STARGATE

Inflatable Crew-lock

Critical Design Review

Overview

- **Administrative Overview**
  - CDR POC: Justin Duewall
- **Analog System Design Solution**
  - CDR POC: Austin Bennett
- **Research and Development**
  - CDR POC: Madison Whiteley
- **System Operations and Interfacing**
  - CDR POC: Josh Pankratz
- **Administrative Review**
  - CDR POC: Michael Raymer

Administrative Overview

- **Requirements Review**
- **PDR Documentation Review**
- **STARGATE Introduction**

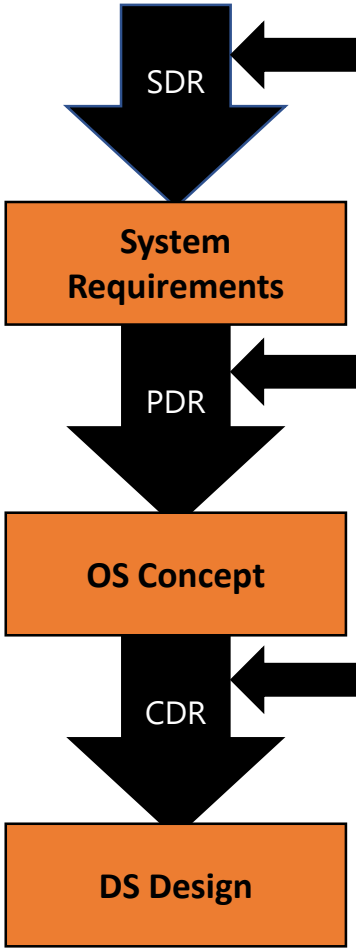
CDR POC: Justin Duewall

Requirements Review
Primary Objectives

- **Deployment Test:** Demonstrate operations through a series of deployment tests
  - Include packaging concept and deployment operations
  - Crew lock inflates with some manual/mechanical assistance assisting low pressure inflation

- **Internal Operations Tests:** Demonstrate crew lock operations for EVA prep
  - Non-pressurized state when open to prototypes/mockups
  - Deploy the crew lock in an unpressurized state with some internal structure
  - Allow crew to transfer between module and other notional prototypes available during test.
  - Crew interaction w/ NASA and university EVA prep payloads

Requirements Review
SDR to CDR



- ✓ Re-iterate design requirements
- ✓ Define initial design space using final deliverable requirements and project intent
- ✓ Identify candidate software and hardware solutions
- ✓ Select methodologies for risk analysis, tracking, and mitigation

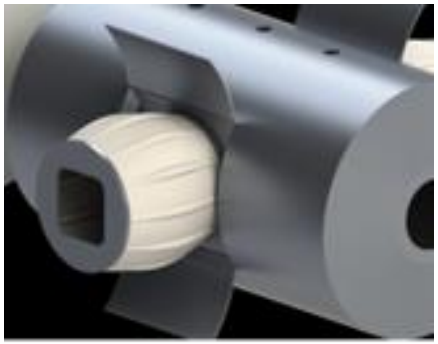
- ✓ Test manufacturing methods for anticipated DS Design components
- ✓ Analyze existing systems to narrow design space
- ✓ Apply system requirements and objectives to develop design candidates
- ✓ Use trade-studies to select final OS concept

- ✓ **Small Scale prototyping to facilitate OS-to-DS transition**
- ✓ **Apply Detailed Objective Requirements to OS concept**
- ✓ **Develop analogs to parallel OS capabilities in laboratory environments**
- ✓ **Design DS system in compliance with safety standards and project requirements**

