STARGATE Infatable Crew Lock

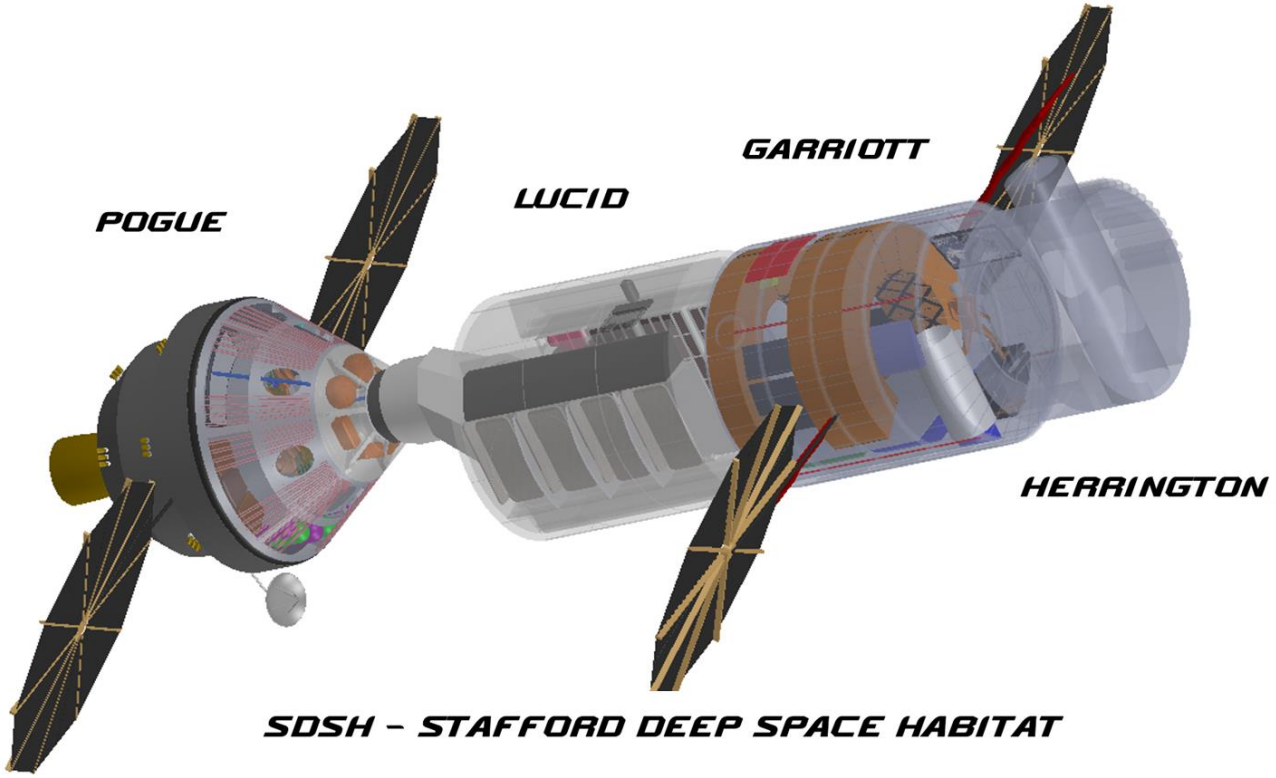
Honors Thesis Report

Adam S. A. Morgan

Overview

- History of X-Hab at OSU
- Project Overview
- Historial Context
- Operational Conceptual Design
- STARGATE Build Phase
- Presentations and Outreach

History of X-Hab at OSU



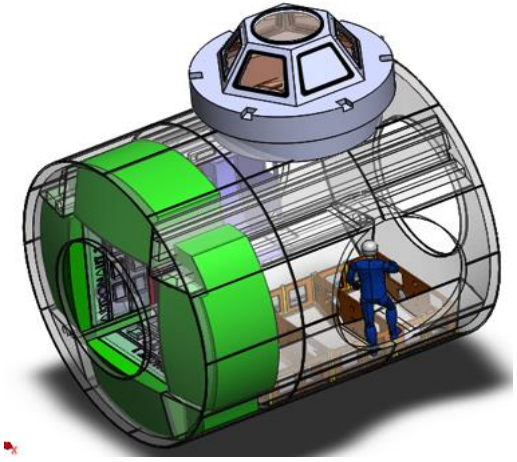
Previous Years and Project Director

History of X-Hab at OSU
X-Hab Program

- **X-Hab**
  - NASA's Exploration Habitat Innovation Challenge
  - Universities selected annually to design systems for NASA ground tests
- **Selection Process**
  - Universities submit proposals for future operational concepts and a proposal for a ground test system
  - NASA reviews proposals, selects ~10 annually
  - Schools are notified near the start of academic year

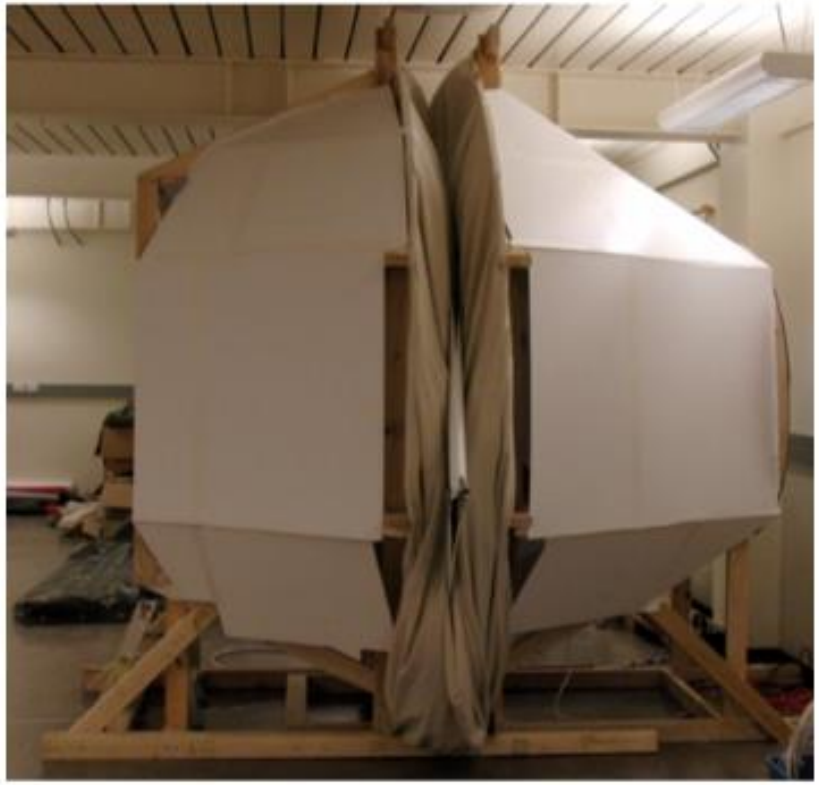
History of X-Hab at OSU

- **Started involvement in X-Hab in 2010**
- **Combined interdisciplinary senior design with outreach efforts**

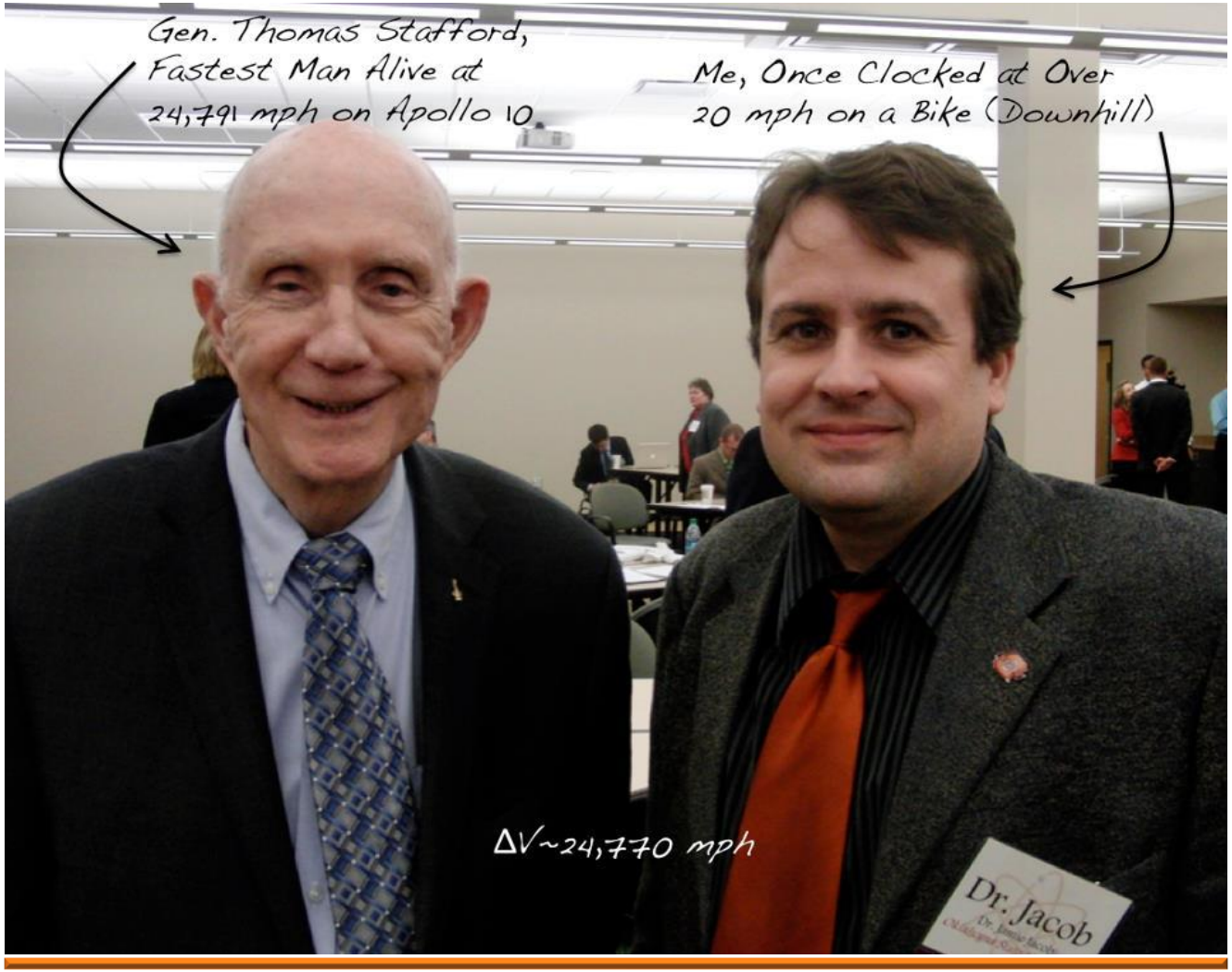


History of X-Hab at OSU
Highly Expandable Module

- **2012 X-Hab**



History of X-Hab at OSU
Director – Dr. Jamey Jacob



Project Overview

Jordan Squire, Brandon White, James Brenner, Austin Bennett, Jackson Jandreau, Michael Raymer
Jake Briles, Gabrielle Isaacs, Madison Whiteley, Joshua Pankratz
Justin Duewall, James Brenner, Joseph Lester, Adam Morgan, Andrew Quinton

Vision, Objectives, Requirements

Project Overview
Vision

- **Vision**

  Design an autonomously deployable crew-lock system which operates in a null gravity environment and enables safe passage from one pressurized environment into another or into a vacuum.

- **Mission**

  Develop a compact analog inflatable system to demonstrate viability of operational system and to enable deployment and employment ground testing.

Project Overview
Objectives

- **Develop an operational concept**
  - Benchmark current operational capabilities
  - Anticipate future needs
- **Design a demonstration analog**
  - Deployment demonstration objective
  - Crewed Internal Ops demonstration objective
  - Additional demonstration features - TBD
- **Document, Iterate, and Test during construction**
  - Compliance w/ Safety Standards
  - Documentation for shipping, future development, & future testing
- **Educational Outreach**
  - Foster interest in & appreciation for STEM

Project Overview
Required System Architecture

- **System Definition:** Inflatable Airlock system deploys from a compact state and expands to permit the passage of astronauts between a pressure vessel and its surroundings.

Concept:

- The design will have an inner support structure that is wrapped in a outer fabric layer.
- The inner skeleton will automatically expand out from its compact state and pressurize.
- The crew members will enter the airlock through one of the two hatches located at the entrance and exit of the airlock.

Layout

- The Analog dimensions will not exceed 8 ft. X 8ft. X 8ft. Space will allow crew activities such as battery charging, tool setup.
- Floor structure will accommodate up to four crew members according to current NASA specifications
- On-Board utilities will include: fire detection system, ventilation, lighting, power distribution lines.

Project Overview
Level 1 Requirements

- Crew lock inflates with some mechanical/manual assistance to slightly higher than 0.5 psig
- Demonstration crew lock allows crew to move throughout module to demonstrate EVA prep
  - Crew of up to 4 people
- Provide a plan for FOD and a user's guide for operating procedures
- Interfaces for doors are not specific but should be able to transfer to other NASA prototypes such as lunar lander payloads

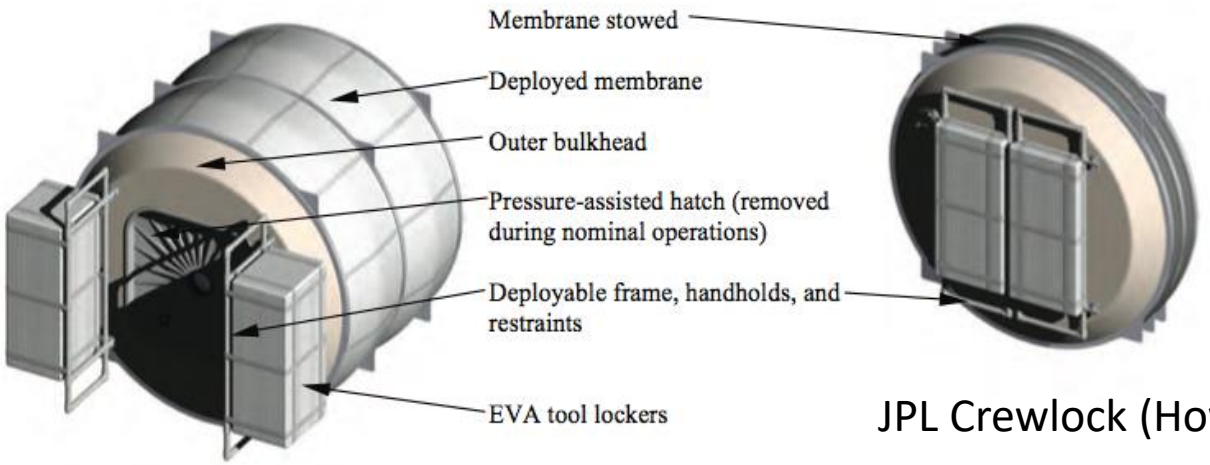
Project Overview
Requirements Summary

- Operational
  - Function as a crew lock which is deployable in an unpressurized environment
  - Structurally sound with 0.5 psig of inflation
  - Feature a hatch to allow crew transfer
  - Allow for crew activities such as gear setup
  - Allow for attachment from structure-to-structure or structure-to-vehicle
- Demonstration
  - Function as a crew lock analog which is deployable
  - Feature an open hatch to allow crew transfer
  - Allow for crew activities such as gear setup
  - Structurally sound with 0.5 psig of inflation
  - Able to be re-stowed for storage
  - Contain a stable floor which can support up to 4 people

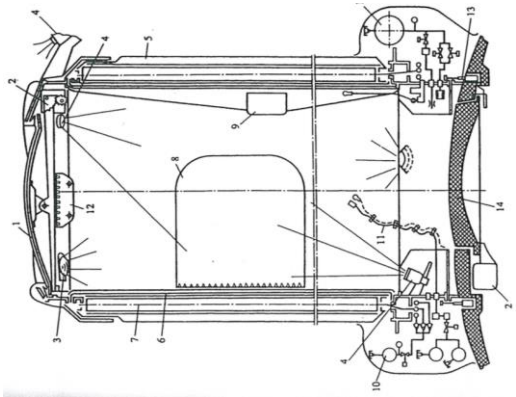
Historial Context

USSR's Volga Inflatable Crewlock

Historical Context
JPL Concept & Volga



JPL Crewlock (Howe et al.)



