u> , <u>S10.1</u> , 2a.1, 3a.1	<u>S10.2</u>	6a.2, 6b.2, 7a.1, 7b.1, 9a.1	
	1	2	3	4	5

Consequence

After Mitigation

Risks

5	9d.1, 9e.1				
4		<u>S1.3</u> , <u>S3.1</u>	<u>S1.2</u>	9b.1	
3	7d.1, 7e.1		7a.2, 7b.2, 8b.1	<u>S1.1</u> , <u>S4.1</u> , <u>S6.1</u> , <u>S7.1</u> , 6a.2, 6b.2, 7a.1, 7b.1	
2	7c.1, 8a.1	<u>S2.1</u> , <u>S5.1</u>	9b.2, 9c.1	<u>S4.2</u>	
1		<u>S5.2</u> , <u>S10.1</u>	<u>S10.2</u> , 6a.1, 6b.1		2.1, 3.1
	1	2	3	4	5

Before Mitigation

- Example Risks:
- S1.2: Power and data routing voxels require unexpected amount of development (Mitigation: 2)
- 9b.1: Dual-arm manipulator damages cassette during voxel removal (Mitigation: 4)
- 7a.1: SOLL-E arm fails to latch to voxel properly, fault is not detected immediately (Mitigation: 3)

5					
4	<u>S1.3</u> , <u>S3.1</u>	<u>S1.2</u> , 9b.2			
3	6a.1, 6b.1, 7d.1, 7e.1, 9d.1, 9e.1	<u>S4.1</u> , <u>S6.1</u> , <u>S7.1</u>	<u>S1.1</u>		
2	7c.1, 8a.1	<u>S2.1</u> , <u>S4.2</u> , <u>S5.1</u>	7a.2, 7b.2, 8b.1, 9c.1	9b.1	
1		<u>S5.2</u> , <u>S10.1</u> , 2a.1, 3a.1	<u>S10.2</u>	6a.2, 6b.2, 7a.1, 7b.1, 9a.1	
	1	2	3	4	5

After Mitigation

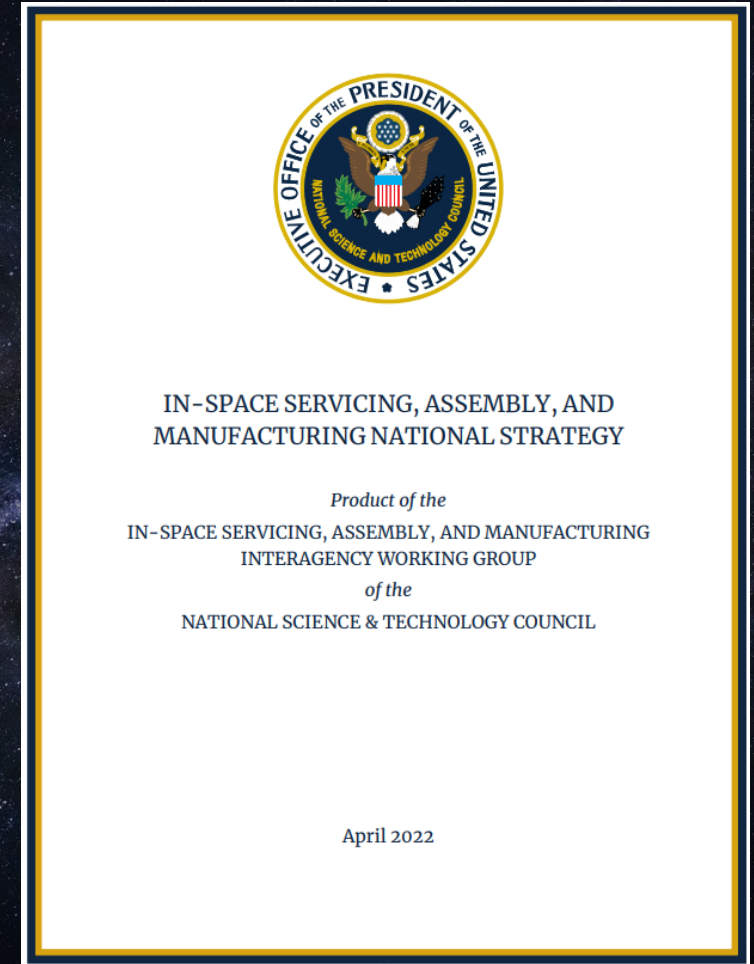
Technology Gaps

- Robot coordination:
 - Internal and external assembly robots collaborate with the dual-arms
 - Automated path planning and robust verification at each step
- Smart decision-making for attitude correction under robot movement
 - Correcting every small movement would be overwhelming
 - Sensitive experimental payloads used for Earth observation
- Modular data and power transfer between voxels
 - Pulling wires is impractical for this many power sources and sinks

Advancing High Value Missions

The Self-Assembled Science Station advances multiple missions objectives outlined by COSMIC and the Federal government.

1. Providing in-space services
2. Flight qualifying ISAM hardware
3. Developing autonomous space technology
4. Improving national scientific output



Most Innovative Concepts Considered

- Shorter crawling arms vs. dual arm rail system
 - Pro: Increased modularity, logistics operations can happen anywhere on the station
 - Con: Large torque/force on voxels, increased autonomy complexity
 - Rails are already proven with large manipulator arms (CANADARM)
- Permanent experiment-holding voxels vs experiments pre-built into voxels
 - Swapping cubesat-format experiments into bays would decrease cost/mass of each experiment
 - All robots are already made to handle voxels, un-voxeled experiments would require extra manipulators
- Studying the volume-savings of origami-folding voxels demonstrates how useful they could be in building smaller space structures
 - Assembling voxels from their basic parts (which could be packed tighter) is impractical for the SASS robots

Biggest Challenges Encountered

Three Biggest Challenges:

- 1. Scope and Goals:** Determining output has been a constant struggle. Most of us work day-to-day on low level technical challenges, we found scoping out a high-level concept difficult.
Suggestion: Determine scope and goal as first step after picking a basic concept.
- 2. Motivation and Commitment:** This has been an exciting change-of-pace from other research activities. Discussing concepts, performing informal trade studies, and sizing our architecture were easily self-motivated. With other commitments, it was difficult to prioritize the detailed work on this project.
Suggestion: It makes sense that this is a capstone competition mostly designed for a class setting, but we had fun and appreciate the opportunity.
- 3. ARMADAS Specifications:** ARMADAS is an active research concept, not a specification. There are several concepts for voxels, and it was difficult to parse what level of development each concept was in.
Suggestion: A disambiguation hub for ARMADAS and other NASA assembly projects.

2.3 Path to PDR



Paper



Our paper "Automated Construction of an Unmanned Scientific Space Platform" is planned to be sent as an extended abstract to SciTech 2027.

Automated Construction of an Unmanned Scientific Space Platform

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University of Cincinnati, Cincinnati, OH, 45221

With the planned decommission of the International Space Station (ISS) scheduled to occur in approximately five years, academic institutions and industrial companies are about to lose one of the only testing facilities that currently exists in outer space. The experiments previously sent up to the ISS have helped increase scientific understanding of how objects interact differently in space conditions compared to normal atmospheric conditions on the Earth's surface. With the resurgence of the focus on space settlement, a new experimental platform would greatly aid humanity in its attempt to live out in space. This paper explores the autonomous construction of a theoretical unmanned space station that would focus on replacing the ISS's scientific capabilities.

I. Nomenclature

A	=	Hub surface area
α_x	=	Absorptivity of surface x
DOD	=	Depth of discharge
ϵ_x	=	Emissivity of surface x
K	=	Trailing-edge (TE) non-dimensional angular deflection rate
P_e	=	Average eclipse load
n	=	Battery to load transmission efficiency
N	=	Number of batteries
\dot{q}	=	Power generated by the hub
q_x	=	Radiation from source x
σ	=	Stefan-Boltzmann constant
T	=	Temperature
T_e	=	Time of eclipse

II. Introduction

The International Space Station is the largest human-made structure ever assembled in orbit and the most complex multi-national engineering project in history [1]. Construction began in November 1998 with the launch of the Russian *Zarya* and continued over more than a decade, culminating in the final configuration's completion in 2011. In total, the station comprises more than 100 major components delivered across approximately 40 assembly flights the Space Shuttle, Soyuz, Progress, and later commercial flights.