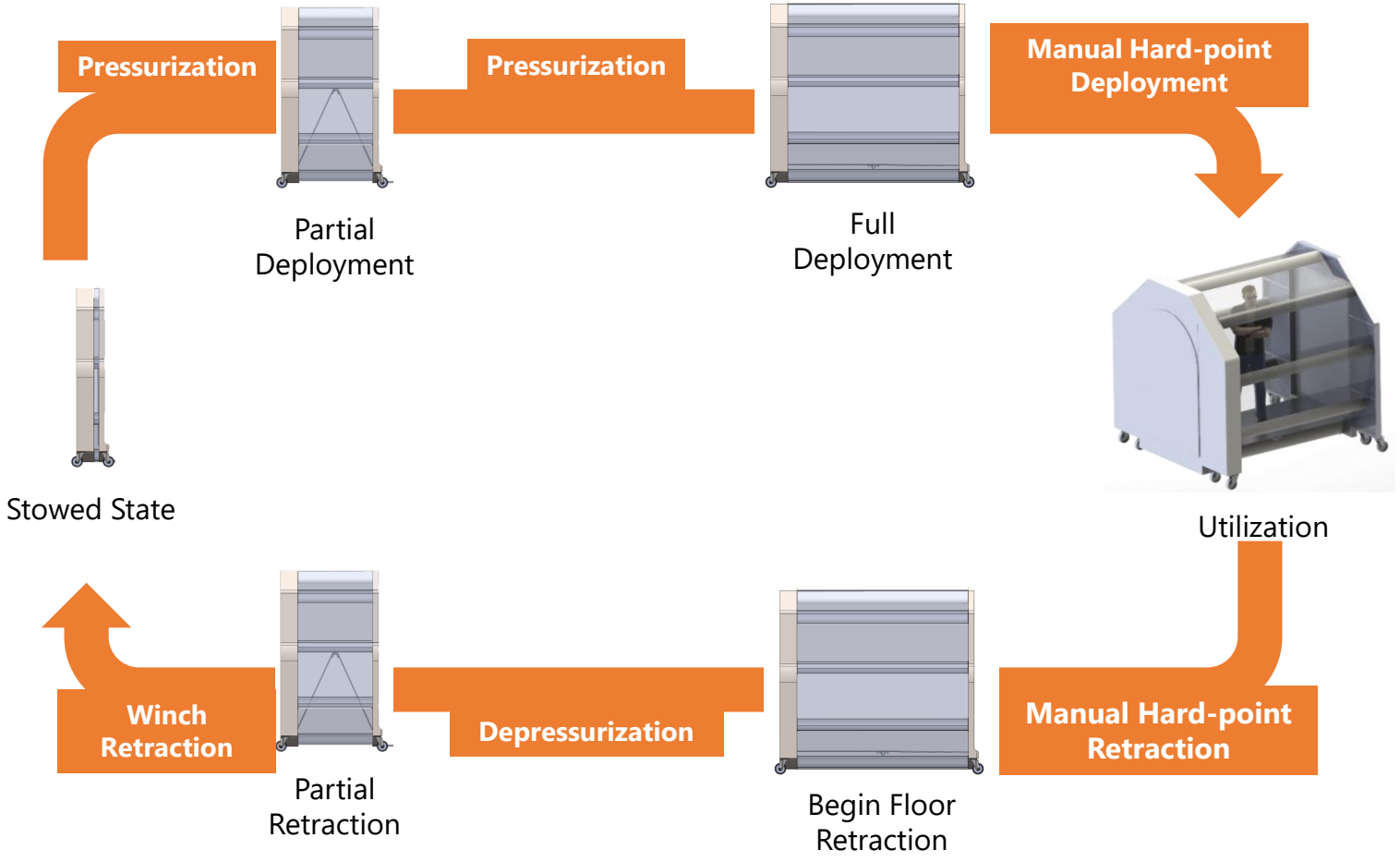
STARGATE Introduction

PDR
OS Design Concept

SDR
STARGATE Demonstrator



Stargate Introduction
CONOPS

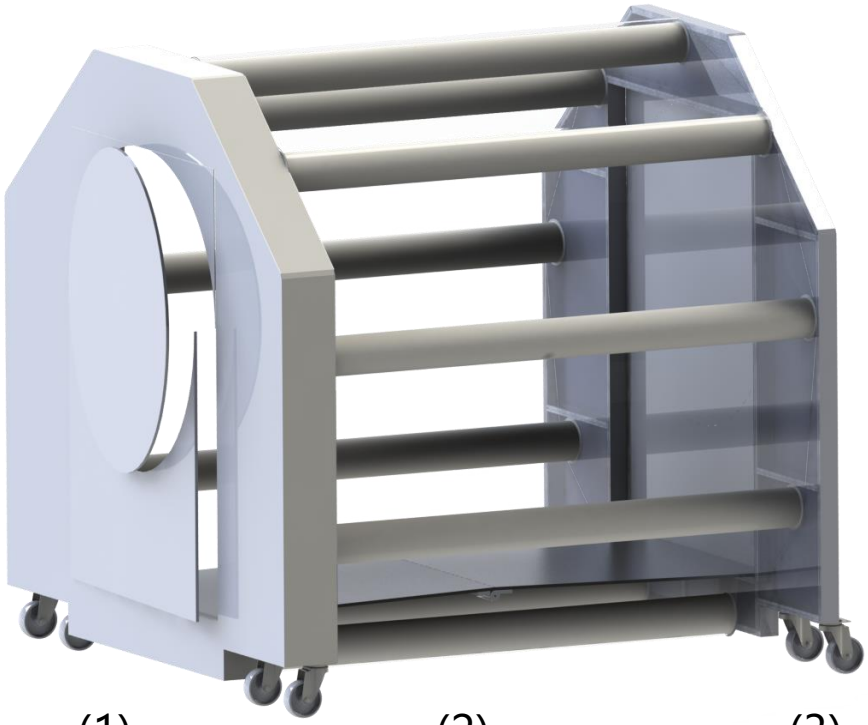


STARGATE Introduction
Component Terminology

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

- **STARGATE Design Solution Components**
- **STARGATE System Operations**

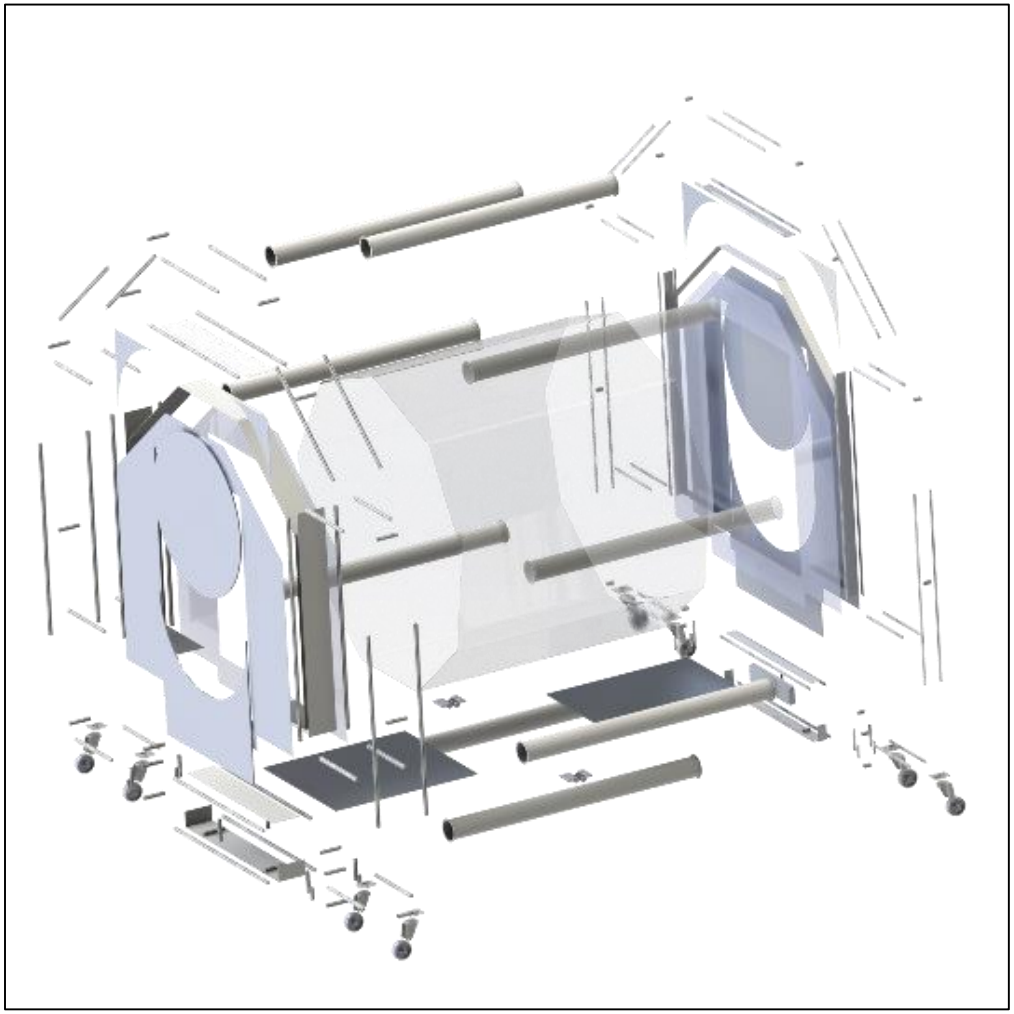
CDR POC: Austin Bennett

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**

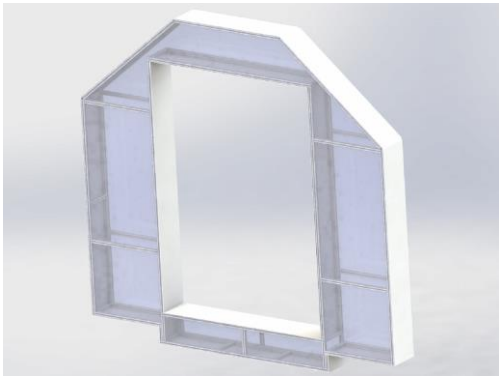
STARGATE Design Solution Overview

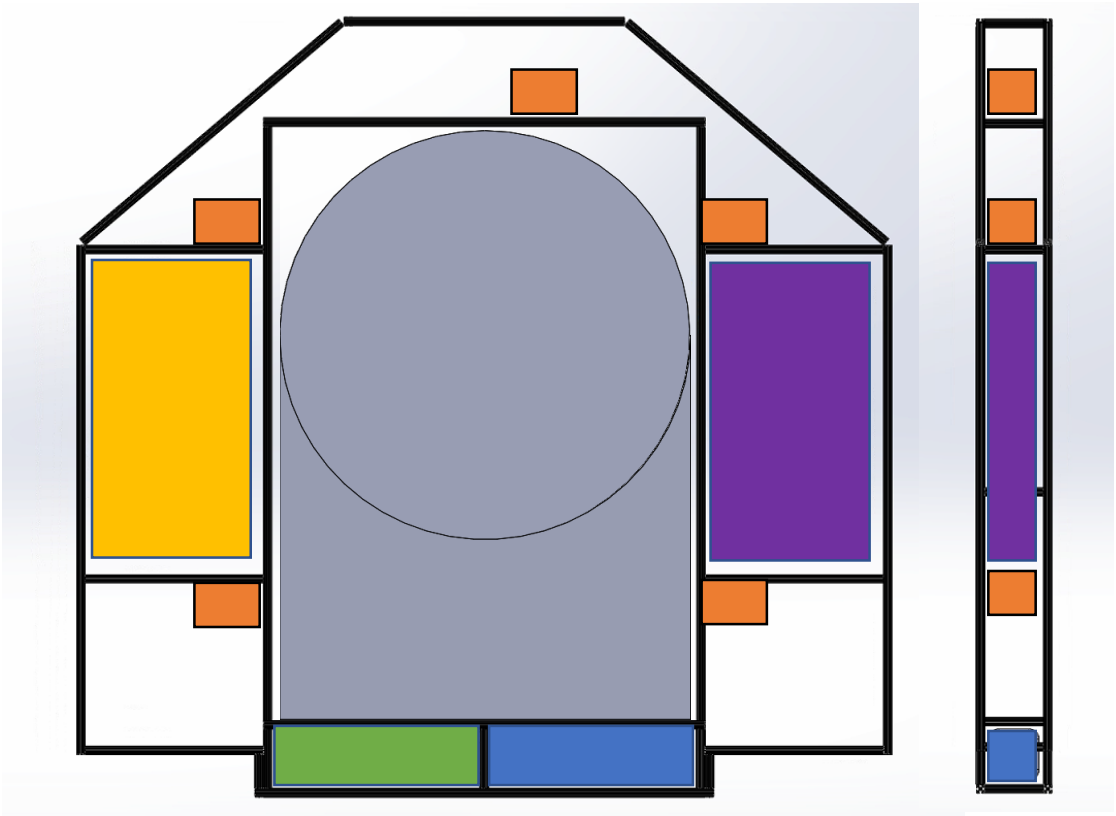
- **Dock Frame**
- **Span Configuration**
  - Air-beam and Wall Construction
  - Floor
- **Bulkhead Frame**
- **Other Design Elements**
  - Hardpoints
  - Wheelbase
  - System Integration



STARGATE Design Solution
Dock Frame

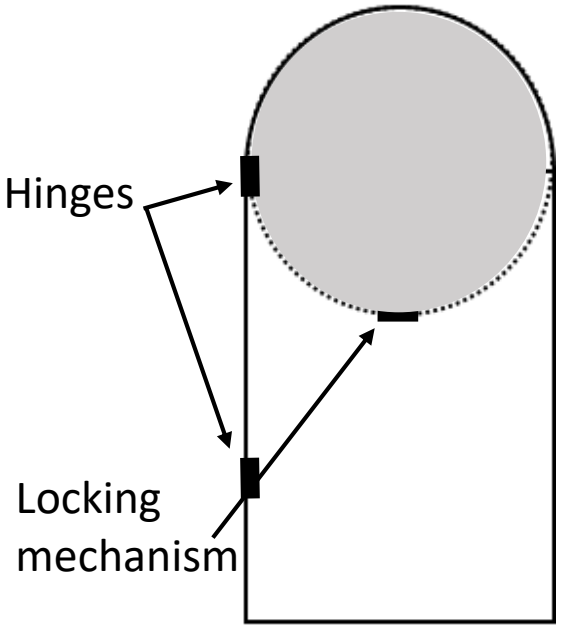
- **Steel 8020 Frame**
- **Plastic Paneling**
- **Systems within:**
  - **Air tanks**
  - **Compressor**
  - **Winches**
  - **Electronics**
  - **Storage & Misc.**

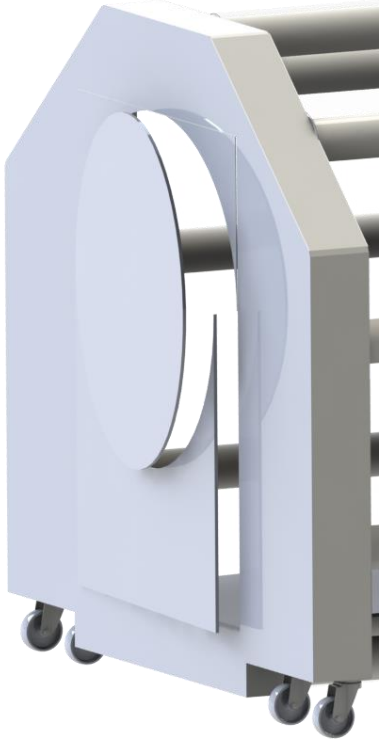




STARGATE Design Solution
Ingress and Egress Method

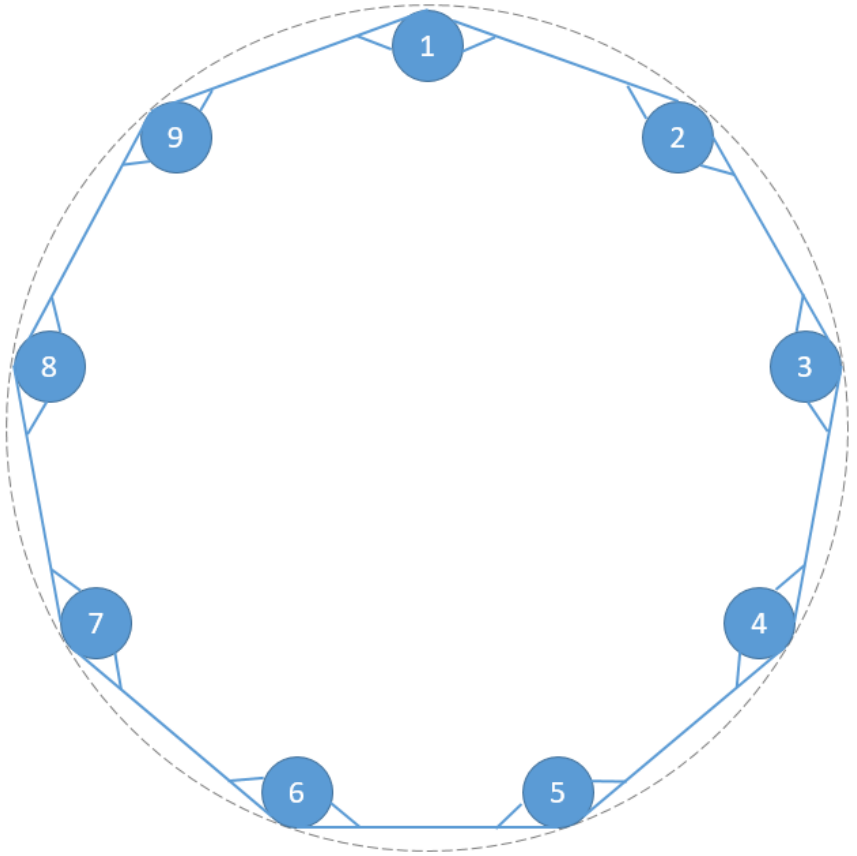
- **Dutch Door styled hatch system**
- **Allows easy access as well as hatch simulation**