Volga – Soviet Era Crewlock used for first spacewalk

Historical Context
Volga Systems Analysis

- **Purpose**
  - Reverse Engineer the Volga inflatable airlock to examine systems integration
- **Major Systems**
  - Structural Pressure System
  - Environment Pressure System
  - Suit Pressure System
  - Exterior Hatch Systems

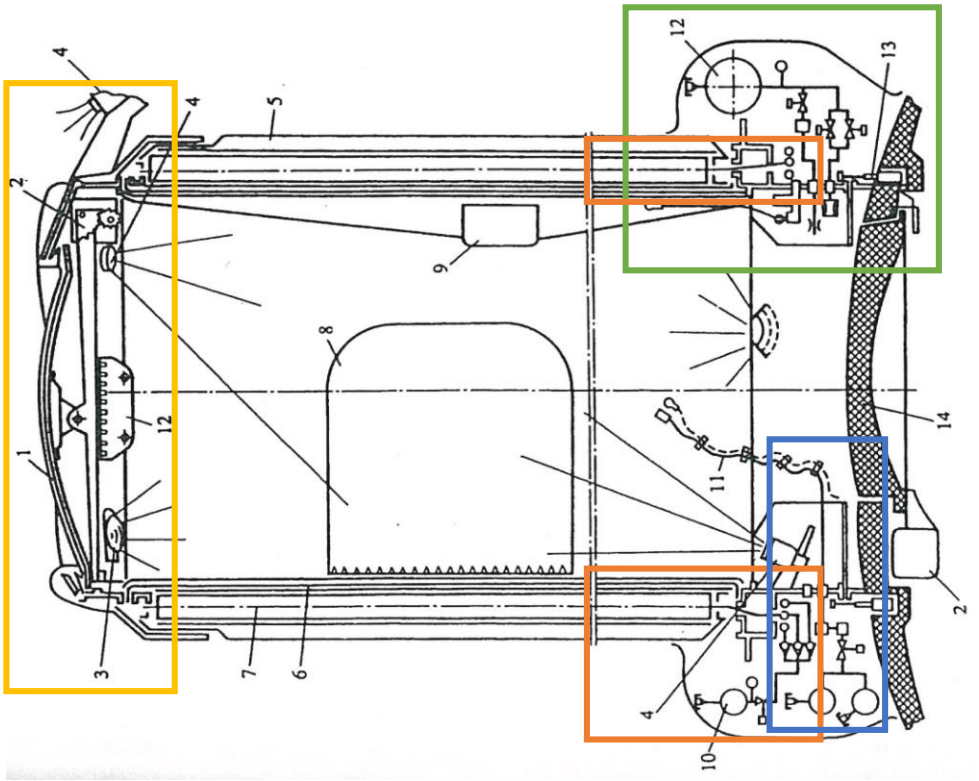
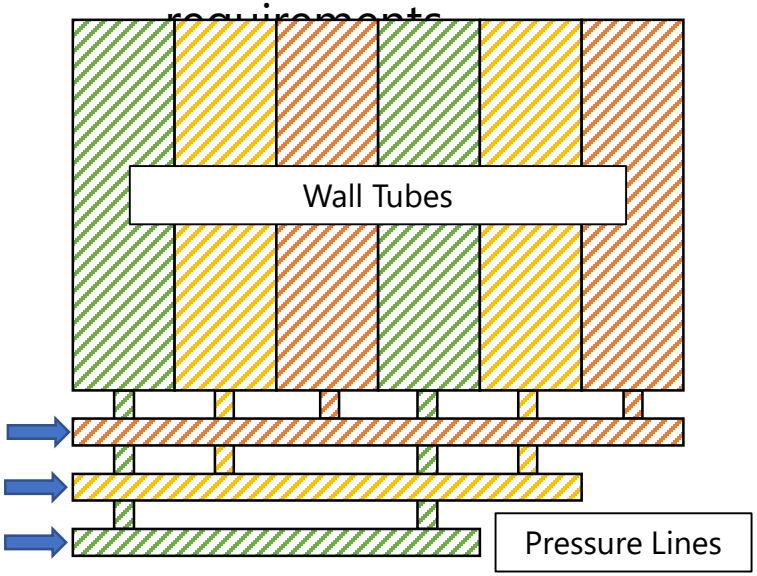


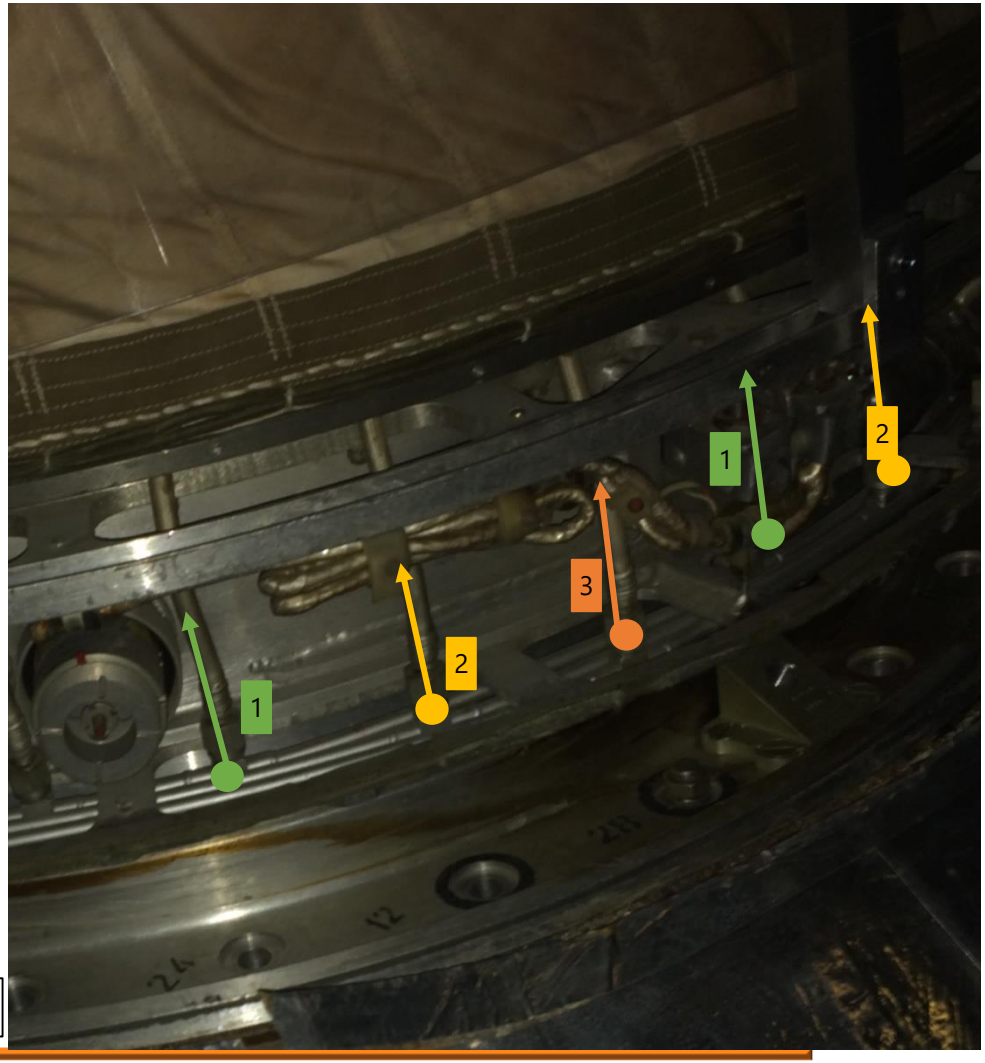
Figure 4.2.2 Design solution for the *Voskhod-2* spacecraft airlock. 1—EVA hatch cover; 2—drives for hatch opening; 3—light; 4—cameras; 5—soft enclosure; 6—pressure bladder; 7—air beams; 8—elements to attach the equipment inside the airlock; 9—control panel; 10—air beam gas inflation system; 11—safety tether with oxygen supply hose; 12—airlock air inflation system; 13—mechanism to blast off the airlock after EVA; 14—hatch of the descent vehicle for *Voskhod-2*.

From Archive Zvezda.

Historical Context
Volga Inflation Analysis

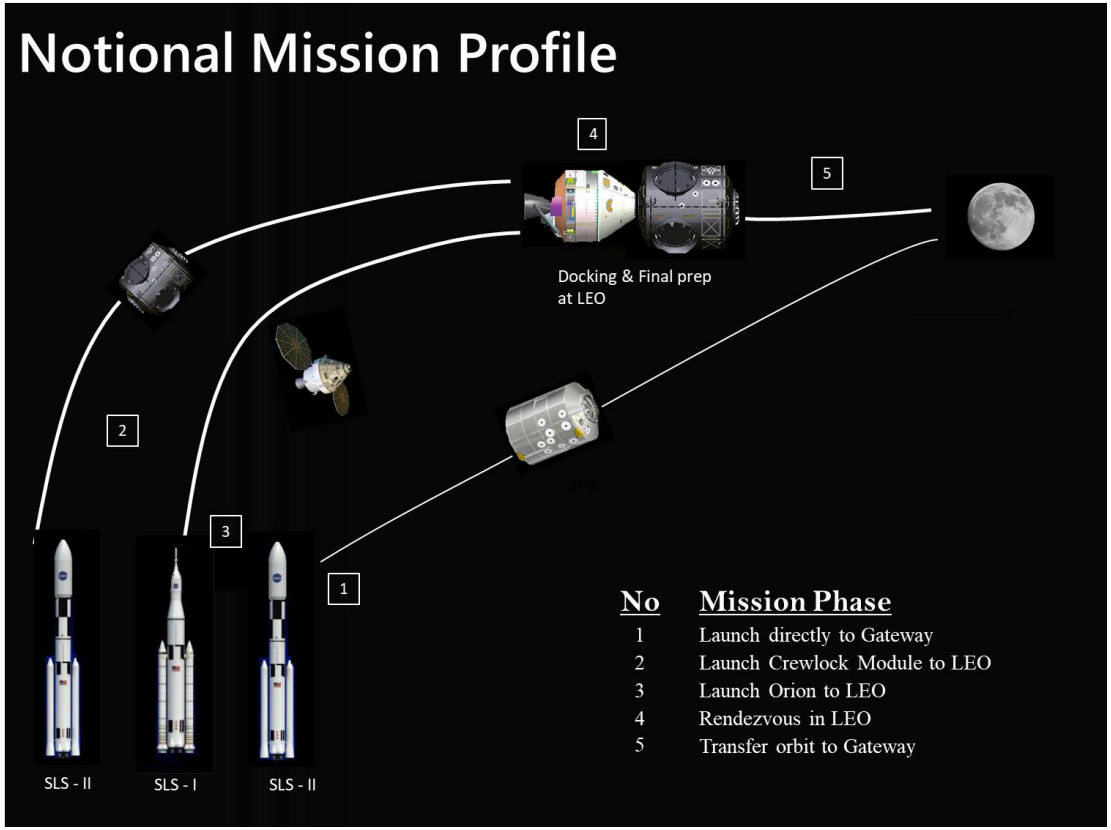
- **Examined pressurization systems**
  - Determine methodology, redundancy & layout
  - Examine design choices in context of the system and mission requirements





Historical Context
Voskhod 2 - Volga Airlock

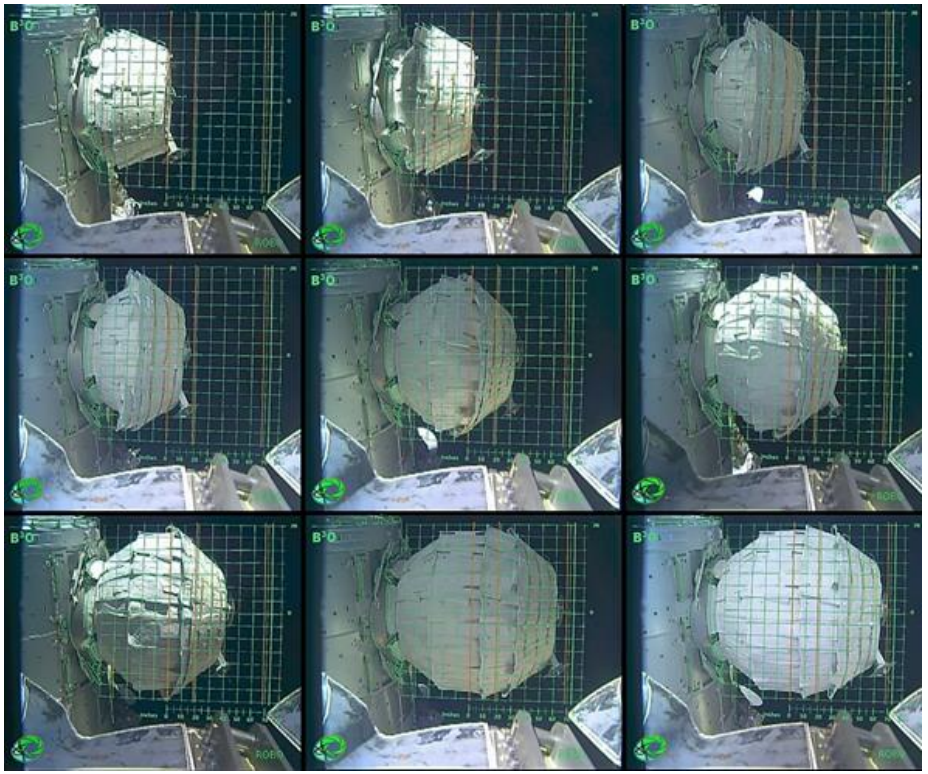
Operational Conceptual Design



Historical Context, CONOPS, Solution Components, Design Space, and Selection

Operational Conceptual Design CONOPs

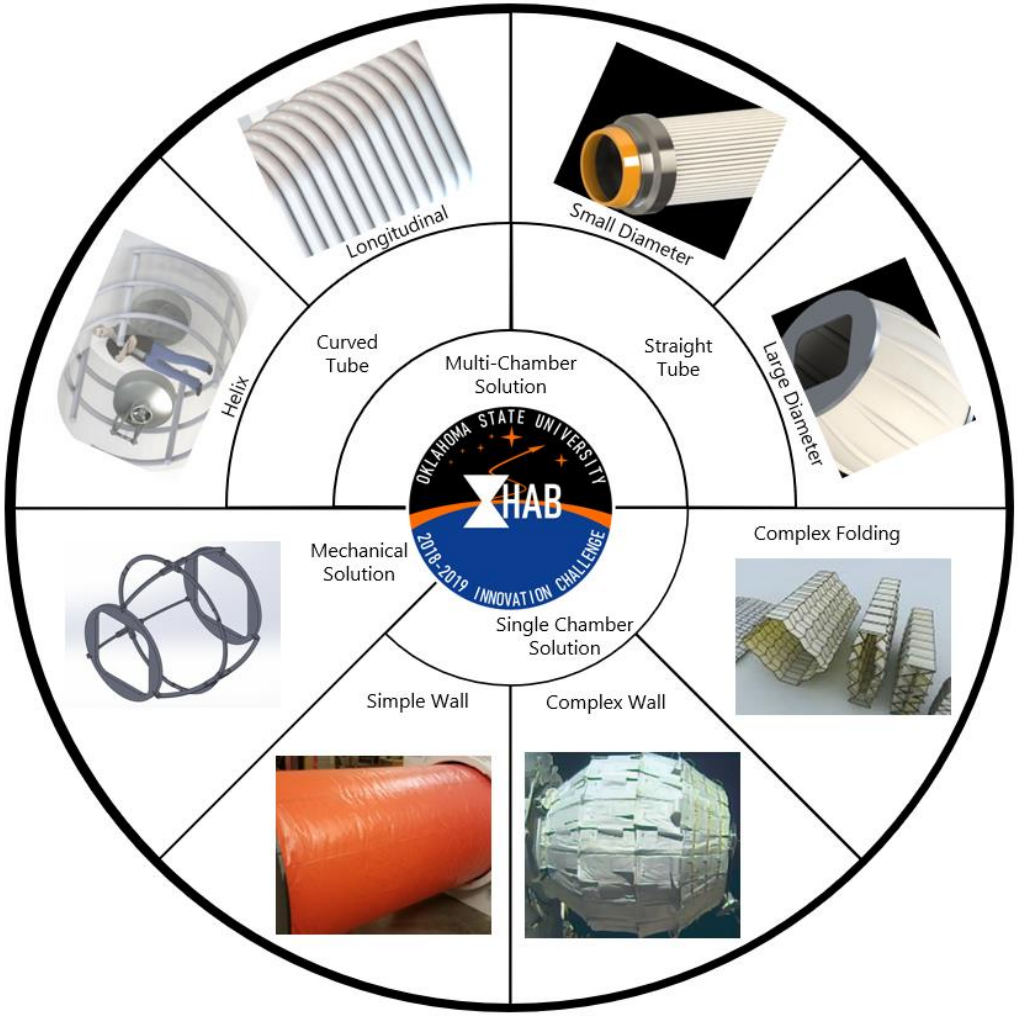
- Initial proposal used terrestrial design. The operational and analogue systems follow similar CONOPs
  - Deployment from stowed state
  - Pressurization
  - Integrity evaluation
  - Utilization as crewed space
  - Depressurization prior to EVA
  - Retraction (Optional)
  - Constant Monitoring and Evaluation



Operational Conceptual Design Components

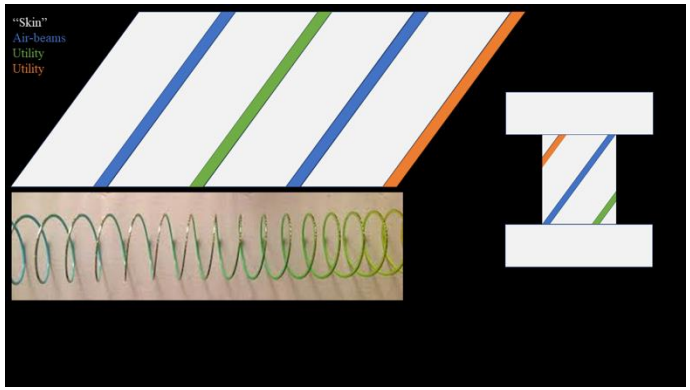
- Hatches for entering and exiting are fully sealed for pressurization
- Structure is inflatable to allow for compact storage
- Automatically deployable
- Safety measures for system failure conditions
  - Safety pressure release valves, CO2, fire detection, lighting and ventilation for all essential systems