Operationally, the ISS has supported a continuous human presence since November 2000 and currently accommodates rotating crews of astronauts serving expeditions of less than a year. The station hosts a diverse portfolio of scientific investigations spanning microgravity biology, materials science, combustion physics, Earth remote sensing, and

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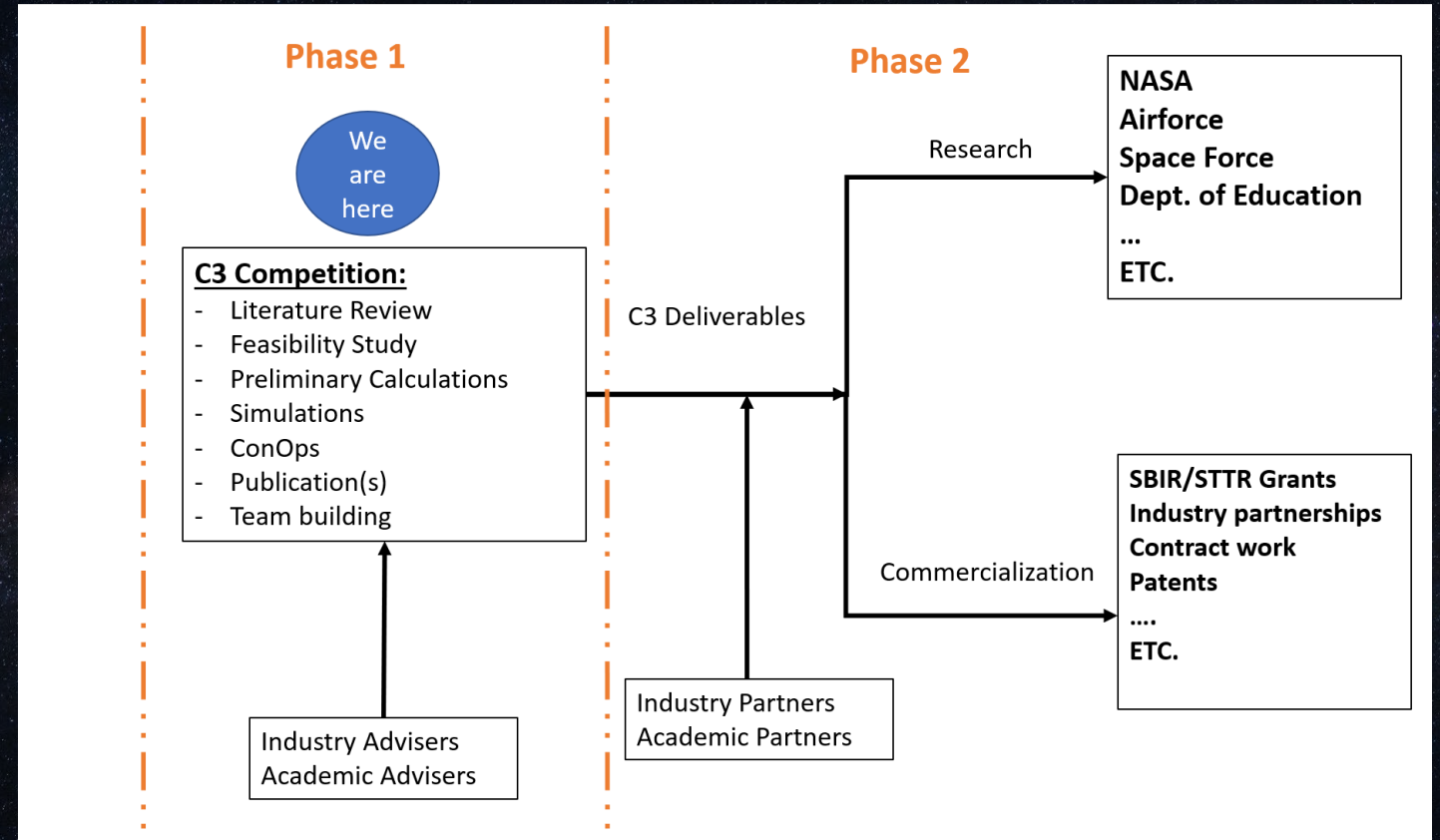
^{||}Graduate Research Assistant, Aerospace Engineering and Engineering Mechanics, IRAS Lab, University of Cincinnati

**Graduate Research Assistant, Aerospace Engineering and Engineering Mechanics, IRAS Lab, University of Cincinnati

^{††}Graduate Research Assistant, Aerospace Engineering and Engineering Mechanics, IRAS Lab, University of Cincinnati

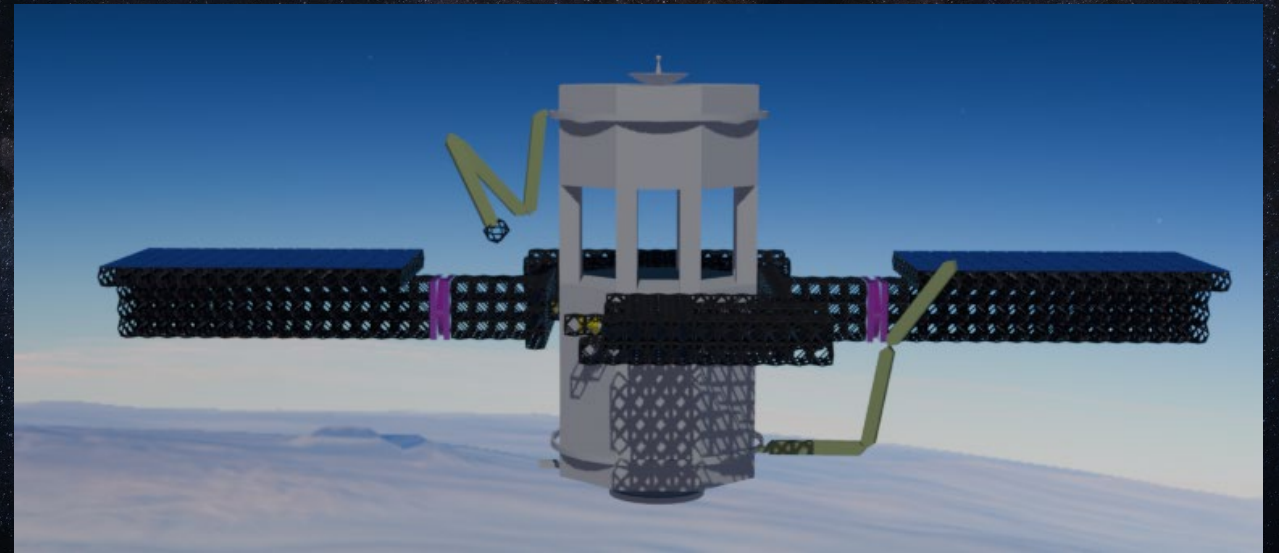
Future Work

1. Simulate momentum canceling and stabilization techniques to account for robot agents and dual arm rail system motion.
2. Design a foldable Voxel with data and power transfer capability.
3. Compete for federally/commercially funded research and advance ISAM concept/capabilities.



Conclusion

- The team has evaluated a mission which has a constrained budget while still raising the TRL of several key components. The mission would demonstrate the power of assembled structures in space, while simultaneously addressing a clear, present, and marketable need.
- The team has identified challenges and risks which require further study.



Questions



Questions?