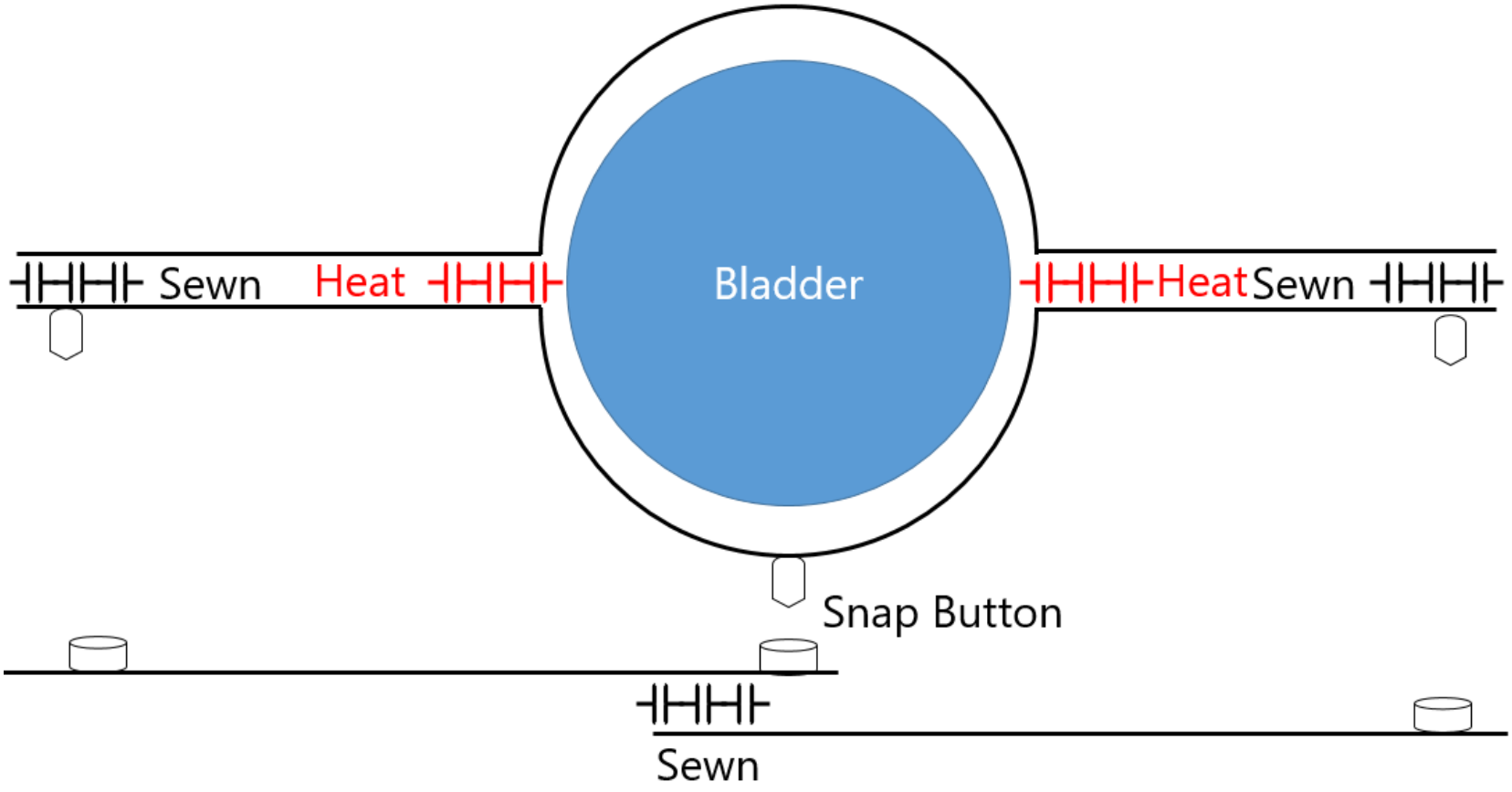


STARGATE Design Solution
Radial Profile

- **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

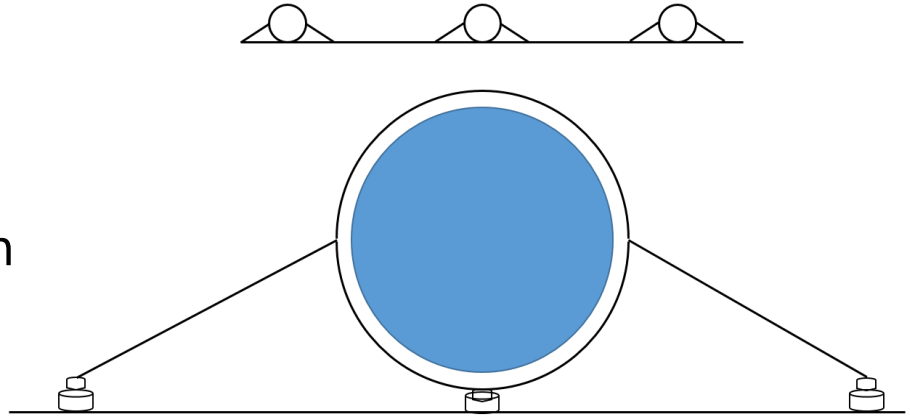


STARGATE Design Solution
Air and Wall Manufacturing

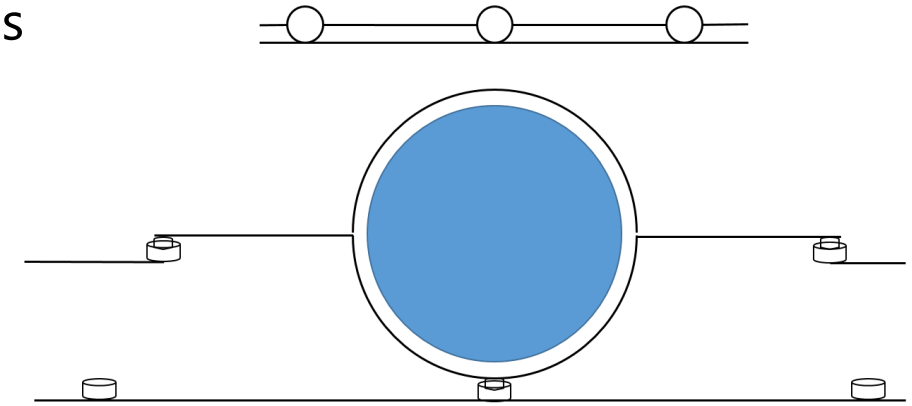


STARGATE Design Solution
Air beam & Wall Design

- **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



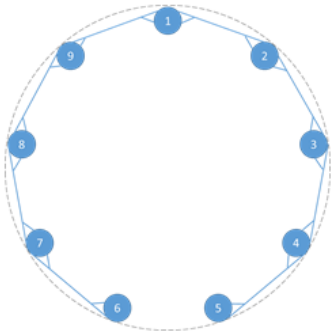
Configuration 1
Narrow channels for wires, lines, and lights



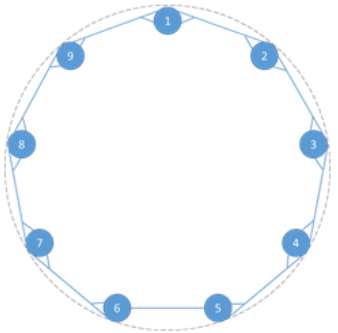
Configuration 2
More realistic "double wall," snaps in

STARGATE System Operations
Ground Test Configurations

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

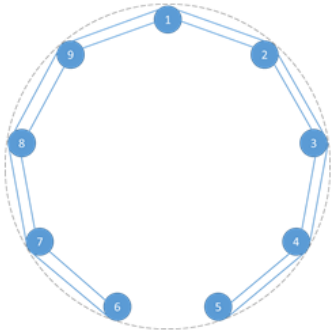


Single Wall, No Floor Panel

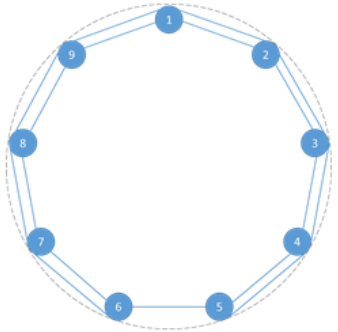


Single Wall, Floor Panel

Double Wall, No Floor Panel

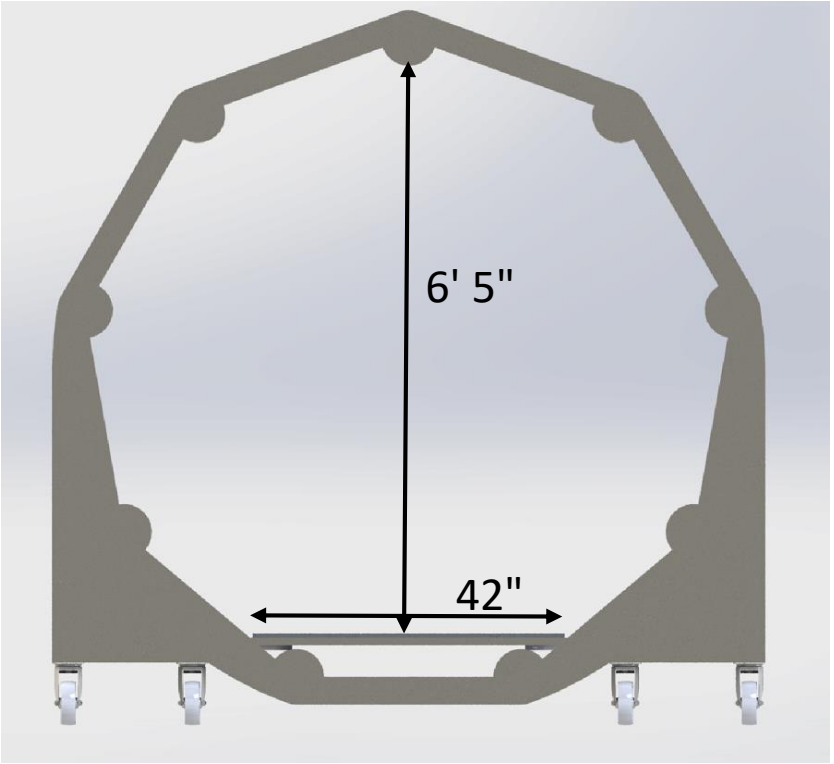


Double Wall, Floor Panel



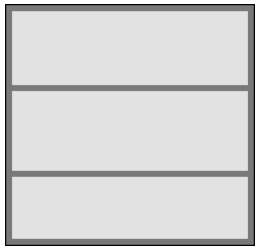
STARGATE Design Solution
Floor and Head Space