Operational Conceptual Design Solution Space



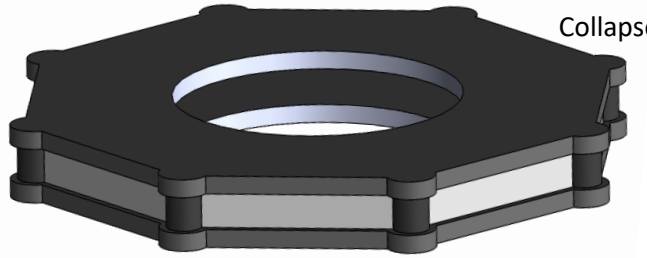
Operational Conceptual Design
Helix Tube Concept

- **Helix Airbeam**
- **Non-uniform geometry**
- **Pressurized deployment and Retraction**
- **Complicated Fabrication**



Operational Conceptual Design
Straight Beam

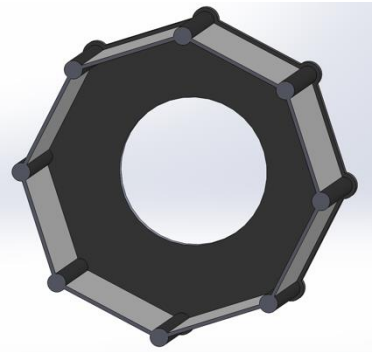
- **Simple geometry and deployment**
- **Easily scalable to meet varying requirements**
- **Multiple beams = redundancy**
- **Proven Design**
- **Horizontal & vertical orientatio**



Collapsed view

Deployed airlock with passenger

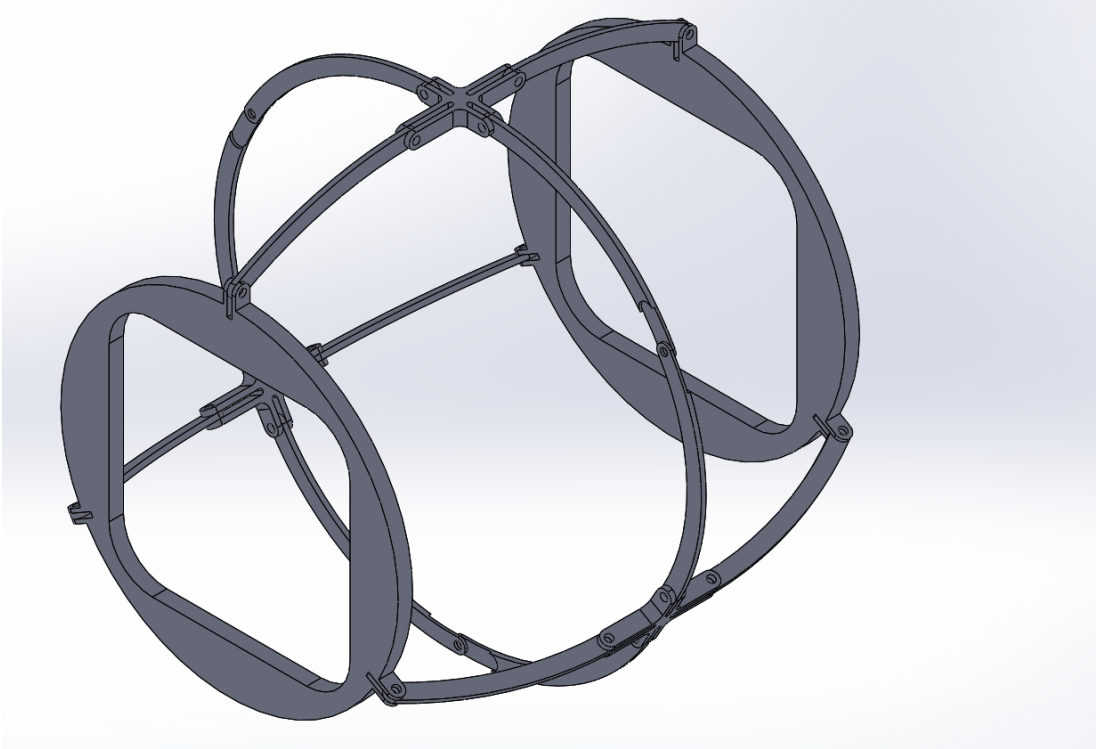
Volga Airlock



Cross-sectional view

Operational Conceptual Design
Mechanical Hybrid System

- **Inflatable deployment structures**
- **Mechanical Redundancy**
- **Simple deployment**
- **Heavy structural components**



Operational Conceptual Design
Deployment Concepts

Lateral vs. circumferential beam designs

Platform Concepts for Earth Analog

E.g., pros/cons of lateral vs. circumferential beams

- Deployment
- Manufacturing
- Cost
- Safety
- Etc.

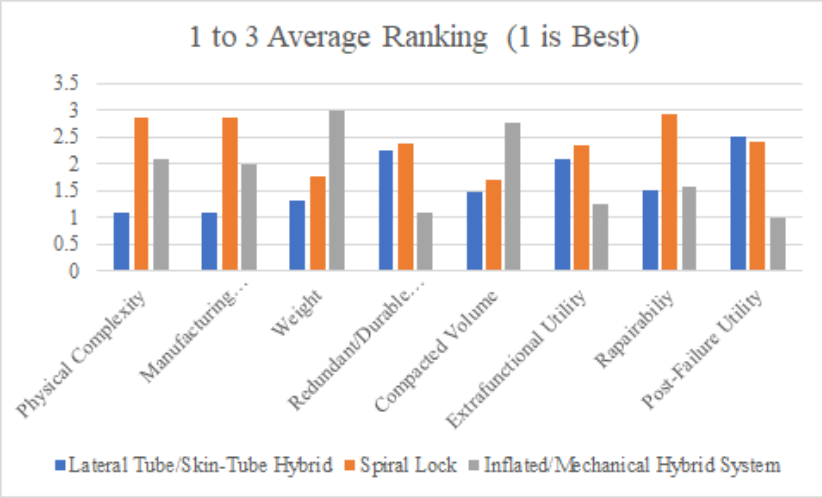
- E.g., pros/cons of folding vs. telescoping supports
- Deployment
- Manufacturing
- Cost
- Safety
- Etc.

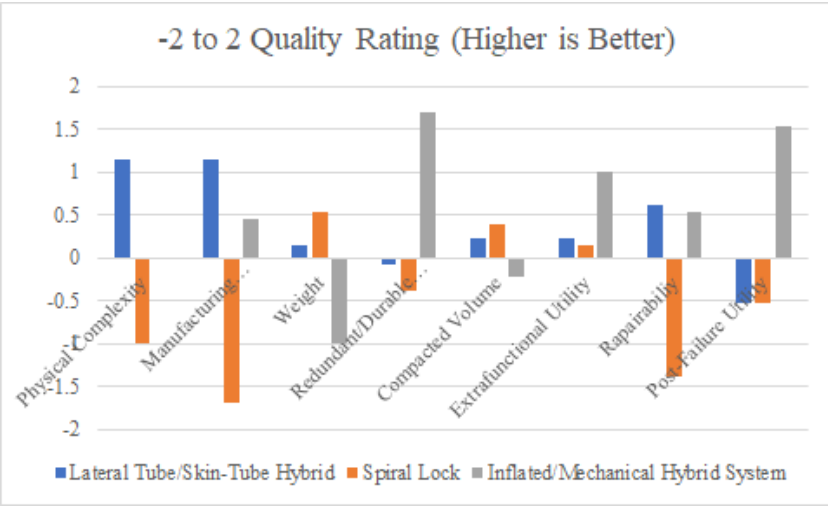
Operational Conceptual Design
Design Trade Study

- **Assessment Criteria**
  - Physical Complexity
  - Manufacturing Complexity
  - Weight
  - Durability
  - Compacted Volume
  - Extra-functional Utility
    - Any extra functionality that the design provides
  - Reparability
  - Post-Failure Utility
    - How usable the design remains after failure.

Operational Conceptual Design Downselect

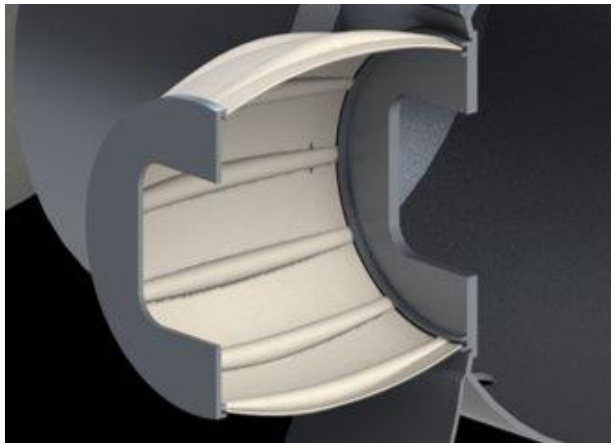
- **Results**
  - Helix
    - Construction complexity
    - Mainly offers Novelty
  - Mechanical Hybrid
    - Redundancy at the cost of weight
  - Straight Beam
    - Outperforms in practical areas
      - Weight, complexity, compactability

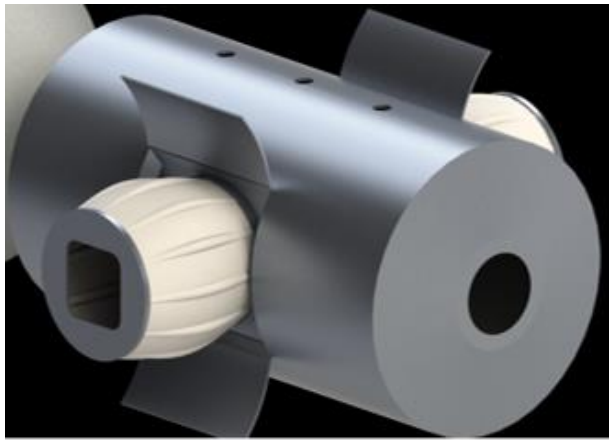




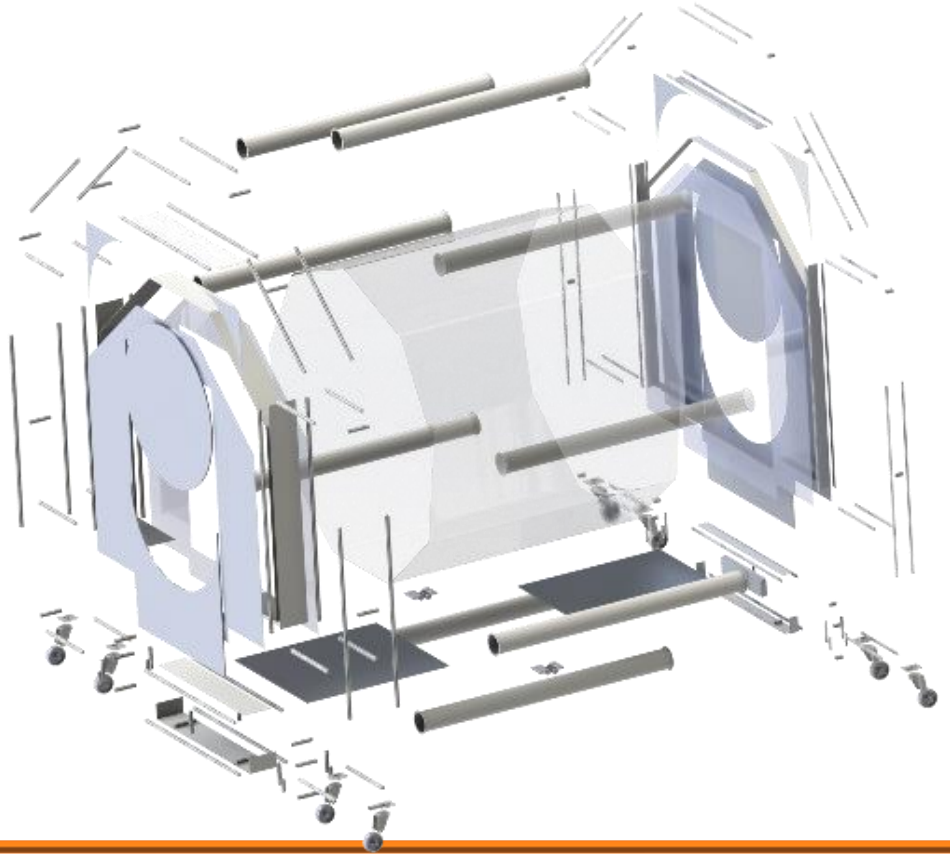
Operational Conceptual Design
Operational System

- **Structural Elements**
  - Large-Diameter Support Tubes
  - Connected by layered fabric
- **Large interior Volume**
  - Integration of other systems
    - Suitport Concept
  - Potential for mechanical redundancy
  - Expanded Utility





STARGATE Design Solution

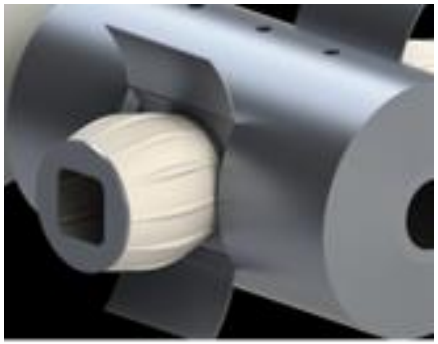


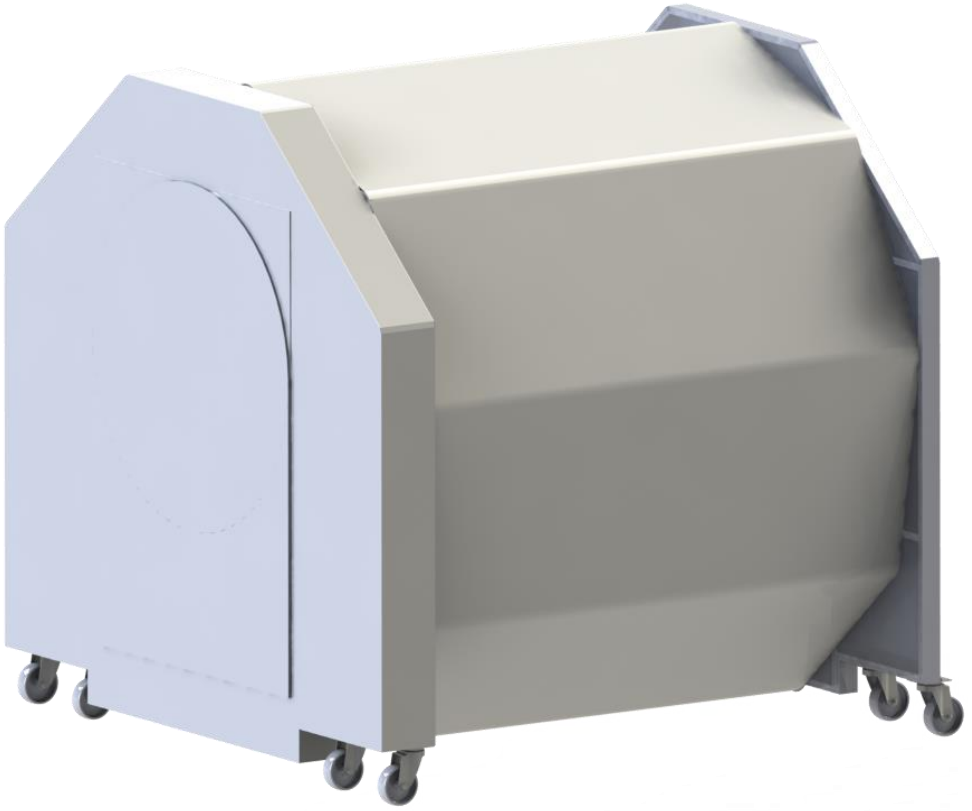
Design Philosophies, Terminology, Overview and Components