Backup Slides

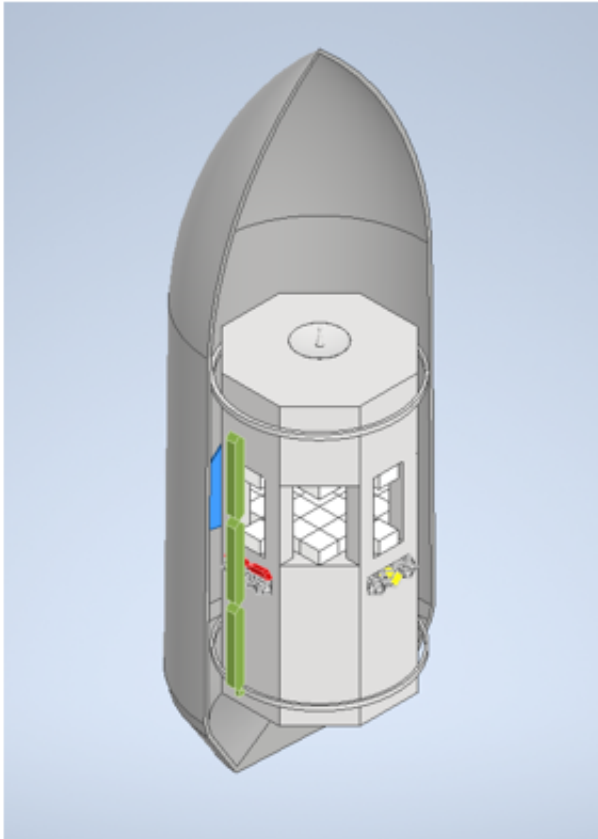
Component # and Description
1a. Standard Voxel
1b. Power Routing Voxel
1c. Solar Panel Voxel
2a. Small Experiment Bay
2b. Large Experiment Bay
2c. Shielded Experiment Bay
3a. Small Experiment
3b. Large Experiment
3c. Shielded Experiment
4. Voxel Cassettes
5. Logistics Arms (Dual Arm Manipulator)
6. External Assembly Arms
7. Internal Assembly Arms
8. Prop and Avionics (and docking) Module
9. Comms and Power Module
10. Solar Panel Joints

Action # and Description
1. Main Structure Launch
2. Temporary Solar Panel Deployment
3. Basic Command Antenna Deployment
4. Whole Station Orbital Maneuver
5. Dual Arm Manipulator Activation
6a. Dual Arm Grasps and Moves External Arm
6b. Dual Arm Releases External Arm
7a. External Arm Attaches to Voxel
7b. External Arm Detaches from Voxel
7c. External Arm Moves on Voxel Grid
7d. External Arm Places Voxel for Assembly
7e. External Arm Removes Voxel from External Arm Backpack
8a. Interior Arm Moves on Voxel Grid
8b. Interior Arm Connects Voxel to Grid
8c. Interior Arm Connects Rotator to Grid
9a. Dual Arm Grasps and Moves Cassette
9b. Dual Arm Removes One Voxel from Cassette
9c. Dual Arm Moves Voxel
9d. Dual Arm Hands Voxel to External Arm

9e. Dual Arm Places Voxel in External Arm Backpack

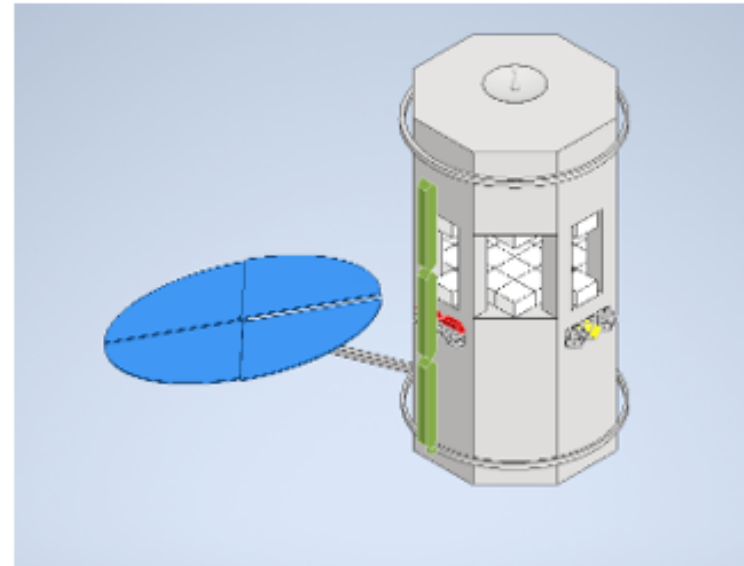
10. Dual Arm Grasps and Moves Rotator

- 1: Assembly
 - 1a: Launch and transfer
 - 1a1: Launch
 - Involves: **All Components** (except Resupply Vehicle)
 - Actions **1.** (Launch)



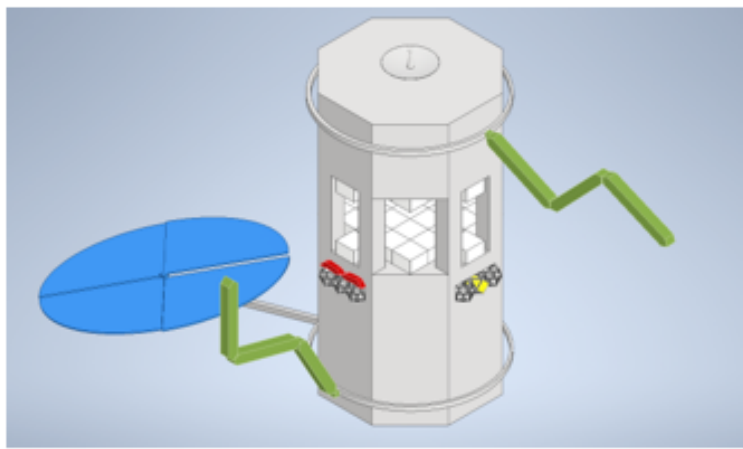
Action 1.

- 1a2: Temporary Solar Panel Deployment and basic command antenna deployment
 - Involves: Component **8.** and **9.** (Prop, Avionics, Comms, Power)
 - Actions: **2.** (TSP Deploy), **3.** (BCA Deploy)

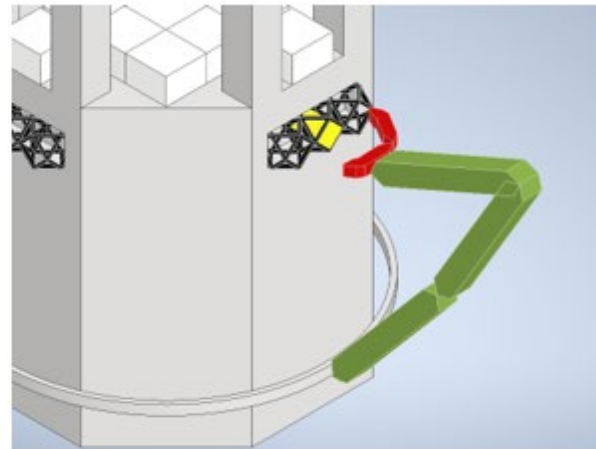


Action 2., 3.

- 1a3: Transfer
 - Involves: Component **9.** (Prop)
 - Actions: **4.** (Orbital Maneuver)
- 1a4: Correction
 - Involves: Component **9.** (Prop)
 - Actions: **4.** (Orbital Maneuver)
- 1b: Central structure construction
 - 1b1: Dual Arm Manipulator Unpacking and Activation
 - Involves: Component **5.** (Dual Arm)
 - Actions: **5.** (Dual Arm Activate)



Action 5.



Action 6a. (2), 6b., 7a.