- **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

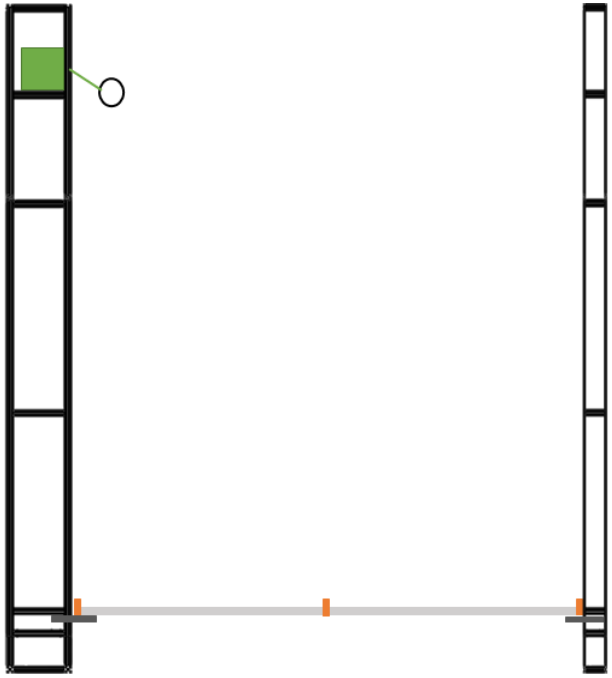


STARGATE Design Solution
Floor Design

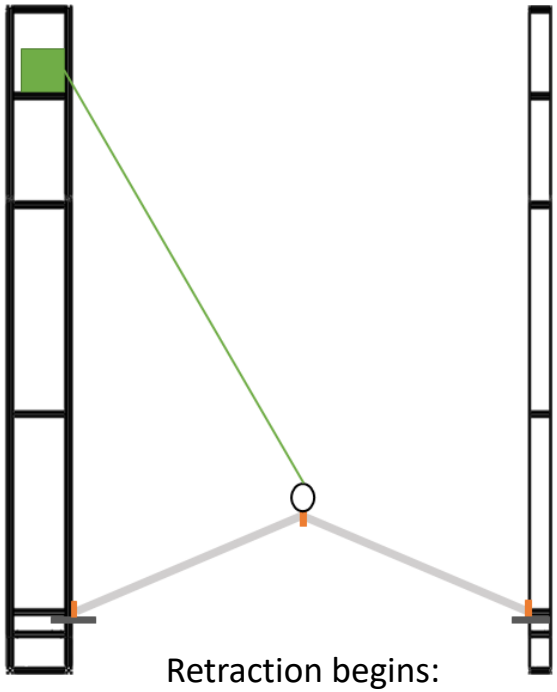
- **Floor folds in middle for improved collapsibility**
  - Simply supported by frame on sides



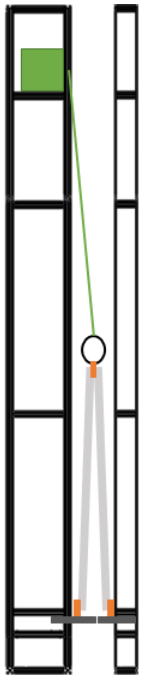
Catwalk Floor Segment



Deployed Floor Condition

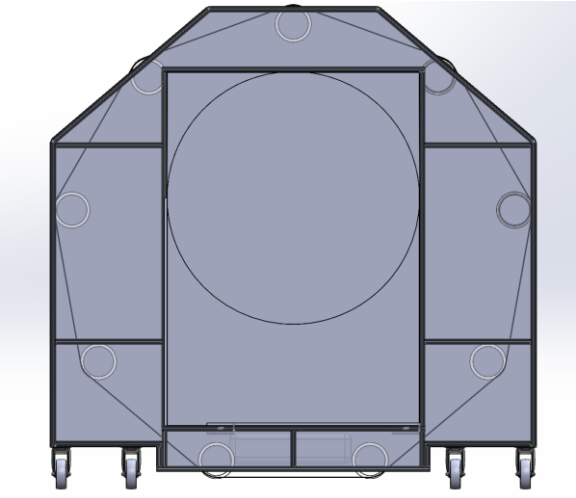


Retraction begins:
Hook is attached to begin retraction



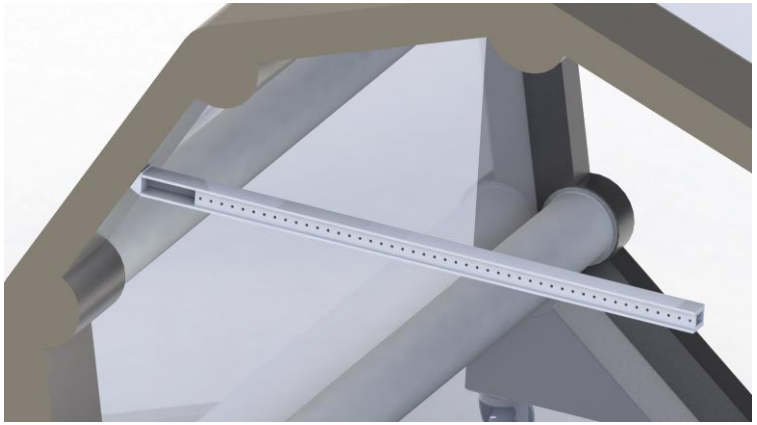
STARGATE Design Solution
Bulkhead Frame

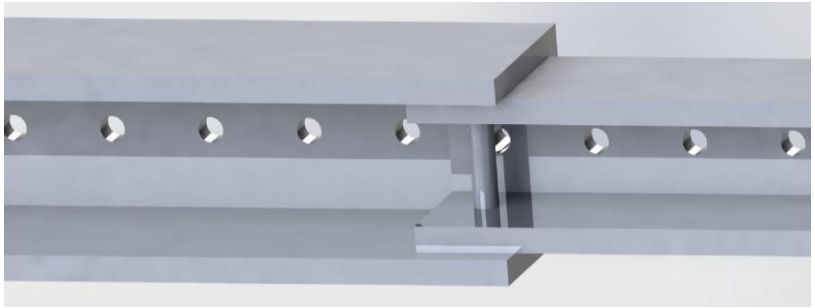
- **Same door assembly as Dock Frame**
  - Can either open standard size door or NASA size hatch
- **Same structural design as the Dock Frame**
  - Adequate room to mount any required systems
  - Lightweight for minimal-resistance deployment
- **Wheelbase can be increased for stability if needed**



STARGATE Design Solution Hardpoints

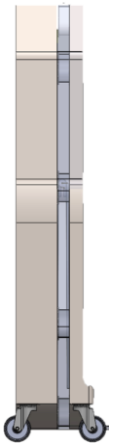
- **Pair of collapsible metal beams**
  - Manually deployed after expansion
  - Folds flat against frame when stored
- **One set on each end**
  - Snap into place on opposite side
- **Allows for crewed operations in 1-g environment**
  - Support tool & equipment loads





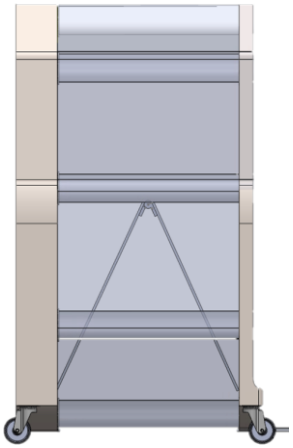
STARGATE System Operations
Deployment Process

Stage 1



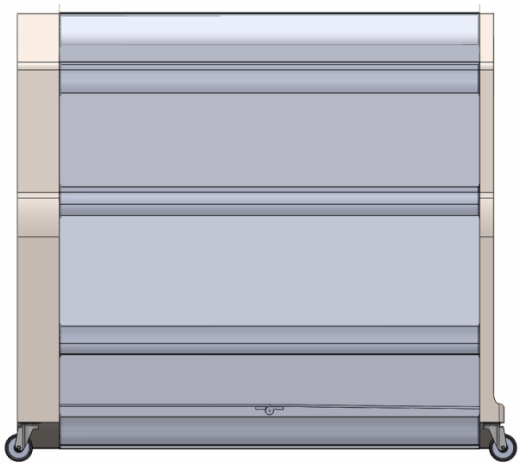
- Fully compacted
- Tube Pressure = 0 psi

Stage 2



- Partially expanded
- Floor begins unfolding
- 0 psi< Tube Pressure < 0.5 psi
- Forward wheelbase in motion

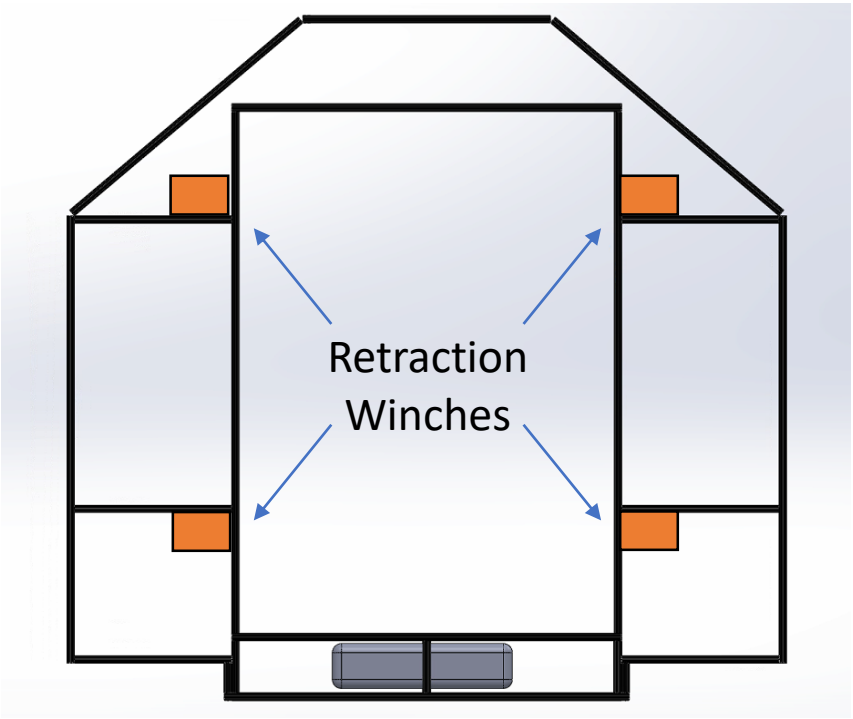
Stage 3



- Fully expanded
- Floor fully expanded
- Tube Pressure = 0.5 psi
- Forward wheelbase stopped