STARGATE Introduction

PDR
OS Design Concept

CDR
STARGATE Demonstrator

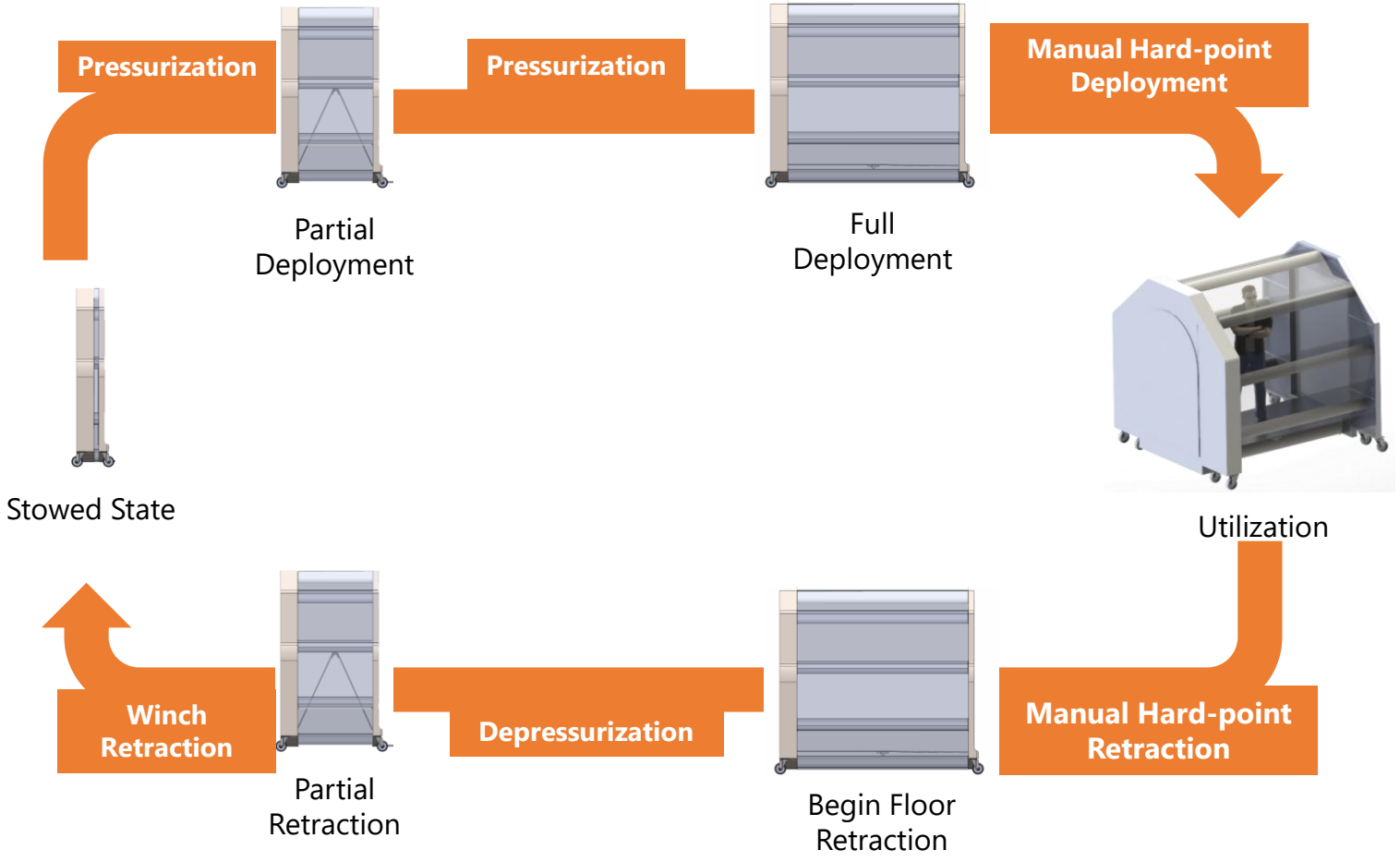




STARGATE Design Solution
Design Philosophies

- **Maximize interior volume while retaining collapsibility**
  - Optimized floor space and head room, compact systems
- **Ease of use by automating system operations**
  - Automatic floor deployment
  - Self-contained systems
- **Incorporating quality of life features**
  - Dutch Doors and hardpoint mounts
  - Variable system configurations
- **Retaining operational system characteristics while meeting demonstrational design requirements**

STARGATE Design Solution
CONOPS

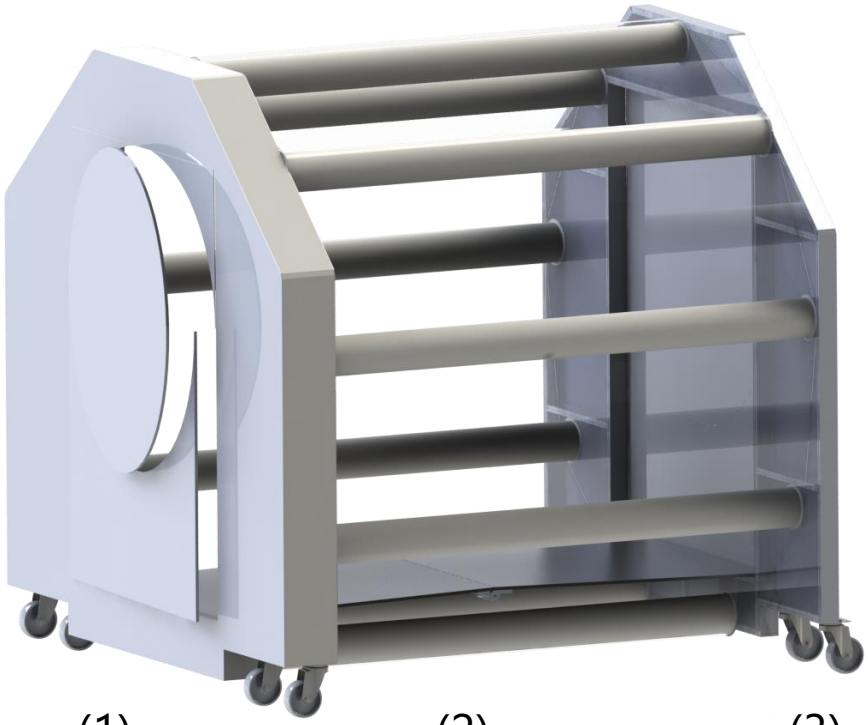


STARGATE Design Solution
Component Terminology

Major Components

1. **Dock**
   a) Frame
   b) Wheel-Base
   c) Door
   d) Paneling
2. **Span**
   a) Air beams
   b) Exterior Wall
   c) Interior Wall
   d) Floor
3. **Bulkhead**
   a) Frame
   b) Wheel Base
   c) Door
   d) Paneling

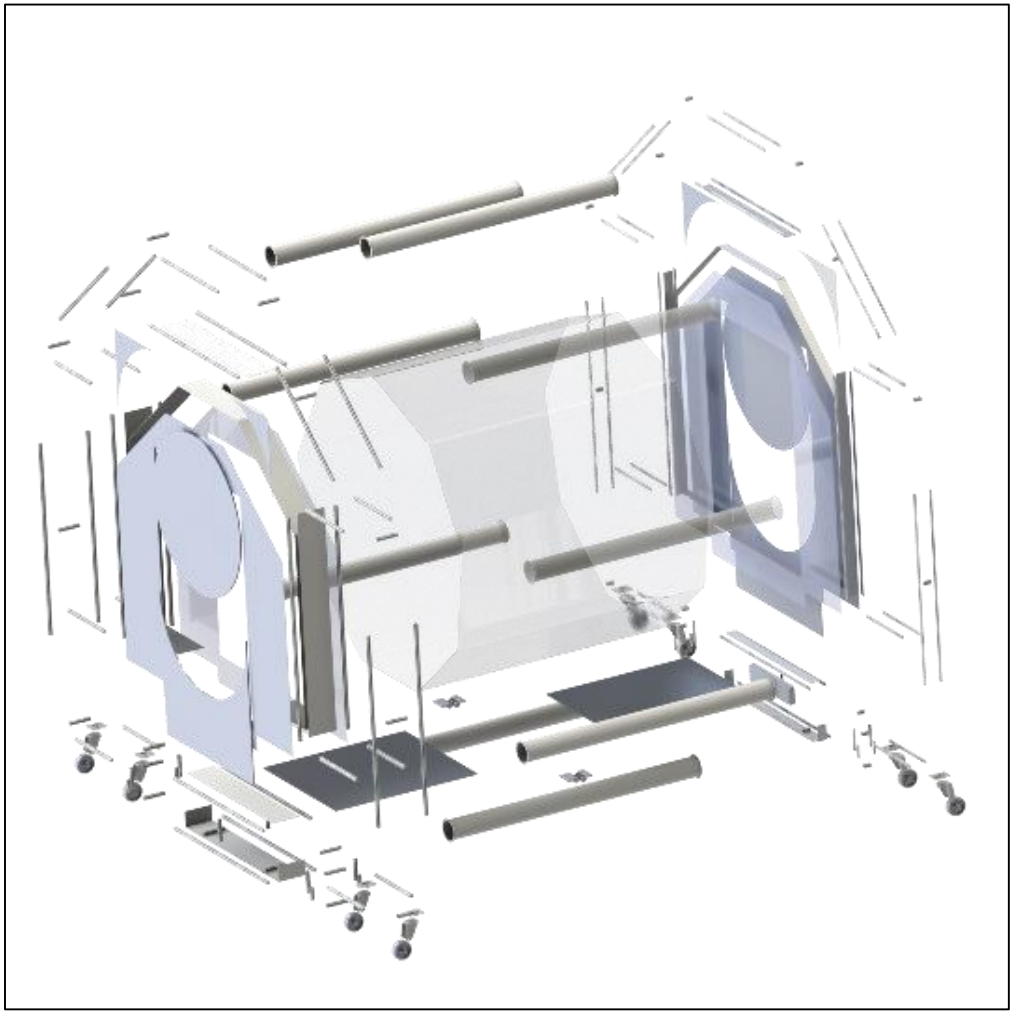
Front → Back



(1) (2) (3)

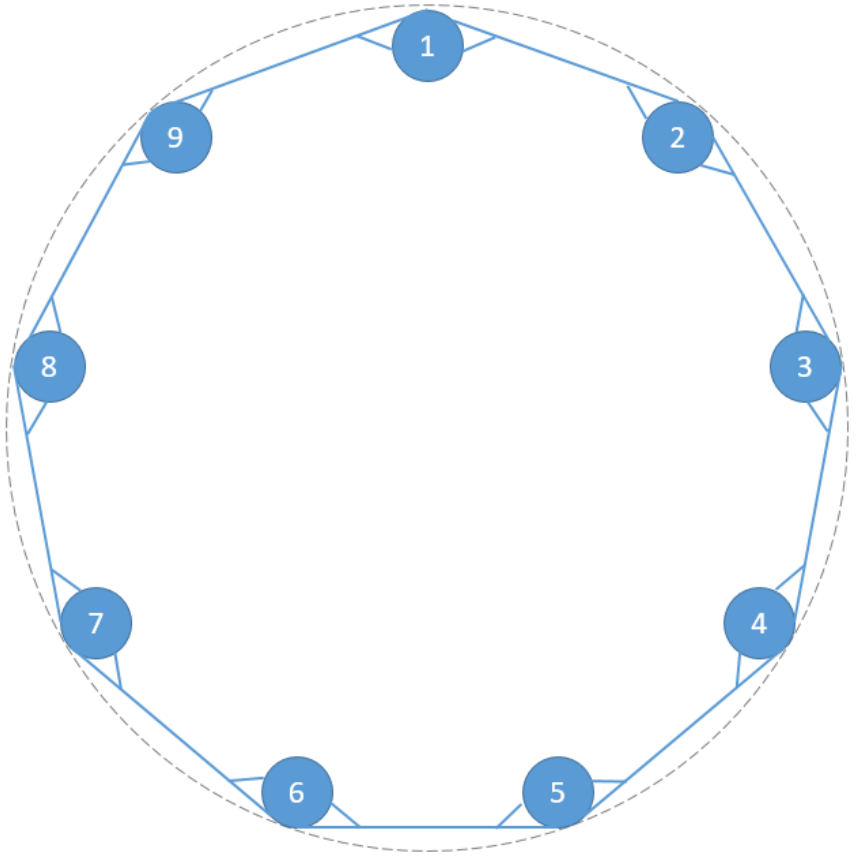
STARGATE Design Solution Overview

- **Dock Frame**
- **Span Configuration**
  - Air-beam and Wall Construction
  - Floor
- **Bulkhead Frame**
- **Other Design Elements**
  - Hardpoints
  - Wheelbase
  - System Integration



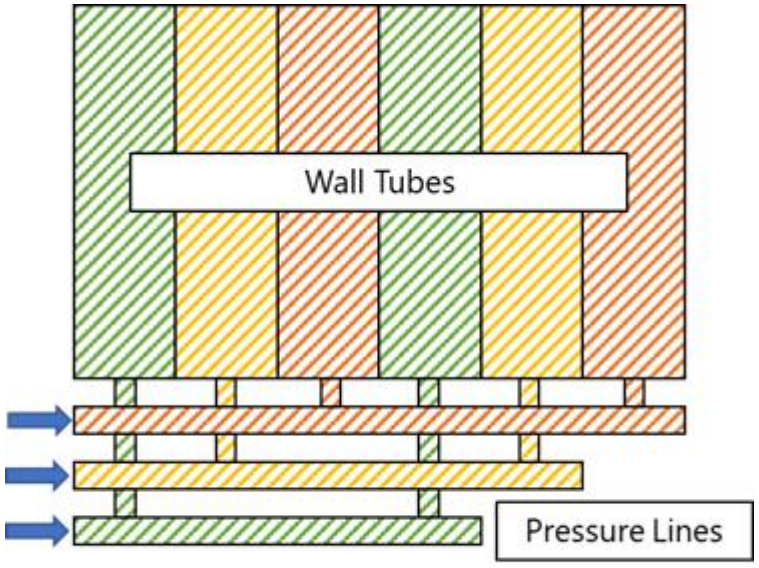
STARGATE Design Solution
Radial Profile

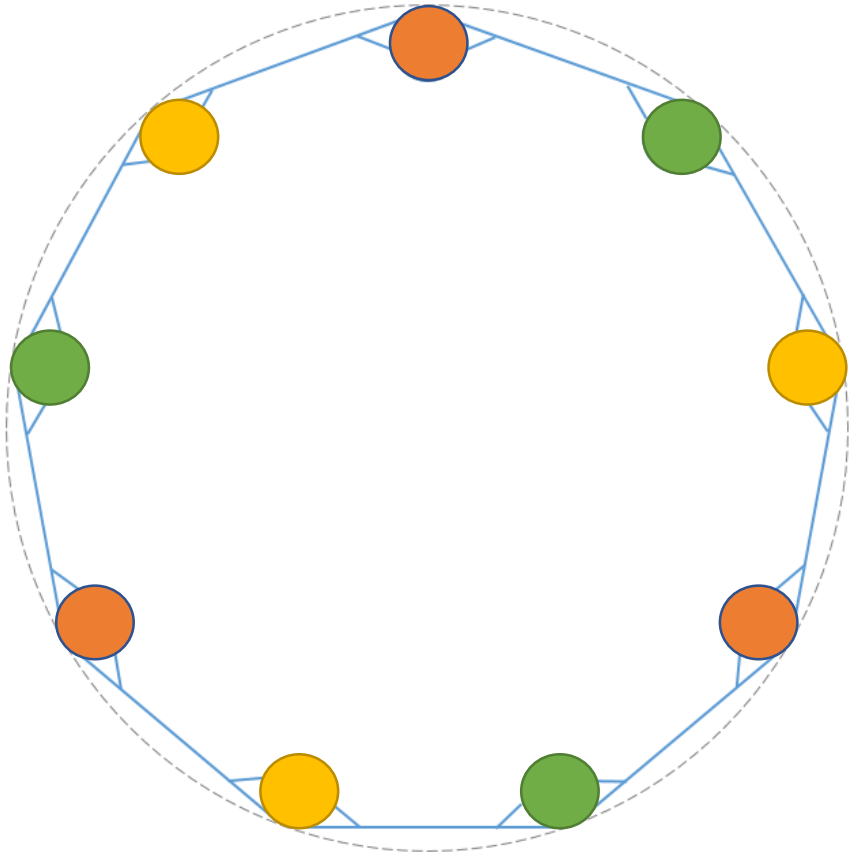
- **6-in. Diameter air beams**
  - Nonagonal configuration
  - Inscribed on 8-foot diameter circle
- **Air beams Sizing**
  - Provide expansion force during deployment
  - Carry small internal loads (fabric hardpoints)
- **Semi-permanent outer wall**
  - Removable using snap-button fastener system



STARGATE Design Solution
Air beam Pneumatic Systems

- **Three Independent Pressure Lines**
  - Tubes alternate lines
  - Single line failure – symmetry maintained



