Process Book

Inflatable Habitat Storage System

Team F.L.E.X - Ziyu (Mark) Nie & Saif Bajnaid

Course: Wearable Technology | IND 302-03

Prof. Rebeccah Pailes-Friedman, FIDSA

Pratt

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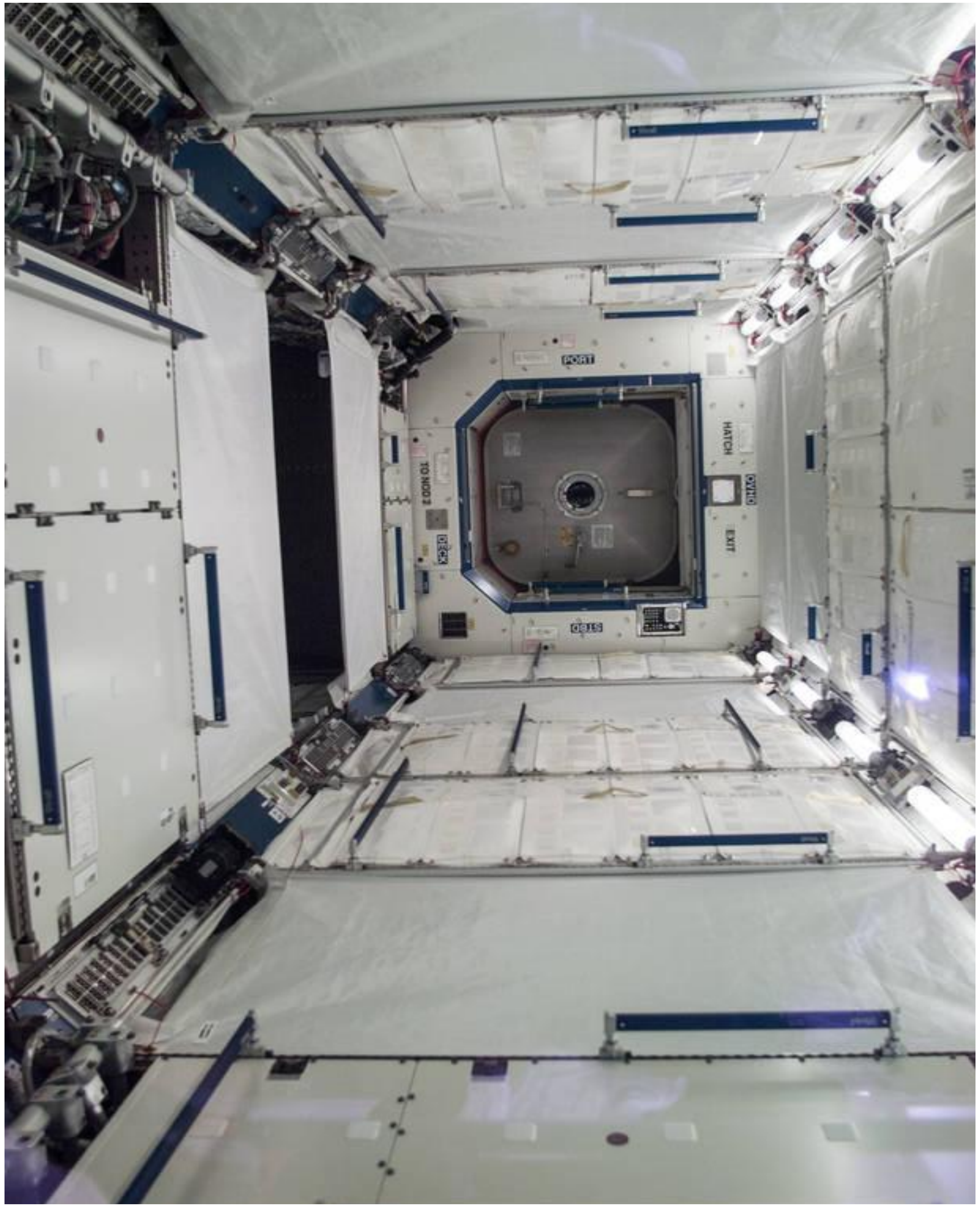
Section 1

Introduction

The Wearable Technology studio introduces students to the emerging product category of wearables and soft goods. Students will be working in teams and choosing a project from a selection of projects curated by the professor to work with various companies or divisions of NASA.

Students will develop proof-of-concept prototypes, with advice from outside subject matter experts and project mentors that are vested in the success of each project. The prototypes will be presented to their Project Mentors at the end of the semester.

- Course description
- Challenge
- Design brief
- Project requirements



Inside the ISS, Image courtesy of NASA.gov

Section 1: Introduction

Course Description

This studio introduces students to the emerging product category of wearables and soft goods. Wearable Technology is a product developed for function, often to increase or measure efficiency and worn on the body. Exploring the territory of technologically integrated apparel and accessories, this course goes beyond the "wristable" (i.e. Apple watch.) Students explore the relationship between soft materials and technological advances in sensors, microcontrollers,flexible conductive materials, trims, threads, yarns, and fibers.

Aesthetics, ethics, environmental impact, and the use of technology in creating wearable products are discussed as prototypes are created to solve a problem affecting astronauts in space. Student teams choose a project from a selection of projects curated by the professor to work with various companies or divisions of NASA. These projects vary from semester to semester.

Working in teams, students will develop proof-of-concept prototypes, with advice from outside subject matter experts and project mentors that are vested in the success of each project. The prototypes will be presented to their Project Mentors at the end of the semester.

Image of the class at NASA

Section 1: Introduction
Challenge

Background

Inflatable structures are being designed as habitats for future deep space stations. These structures are made of high strength materials that are flexible and packed during launch, then inflated and rigidized in space – much like packing up an air mattress and inflating it when needed.

Problem Statement & Goals

For inflatables, just like any spacecraft, we will need permanent storage and equipment to line most of the interior walls. For inflatables, however, this equipment and storage cannot be installed on the ground. Instead, it needs to start in a collapsed, low-volume state, then deploy and get installed on orbit. We are seeking a permanent storage installation which can launch in a packed, low-volume configuration, deploy to its final configuration, attach to the pressure wall of an inflatable module, and become rigid enough for astronauts to interact with and move around on when deployed.

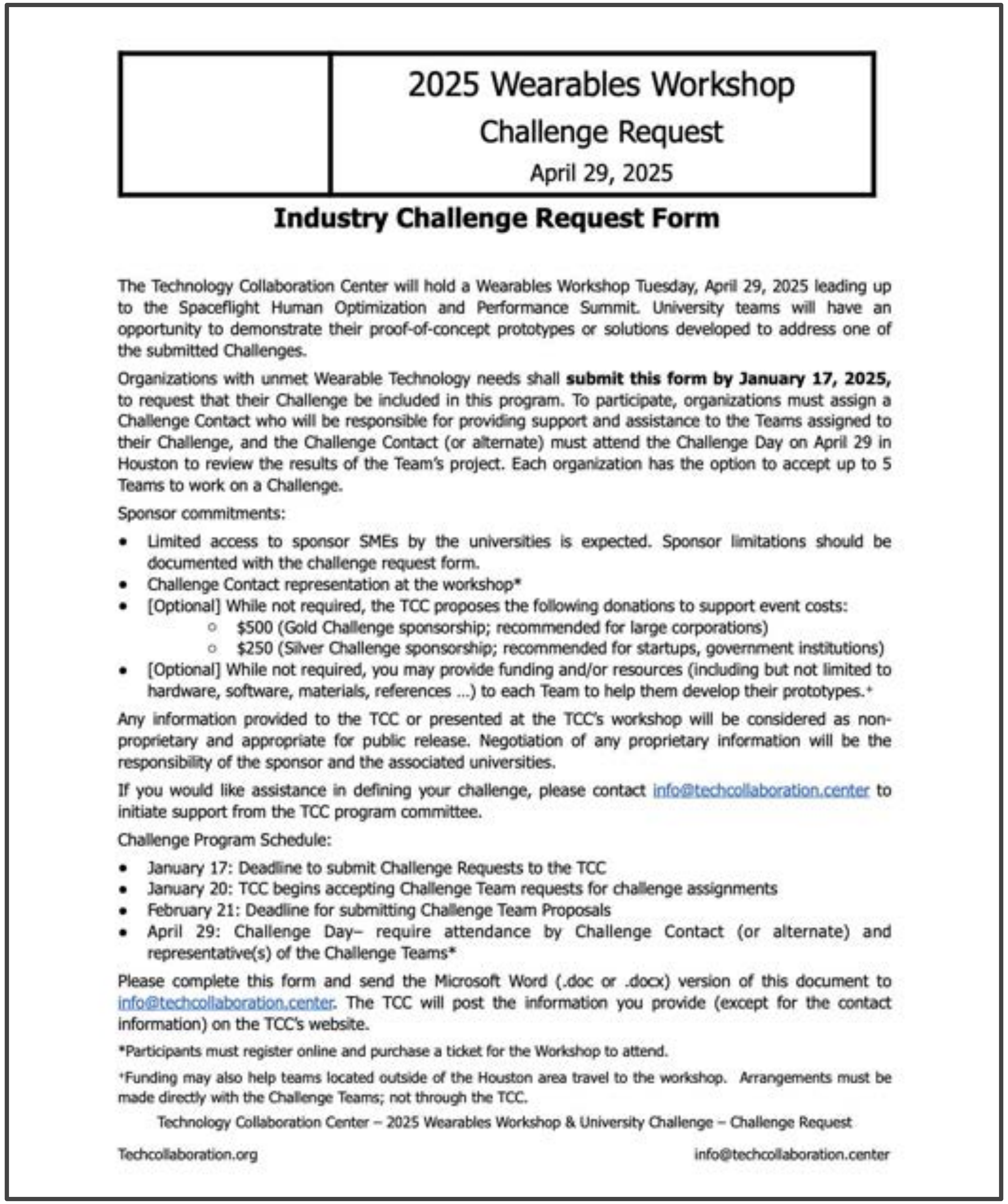
Important Design Considerations

• The interior wall of an inflatable module will be an ~20 ft diameter cylinder. Your storage system should either conform to this diameter or be made up of cells that can tile around the circumference.

• A full-size storage wall might occupy a significant area, and astronauts need to be able to move around by grabbing onto handrails mounted to the wall. The proposed solution should be rigidized after it is deployed so that astronauts can push off it and move around.

• For launch, the storage wall should be able to pack into a very small volume

• The storage wall should feature separate storage segments for organizing materials and equipment



2025 Wearables Workshop
Challenge Request
April 29, 2025

Industry Challenge Request Form

The Technology Collaboration Center will hold a Wearables Workshop Tuesday, April 29, 2025 leading up to the Spaceflight Human Optimization and Performance Summit. University teams will have an opportunity to demonstrate their proof-of-concept prototypes or solutions developed to address one of the submitted Challenges.

Organizations with unmet Wearable Technology needs shall **submit this form by January 17, 2025,** to request that their Challenge be included in this program. To participate, organizations must assign a Challenge Contact who will be responsible for providing support and assistance to the Teams assigned to their Challenge, and the Challenge Contact (or alternate) must attend the Challenge Day on April 29 in Houston to review the results of the Team's project. Each organization has the option to accept up to 5 Teams to work on a Challenge.

Sponsor commitments:

- Limited access to sponsor SMEs by the universities is expected. Sponsor limitations should be documented with the challenge request form.
- Challenge Contact representation at the workshop*
- [Optional] While not required, the TCC proposes the following donations to support event costs:
  - $500 (Gold Challenge sponsorship; recommended for large corporations)
  - $250 (Silver Challenge sponsorship; recommended for startups, government institutions)
- [Optional] While not required, you may provide funding and/or resources (including but not limited to hardware, software, materials, references ...) to each Team to help them develop their prototypes.+

Any information provided to the TCC or presented at the TCC's workshop will be considered as non-proprietary and appropriate for public release. Negotiation of any proprietary information will be the responsibility of the sponsor and the associated universities.

If you would like assistance in defining your challenge, please contact info@techcollaboration.center to initiate support from the TCC program committee.

Challenge Program Schedule:

- January 17: Deadline to submit Challenge Requests to the TCC
- January 20: TCC begins accepting Challenge Team requests for challenge assignments
- February 21: Deadline for submitting Challenge Team Proposals
- April 29: Challenge Day– require attendance by Challenge Contact (or alternate) and representative(s) of the Challenge Teams*

Please complete this form and send the Microsoft Word (.doc or .docx) version of this document to info@techcollaboration.center. The TCC will post the information you provide (except for the contact information) on the TCC's website.

*Participants must register online and purchase a ticket for the Workshop to attend.

+Funding may also help teams located outside of the Houston area travel to the workshop. Arrangements must be made directly with the Challenge Teams; not through the TCC.

Technology Collaboration Center – 2025 Wearables Workshop & University Challenge – Challenge Request

Techcollaboration.org info@techcollaboration.center

PDF of Challenge request from NASA

Design Brief

Problem:

An inflatable habitat on the International Space Station needs a permanent storage system that utilizes handrails for maneuverability in its interior space (a cylinder with cross-sectional diameter of 20 ft). The current storage system faces challenges of deployment methods, astronauts maneuverability, accessibility and storage efficiency.

Objective:

To design a working prototype of a modular storage solution that efficiently accommodates multiple sizes of Cargo Transfer Bags (CTBs) while ensuring accessibility and organization. The system will also incorporate handrails for astronaut maneuverability and will be compactly packed into a core before launch to meet volume constraints.

Hypothesis:

If the prototype successfully demonstrates a modular storage system that can compactly deploy and fit multiple sizes of CTBs while integrating rigid handrails for astronaut maneuverability, then the storage capacity and operational efficiency of the inflatable habitat will increase significantly for long-duration missions.