STARGATE System Operations
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



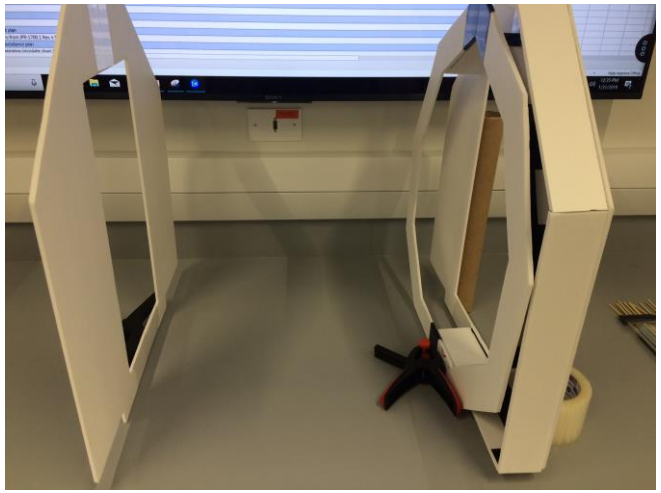
Research and Development

- **Model Development**
- **System Analysis**
- **Critical Load Analysis**
- **Engineering Development Tests**

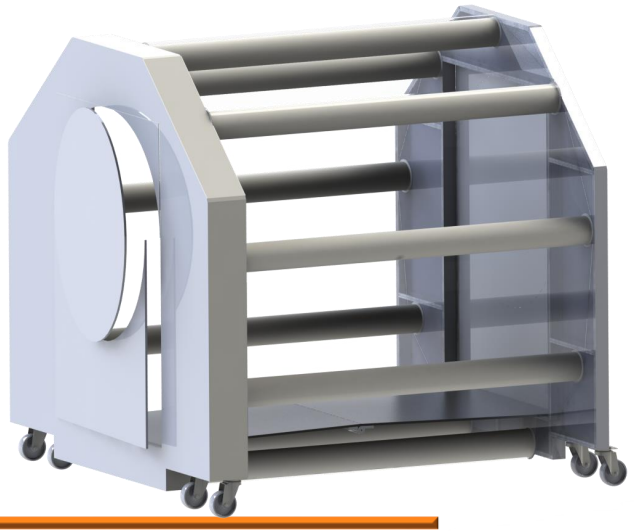
CDR POC: Madison Whiteley

Model Development
Scale Model

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

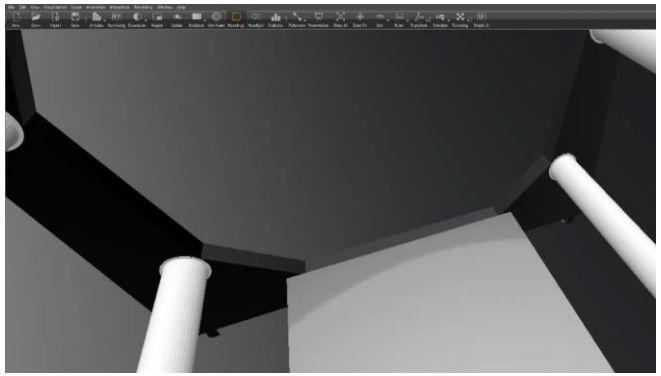


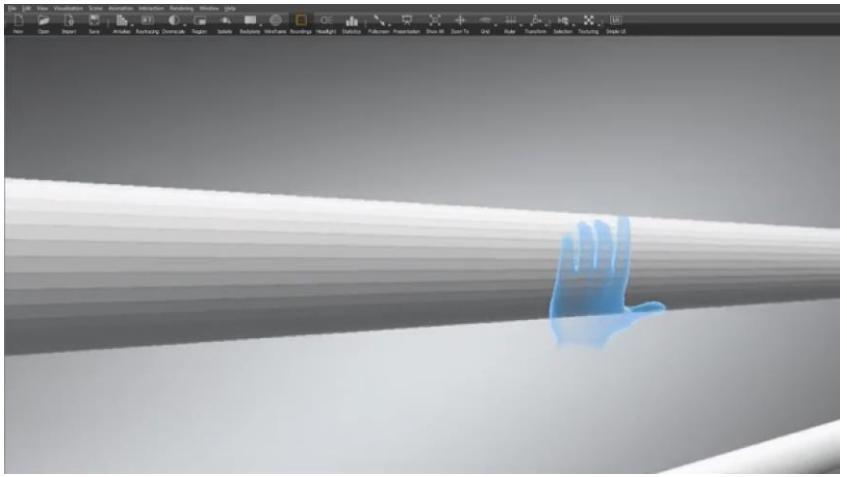
- **Purpose**
  - Reference material for proportions of STARGATE
  - Display model for design and manufacturing space
  - Manufacturing space frequented by campus tours



Model Development
Virtual Reality

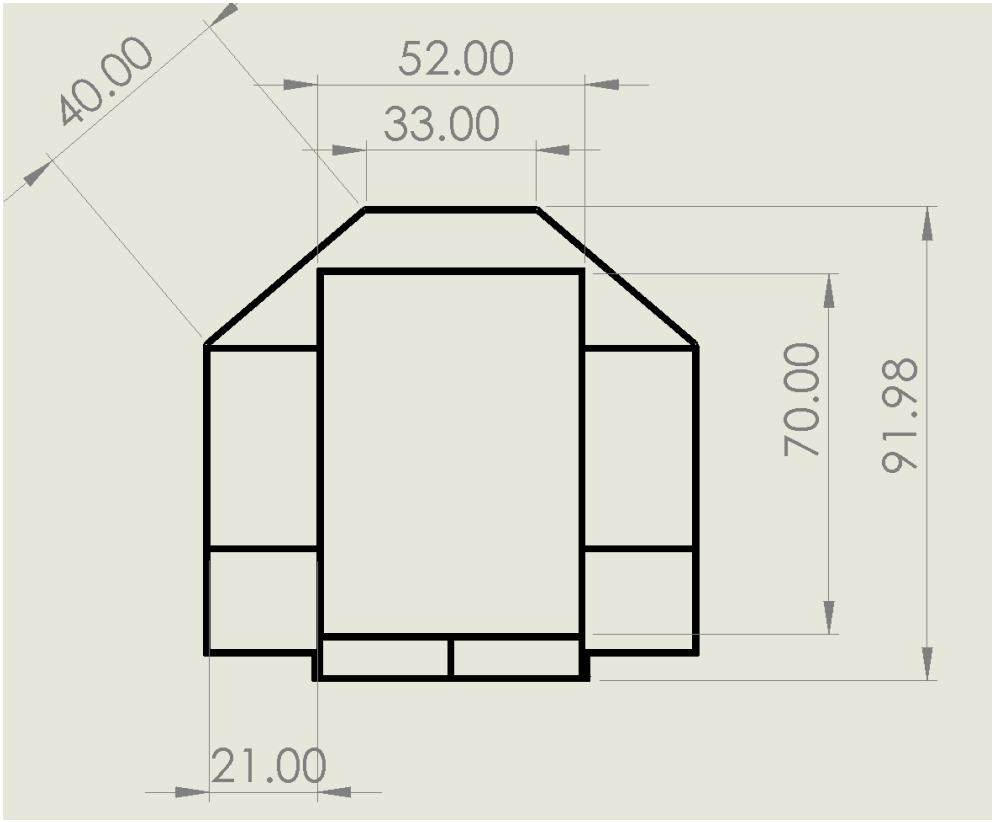
- **VR Model**
  - Using Autodesk software
- **Purpose**
  - Better understand physical proportions of STARGATE
  - Visualize scale model at 1:1 scale with no expense
  - Rapidly analyze impact of design changes on system configuration