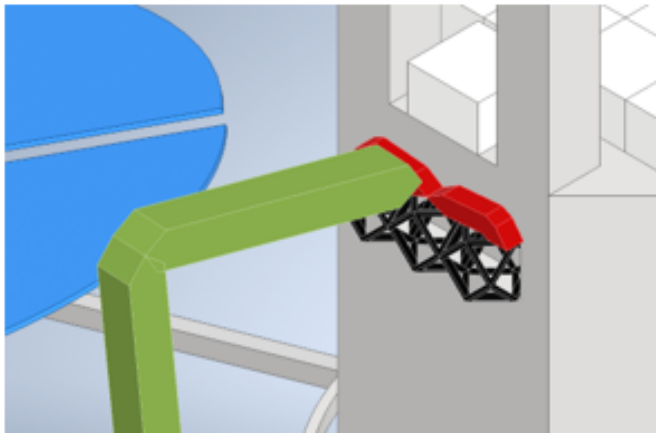
▪ 1b2: Exterior Assembly Robot Placement and Activation

- Involves: Component **5.** (Dual Arm), **6.** (External Arm), **9.** (Prop Module), **1.** (Voxel)
- Actions: **6a.** (Dual Arm Grasps and Moves External Arm), **6b.** (Dual Arm Releases External Arm), **7a.** (External Arm Connects/disconnects to voxels)

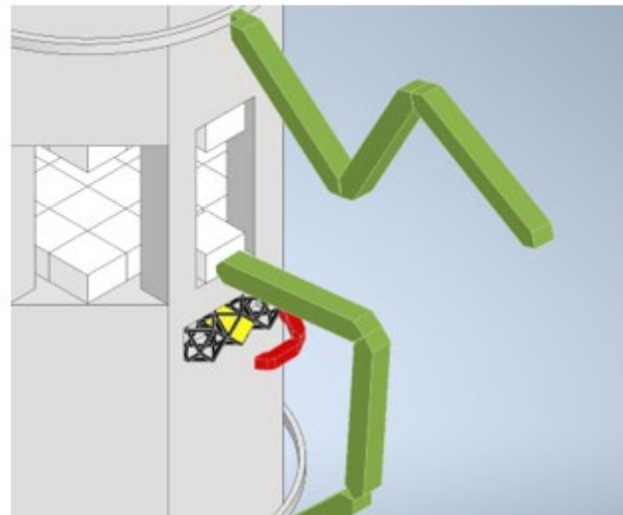
1b2 is repeated.

▪ 1b3: First Voxel Unpacking

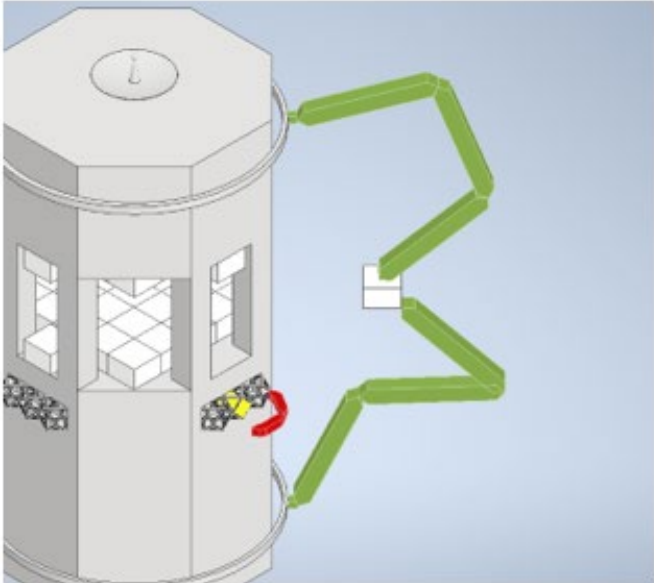
- Involves: Component **5.** (Dual Arm), **4.** (Voxel Cassette), **1.** (Voxel)
- Actions: **9a.** (Grasp Cassette), **9b.** (Remove Voxel from Cassette)



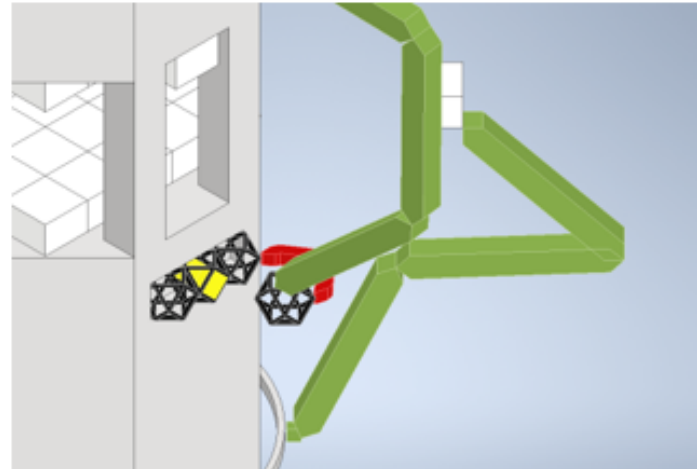
Action 6a. (1)



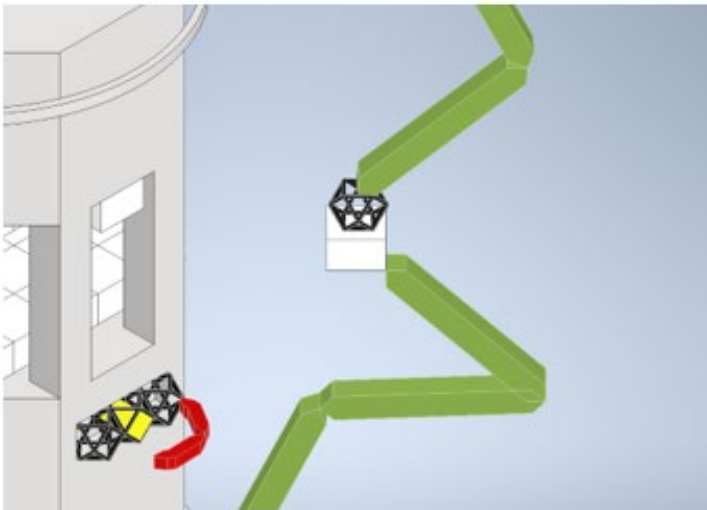
Action 9a. (1)



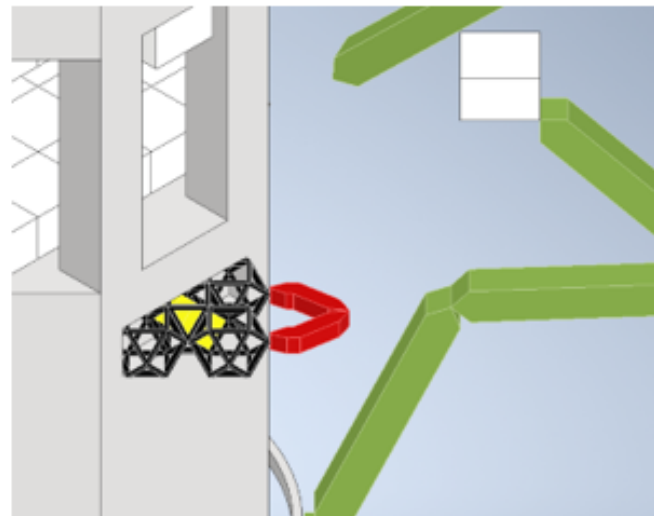
Action 9a. (2)



Action 9c., 9d.



Action 9b.



Action 7d., 8b.

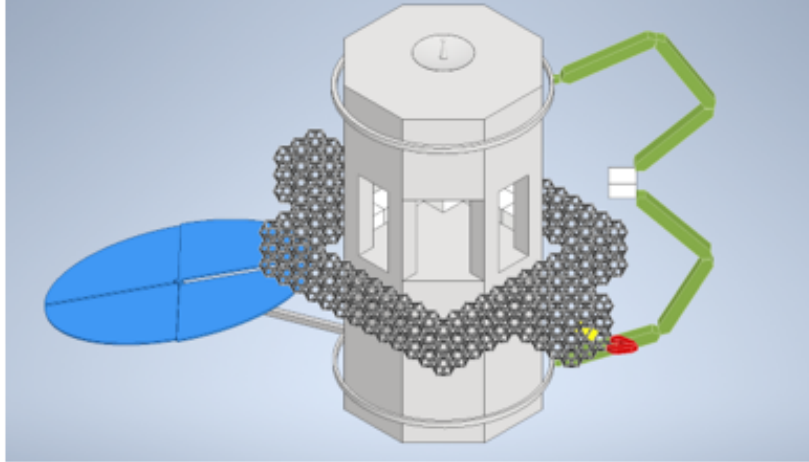
- Actions: **9c.** (Move Voxel), **9d.** (Hand Voxel to External Assembly), **7d.** (External Assembly Place Voxel), **8b.** (Internal Assembly Connect Voxel)

1b3 and 1b4 are repeated for other side.