Image courtesy of NASA.gov

Requirements

Our design solution should aim to successfully address the following points:

- Packed into a 30-40 ft^3 core during launch
- Expand to 25 ft diameter upon deployment.
- Installation time < 8 Hours
- Accommodates Cargo Transfer Bags (CTBs) (0.5 to 6.0)
- Handrails must be spaced 36 inches apart for easy reach in microgravity.
- 50-inch diameter for cargo transport, 30 inches for maneuverability without cargo.

Image courtesy of NASA.gov

Section 2
Research

Before trying to tackle the project, we took it upon ourselves to become subject matter experts in what we would be designing. This required us to do extensive and thorough research. The research entailed reading 20+ academic papers and separating them into what is relevant and what is not and we ended up with 3 relevant academic papers. In addition to creating a competitive landscape in order to understand what currently exists and what possible solutions have been pitched before. The following is what will be covered within this section:

- Competitive Landscape
- Academic Paper 1
- Academic Paper 2

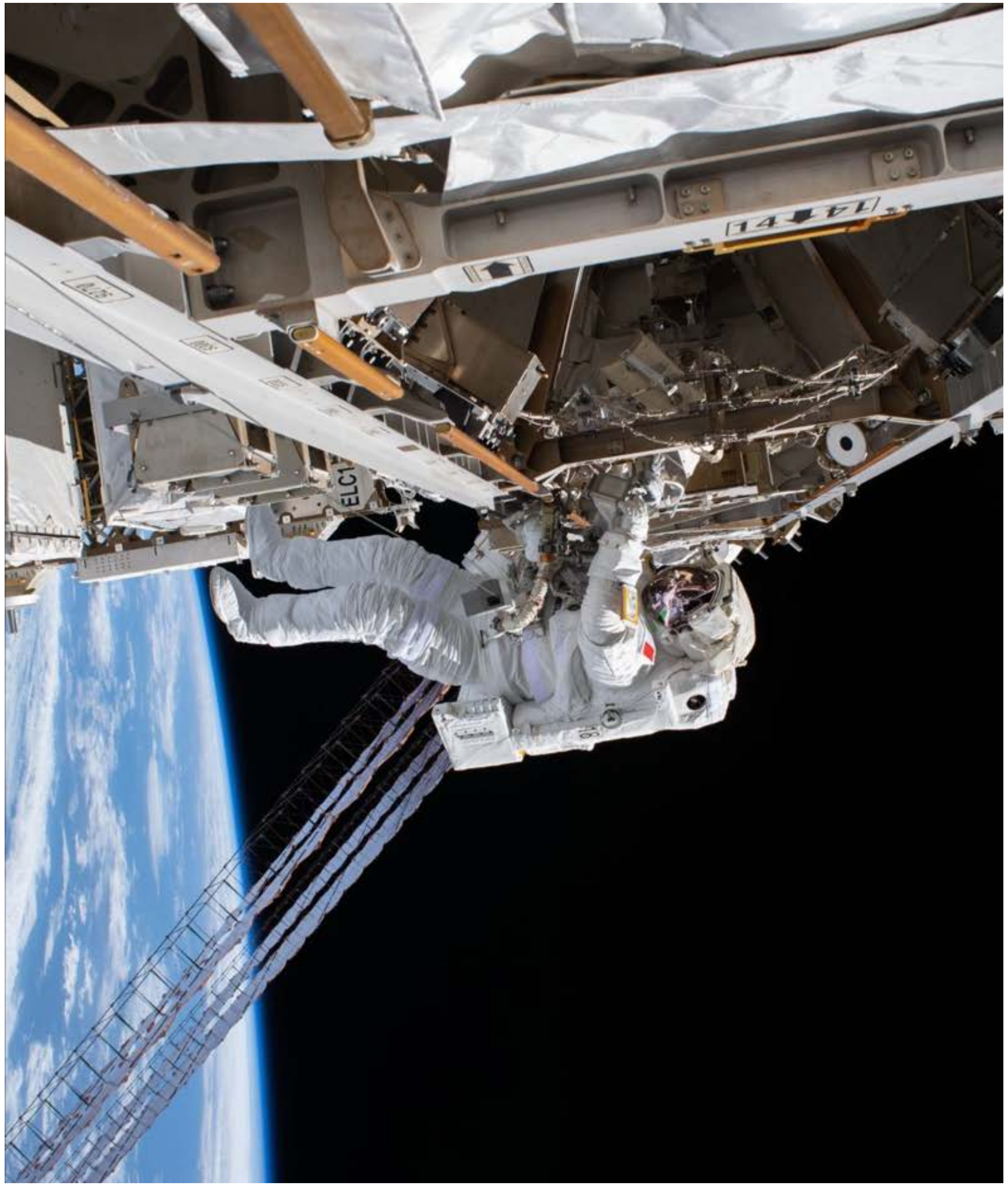


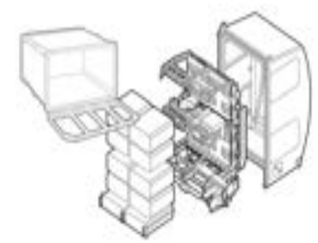
Image courtesy of NASA.gov

Section 2: Research

Competitive Landscape

Prior to undertaking this challenge, we had to create a competitive landscape of existing solutions that have been proposed, adopted or hypothetical. This was done in order to gain further insight and also inspiration of how our proposed model would eventually look like.





	BEAM	**LIFE**	**DMF**	**ISPR**	**Max Space Expandable Habitats**	**ESA Flexible Storage Solutions**	**Mo.Mo Habitat**	**EXPRESS Rack System**
Mechanism	Inflates with gas, rigidizes with pressure	Inflatable with internal support	Deployable sliding racks	Fixed modular installation	Inflatable modules expanding in orbit	Expandable polymer bladder	Self-assembling modules	Modular plug-and-play racks
Cost	Low - Prototype tested on ISS	High - Multi-story habitat design	Medium - Experimental modular frame	Medium - Standardized system	Not disclosed but assume medium due to lightweight designs.	Low - Simple tank structures	High - Lunar habitat concept	Medium - ISS experiment support
Material	Kevlar, Vectran, Nextel	Vectran fabric with polymer layers	Aluminum frame with modular panels	Aluminum with composite panels	Lightweight fiber materials	Flexible polymer tanks	Aluminum frame with HDPE membrane	Aluminum with standard components
Industry / Organization	Bigelow Aerospace	Sierra Space	NASA	NASA	Max Space Space habitation (Moon/Mars)	ESA	M.I.T	NASA

Section 2: Research

Academic Paper (1)

We chose to include this paper as it provides insight on materials and overall mass of the wall that we should be designing, from payload considerations to an innovative material called MadFlex, which is a composite material that is a sandwich-like structure with dual stiffness and folding properties. It's designed to be lightweight and flexible while providing acoustic and thermal isolation, vibration protection, and high resistance.

Main insight gained by reading:

Madflex material and overall Mass of the wall ideally the overall mass of the wall must be minimized to fit within launch payload constraints, typically under 236.6 kg per habitat while maintaining structural integrity. The main challenge is balancing low mass with durability and rigidity for astronaut interaction - Page 214 of thesis

Master's Thesis in Aerospace Engineering

Preliminary design of deployable habitat for lunar outpost made by innovative material

Federico Cumino

Polytechnic of Turin
Accademic year 2019/2020

Polytechnic rapporteur — Frulla Giacomo
Polytechnic co-rapporteur — Cestino Enrico

CoRe external supervisors — Giulietti Nicola, Fossat Eugenio

Academic Paper (2)

We recognized the importance of the paper due to key insights it gave us in regards to how people thought about improving the current storage system on inflatable habitats as the proposed system enables astronauts to manually mount storage racks onto rails after deployment - The key insights were as follows:

- The racks are equipped with sliders that allow astronauts to move storage units manually, locking them into place once positioned .
- The cargo module configuration in the DMF system includes 16 storage compartment racks and 2 dedicated CTB compartments. The submodule system in DMF allows for modular storage arrangements and adaptable work surfaces.
- The submodule system in the DMF allows for different storage configurations. Each submodule can provide either open-access working surfaces or enclosed spaces for crew quarters, greenhouses, or controlled environments

70th International Astronautical Congress (IAC), Washington D.C., United States, 21-25 October 2019.

IAC-19,B3,8-GTS.2,4,x48931

DMF: Deployable Modular Frame for Inflatable Space Habitats

Vittorio Netti[1,*]

[1] *University of Houston,* [illegible]
[*] Corresponding author

Abstract

Inflatable Space Modules for space exploration are now a reality. In 2016, Bigelow Aerospace tested the first inflatable module Bigelow Expandable Activity Module (BEAM) on the International Space Station (ISS), achieving success. This technology has higher volume limits than other launchers, substantially changing the previous concepts of construction and life in space. Nevertheless, inflatable modules technology lacks a reliable and functional platform to efficiently use all this space. Due to its limited dimension, the International Standard Payload Rack (ISPR), currently used on ISS, is not suitable for this purpose. The project aims at developing a new standard for payload rack in the inflatable space modules: the Deployable Modular Frame (DMF). The DMF expands itself radially from the center of the module, starting from four structural pylons. It creates a solid infrastructure allowing for the configuration of a variety of spaces, including storage space, laboratories, workstations and living quarters. The DMF consists of two main parts: the Deployable Frame (DF) and the Modular Rack (MR). Once the frame is deployed, it provides four linear slots suitable to install the modular racks. The rack is the basic element that allows for the storage of equipement inside the frame. Once they are installed, the racks can slide on the frame's rails, dynamically changing the space inside the module. This system, inspired by the Random Access Frame Random Access Frame (RAF) designed by A. Scott Howe for the Jet Propulsion Laboratory (JPL), achieves a high deployability through the use of constant force springs, deploying a radial rail system which reduces the work load of the astronauts on the rack. This asset reverses the internal configuration proposed by the Bigelow Aerospace. The frame includes a stereo-vision camera system to verify the correct deployment of the inflatable modules and the frame itself. The stereo-vision system checks whether the correct shape is constantly maintained.

Keywords: Inflatable, modular, ISPR, Space Operations.

Acronyms
BEAM Bigelow Expandable Activity Module
CTB Cargo Transfer Bag
DF Deployable Frame
DLR German Aerospace Agency
DMF Deployable Modular Frame
DREX Deployable Reflector EXperiment
ECLSS Environmental Control and Life Support System
ESA European Space Agency
FDM Fused Deposition Modeling
ISPR International Standard Payload Rack
ISS International Space Station
JPL Jet Propulsion Laboratory
LED Light Emitting Diode
MR Modular Rack
NASA National Aeronautics and Space Administration
RAF Random Access Frame
SNSB Swedish National Space Board

1. Introduction

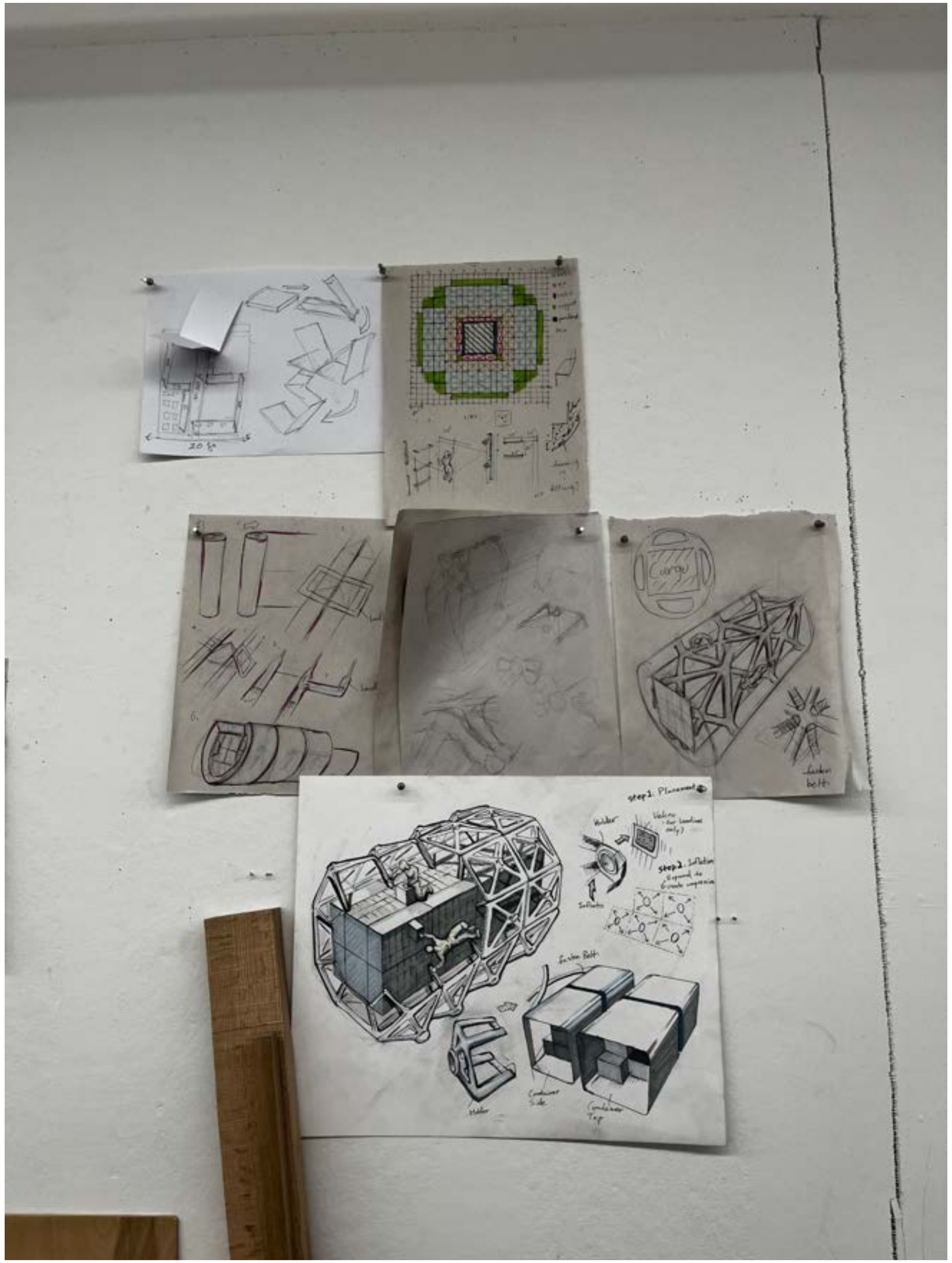
Inflatable technologies for Space applications are not a new asset, but recent R&D provided by the private sector (e.g. Bigelow Aerospace ltd, Sierra Nevada Corp.) has demonstrated that these structures are a viable solution. Inflatable structures have larger diameter limits than commercial rocket fairings, thereby allowing current launchers to bring structures of much larger volume into

Section 3

Concept Development

After completing our initial research and defining the problem, we moved into the concept development phase. This stage focused on generating ideas through sketches and discussions, laying the foundation for multiple directions we would later prototype. The following pages document our early ideation process, proposed directions, and the evolution of our thinking.