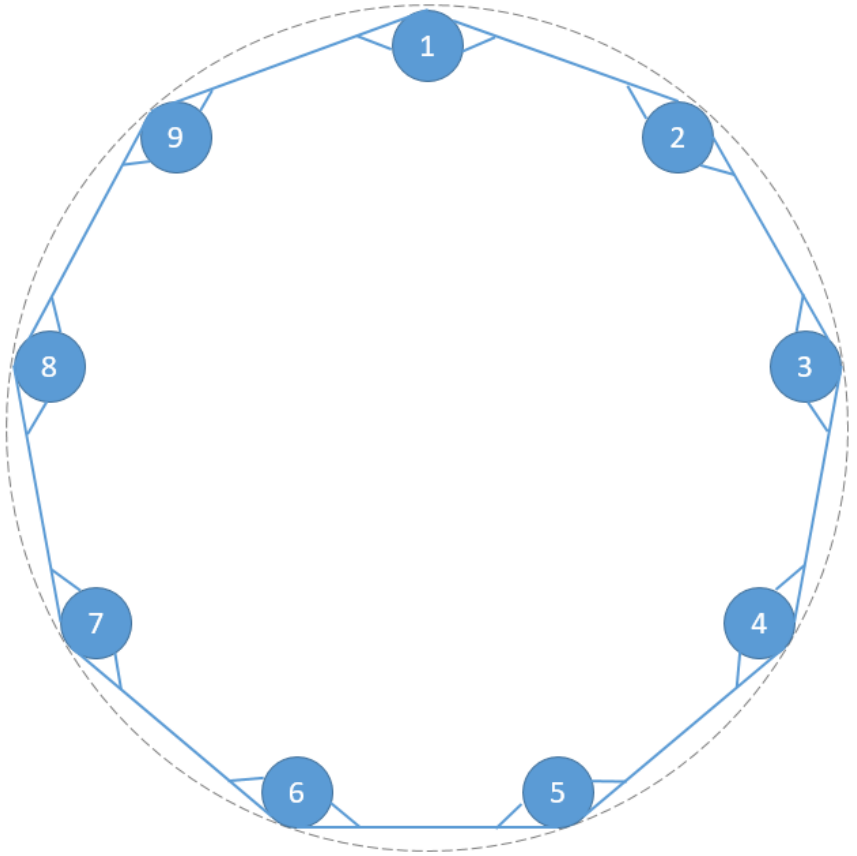


14 Dec 18

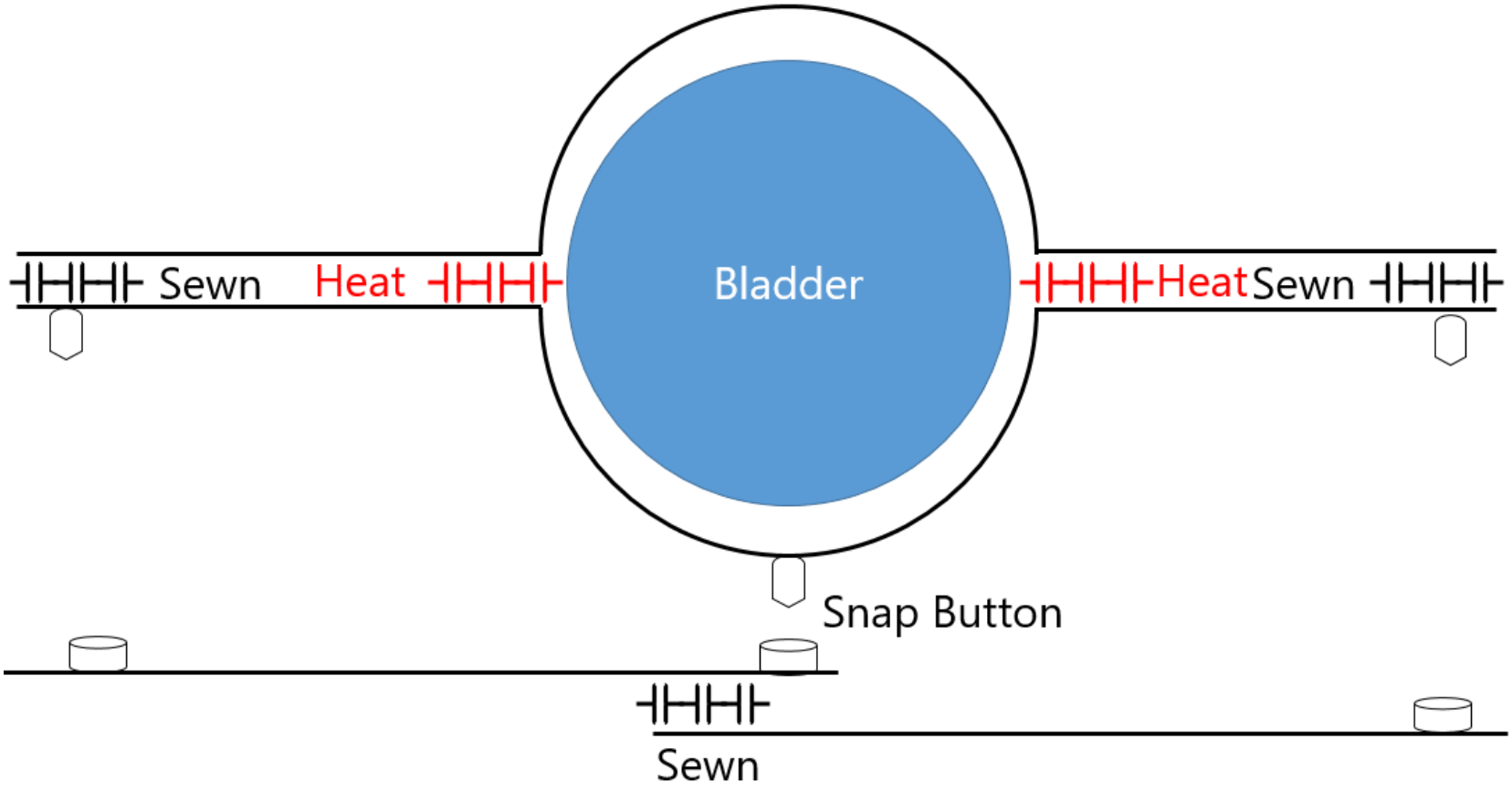
STARGATE Design Solution
Airbeam Expansion Forces

- **Maximum Expansion Forces**
  - 9 Airbeams
  - Area of 28 – sq. in.
  - Peak Force – 127-lbf

- **With intended method of airbeam contraction, nearly peak force should be maintained throughout inflation**

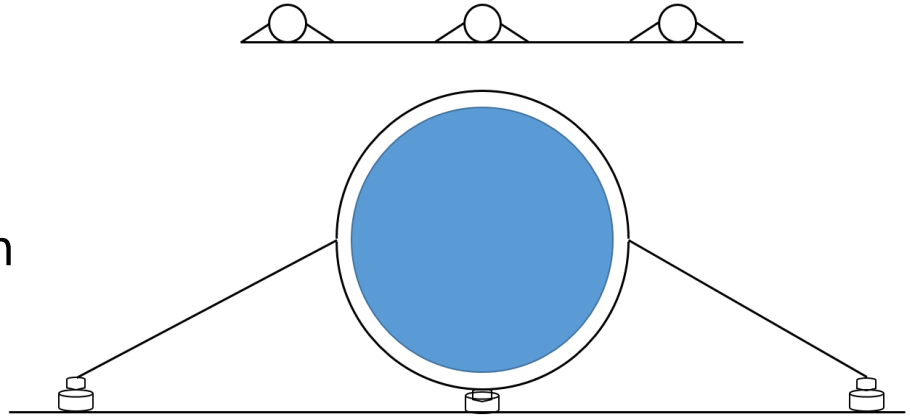


STARGATE Design Solution
Air and Wall Manufacturing

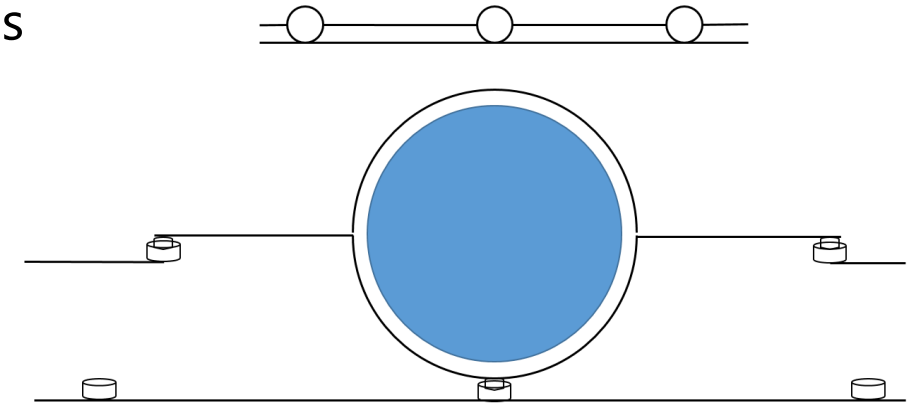


STARGATE Design Solution
Air beam & Wall Design

- **As-shipped interior configuration**
  - Triangular channels on either side of each air-beam
  - Housing space for electronics, lights
- **Optional interior wall**
  - Attaches with snap-buttons
  - Expands interior wall volume for integration of other systems (e.g. umbilical's)
  - Variable level of flight fidelity



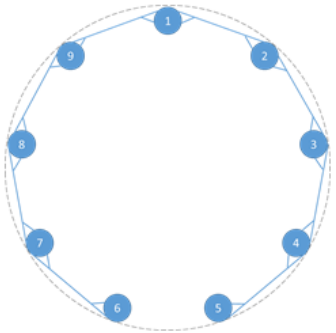
Configuration 1
Narrow channels for wires, lines, and lights



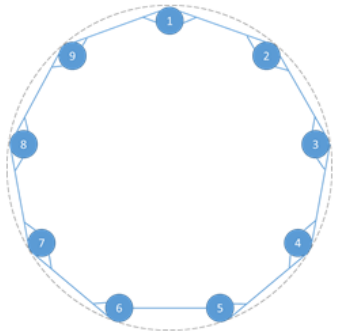
Configuration 2
More realistic "double wall," snaps in

STARGATE Design Solution
Ground Test Configurations

- **Four wall geometry configurations**
  - With and without a floor panel
  - With and without interior wall Panel
- **Easily configurable using "snap buttons"**

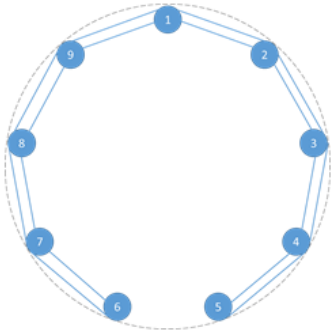


Single Wall, No Floor Panel

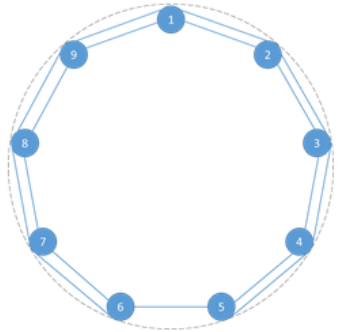


Single Wall, Floor Panel

Double Wall, No Floor Panel

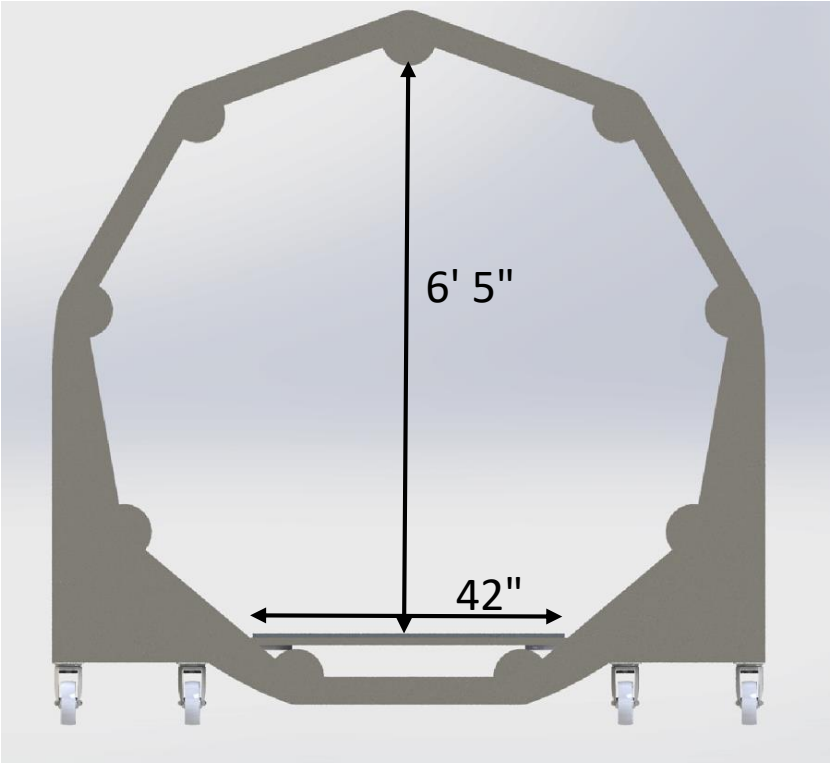


Double Wall, Floor Panel



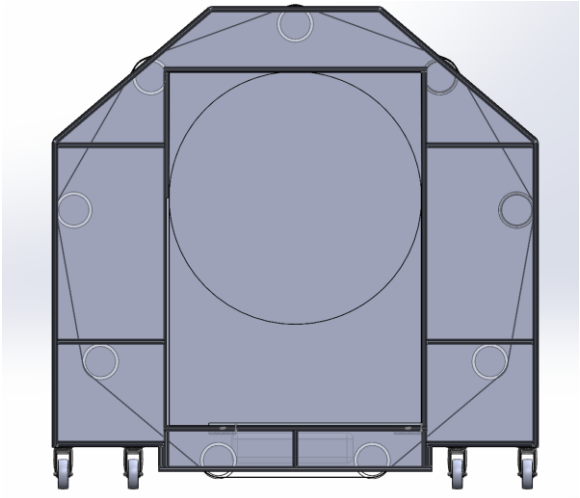
STARGATE Design Solution
Floor and Head Space

- **6' 5" of head space**
  - Designed to accommodate a standing suited astronaut
- **42" x 93" of floor space**
  - Designed to accommodate four crew members for demonstration with appropriate space



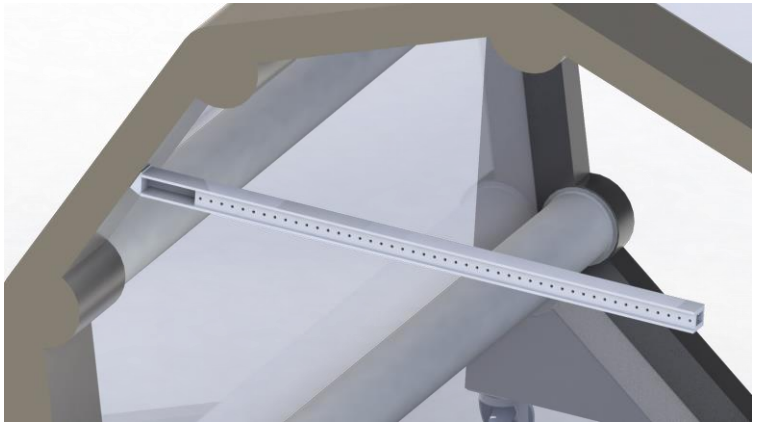
STARGATE Design Solution
Bulkhead Frame

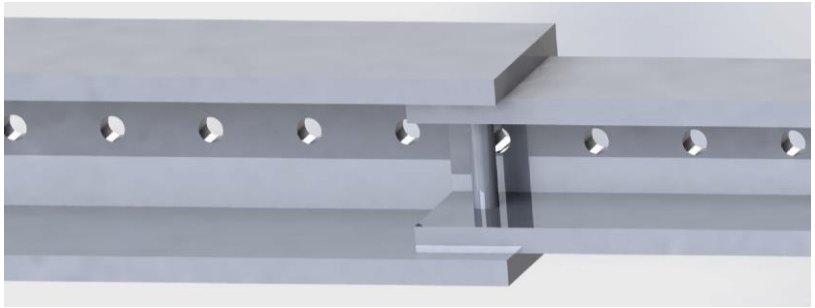
- **Same door assembly as Dock Frame**
  - Can either open standard size door or NASA size hatch
- **Same structural design as the Dock Frame**
  - Adequate room to mount any required systems
  - Lightweight for minimal-resistance deployment
- **Wheelbase can be increased for stability if needed**



STARGATE Design Solution Hardpoints

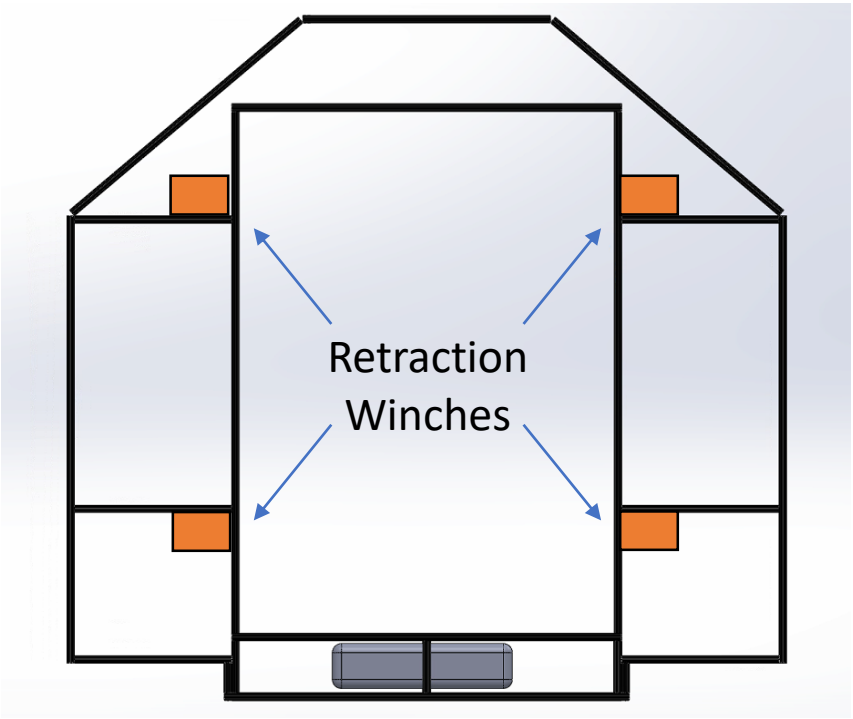
- **Pair of collapsible metal beams**
  - Manually deployed after expansion
  - Folds flat against frame when stored
- **One set on each end**
  - Snap into place on opposite side
- **Allows for crewed operations in 1-g environment**
  - Support tool & equipment loads