- 1b4: Voxel Placement
 - Involves: Component 5. (Dual Arm), 1. (Voxel), 6. (External Assembly), 7. (Internal Assembly), 9. (Prop)

- 1b5: Subsequent Voxel Placement
 - Involves: Component 5. (Dual Arm), 1. (Voxel), 4. (Voxel Cassette), 6. (External Assembly), 7. (Internal Assembly), 9. (Prop)

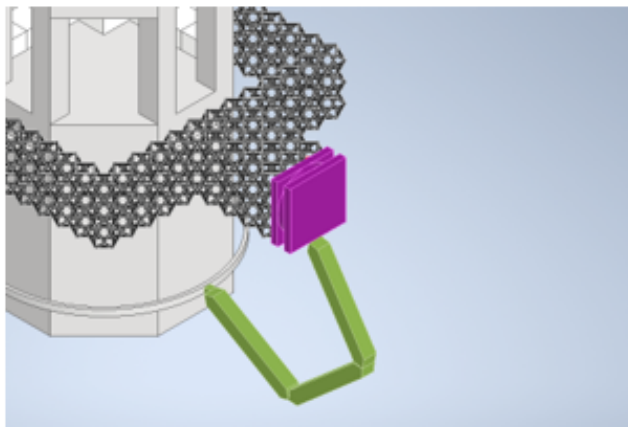
- Actions: **9a.** (Grasp Cassette), **9b.** (Remove Voxel from Cassette), **9c.** (Move Voxel), **9d.** (Hand Voxel to External Assembly), **7d.** (External Assembly Place Voxel), **8b.** (Internal Assembly Connect Voxel), **8a.** (Internal Assembly Move)



o 1c: Solar panel construction

▪ 1c1: Rotator Placement

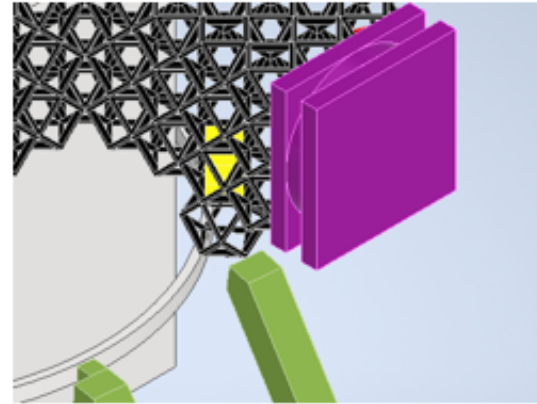
- Involves: Component **5.** (Dual Arm), **10.** (SP Joints), **1.** (Voxel), **7.** (Internal Assembly)
- Actions: **10.** (Dual Arm Moves Rotator), **8c.** (Interior Arm Connects Voxel to Grid)



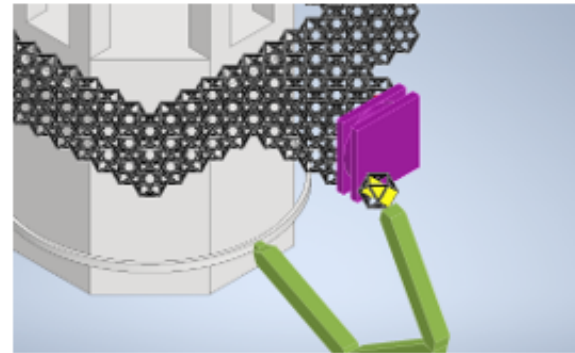
Actions: **10.**, **8c.**

▪ 1c2: Internal Assembly Placement on Solar Panel

- Involves: Component **5.** (Dual Arm), **1.** (Voxel), **7.** (Internal Assembly)
- Actions: **9c.** (Dual Arm Moves Voxel), **8a.** (Interior Arm Moves on Voxel Grid), **8c.** (Interior Arm Connects Rotator to Grid)



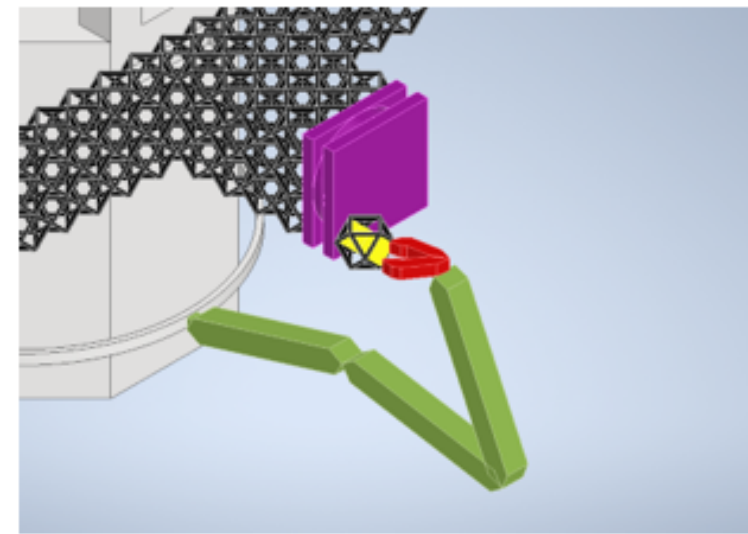
Actions: **9c.**



Actions: **8a.**, **9c.**, **8c.**

▪ 1c3: External Assembly Placement on Solar Panel

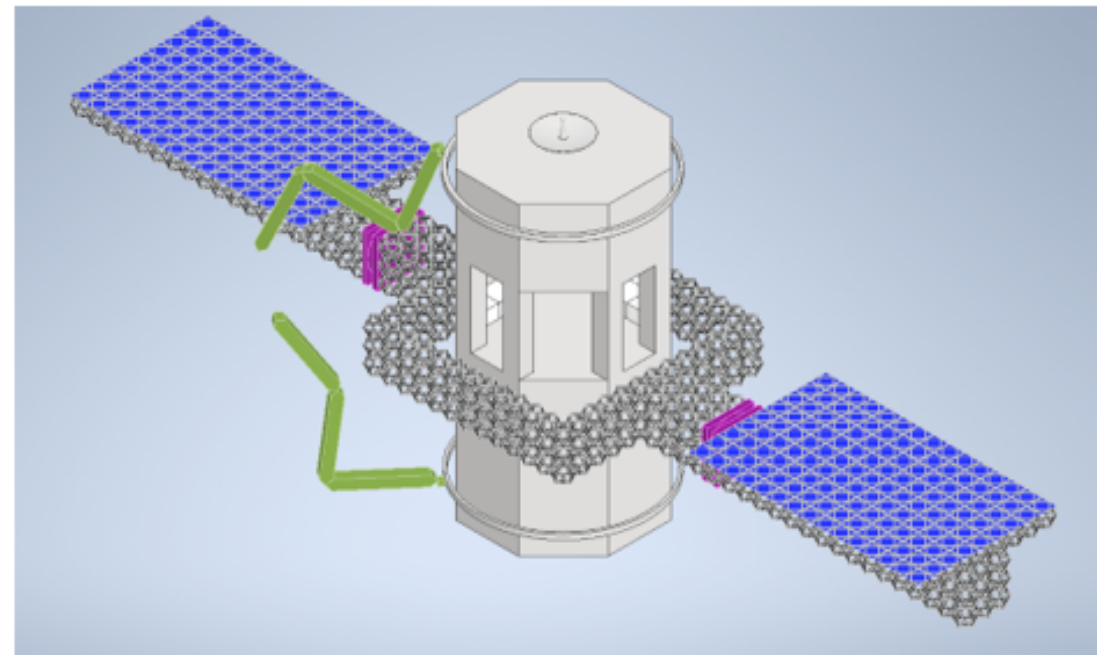
- Involves: Component **5.** (Dual Arm), **6.** (External Arm), **1.** (Voxel)
- Actions: **6a.** (Dual Arm Grasps and Moves External Arm), **6b.** (Dual Arm Releases External Arm), **7a.** (External Arm Connects/disconnects to voxels)