- Ideation Sketches
- Proposed Concepts
- Velaris
- Quad-Axis
- Webcore

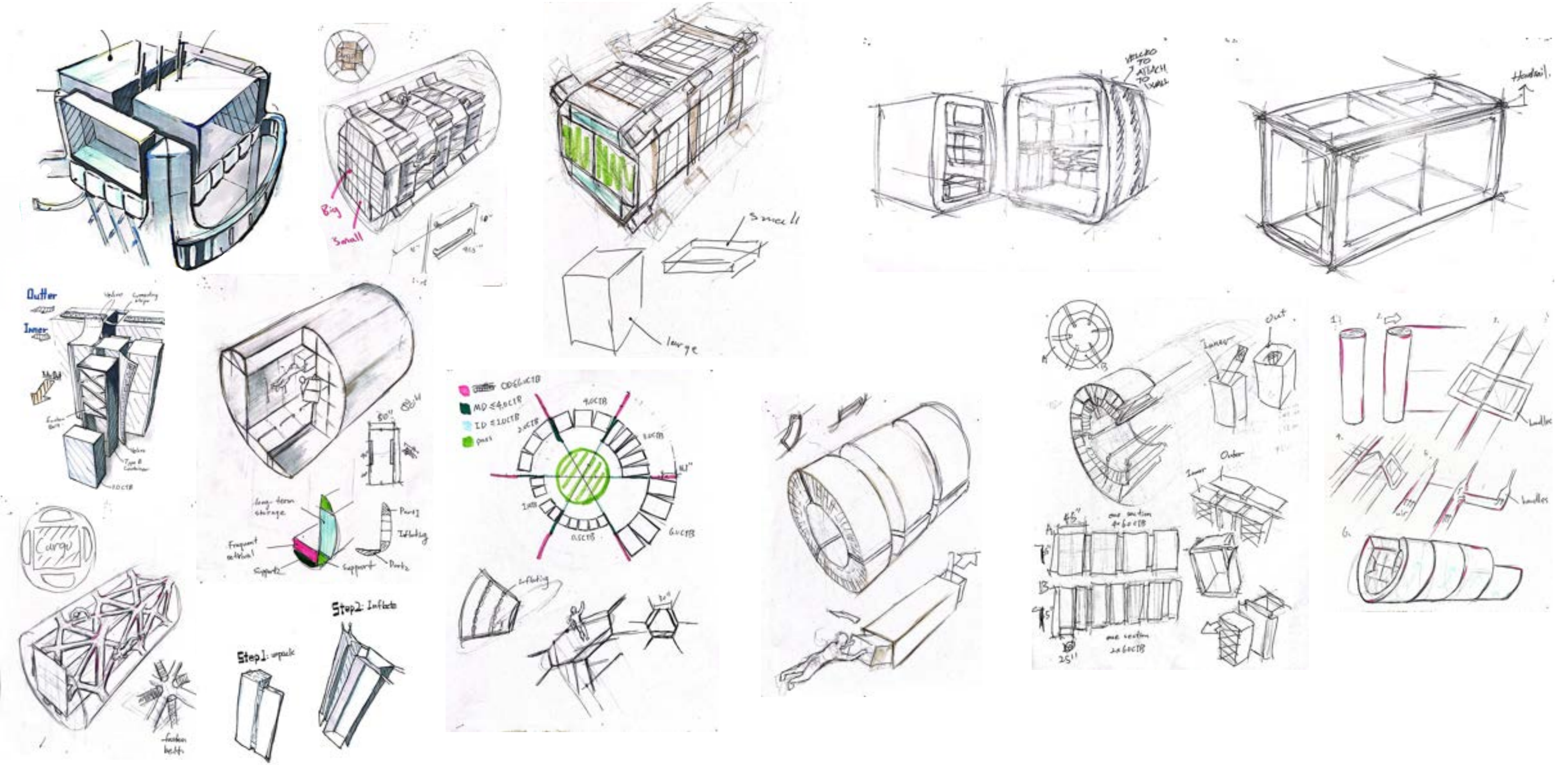


Our early sketches pinned on our studio wall.

Section 3 - Concept Development

Ideation sketches

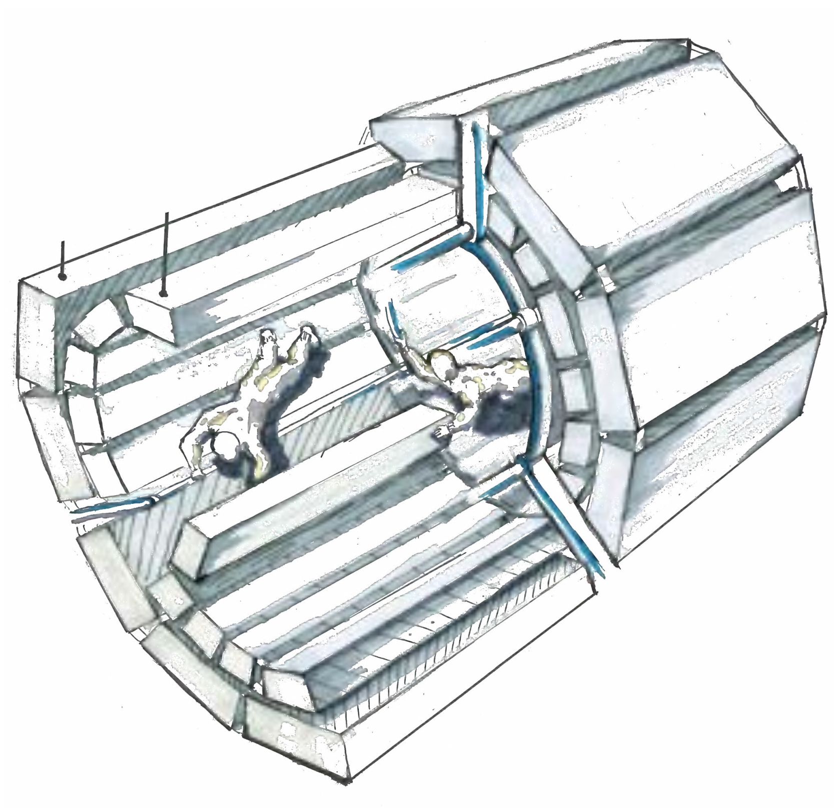
Within our ideation phase, we focused on deployment methods, structure and accessibility. We generated a plethora of sketches exploring different methods and geometries in hopes of finding viable solutions. We ended coming up with three different concepts which will be discussed in the following pages.

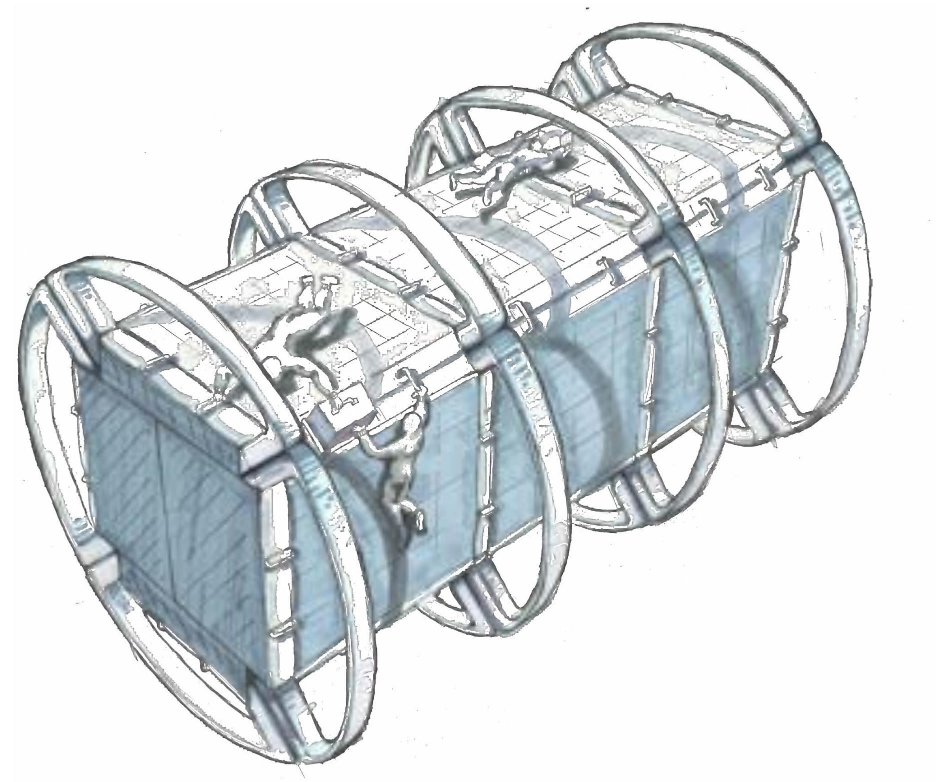


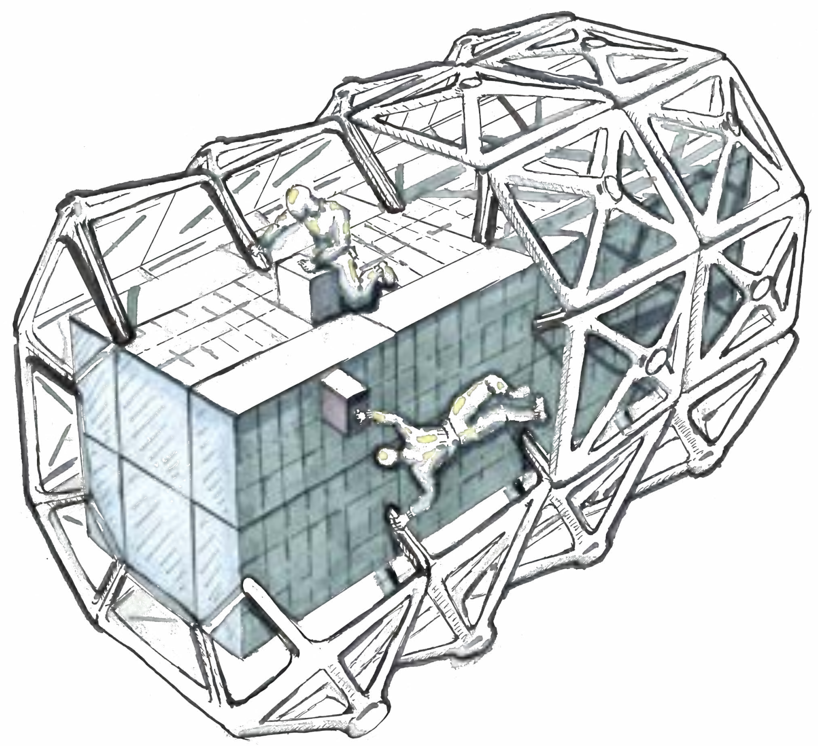
Section 3 - Concept Development

Proposed concepts

After exploring various different methods of deployment and geometries, we proceeded on refining our scattered sketches into a more cohesive approach by creating three separate concepts to pitch to our mentor and gauge which is the best one to move forward with.







Velaris

Concept Velaris is a radial modular storage concept composed of three repeating segments that surround the inner circumference of the habitat. Each module is Velcro-mounted, allowing for compact packing pre-launch and intuitive deployment post-inflation. The design emphasizes efficient use of wall space, accessibility, and symmetry, supporting astronaut maneuverability and quick cargo retrieval in microgravity.

Quad-Axis

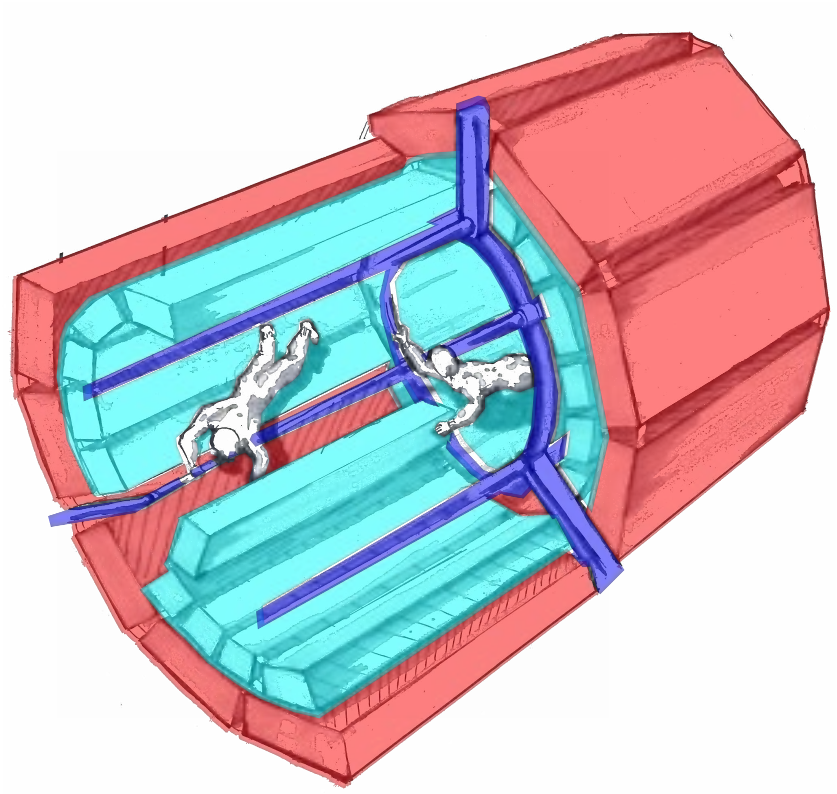
Concept Quad-Axis organizes the storage system around four longitudinal channels, enabling multiple astronauts to access different zones simultaneously. This concept maximizes central clearance while dividing storage by priority; frequent-use CTBs are placed on outer layers, long-term storage toward the core. The ring-based structure reinforces modularity and structural consistency across sections.