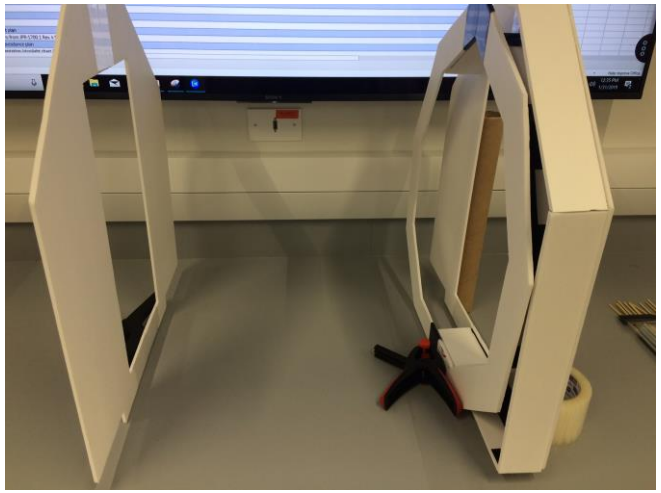
STARGATE Design Solution
Retraction Method

- **Totally automated retraction**
  - Winches apply variable contracting force
  - Encoders on winch lines ensure even and consistent retraction
- **Microcontrollers interface with main control system**
- **Relief valves open on all lines**
  - Controlled slow release of air
  - Allows for even contracting & compacting

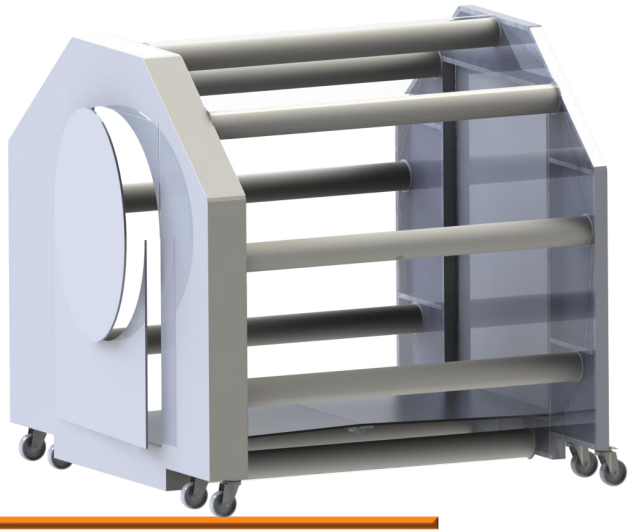


STARGATE Design Solution
Scale Model

- **Quarter scale model**
  - Foamboard, tape, and glue construction
  - Will model retraction methods and floor construction

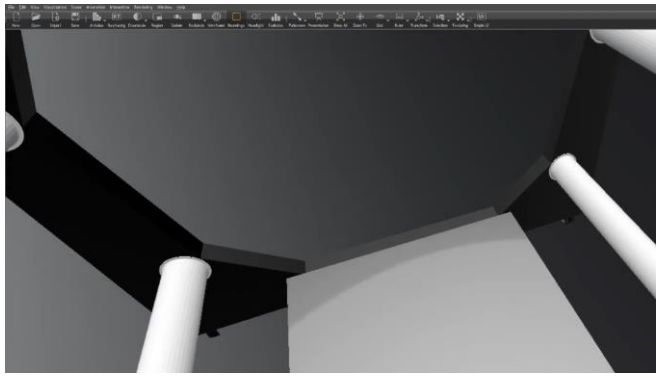


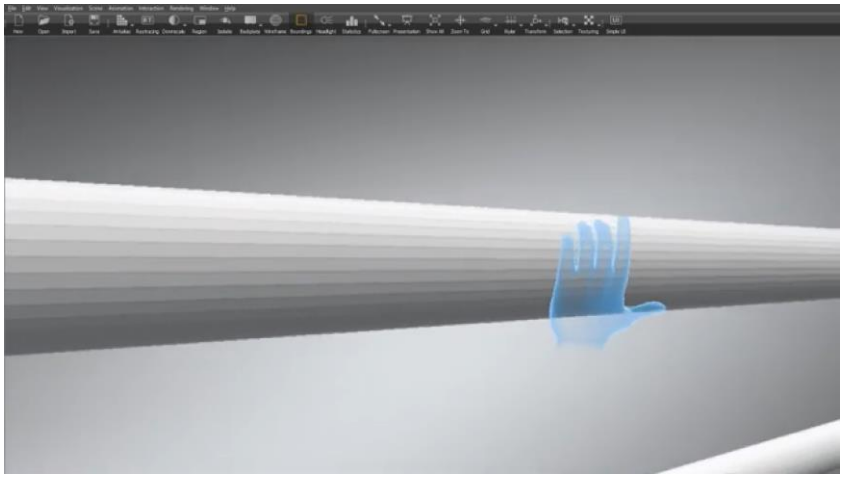
- **Purpose**
  - Reference material for proportions of STARGATE
  - Display model for design and manufacturing space
  - Manufacturing space frequented by campus tours



STARGATE Design Solution
Virtual Reality

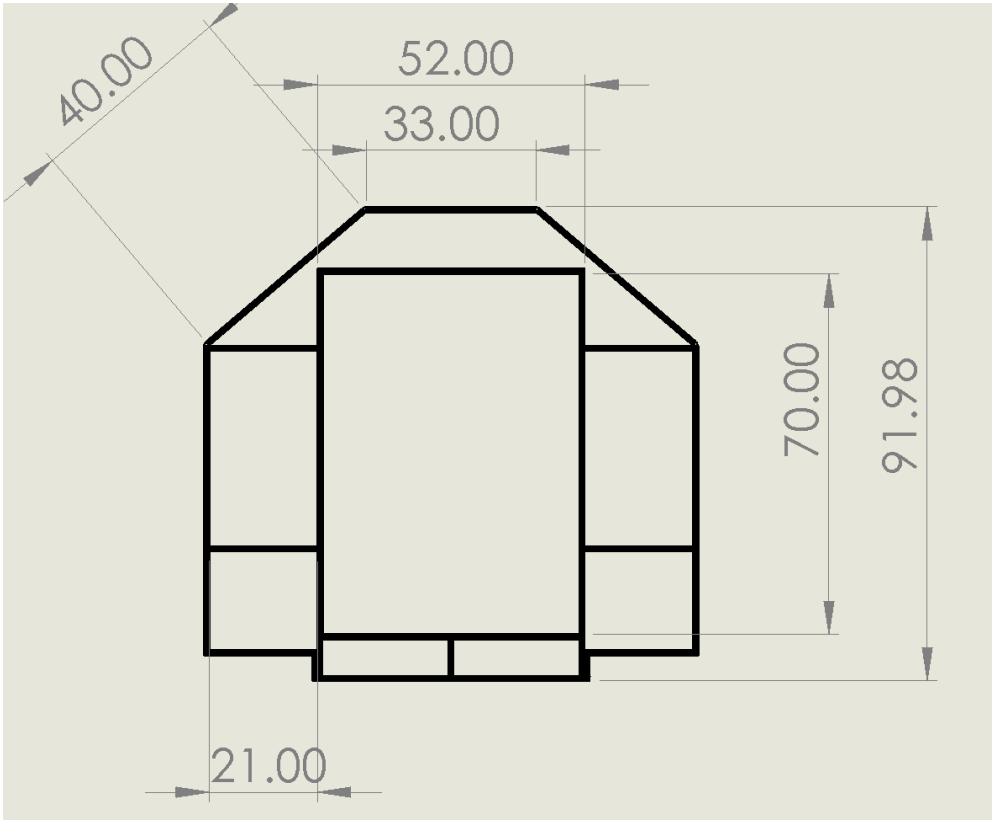
- **VR Model**
  - Using Autodesk software
- **Purpose**
  - Better understand physical proportions of STARGATE
  - Visualize scale model at 1:1 scale with no expense
  - Rapidly analyze impact of design changes on system configuration



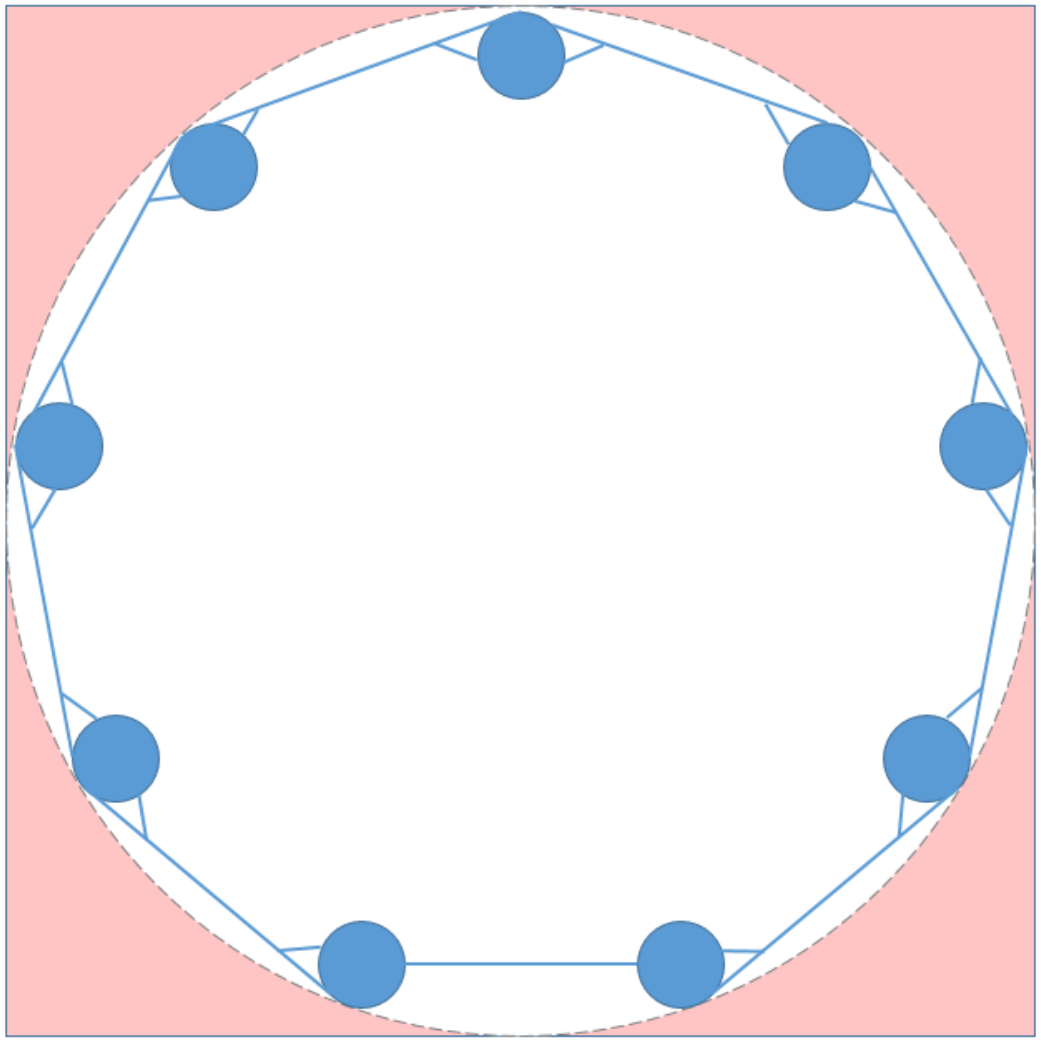


STARGATE Design Solution
Weight Estimation

- **Estimated Structural Weight**
  - 720-lbs
  - Includes both the Dock frame and bulkhead frame
  - Determined from major structural dimensions
- **8020.net Structural Members**
  - Estimated with 80mm x 40mm members
  - 0.2317 lbs per inch
- **Factor of Safety of 1.5 applied to initial estimate**
  - Accounting for fastener mass



STARGATE Design Solution
Space Efficiency



Typical Cross Section

Available Area

$64.00 - ft^2$

After Circularization

$50.27 - ft^2$

After Nonagonalization

$46.30 - ft^2$

After Air beam Incorporation

$44.50 - ft^2$

Volume Available

$512 - ft^3$

Interior Volume

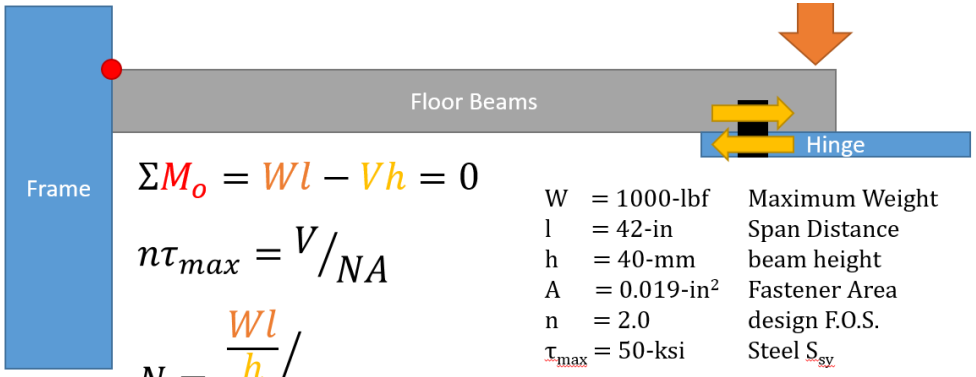
$356 - ft^3$

Space Efficiency

69.5%

STARGATE Design Solution
Floor Loading Analysis

- **Critical load-bearing structure: hinge fastener**
  - Expected Failure Mode: Shear
  - 14 fasteners per side to achieve 2.0 F.O.S.
  - Can be increased w/ minimal weight penalty
- **Bending Analysis**
  - Current floor design results in a F.O.S. of 4.96 at worst case



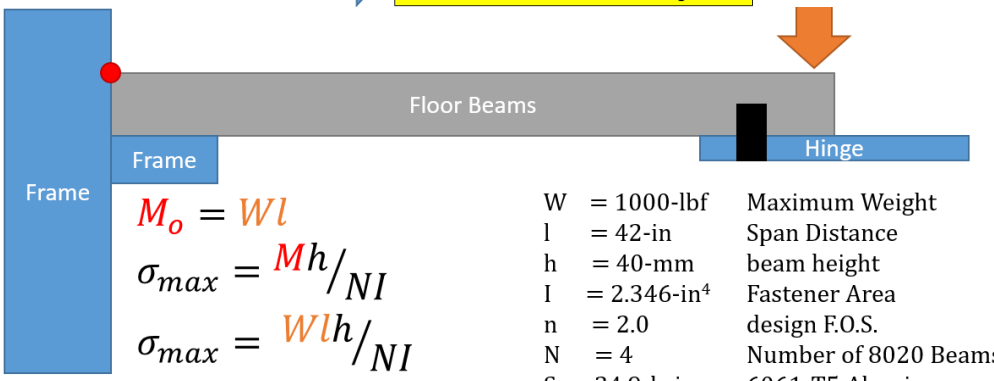
$$\Sigma M_o = Wl - Vh = 0$$

$$n\tau_{max} = {V}/{NA}$$

$$N = \frac{{Wl}/{h}}{n\tau_{max}A}$$

$$N = 13.99 \Rightarrow \boxed{N = 14 \text{ fasteners required}}$$

W	= 1000-lbf	Maximum Weight
l	= 42-in	Span Distance
h	= 40-mm	beam height
A	= 0.019-in^2	Fastener Area
n	= 2.0	design F.O.S.
τ_{max}	= 50-ksi	Steel S_{sy}



$$M_o = Wl$$

$$\sigma_{max} = {Mh}/{NI}$$

$$\sigma_{max} = {Wlh}/{NI}$$

$$\sigma_{max} = 7027\ psi$$

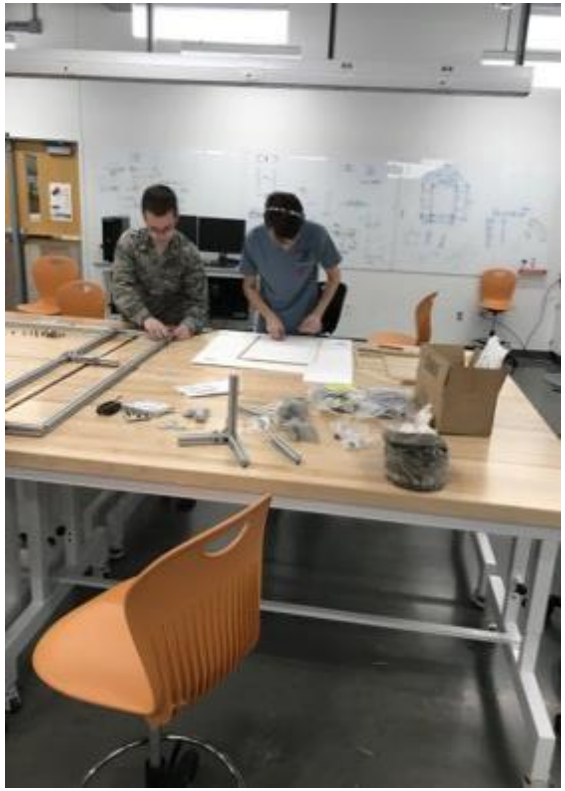
$$n = {S_y}/{\sigma_{max}} \Rightarrow \boxed{n = 4.96}$$

W	= 1000-lbf	Maximum Weight
l	= 42-in	Span Distance
h	= 40-mm	beam height
I	= 2.346-in^4	Fastener Area
n	= 2.0	design F.O.S.
N	= 4	Number of 8020 Beams
S_y	= 34.9-ksi	6061-T5 Aluminum