Actions: **6a.**, **6b.**, **7a.**

1c4: Subsequent Solar Panel Construction

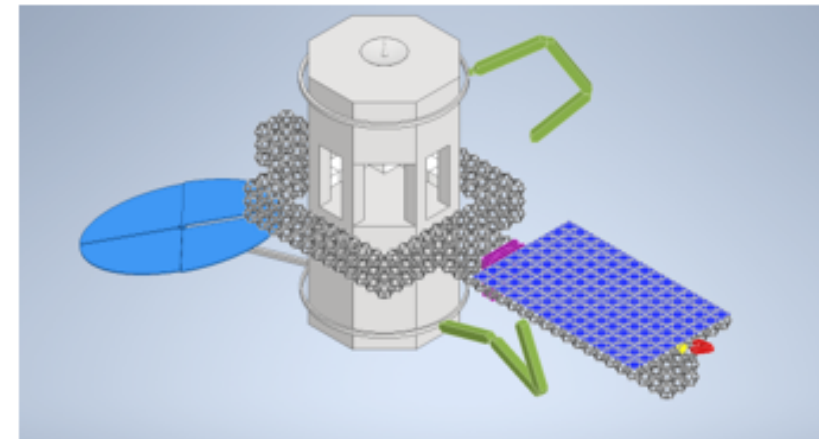
- Involves: Component **5.** (Dual Arm), **1.** (Voxel), **4.** (Voxel Cassette), **6.** (External Assembly), **7.** (Internal Assembly), **9.** (Prop)
- Actions: **9a.** (Grasp Cassette), **9b.** (Remove Voxel from Cassette), **9c.** (Move Voxel), **9d.** (Hand Voxel to External Assembly), **7d.** (External Assembly Place Voxel), **8b.** (Internal Assembly Connect Voxel), **8a.** (Internal Assembly Move)



1d: Experiment bay construction

1d1: Experiment Structure Construction

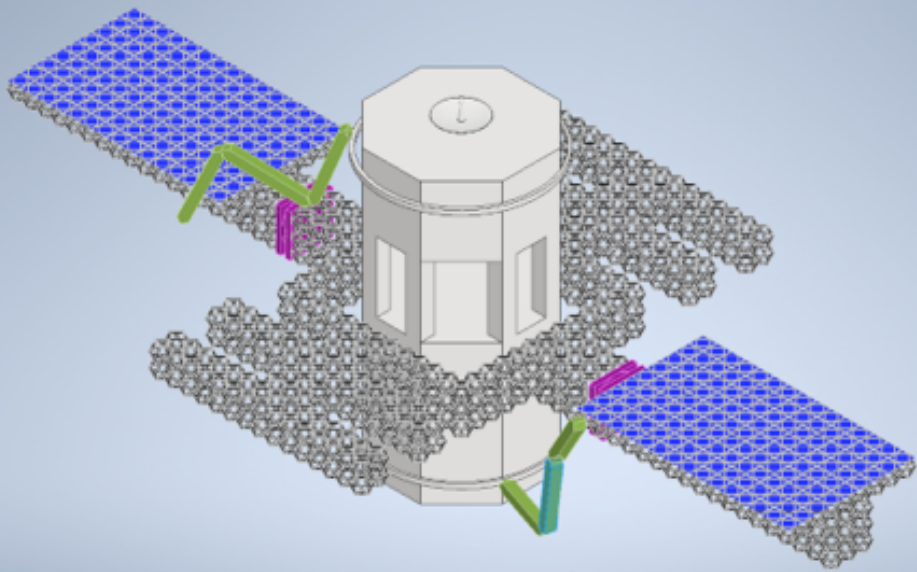
- Involves: Component **5.** (Dual Arm), **1.** (Voxel), **4.** (Voxel Cassette), **6.** (External Assembly), **7.** (Internal Assembly), **9.** (Prop)
- Actions: **9a.** (Grasp Cassette), **9b.** (Remove Voxel from Cassette), **9c.** (Move Voxel), **9d.** (Hand Voxel to External Assembly), **7d.** (External Assembly Place Voxel), **8b.** (Internal Assembly Connect Voxel), **8a.** (Internal Assembly Move)



REPEAT FOR OTHER SIDE, DEACTIVATE TEMPORARY SOLAR PANEL (Not sure what this will look like, do we just fold it back up? Can we fold it up? Who knows.)

ConOps

Self-Assembled Science Station



- 1e: Initial experiment activation
 - 1e1: Power System Checkout
 - 1e2: High-rate communications established
 - 1e3: Experiments are removed from main body and brought to the experiment bays
 - Involves: 1. (Voxel), 3. (Experiment), 5. (Logistics Arms (Dual Arm Manipulator), 6. (External Assembly Arms), 7. (Internal Assembly Arms)
- 2: Resupply
 - 2a: Berthing and Refueling
 - 2a1: Robotic capture of resupply vehicle
 - 2a2: Robotic berthing of resupply vehicle
 - 2a3: Refueling operations
 - 2b: Experiment Swapping Operations
 - 2b1: New experiments are removed from resupply vehicle and stored on the core of the station
 - 2b2: Old experiments are removed from the station and moved to the resupply vehicle

ConOps

MITIGATION STRATEGIES:

Schedule:

- 1: Thorough analysis before finalized PDR design
- 2: R&D and prototyping before finalized PDR design

SCHEDULE RISKS

Component schedule risks:

1: Voxels

***S1.1: Origami voxel structure cannot achieve assumed strength to weight ratio**

Many assumptions were made about the strength of the origami folding voxels. The number of voxels may be much higher than expected or each voxel may be much heavier than expected.

MITIGATION: 1

Likelihood: 3

Consequence (Schedule): 4->3

***S1.2: Power and data routing systems take more development than expected**

Each voxel connection would need at least two contacts for DC power and at least four contacts for an ethernet connection. This could take a lot of additional work to be made reliable enough.

MITIGATION: 2

Likelihood: 4

Consequence (Schedule): 3->2

S1.3: Solar panel voxels produce less power than expected

Solar panels were assumed to be 11in by 11in and perfectly fill that space with photovoltaic cells. This is likely to not be the case, but margin was already put into the calculations by assuming low panel performance.

MITIGATION: 1

Likelihood: 4

Consequence (Schedule): 2->1

2: Experiment Bays

S2.1: Thermal management of experiment bays takes more development than expected

Not likely based on thermal calculations, the power consumption is relatively low for the size of the station.

MITIGATION: none

Likelihood: 2

Consequence (Schedule): 2

3: Experiments

S3.1: Customer needs do not match designed experiment bays

This would require a redesign and a resize of all components. This is already assumed as part of our path to PDR.

MITIGATION: 1

Likelihood: 4

Consequence (Schedule): 2->1

4: Cassettes

S4.1: Cassettes must be heavier and more complex than expected

The cassettes are assumed to be made of thin aluminum and just used to hold the voxels together during launch. They must be partially internally actuated, unless a [more clever](#) solution is found for removal by the dual arms. They may need to be heavier than expected.

MITIGATION: 2

Likelihood: 3

Consequence (Schedule): 4->2

S4.2: Cassette actuation requires additional end-effectors on dual-arms

This would require significant increases [in](#) the complexity of the dual-arms and their autonomy. Unlikely, [as](#) internal actuation should make up most of the work.

MITIGATION: 2

Likelihood: 2

Consequence (Schedule): 4->2

5: Logistics Arms

S5.1: Logistics arms cannot be made as light as proposed for use in GEO

Logistics arms are sized based on Canadarm development and necessary reach for this project. It may be the case that the technology used in Canadarm needs to be made heavier/more protected to work outside of LEO. Because there are only two arms, this should not [be](#) a major impact.