Webcore

Concept Webcore uses a spiderweb-inspired support frame that creates tension across the inner habitat wall. This tensile grid allows modular storage cubes to “dock” into place, distributing load efficiently while maintaining flexibility. The hexagonal or radial web layout ensures consistent attachment points and supports large-scale scalability without compromising mobility or clear organization.

Section 3 - Concept Development

Velaris

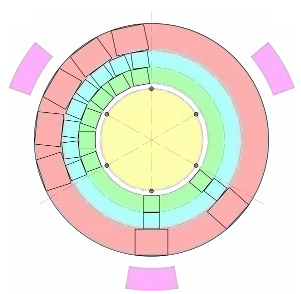


- Storage Area I
  360 CTBE per Section
- Storage Area II
  192/144 CTBE per Section
- Handrails
  Modified from the core

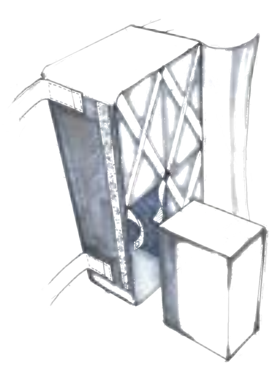
Attachment: Velcro

Deployment Time: 4 hrs

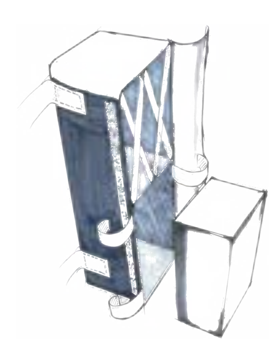
Layout



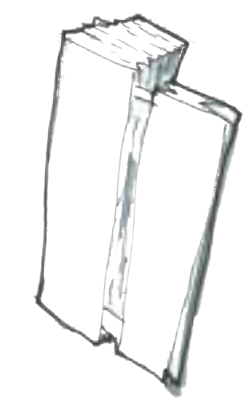
Storage Unit I (OR)



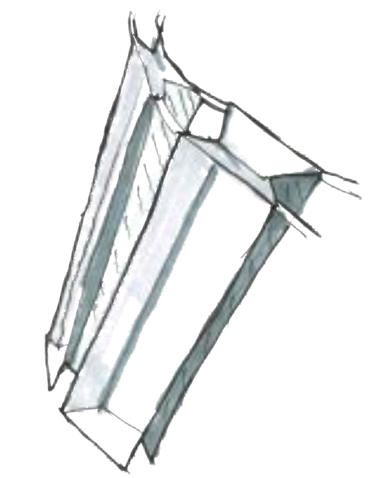
Storage Unit II (MR&IR)



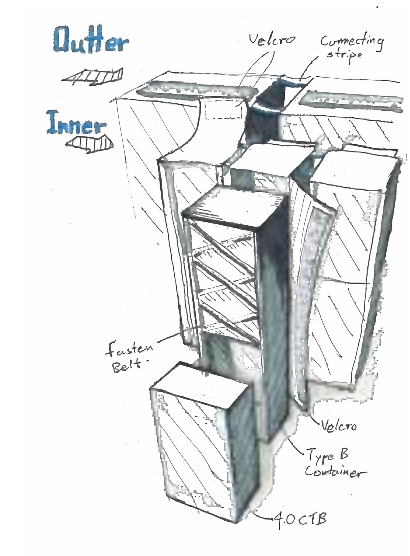
Deployment method:



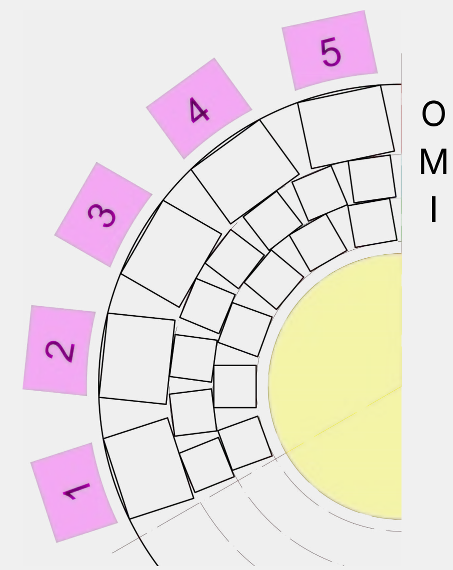
Step 1: Unpack



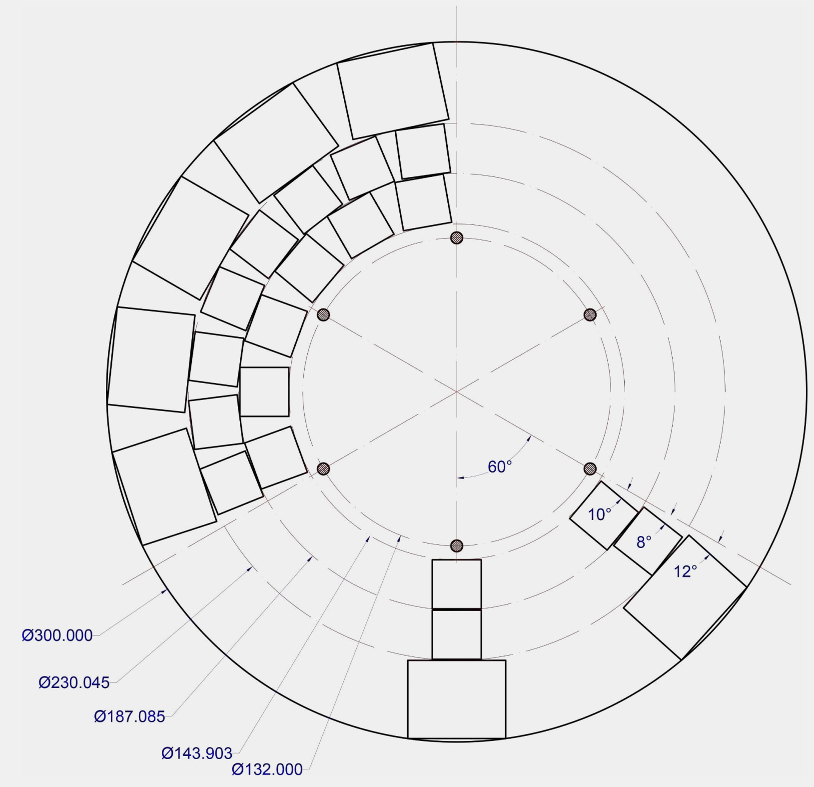
Step 2: Expand

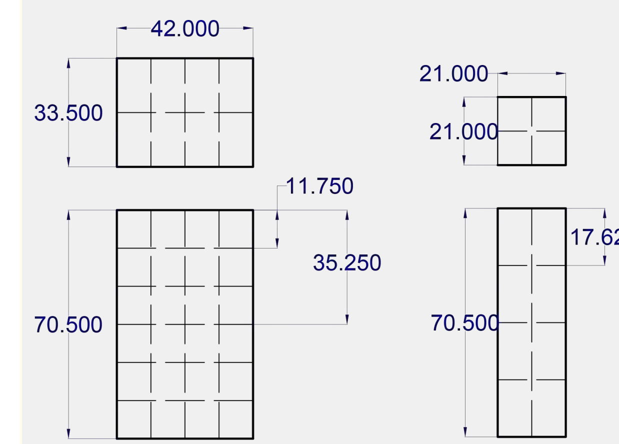


Step 3: Install



Internal organization:
Each bundle has its unique coordinates.





Storage Unit I

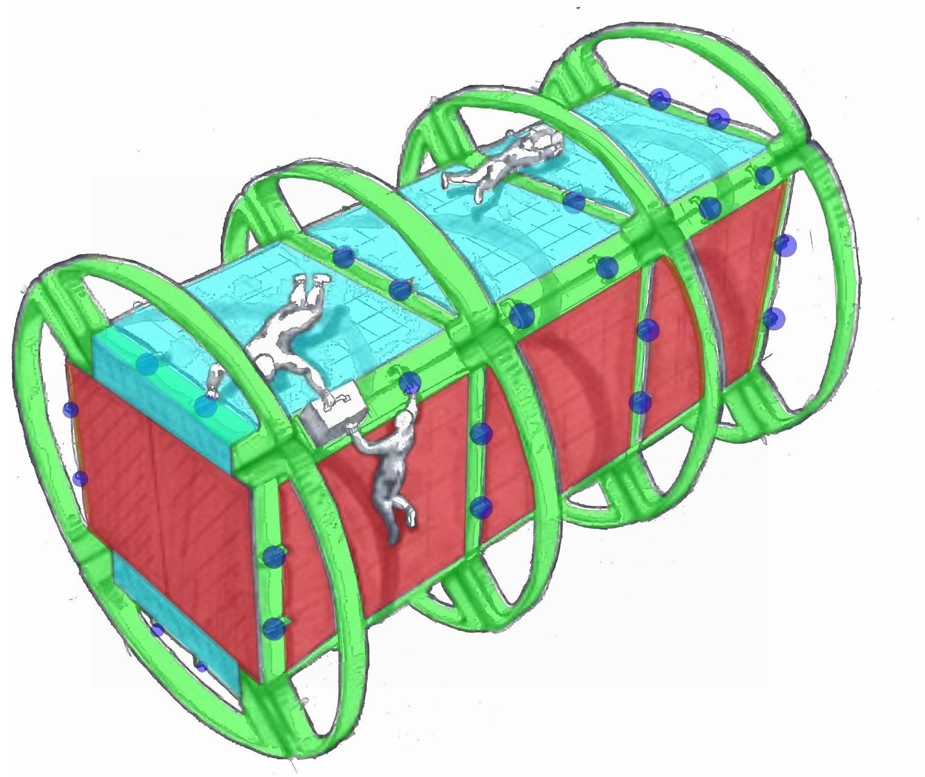
Storage Unit II

Unit Capacity:

Storage Unit I: 24 CTBE

Storage Unit II: 8 CTBE

Section 3 - Concept Development
Quad-Axis

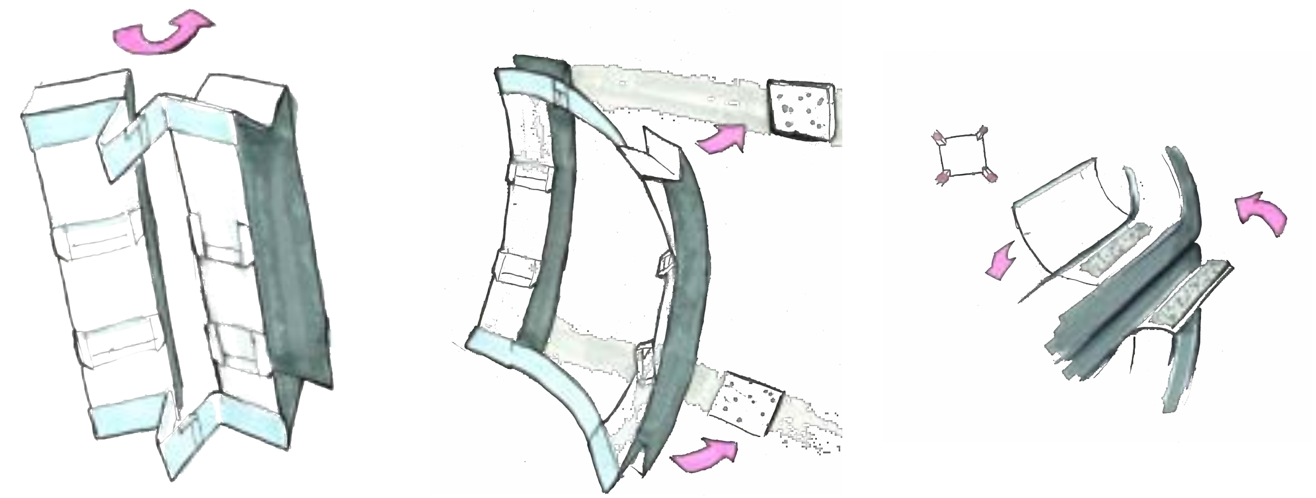


- Storage Area I: 264 CTBE per Section
- Storage Area II: 72 CTBE per Section
- Supportive frame: Inflatable Structure
- Handrails: Inflatable/Stripe

Arch Compression

Deployment time: 2 hrs

Deployment method:

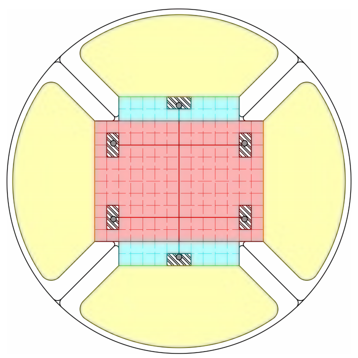


Step 1: Unpack

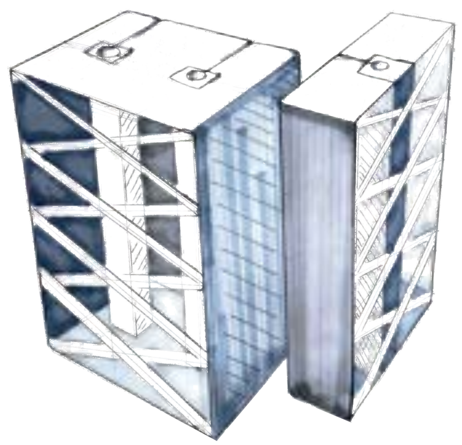
Step 2: Inflate

Step 3: Interlock

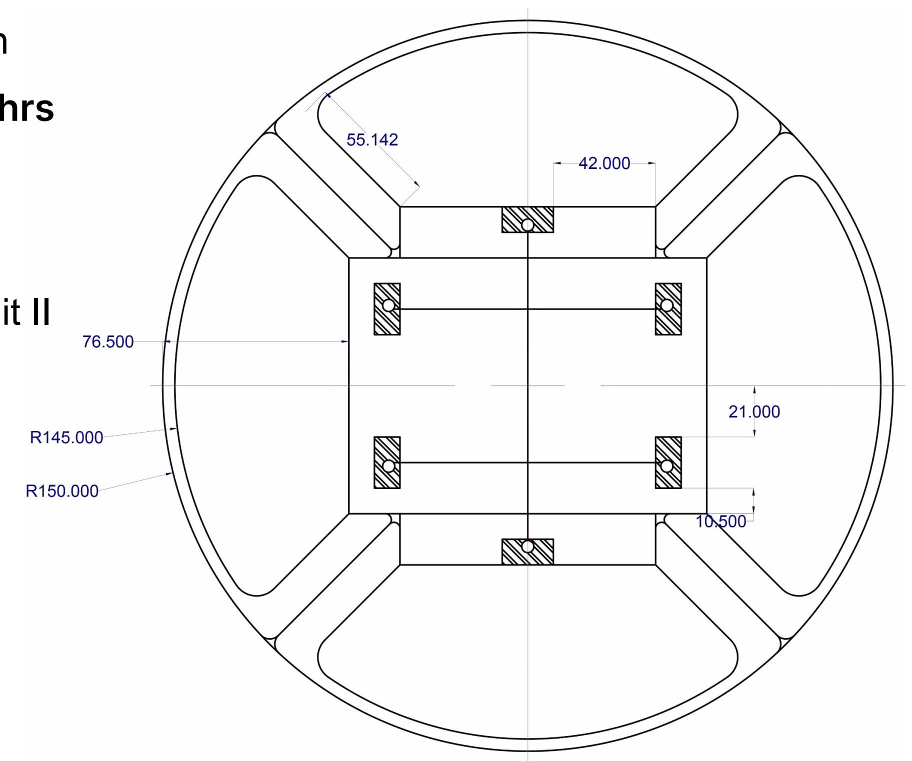
Layout

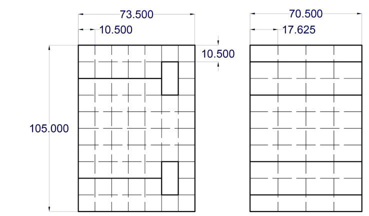


- Storage Unit I
- Storage Unit II
- Passageway

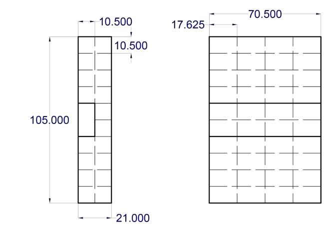


Storage Unit I — Storage Unit II





Storage Unit I



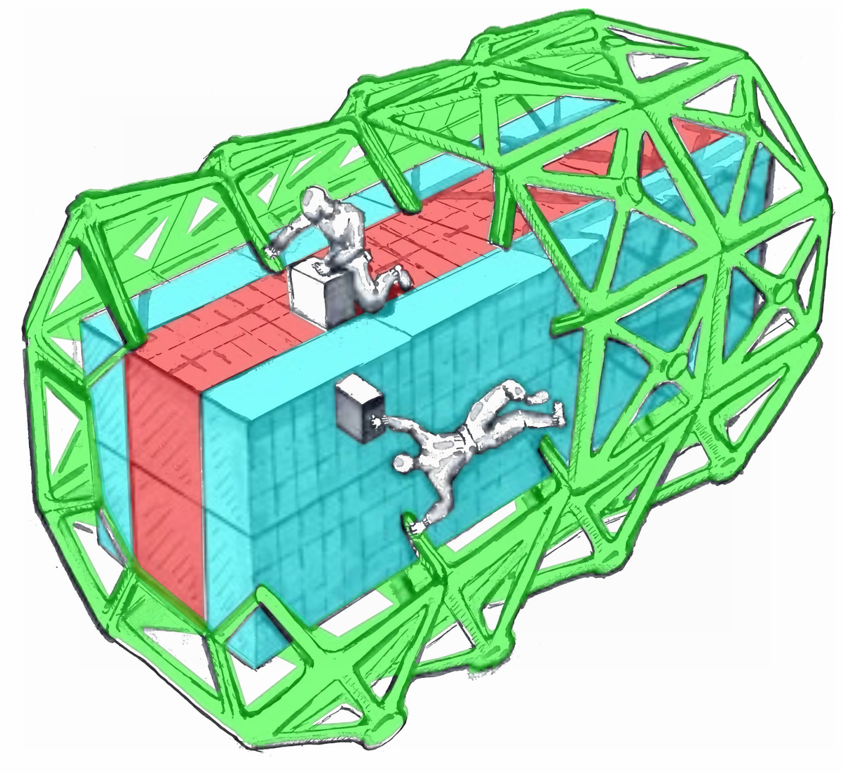
Storage Unit II

Unit Capacity:

Storage Unit I: 132 CTBE

Storage Unit II: 36 CTBE

Section 3 - Concept Development
Webcore

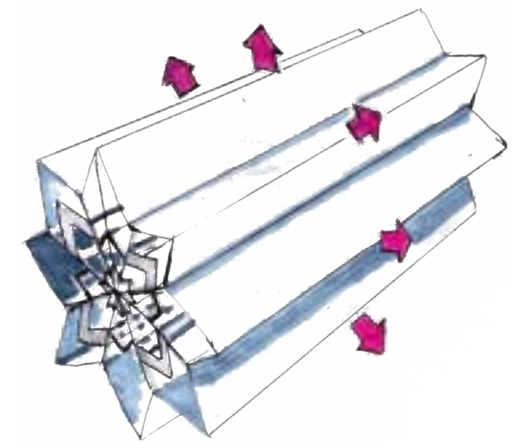


- Storage Area I: 160 CTBE per Section
- Storage Area II: 208 CTBE per Section
- Supportive frame: Strips in tension

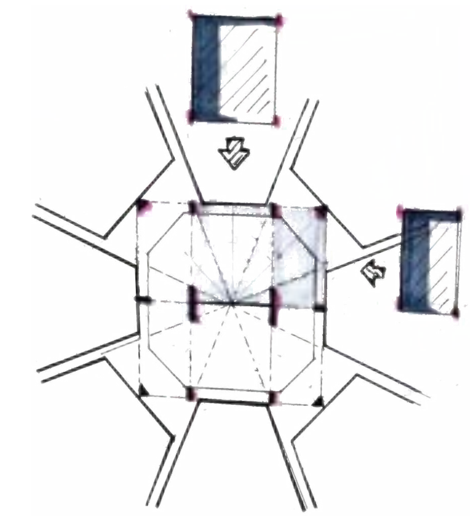
String Tension

Deployment time: 1 hr

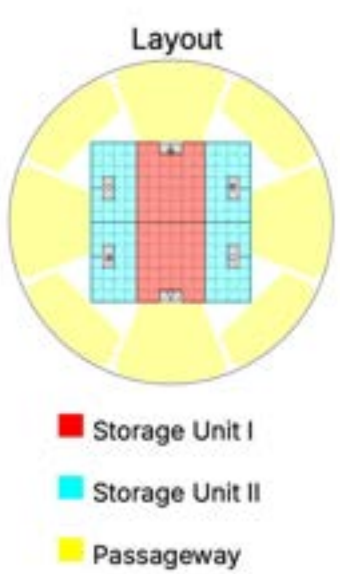
Deployment method:

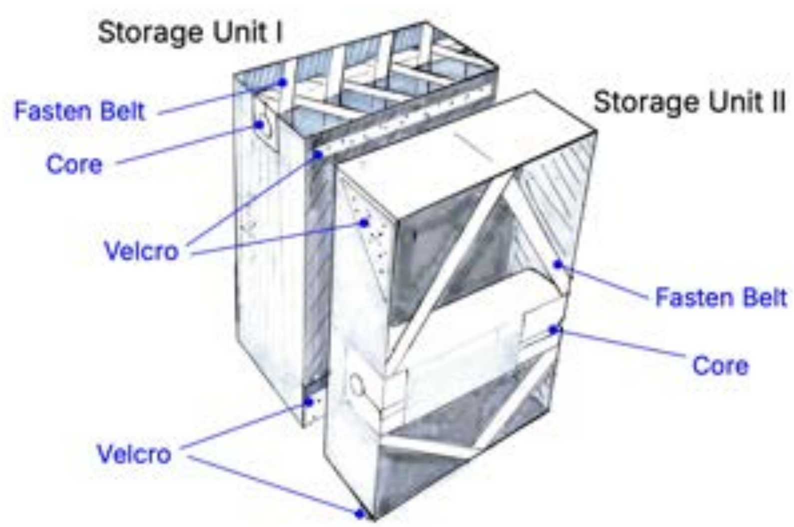


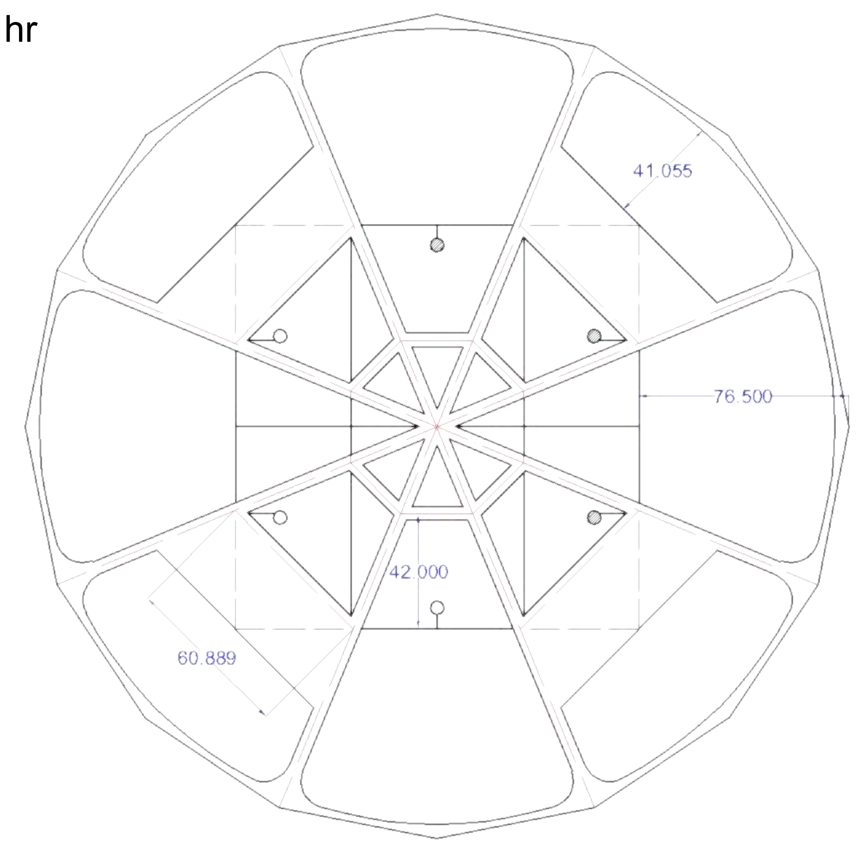
Step 1: Unpack

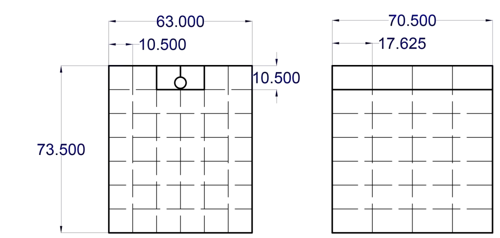


Step 2: Install Units

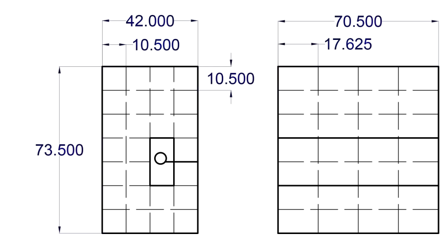








Storage Unit I



Storage Unit II

Unit Capacity:

Storage Unit I: 80 CTBE

Storage Unit II: 52 CTBE

Section 4 - Design Development

NASA Feedback 1 / 2

Throughout the journey of developing our concepts, we've met with both our mentors via zoom twice; Once in early February as a discovery call to understand the project further and another in late March in order to present to them our three concepts and come up with a final one - Their insight and feedback were as follows:

Meeting 1:

- The design could be quite free, as the inflatable wall is a passive structure (there will not be too many cables or pipes).

- We need to consider the complexity of deployment. Since it needs to be a permanent structure, any deployment must be durable enough. A possible solution to explore could be through a dial that releases gas to inflate the habitat or a set that can be manually constructed by astronauts.

- Our solution should be a single design to house all different sizes or multiple CTB's (Cargo Transfer Bags)

- Create one section that is a full module of the system which can be duplicated as instead of doing four or more separate ones.

- The inflatable has an inner lining that we can stitch onto.

Section 4 - Design Development
NASA Feedback 2 / 2

Meeting 2:

Concept Velaris might be too restrictive in the sense where you might have to fold up modules in order to get to the one at the back. We should explore the possibility of potentially having the inner layer of an empty one collapse on its own.

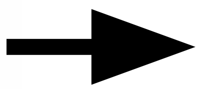
Quad axis faced the question of if a storage module empties out, how would you keep it in place? The answer to it was velcro strips For webcore, make sure to be able to host tension as we were told to think about a post strap tensioning system.