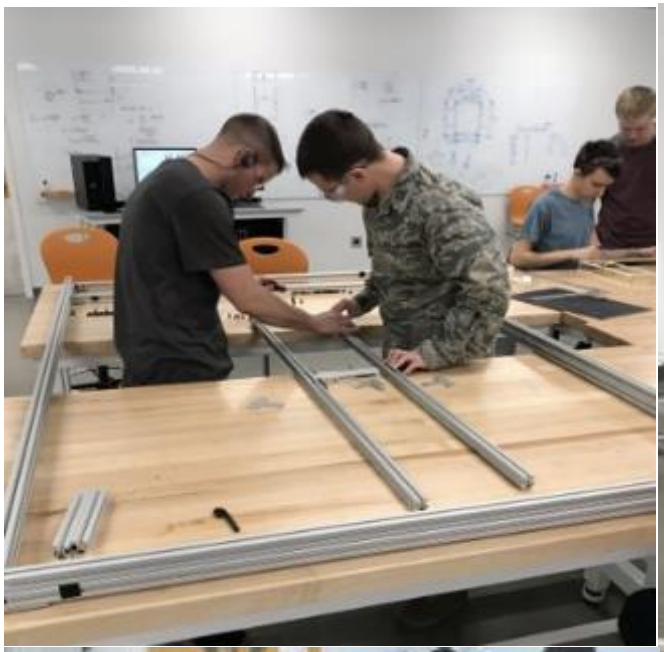
STARGATE Build Phase

Photo Slideshow

STARGATE Build Phase
Framework Construction



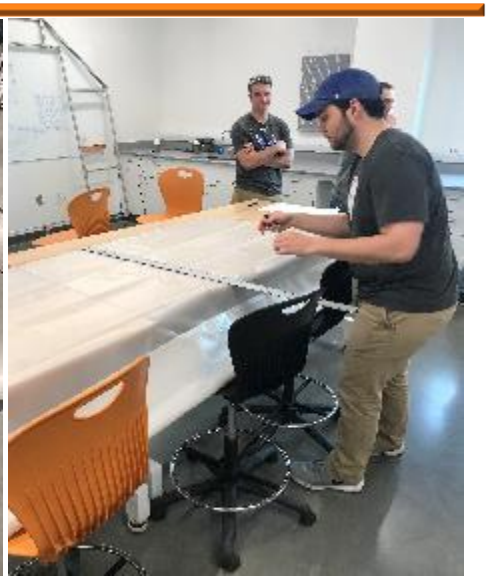
STARGATE Build Phase
Framework Construction



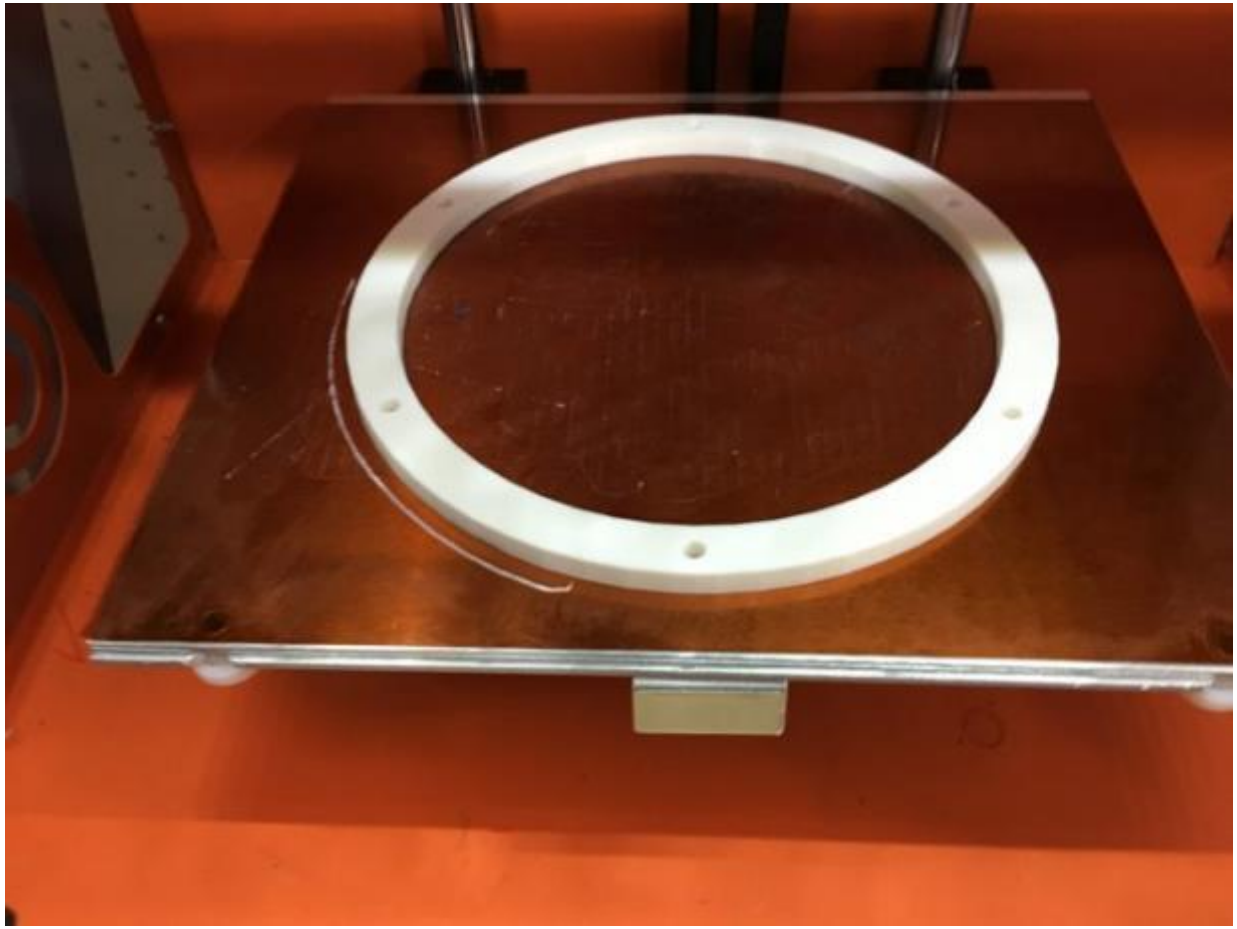
STARGATE Build Phase
Exterior Paneling Installation

STARGATE Build Phase
Airbeam Development



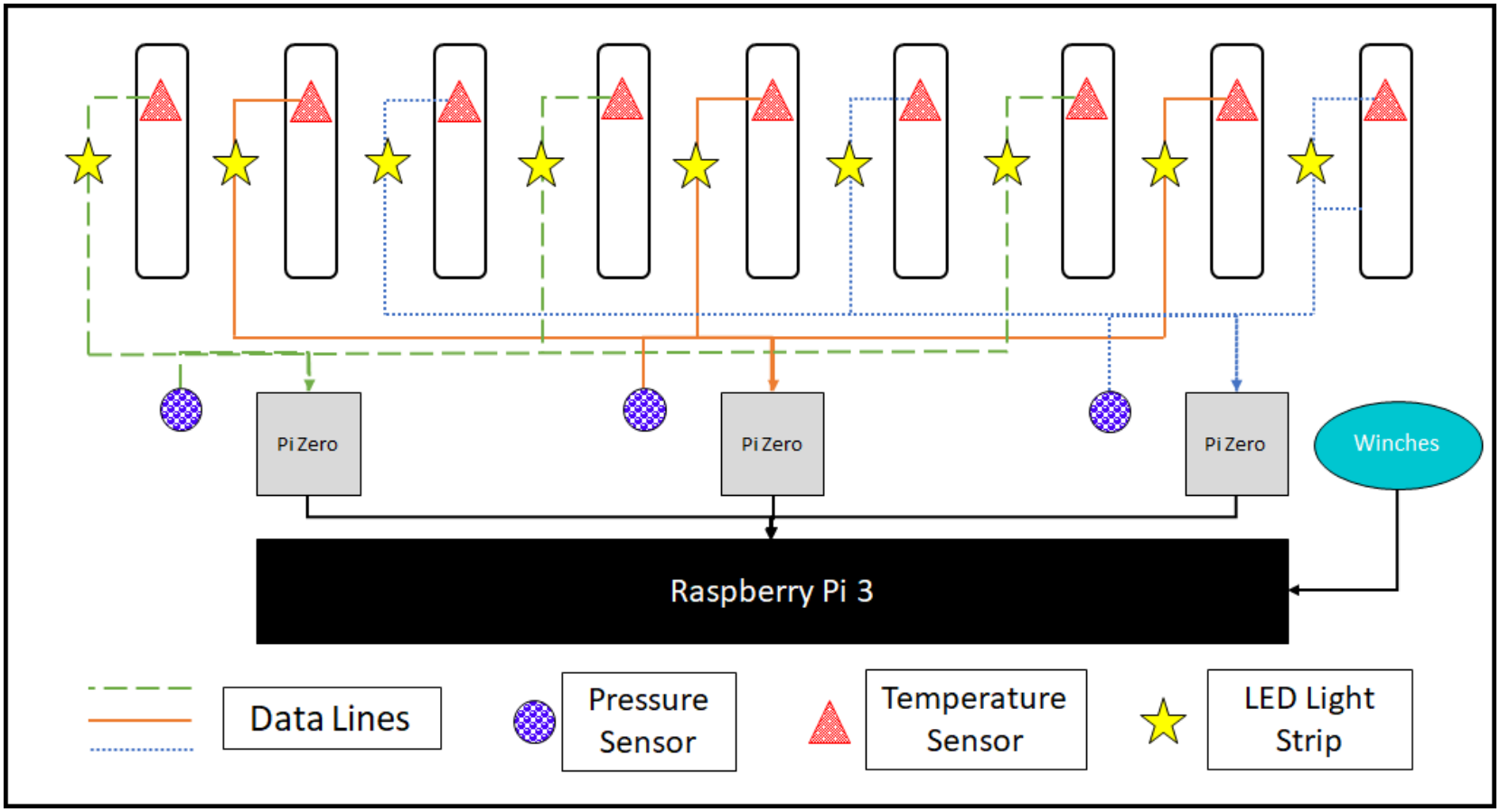


STARGATE Build Phase
Framework-Airbeam Interface

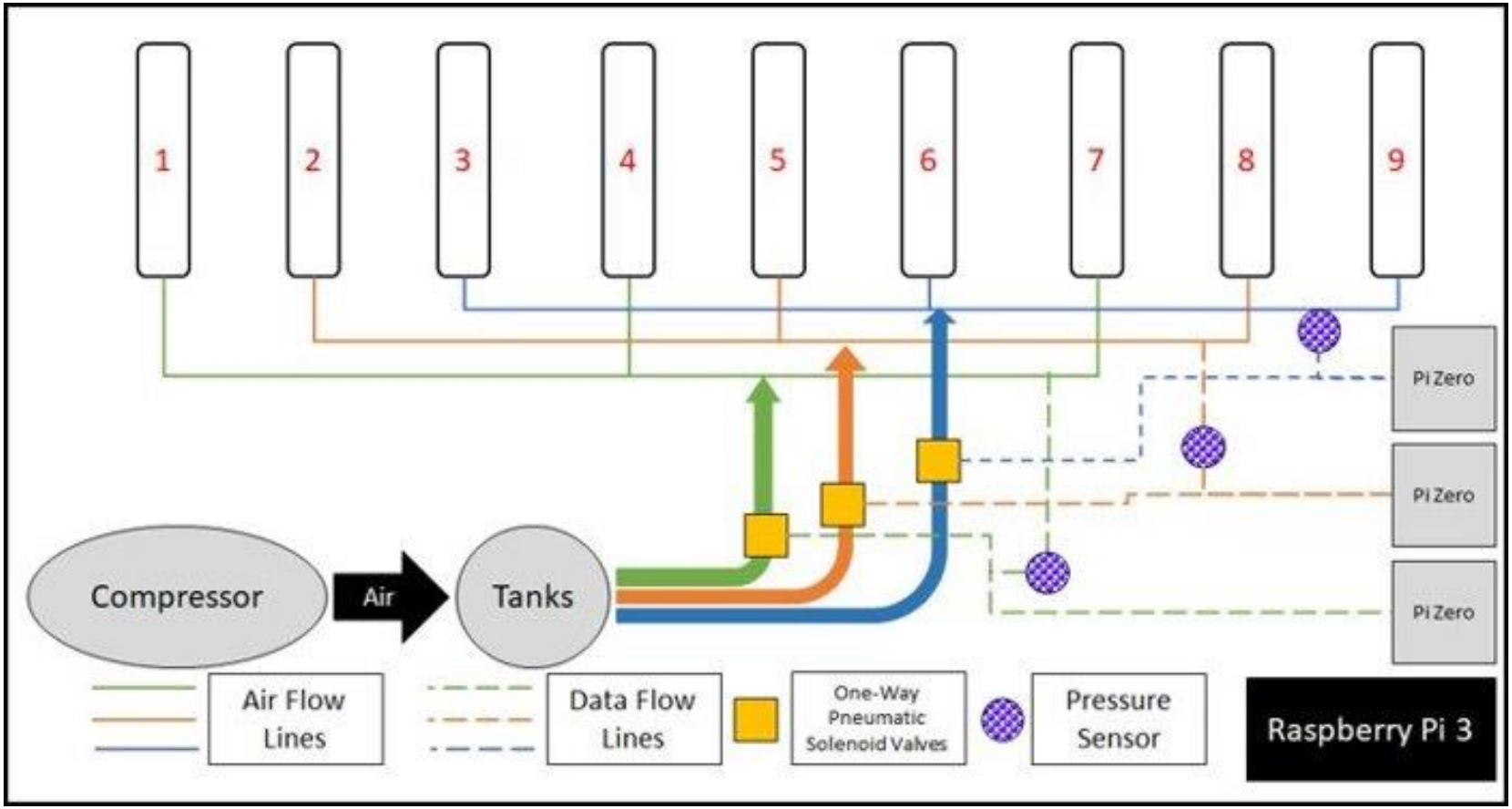


STARGATE Build Phase
Sewing and Installation

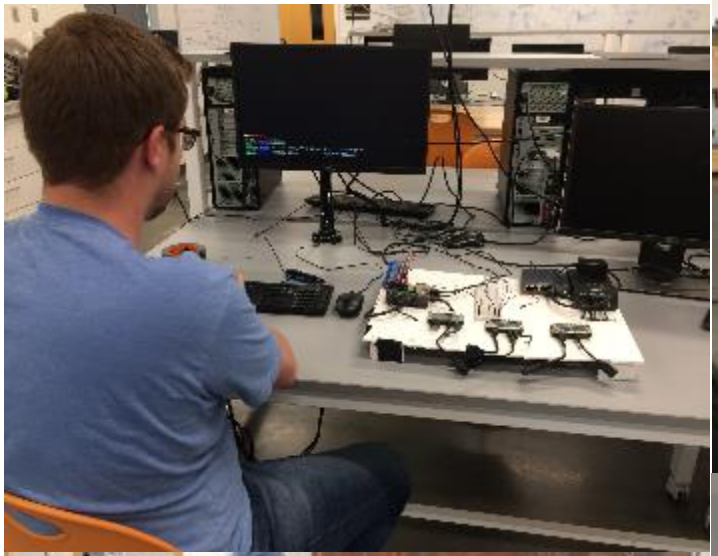
STARGATE Build Phase
Electronics Schematic