MITIGATION: none

Likelihood: 2

Consequence (Schedule): 2

S5.2: Logistics arms must use more power than expected

Logistics arms electricity use is sized based on Canadarm. Seems unlikely.

MITIGATION: none

Likelihood: 1

Consequence (Schedule): 2

6: External Assembly Arms

S6.1: SOLL-E design cannot be radiation and vacuum hardened easily

The SOLL-E design was made with vacuum and radiation operation in mind, but it is a very low TRL prototype, significant complications are likely.

MITIGATION: 2

Likelihood: 3

Consequence (Schedule): 4->2

7: Internal Assembly Arms

S7.1: MMIC-I design cannot be radiation and vacuum hardened easily

Same logic as S6.1

MITIGATION: 2

Likelihood: 3

Consequence (Schedule): 4->2

8: Prop, Avionics, and Docking Module

9: Comms and Power Module

10: Solar Panel Joints

S10.1: Solar Panel Joint development is more complex than expected

These joints should be simple, with the only major complications being 1: the connection between the voxel grid and a slip-ring or limited joint-angle wiring system and 2: a powered motor which can slowly and smoothly turn the solar panels.

MITIGATION: none

Likelihood: 1

Consequence (Schedule): 2

S10.2: Solar panels as designed would induce too much torque in the system, must use a different method of simultaneously tracking earth and sun.

Only did a basic analysis on torque, though this risk seems unlikely as the panels only need to rotate at 0.005 degrees/second.

MITIGATION: none

Likelihood: 1

Consequence (Schedule): 3

TECHNICAL RISKS

Technical risk mitigation strategies:

3: Latch detection at the end-effector and joint level

4: Runtime performance evaluation and early replacement

5: Robotic assistance for deployables.

Action-Based Risks:

2a.1: Temporary Solar Panel Fails to Deploy

Deployables failures are common, several studies have been done to show how a robotic arm could assist a solar panel deployment. If the craft has enough battery power to move one of the logistic arms to unlatch/assist the solar panel, this risk could be mitigated after the failure, reducing overall impact.

Additionally, using a commercially widespread bus/solar panel for the basis of the core of the station could mitigate most similar risks significantly.

MITIGATION: 5

Likelihood: 1

Consequence (Technical): 5->2

3a.1: Command Antenna Fails to Deploy

Similar reasoning as 2.1, fault detection and failure modes for the robotic arms to assist the antenna unlatch could help.

MITIGATION: 5

Likelihood: 1

Consequence (Technical): 5->2

6a.1/6b.1: Dual Arm fails to latch or unlatch from external arm properly, fault is detected and resolved

Robust latch detection sensing will be required on each component, and it is assumed latch failure resolution will be required many times during the lifespan of the station. The inclusion of position sensors and force or current sensing will make fault detection much more likely, extensive testing will be required to ensure that faults can be resolved autonomously (or by ground crew intervention in a worse-case scenario).

Likelihood: 3

Consequence (Technical): 1

6a.2/6b.2: Dual Arm fails to latch or unlatch from external arm properly, fault is not detected immediately

Robust sensor packages and testing will make this scenario very unlikely, but it could have a large consequence on mission success if it is not detected properly. In the best case scenario, one of the robotic components realizes that the forces it is experiencing are not aligned with anticipated forces and the task is stopped so a ground crew can intervene and manually resolve the situation. In the worst case scenario, the dual arm rips the external arm away from a voxel, or releases it into a free-floating state. Either would be catastrophic. An additional SOLL-E arm would need to be made available, either because extra arms were brought along or through a resupply mission.

MITIGATION: 3

Likelihood: 3->1

Consequence (Technical): 4

7a.1/7b.1: External arm fails to attach or detach from voxel, fault is not detected immediately:

Because the external arms move on the discrete grid of voxels, a fully unlatched scenario is very unlikely after extensive testing.

MITIGATION: 3

Likelihood: 3->1

Consequence (Technical): 4

7a.2/7b.2: Latching mechanism is stuck:

After several thousand cycles, the mechanism could significantly degrade and become stuck. This would require replacement of an arm. As this would only be likely to happen well into the mission when a resupply would happen according to the normal ConOps, a resupply mission is a less consequential risk mitigation strategy.

MITIGATION: 4

Likelihood: 3->2

Consequence (Technical): 3

7c.1: External arm moves erroneously on voxel grid:

An alignment of 7c.1 with 7a.1/7b.1 would need to happen for any serious consequence to arise from this risk, otherwise a recalibration of the position sensors on the SOLL-E would likely need to be done to mitigate further move errors.

MITIGATION: none

Likelihood: 2

Consequence (Technical): 1

7d.1: External arm erroneously places voxel for assembly:

With so many moving pieces, a misaligned voxel seems likely. Work would need to stop for a recalibration, but an alignment with several other risks would need to happen for this to cause serious consequence.

MITIGATION: none

Likelihood: 3

Consequence (Technical): 1

7e.1: External arm erroneously removes voxel from external arm backpack:

Requires localization of two separate robot frames on a flexing grid of voxels. Seems likely, but should not have serious consequence unless it aligns with a latching/unlatching error.

MITIGATION: none

Likelihood: 3

Consequence (Technical): 1

8a.1: Interior arm moves erroneously on voxel grid:

Unlikely as the free play between the interior arm and the grid is minimal, however positioning errors in the interior arm joints could make this possible, requiring recalibration.

MITIGATION: none

Likelihood: 2

Consequence (Technical): 1

8b.1: Interior arm misalignment of voxel latch actuators:

Again, reduced free play makes this unlikely. Over time the latch actuation could wear down and need replacement, which likely means replacement of the entire interior assembly arm.

MITIGATION: 4

Likelihood: 3->2

Consequence (Technical): 3

9a.1: Dual arm erroneously detaches cassette from storage:

The arm and the cassette are both attached to the same rigid body, but positioning errors in the arm could cause a failed grasp or misaligned removal. Because the cassettes will need to be lightweight and weak structures (as there are so many of them and they serve no purpose other than storage), they could be ripped apart by an erroneous detachment, spilling unfolded voxels and creating free-floating debris.

MITIGATION: 4

Likelihood: 3->1

Consequence (Technical): 4

9b.1: Dual arm damages cassette during voxel removal:

Same reasoning as 9a.1, but with the additional risk of using both of the dual arms at the same time.

MITIGATION: 4

Likelihood: 4->2

Consequence (Technical): 4

9b.2: Voxel become stuck in cassette:

Because the voxels only have one way to be removed from the cassette, and because forces are limited when handling the cassettes to prevent spilling voxels, there is a high likelihood that they would become stuck during removal and the force required to get them out would be too high to risk. Low overall consequence unless it happens to many of the cassettes, rendering a large number of voxels unusable.

MITIGATION: none

Likelihood: 4

Consequence (Technical): 2

9c.1: Dual arm fails to latch on to a voxel and does not detect the fault before trying to move it:

The dual arm has a large mass difference to the voxel, checking latch at joint level may be difficult due to this. There is a large safety consequence of allowing a voxel to go into a free-floating state, but not a lot of consequence to damaging one voxel otherwise.

MITIGATION: none

Likelihood: 2

Consequence (Technical): 3

9d.1/9e.1: Handover failure between Dual arm and External arm:

Similar reasoning to 7e.1.

MITIGATION: 4

Likelihood: 5->3

Consequence (Technical): 1

<https://www.nlyte.com/blog/data-center-rack-power-costs-a-condensed-analysis/>

Annual industry average cost to run an AI datacenter rack for one year in a high-electricity-cost area: \$207,934.11

This represents 883MWh, or 95kW continuously

Each panel can generate 32W, we need almost 3000 panels for this. That's 1.6 tons of solar panels, and we almost certainly need backing voxels, let's assume just one layer of structural voxels for a total of 2.8 tons

The cost to get about 5-7 times that amount of solar panels and structure to a sun-synchronous orbit is \$74mil (which would take 74 years to pay off compared to a ground-based datacenter). If costs come down to \$200/kg like in Google's suncatcher study (<https://arxiv.org/pdf/2511.19468>), the launch cost would be higher due to the high inclination and apogee, but maybe around \$400/kg to be conservative. That would represent a launch cost of \$1.1mil per rack's worth of solar panels. This does not include the rack itself, cooling equipment, or anything else. That would cost 5 years to pay off just the launch costs for the solar panels.