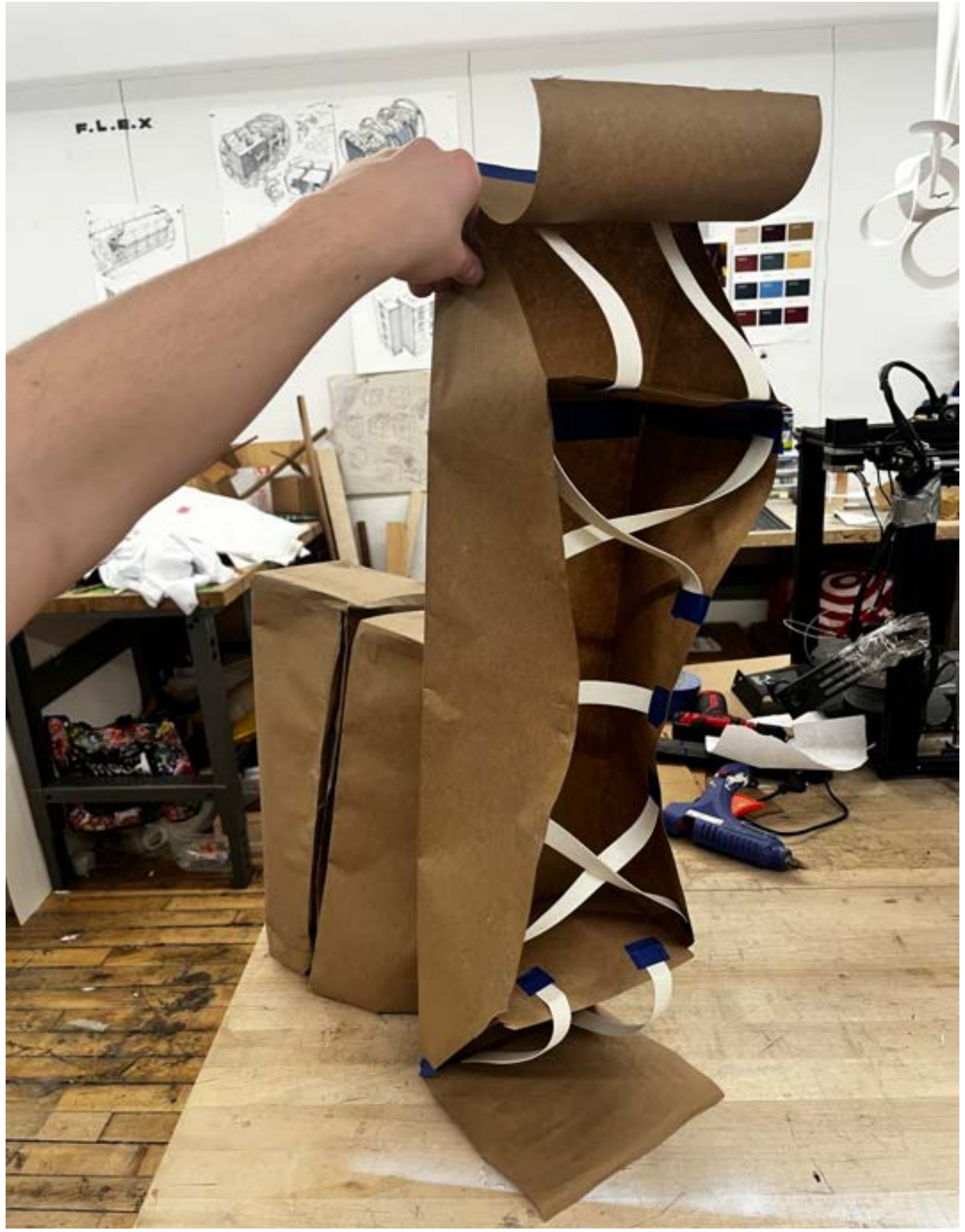
We were told to blend Quadaxis concept with Webcore. Overall, Mr. Carson liked how efficient the storage system is and was wondering if we could structurally integrate the core within our design. In conclusion, we agreed that the following is what should be delivered:

- A small scale operational cross section. (6ft section) that combines quad axis with webcore and present the solution (Keep in mind that the outer part of the inflatable can be rigid, no need for it to be fabric.)
- Components of the final should be functional, made out of fabric and include 3D printed CTB's

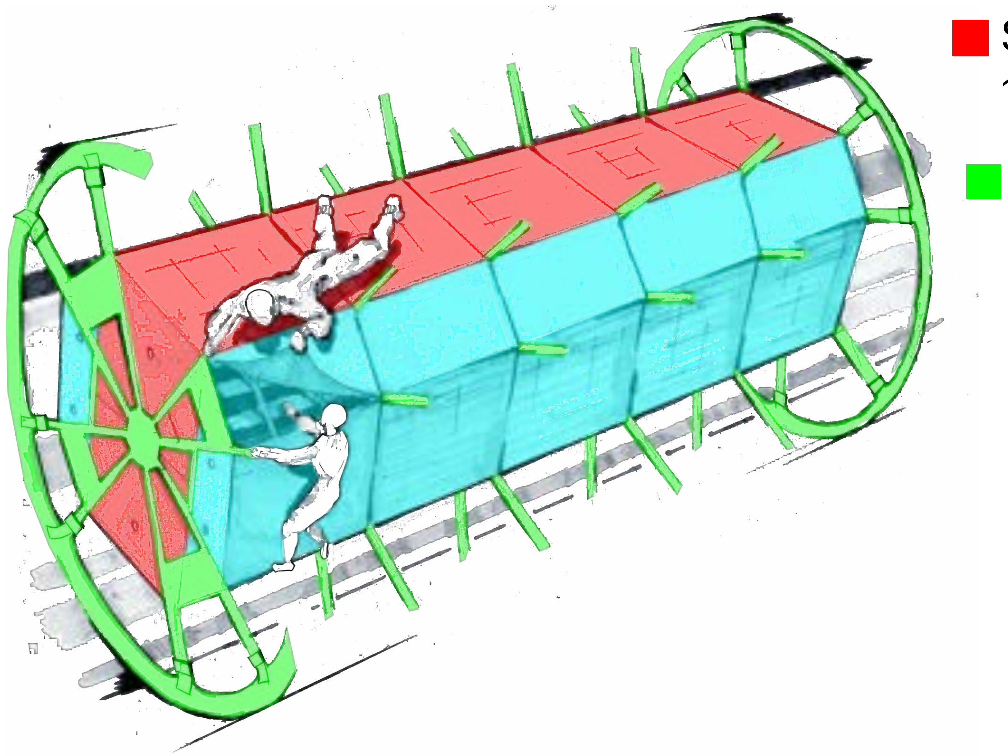
Section 4 - Design Development
Mockups

After presenting these ideas to our mentors, the feedback we got lead us to recognize that the first idea is great but the second and third are even better. The proposed game plan was to come up with one concept that combines both Quad-Axis and Telacore which were concept 2 and 3.