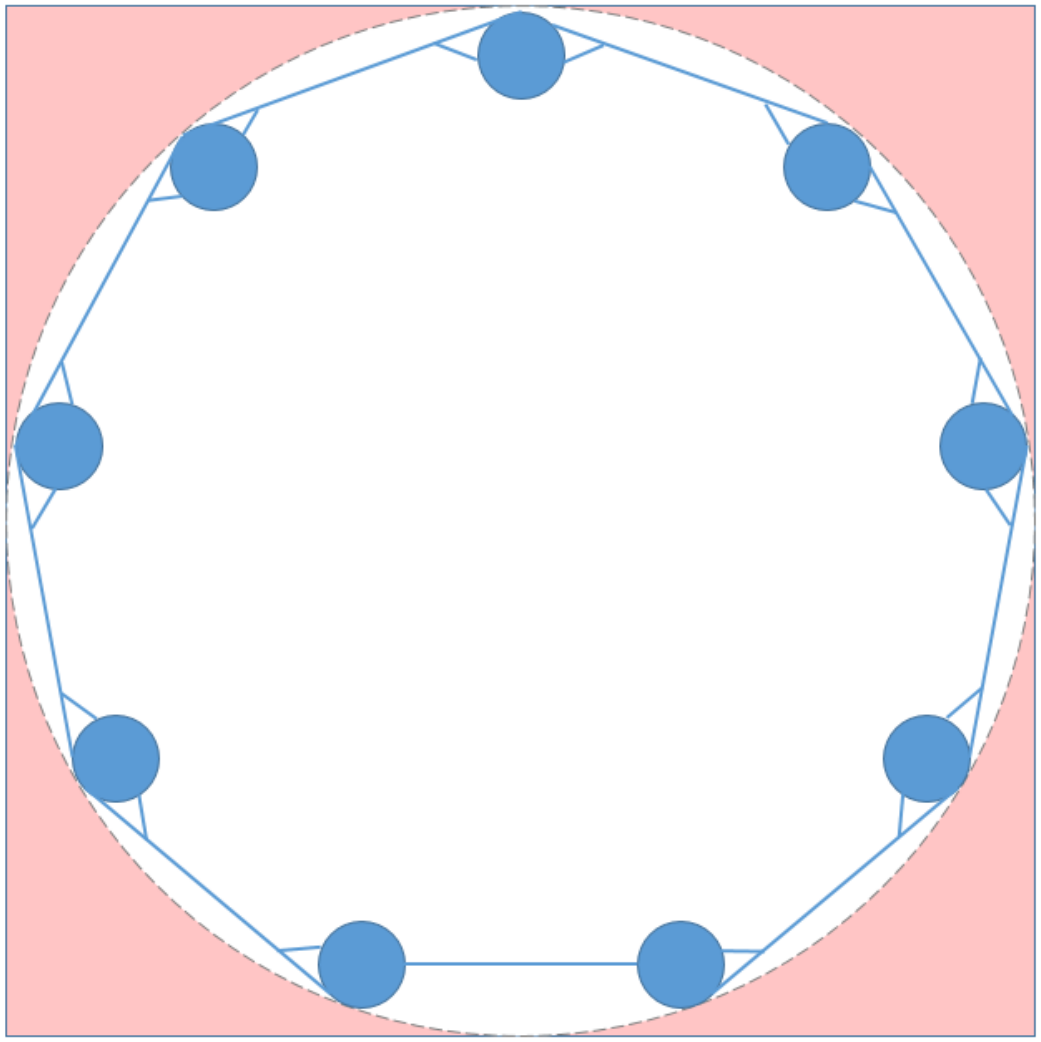


System Analysis
Weight Estimation

- **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



System Analysis
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

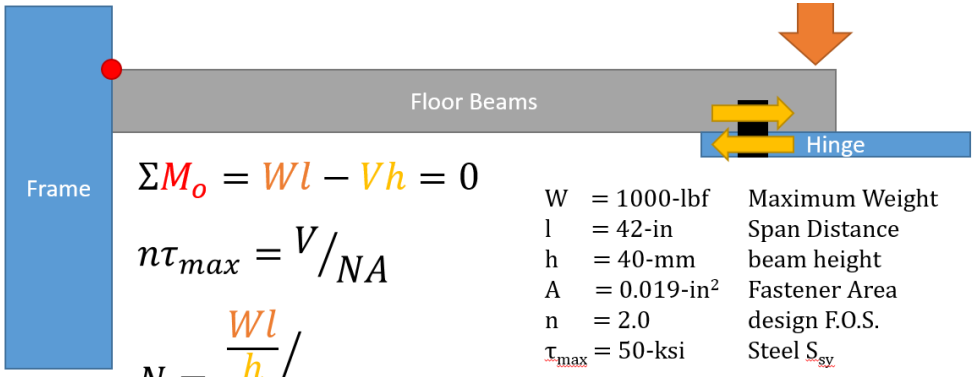
$356 - ft^3$

Space Efficiency

69.5%

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



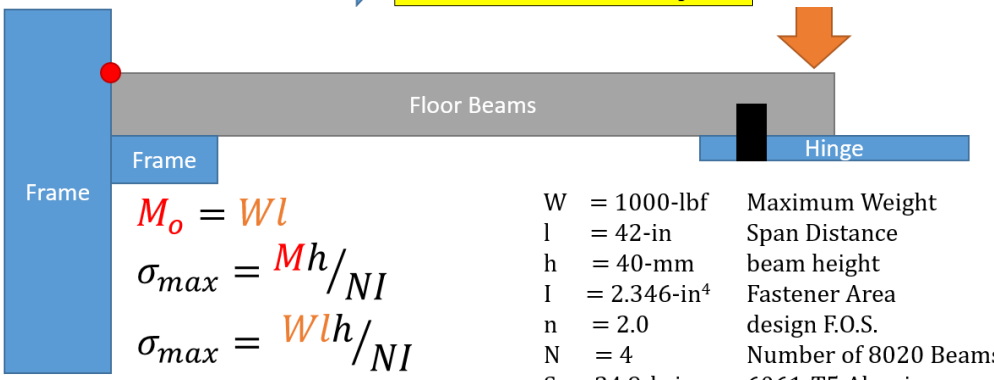
$$\Sigma M_o = Wl - Vh = 0$$

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

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

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

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}



$$M_o = Wl$$

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

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

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

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

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

Validation & Experimentation

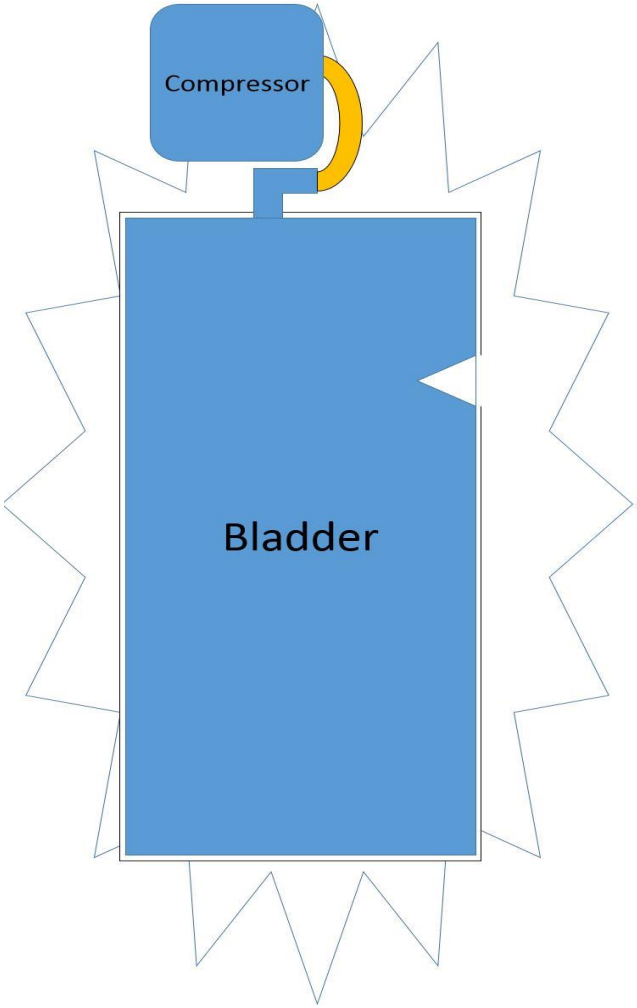
- **Senior Aerospace Courses require capstone related experimentation**
  - Use required experimentation to develop safety documentation for air beam systems
  - Final reports and data will be incorporated into final delivery user guide

- **Major Validation Areas**
  - Airbeam Contruction Methods
  - Air Beam Burst Test – expected failure mode of air beams
  - Air Beam Bending Test – maximum point and distributed load
  - Pressure Lift Test – maximum load displaced by an expanding pressurized volume
  - Pressure Push Test – horizontal displacement of mass and transient pressures

Validation & Experimentation
Air Beam Construction Methods

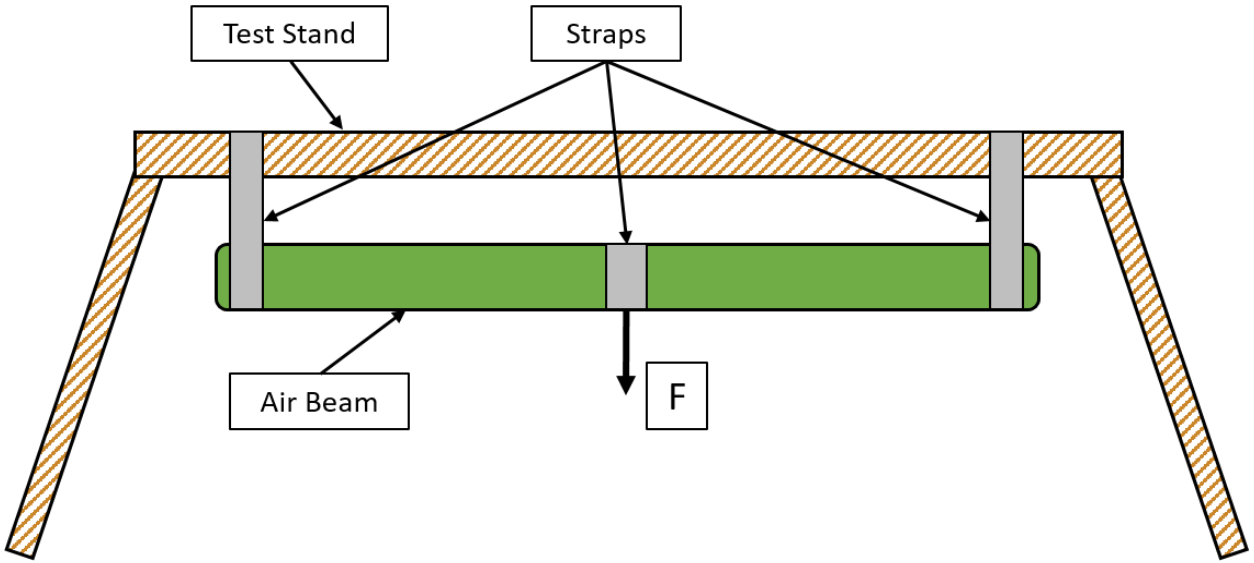
Validation & Experimentation
Air Beam Burst Test

- **Objective:**
  - Verify strength of beam-bladder system
  - Ensure worker safety
- **Process:**
  - Beams with bladders will be inflated until either the bladder or fabric encasing the bladder bursts.
  - Will test to ensure beams will not burst at high pressure or through multiple uses.



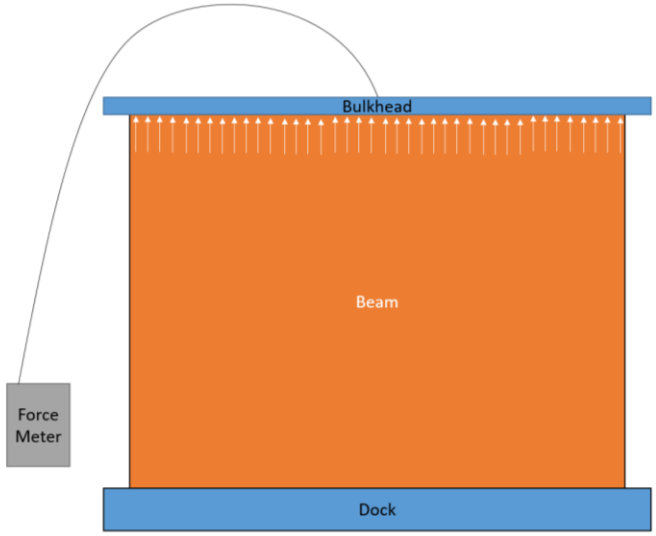
Validation & Experimentation
Air beam Bending Test

- **Objective:**
  - Determine accurate buckling resistance of large-diameter, low-pressure for proposed materials and manufacturing techniques
- **Test Rig:**