Based on the structure build hardware demo video released by NASA:

<https://www.nasa.gov/general/robot-team-builds-high-performance-digital-structure-for-nasa/>

~50 voxels in 60,000 seconds (17 hours).

Assume we're about 4x slower because there are more robotic operations involved and we're working very slowly in microgravity, so 50 voxels takes 4 days.

Core structure takes 5 days

Each solar panel wing takes 40 days (x2)

Each experiment wing takes 20 days (x2)

About half a year of construction time

Explanations next, references at the bottom.

Component # and Description	Mass (kg)	Power (W)	Number
1a. Standard Voxel	0.38	0	200
1b. Power Routing Voxel	0.5	0	100
1c. Solar Panel Voxel	0.55	0	500
2a. Small Experiment Bay	1	0	25
2b. Large Experiment Bay	4.5	0	5
2c. Shielded Experiment Bay	4	0	3
3a. Small Experiment	6	30	25
3b. Large Experiment	100	100	5
3c. Shielded Experiment	20	60	3
4. Voxel Cassettes	5	0	80
5. Logistics Arms (Dual Arm Manipulator)	300	250	2
6. External Assembly Arms	5	20	2
7. Internal Assembly Arms	3.5	5	2
8. Prop and Avionics (and docking) Module	1000	100	1
9. Comms and Power Module	300	150	1
10. Solar Panel Joints	30	10	2

Mass (kg) Power (W)

Total for Mission 1 3547.5 2250

CONVERSION TO ACTUAL SOLAR PANEL REQUIREMENTS

Power required: 2250W

At maximum eclipse, sat can be in the shadow of the earth for around 1 hour. Need 2250*23Wh for sunlight period and 2250*1Wh for eclipse period. Assume 80% energy path efficiency in sunlight and 60% efficiency in eclipse.

$$P_{sp_{min}} = \frac{E_s}{X_s} + \frac{E_e}{X_e}$$

Require 3000W of solar panel generation

Looked at a few sources, let's say 300W/m² to be conservative for our solar panels. Each of the voxels have about 0.0778m² of solar panel area. Each panel can generate 22W. We therefore need about 140 solar panel voxels. We will never be able to get perfect pointing because we only have 1DOF for the solar panels. Assume we need more, about double that. Also bring a lot of replacement panels because they do not weigh much and it's part of our ~~ConOps~~ ^{ConOps}.

Small Experiment Bay: RAFTI module with all its fuel stuff is 1.1kg, assuming it's around 0.5 kg without all that and the voxel is 0.38kg, round to 1kg.

Large Experiment Bay: 8x voxels and 1x RAFTI, round to 4.5kg.

Shielded Experiment Bay: Not sure really, but let's say 4kg to be safe.

Small Experiment: 6U ~~cube~~ ^{cube}sat, so 6kg and we said 30 watts.

Large Experiment: Bosun locker, 100kg, we said 100 watts.

Cassettes: basically going to be the perimeter of a 16.5x16.5x12in cube made of very lightweight material, let's say 5kg.

Shielded experiment: Not sure why our original notes had this with 20W and 12U when the 6U was 30W, I made it 60 in this table.

Logistics Arms: The resupply module will likely only be 1-3 tons, which is around 1% of the weight handling capability of ~~canadarm~~ ^{canadarm}. Additionally, the length will only need to be 5m or so assuming the logistics arms can crawl around the station to where they need to go. I'm going to assume 300kg for each arm, and 500W each for now. Maybe we can find some better assumptions in the future. Assume 50% duty since they pass voxels, then just sit there while the SOLL-E's assemble.

External Assembly/SOLL-E Arms: They weigh 4.8kg each. Compute probably takes 10W or so the motor torque was a max of 21Nm on the ground but would be much less in microgravity. did a quick calculation assuming a nominal step between blocks of 20s (what they used in the paper) and made some assumptions about the inertia of one leg held at its end. Got a max of 0.01Nm at an average of 1deg/s. This equates to about 2W nominal, I'll just assume 10W for actual required power.

Internal Assembly/MMIC-I Bots: They weigh 3.5kg each. Fortunately the paper provides actual battery specs and endurance, it drains an 11.1V, 1000mAh battery (11.1Wh) in 4 hours. This is a draw of about 3W. I'll just round up to 5W.

Comms Module: From Gerardo's findings, 50kg and 150W.

Power Module: Not sure, let's say 250kg for now.

Prop and Avionics Module: 1000kg and 500W, eyeballing based on Cygnus and Geostar3

Solar panel joints: I have no idea, we should do some quick math on this.

ISS Reference:

Automation (ICRA), London, United Kingdom, 2023, pp. 7303-7309, doi: 10.1109/ICRA48891.2023.10161263.

Item/Parameter	SSRMS/ Canadarm2	SPOM/ Dextre	MBS (Mobile Base System)
Arm length	17.5 m	3.5 m linear stroke	5.7 m x 4.5 m x 2.9 m
Mass	~1800 kg	1662 kg	1450 kg
Mass handling/ transportation capacity	116,000 kg	600 kg	20,900 kg
Dof (Degrees of Freedom)	7	15	Fixed
Peak power (operational)	2 kW	2 kW	825 W
Average power (idle)	435 W	600 W	365 W
Applied tip load range	0-1 kN	0-111 N	N/A
Stopping distance	0.6 m	0.15 m	N/A

Table 1: MSS (Mobile Servicing System) subsystems.

<https://www.eoportal.org/satellite-missions/iss-mss#iss-servicing-mss-mobile-servicing-system>

SOLL-E Reference:

I. -W. Park et al., "SOLL-E: A Module Transport and Placement Robot for Autonomous Assembly of Discrete Lattice Structures," 2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Detroit, MI, USA, 2023, pp. 10736-10741, doi: 10.1109/IROS55552.2023.10341479.

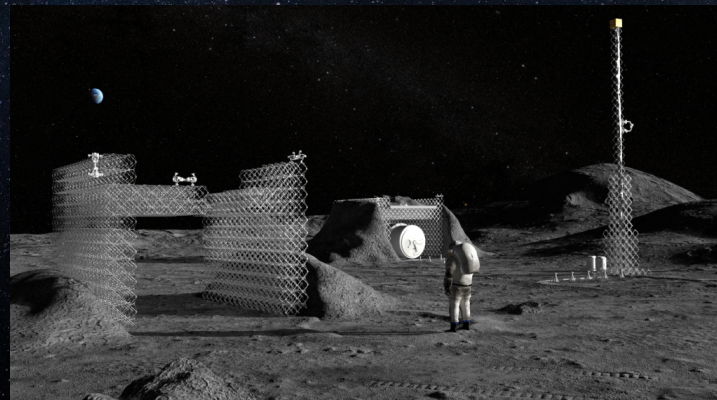
MMIC-I Reference:

O. Formoso, G. Trinh, D. Catanoso, I. -W. Park, C. Gregg and K. Cheung, "MMIC-I: A Robotic Platform for Assembly Integration and Internal Locomotion through Mechanical Meta-Material Structures," 2023 IEEE International Conference on Robotics and

Feasibility

Mission items	Possibility to be built or designed within 5 years (1-5)*
Bill of Materials	5
CAD Drawings	5
Manufacturing & Testing approach	2
Technological Development	4
Launch/Delivery	5

*1 being unlikely within 5 years
5 being possible within 5 years



Team Overview

Also: Everyone PLEASE PUT YOUR PHOTO IN THE PRESENTATION OR I'M USING A MUPPET TO REPRESENT YOU



Diego Quevedo



Conrad Kent



Sarah Hudson



James Talavage



Gerardo Martinez-Avila



John Radey



Dylan Roach



Sophia Yu