Final Concept

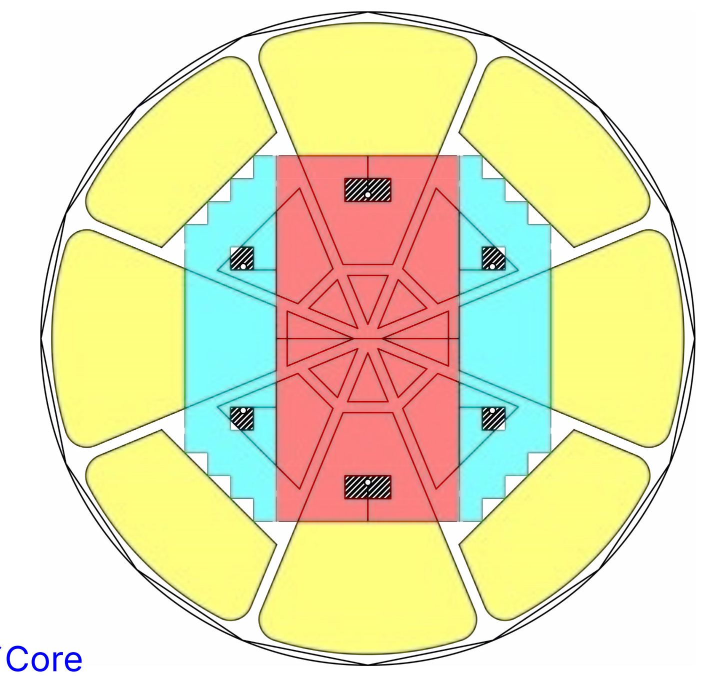


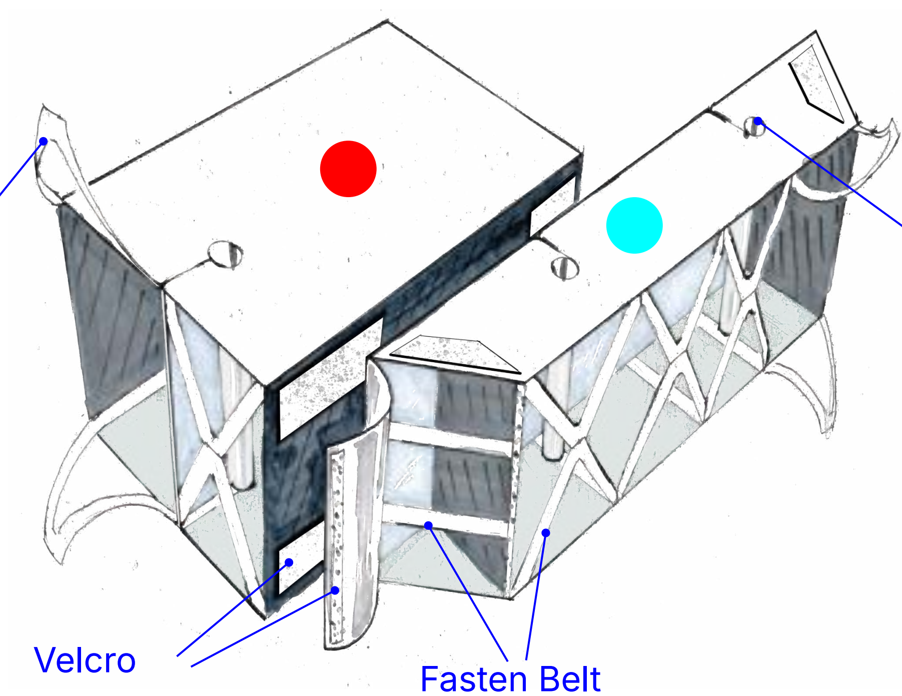
Storage Area I
124 CTBE / Section

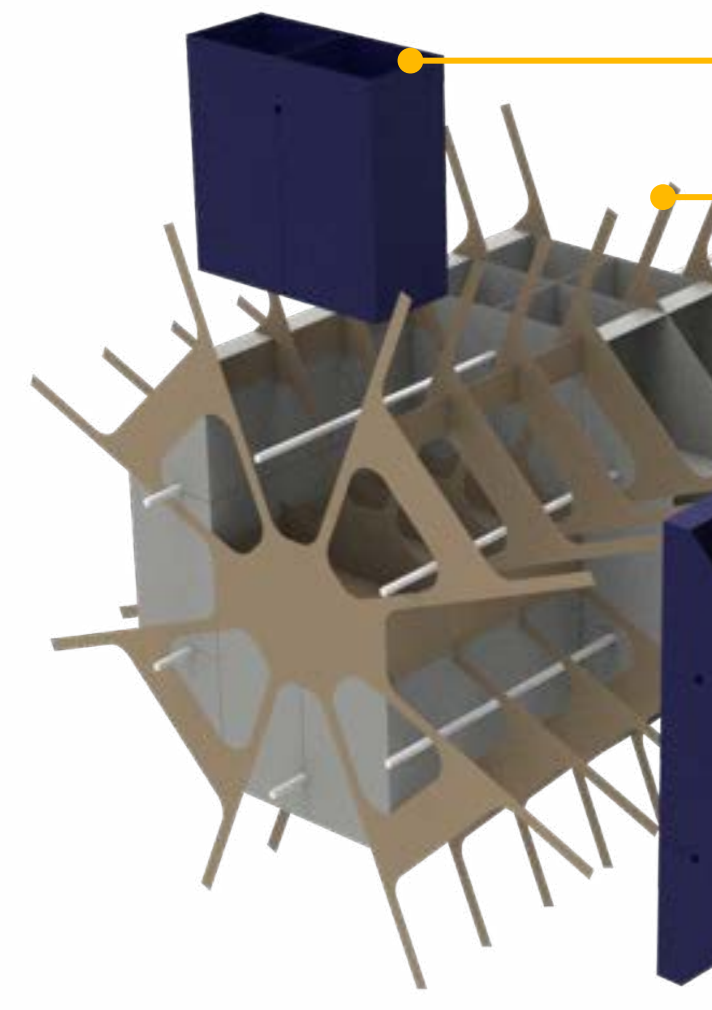
Storage Area II
100 CTBE / Section

Webbing
Strips in tension

Layout

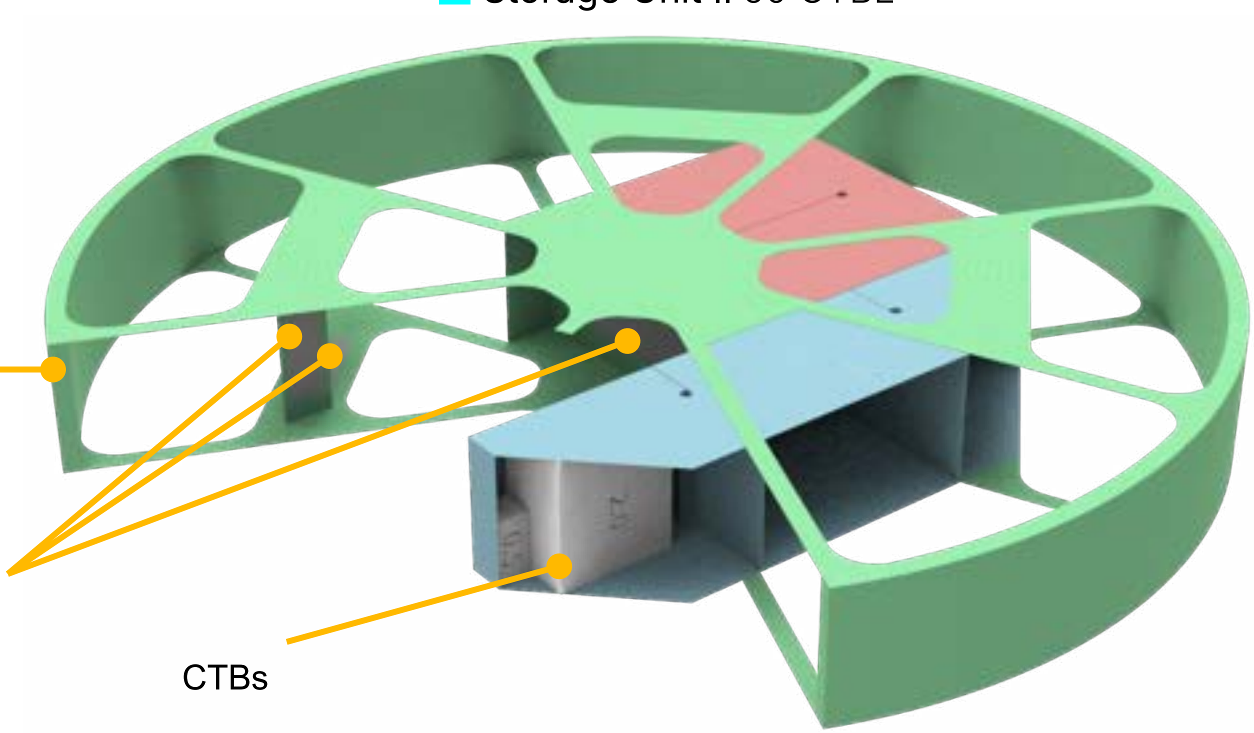






Storage Unit I 62 CTBE

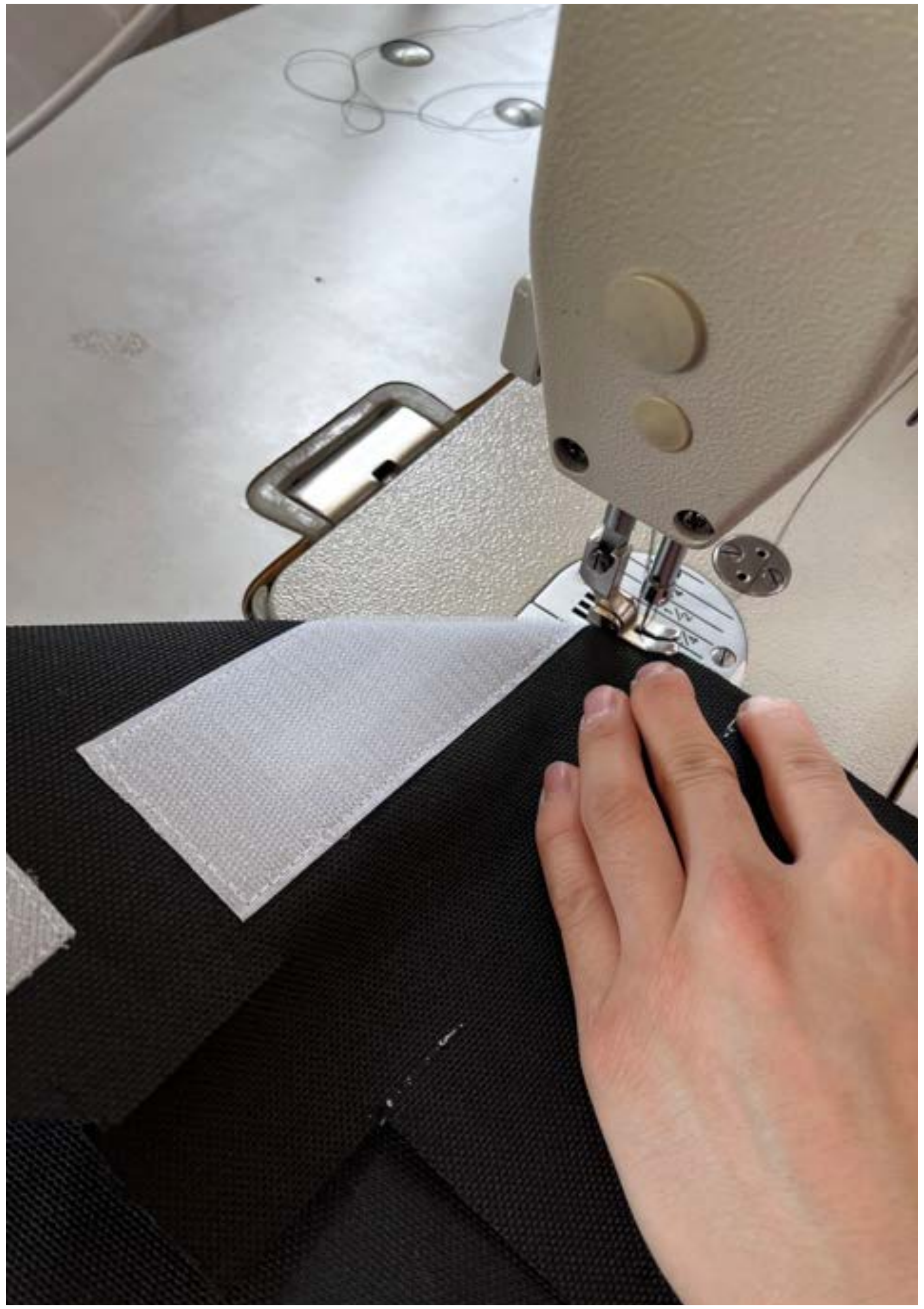
Storage Unit II 50 CTBE



Section 4 - Design Development

Fabric Prototyping

Once our ideas were clearer digitally, it was time to move on to physical prototyping in final materials. We started with a muslin mock up of the first storage unit to gauge how it would behave in fabric, and once we were confident enough we started creating the inner lining of the second module of the storage unit.

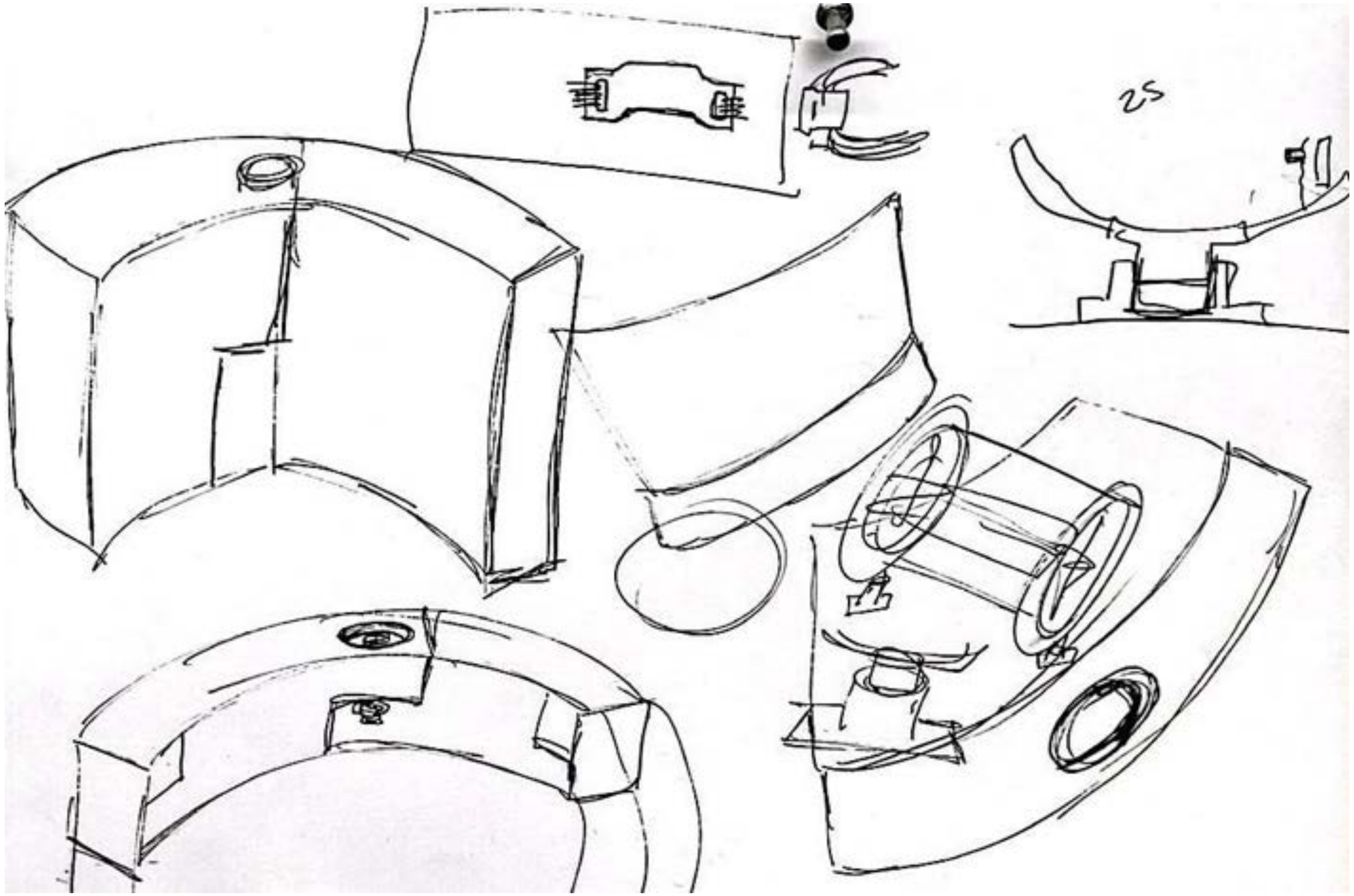


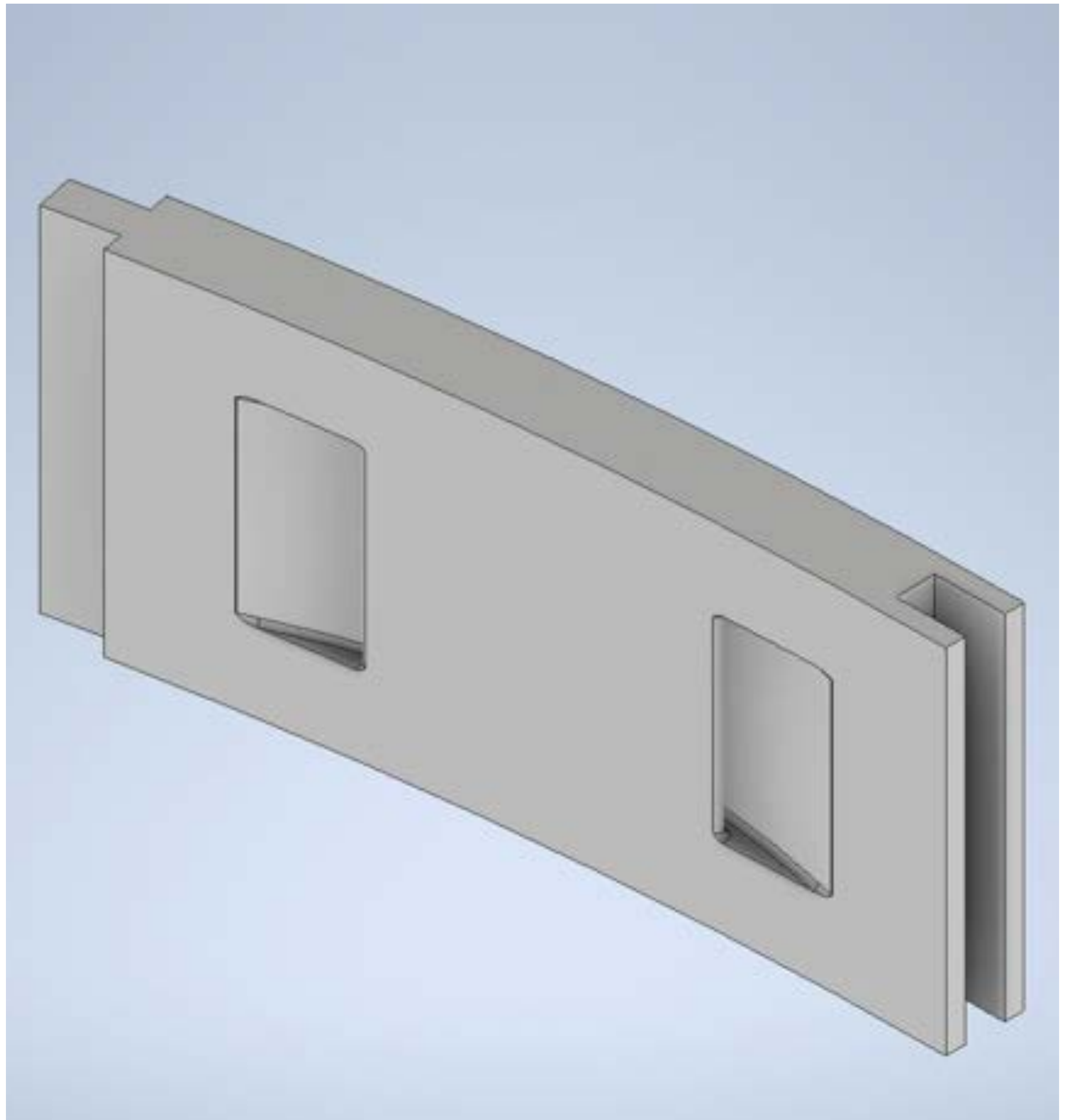
Section 5
Final Prototype

This full-scale module demonstrates our final storage unit design. It includes 3D-printed CTBs, adjustable buckle straps, and a Velcro-backed fabric shell. The unit attaches directly to the tensioned circular frame using pre-defined mounting points, confirming proper fit, secure attachment, and spatial efficiency within the inflatable habitat.