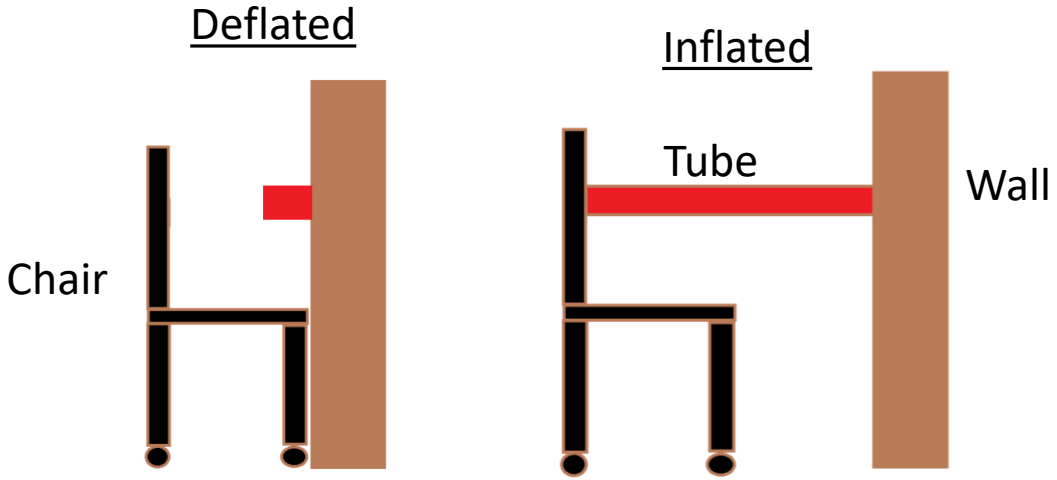
Validation & Experimentation
Pressure Lift Test

- **Objective:**
  - Determine maximum opposing force that air-beams can overcome during deployment
- **Process:**
  - With the exterior design on its side, weight is added to upper surface to measure the vertical deployment force at 0.5psig.
- **Test Rig:**



Validation & Experimentation
Preliminary Push Test

- **Objective:**
  - Determine the maximum weight which can be pushed on rollers during tube expansion
- **Results:**
  - 170 lb. weight which could be pushed
  - Expansion force = 5.5 lbf
  - Force varies on tube contraction method
- **Test Rig:**

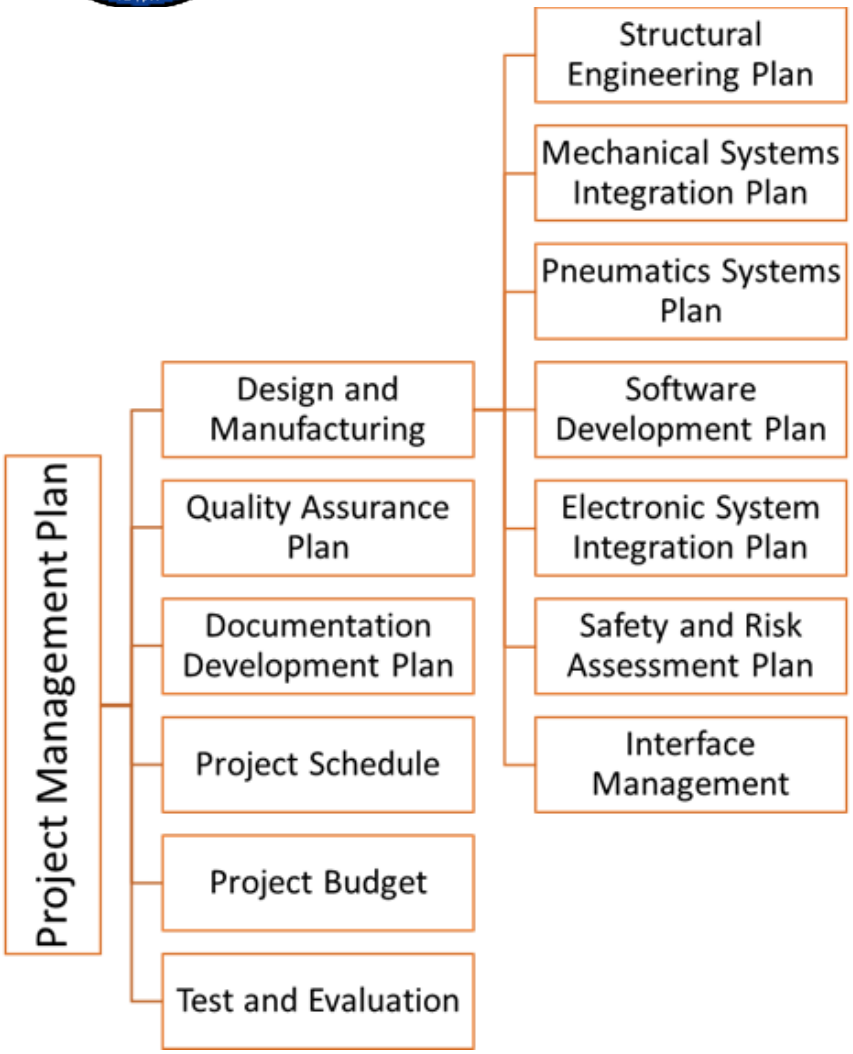


System Operations and Interfacing

- **Engineering Specialty Plans**
- **Wiring Schematic**
- **Pneumatic System Diagram**
- **Control Methods**
- **Facilities Tour**