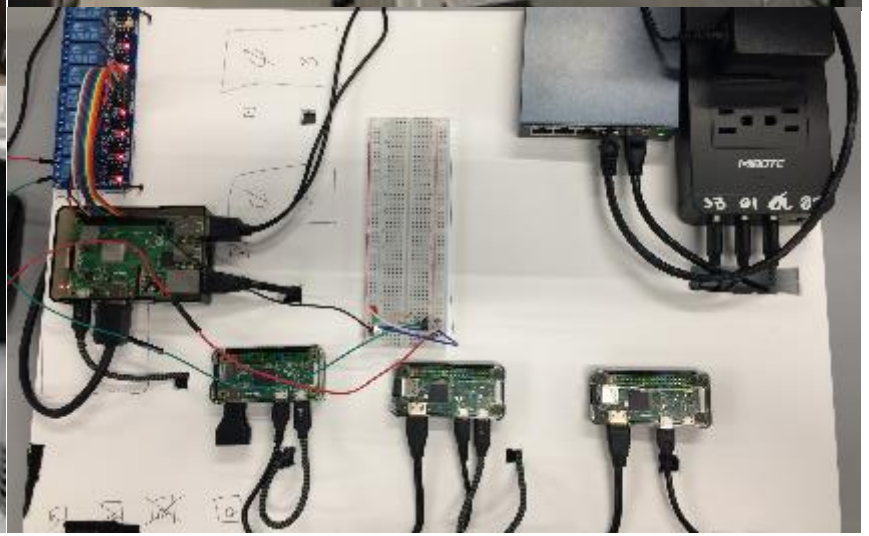


STARGATE Build Phase
Pressure Schematic

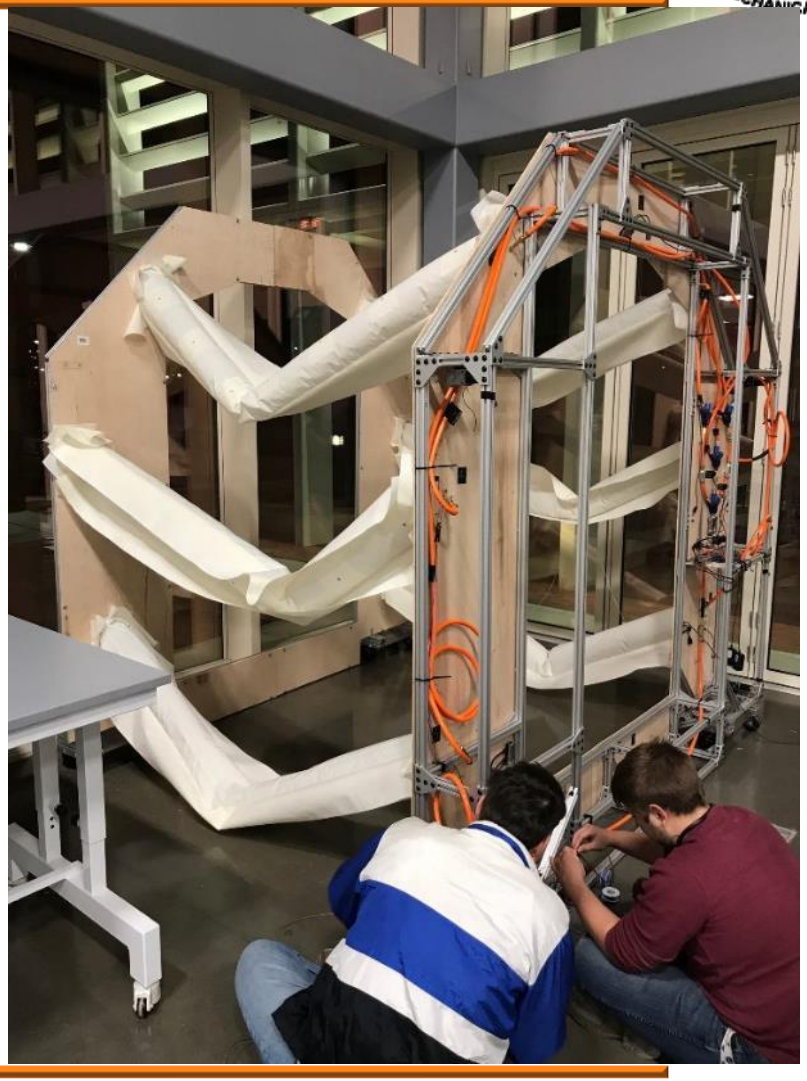


STARGATE Build Phase
Bay Development

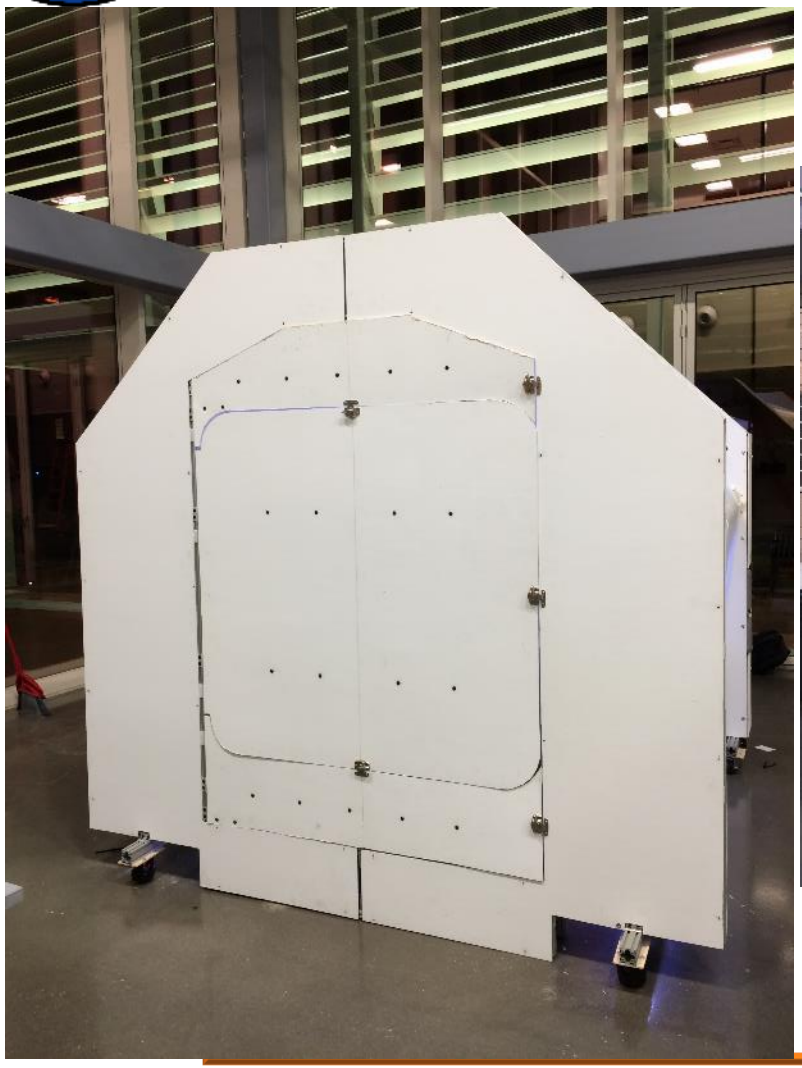


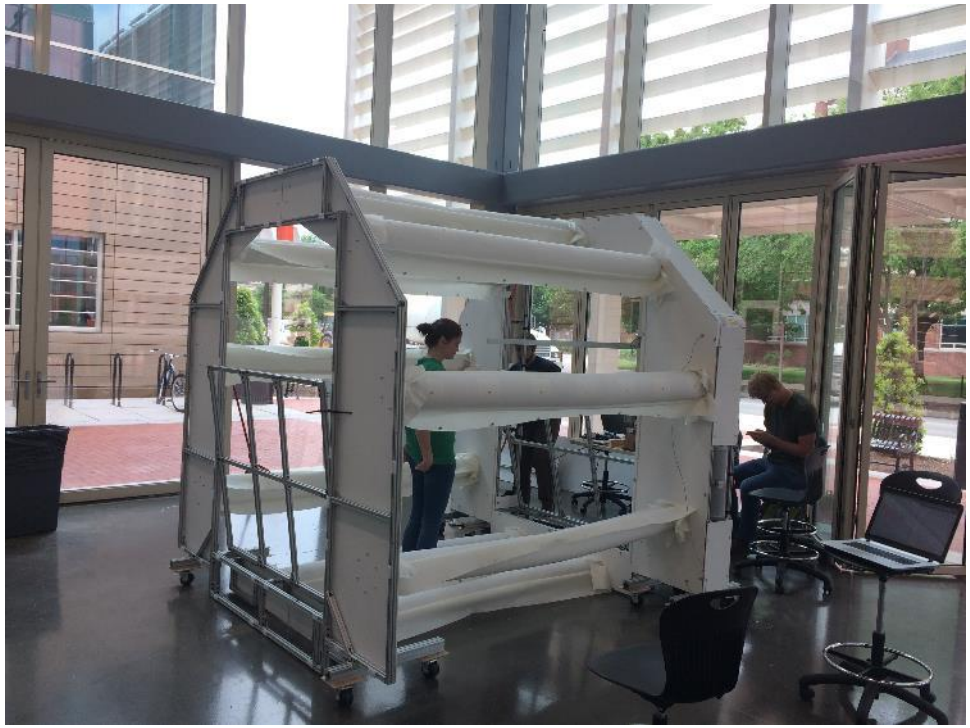


STARGATE Build Phase
Bay Installation

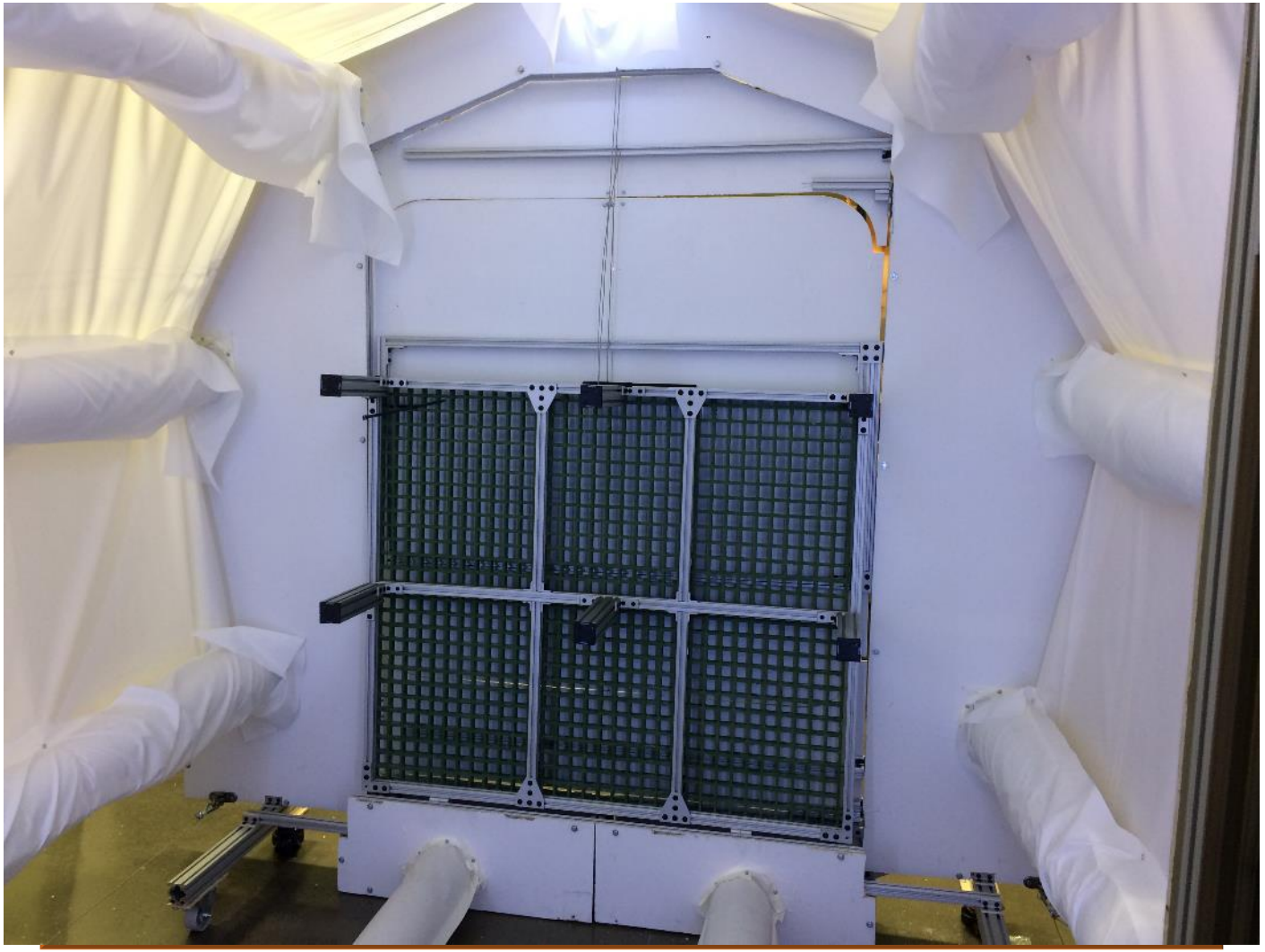


STARGATE Build Phase
Paneling and Door Installation

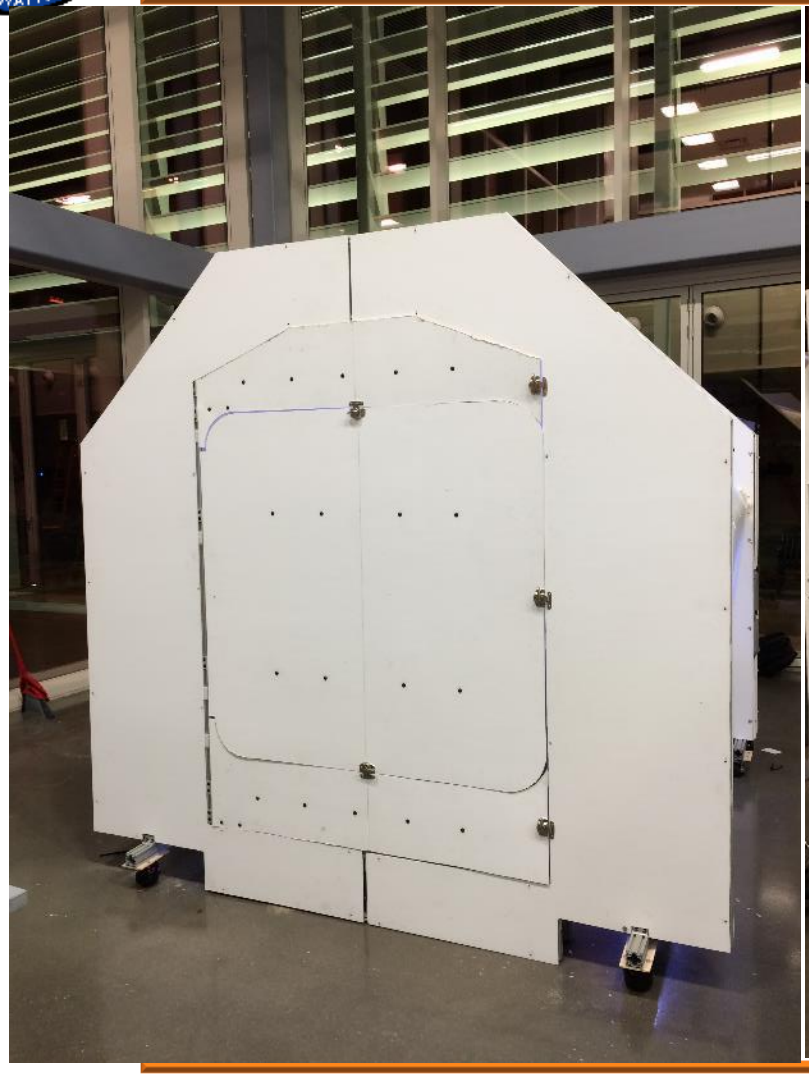




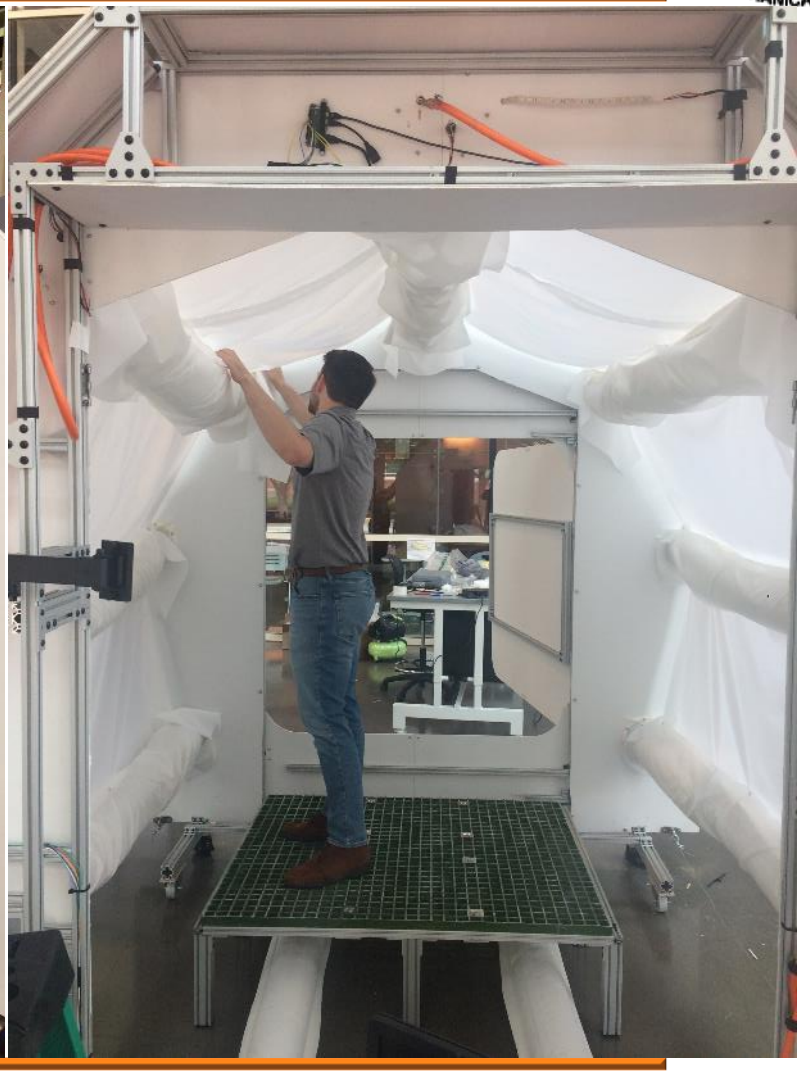
STARGATE Build Phase
Finished Interior



STARGATE Build Phase
Exterior Door



STARGATE Build Phase
Exterior Hatch and Floor



STARGATE Build Phase
Finished Exterior

Presentations and Outreach

News Visit, Expo, and Delivery

Presentations and Outreach
Fox23 News Team Visit

Presentations and Outreach
Senior Design Expo

Presentations and Outreach
Project End

- **13 May 2019 – 15 May 2019**
  - Visit to NASA Johnson Space Center (JSC), Houston, TX
  - Observe other projects, familiarity with operational space
  - Meet NASA Point of Contact
- **11 June 2019**
  - Return to NASA JSC
  - Delivery of final product, operations manual, and technical manual