Section 5 - Final Prototype

Creating a scale model of an inflatable habitat





The next order of operations was to have somewhere to store our section of the storage unit we'd have designed. Modelling a part of the inner wall of the inflatable habitat to meet our 1:6 scale and printing it 32 times was essentially what we moved forward with.

Section 5 - Final Prototype

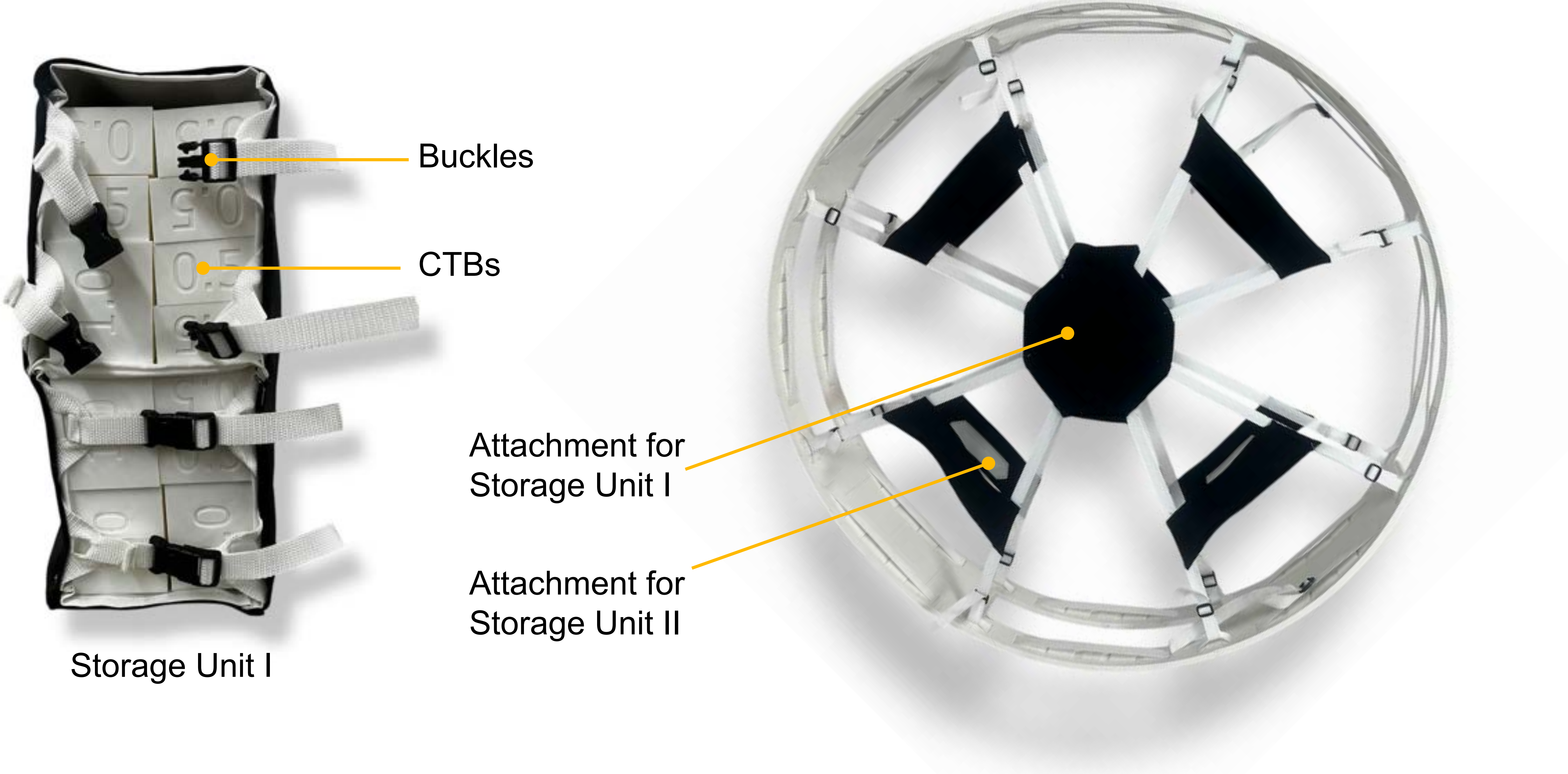
Assembling The Inner Wall

Utilizing nylon straps and buckles in order to create a mechanism where a person can adjust the tension of the habitat and so it can all come together as a full circle which measures to 50 inches in diameter. The image on the far right is the assembled outer wall with our prototype in the middle. We planned on printing multiple sizes of CTB's so we can fit them in our prototype

Section 5 - Final Prototype

Features & Benefits

This prototype showcases our modular storage unit designed for inflatable habitats. Each unit fits CTBs from 0.5 to 6.0 and attaches to a tensioned inner frame using Velcro. Buckles secure the load, while designated zones separate short-term and long-term storage. The system is reconfigurable, lightweight, and optimized for astronaut access in microgravity.

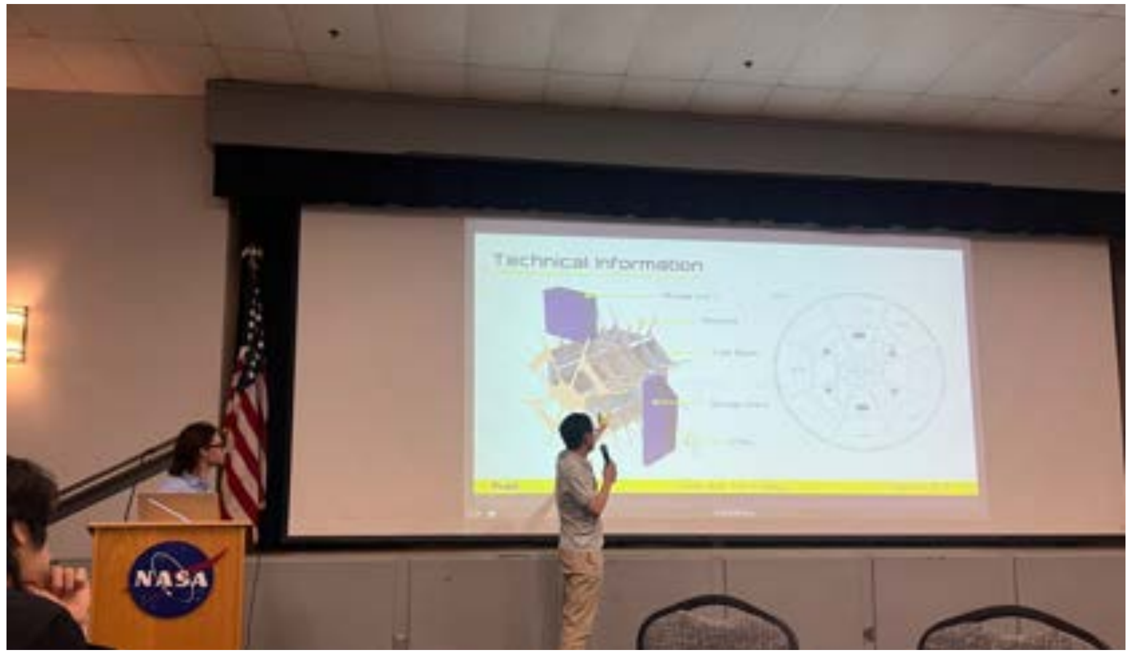


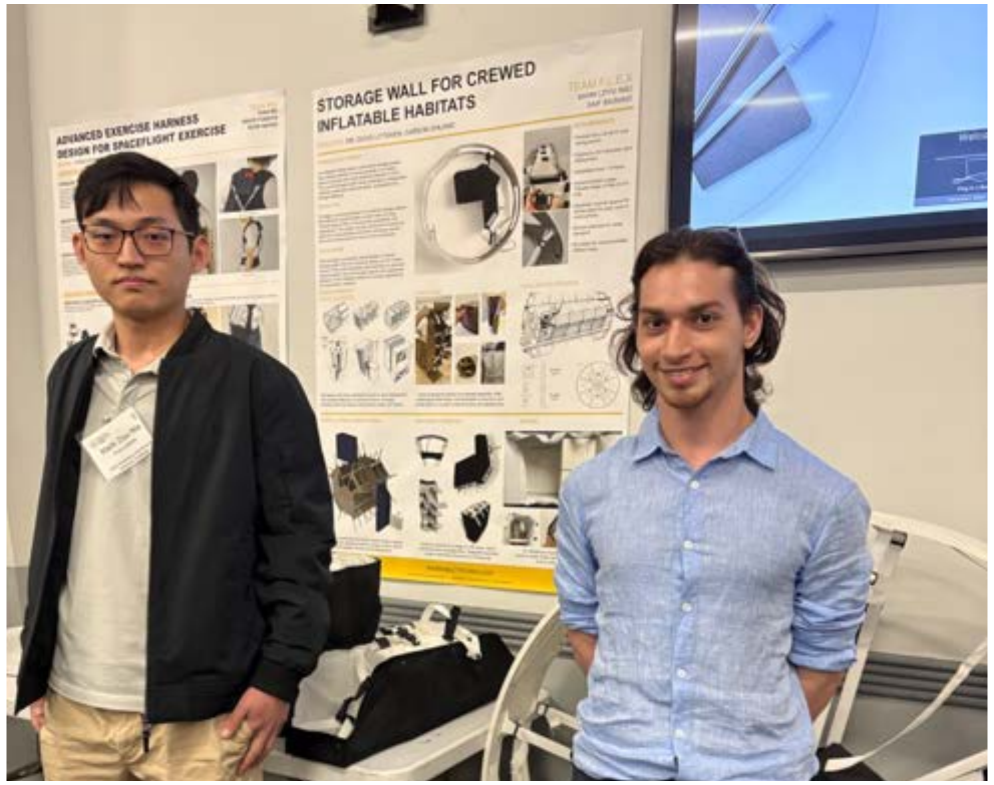
Section 6
Testing & Validation

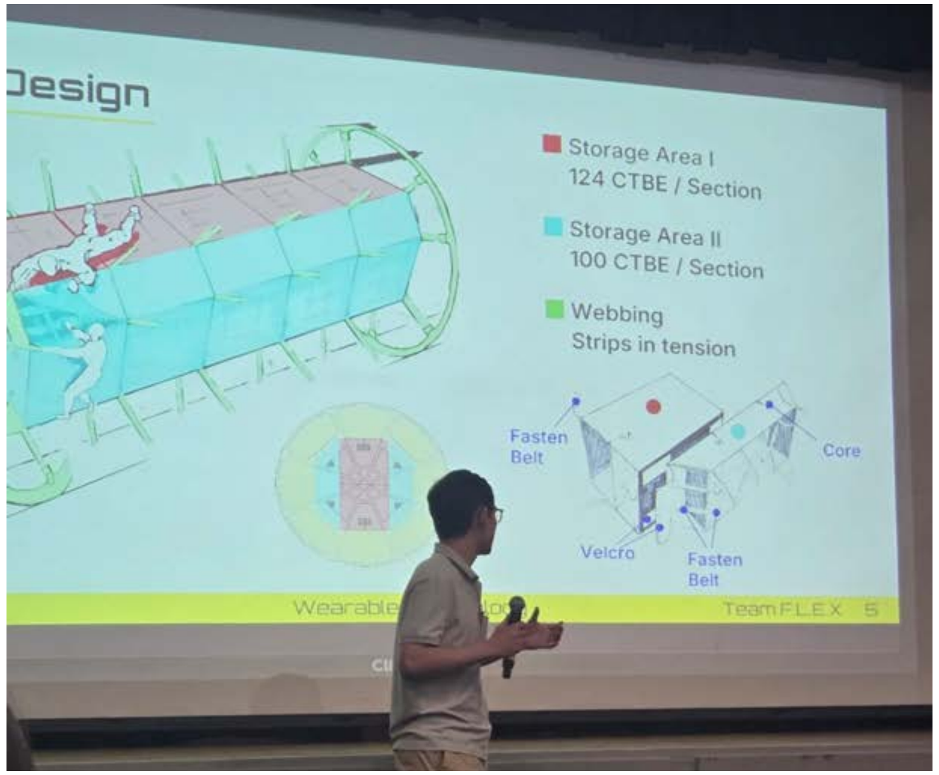
Once we printed out the first couple sizes of CTB's and figuring out that it's the right size, we proceeded on printing enough to be able to fill most of one of the modules, ranging from 0.5 to 6.0.

Section 6 - Testing & Validation
NASA Presentation

Presenting our idea in Houston to other students participating in the competition in addition to multiple representatives from NASA was a privilege and an honor for the both of us. We enjoyed all the insights gained as we also networked after the presentation with students from other schools who attempted to tackle the same challenge we did.







Next Steps

After our presentation we got great feedback from one of our mentors (Dr. Carson Ohland) who was present for our showcase, he elucidated the fact that if this solution were to be implemented it would be adopted in the next 20 years. This gives us a vast amount of time to think about what else we could improve upon, the following is a couple of things we would potentially consider if we were to move forward:

- Considering creating a module out of selected final material such as Vectran
- Creating a full module to see how it would actually behave
- Simulate launch compression and post-deployment expansion to assess dimensional integrity of the packed system.
- Explore automated or semi-automated deployment mechanisms to reduce astronaut setup time and error.
- Evaluate long-term material fatigue and Velcro degradation under repeated use and microgravity exposure.

With all that being said, we enjoyed every second of this project and we look forward to potentially exploring the rooms for improvement stated above.

Pratt | Team F.L.E.X