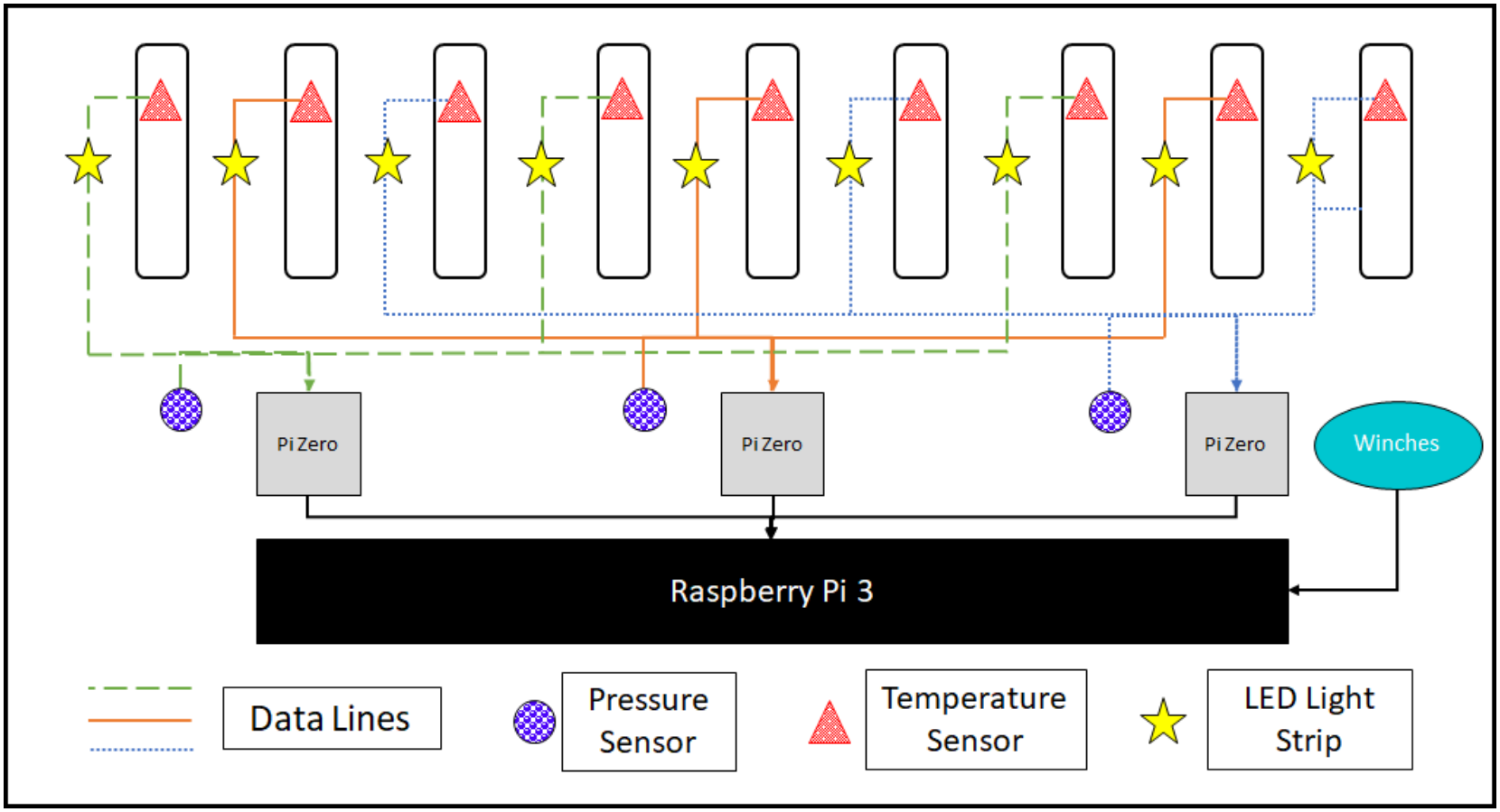
CDR POC: Josh Pankratz

Engineering Specialty Plan

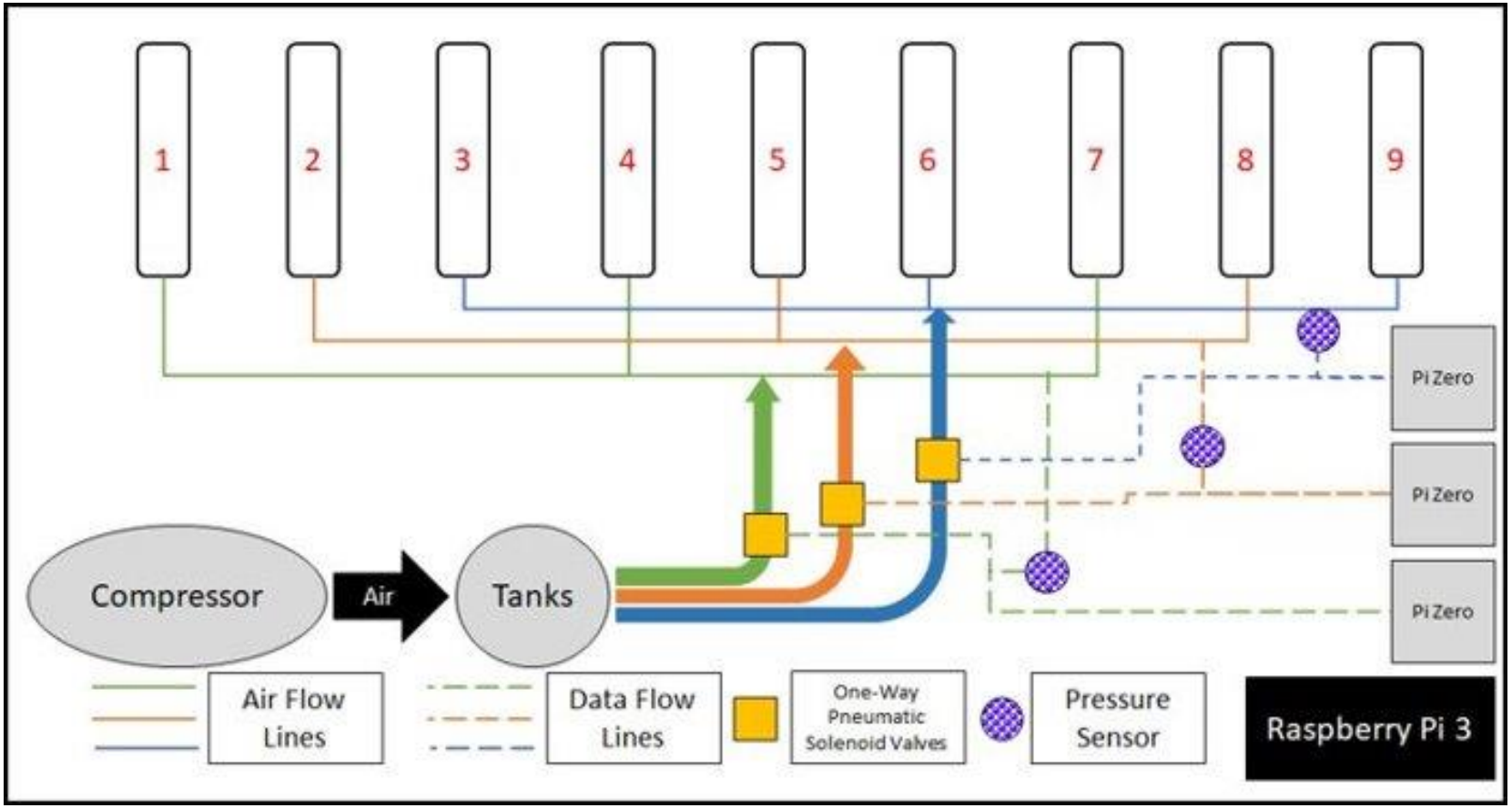


- **Broad Categories**
  - Project separated into six broad categories areas for planning
  - Broad categories monitored weekly at university level
  - Effort to communicate bi-weekly
- **Design and Manufacturing Specialties**
  - Seven critical areas identified
  - Each will have an appointed Subject Matter Expert (SME)
  - SME will monitor all progress in critical area, and will update management regularly
- **More Detail in Backup Slides**

Basic Wiring Schematic



Pneumatic System Diagram



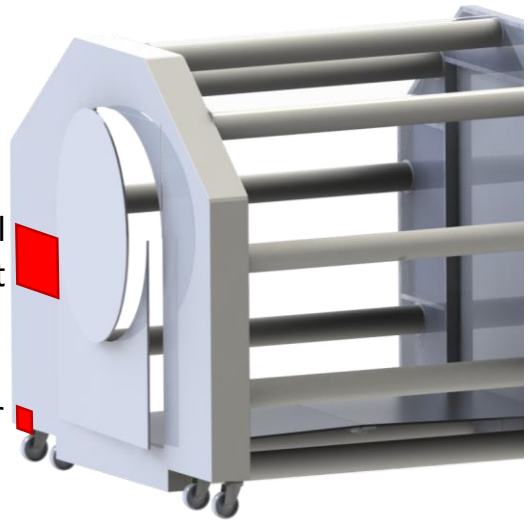
Control Methods

Current Board:

Raspberry Pi Zero

Alternative Board:

MyRio from National Instruments



Reasons:

Field programmable gate arrays (FPGA)

- Allows for fast I/O response
- Fast prototyping
- Logic control is run on hard circuits
- Industry level control setup that is reprogrammable

Labview:

- Direct interface with FPGA
- Easy to use graphical programing

Administrative Review

- **Hazard Matrix**
- **Risk Management**
- **FOD Avoidance**
- **Budgeting Data**
- **Post-CDR Schedule**

CDR POC: Michael Raymer

Hazard Matrix

P= Risk to Personnel A= Risk to Assets	Probability [Pr] Estimations				
Severity Classifications	A: Frequent	B: Probable	C: Occasional	D: Remote	E: Improbable
I: Catastrophic					**P07**
II: Critical					**A02, P02, A07**
III: Moderate				**A04**	**P04**
IV: Negligible			**P05, P09**	**P06, A08**	**A01, P01, P03**

RAC: 1	**Unacceptable** – All operations shall cease immediately until the hazard is corrected, or until temporary controls are in place and permanent controls are in work.
RAC: 2	**Undesirable** – All operations shall cease immediately until the hazard is corrected or until temporary controls are in place and permanent controls are in work.
RAC: 3	**Acceptable with controls** – Division Chief or equivalent management is authorized to accept the risk with adequate justification.
RAC: 4-7	**Acceptable with controls** – Branch Chief or equivalent management is authorized to accept the risk with adequate justification

Hazard Code	Hazard Description
01	Electrocution
02	Fire
03	C02
04	Structural Failure
05	Minor Injury
06	Thermal
07	Compressor Explosion
08	Pressure Lines
09	Entering Confined Spaces

More Detail in Backup Slides

JPR 1700 Regulations

Detailed review pending access to checklist provided by NASA contact

- 6.3.4: Warehouse Safety and Health
- 6.7: JSC's Policy for handling Unique Hardware or Materials
- 6.9: Space Systems and Test Safety
- 6.10: Confined Spaces
- 6.11: Pressurized Gas

Regulation	Applicability	Status
6.1	N/A	
6.2	N/A	
6.3	Applies	Reviewed
6.4	N/A	
6.5	N/A	
6.6	N/A	
6.7	Applies	Reviewed
6.8	N/A	
6.9	Applies	Reviewed
6.1	Applies	Reviewed
6.11	Applies	Reviewed
6.12	N/A	
6.13	N/A	

FOD Avoidance

- **Design Consideration for FOD prevention**
  - Systems and hardware will be enclosed for the duration of the analogue deployment and retraction.
  - Removeable panels will be implemented for ease of access for inspection and cleaning in FOD control areas
  - FOD critical areas are sealed off to prevent debris and water from entering and damaging crew-lock
  - Open floor scheme prevents FOD entrapment within crew-lock

- **FOD Area Classification**
  - FOD Critical Areas: Inflatable air-beams
  - FOD Control Areas: Electronics and hardware housed within airlock within removable panels, hardpoints, bulkhead frames
  - FOD Awareness Areas: Inner crew lock area, crew-lock walkway

Cost and Schedule Data
Itemized Budget for Materials

- **Fabrics**
  - Based on cost-per-yard from manufacturer
  - Allowance for F.O.S. of 1.5
- **Structural Hardware**
  - Cost values sourced from 8020.net
  - "Finishing" category includes cost of exterior paneling, floors, etc.
- **Electronics**
  - Subject to change in-lieu of contact with National Instruments

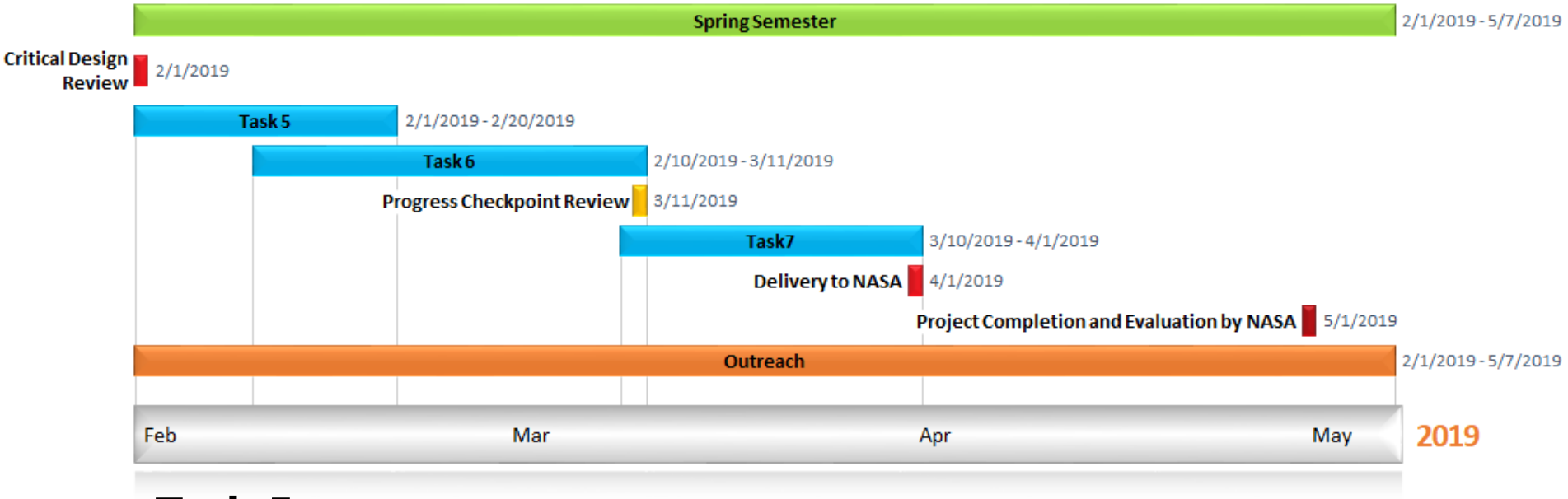
Area/Item	Subtotal	Itemized
Fabrics	**$ 950.00**	
Bladders		$ 60.00
Air beam Walls		$ 450.00
Demonstrator Wall Panels		$ 320.00
Allotment for Cost Overrun		$ 120.00
Structural Hardware (8020.net estimate)	**$ 3500.00**	
Catwalk Construction		$ 660.00
Catwalk Finishing		$ 100.00
Dock and Bulkhead Frames		$ 2000.00
Dock and Bulkhead Finishing		$ 300.00
Allotment for Cost Overrun		$ 440.00
Electronics	**$ 1050.00**	
Control Systems (Raspberry Pi)		$ 50.00
Air beam Control Sensors		$ 315.00
Pneumatic Systems		$ 300.00
Crewed Volume Sensors & Lighting		$ 250.00
Allotment for Cost Overrun		$ 135.00
Total	**$ 5500.00**	

Cost and Schedule Data
Overall Budget

- **JSC Delivery Estimate**
  - 550-mi. U-Haul rental (one way)
  - Two vehicles for student and faculty travel
  - Two nights in Houston/JSC area
- **Current estimate for unallotted budget**
  - $1800.00
  - Used for large unexpected cost overruns
  - Development of extra functions, tools, and features

Area/Item	Subtotal	Itemized
Demonstration Article	**$ 5500.00**	
Fabrics		$ 950.00
Structural Hardware		$ 3500.00
Electronics		$ 1050.00
JSC Delivery Estimate	**$ 2700.00**	
Vehicle Rental (U-Haul Est.)		$ 293.00
Gas (1 vehicle at 12-mpg, 2 at 18-mpg)		$ 535.00
Lodging		$ 1400.00
Allotment for Cost Overrun		$ 472.00
Estimated Remaining Budget	**$ 10000.00**	
Unallotted Budget	**$ 1800.00**	

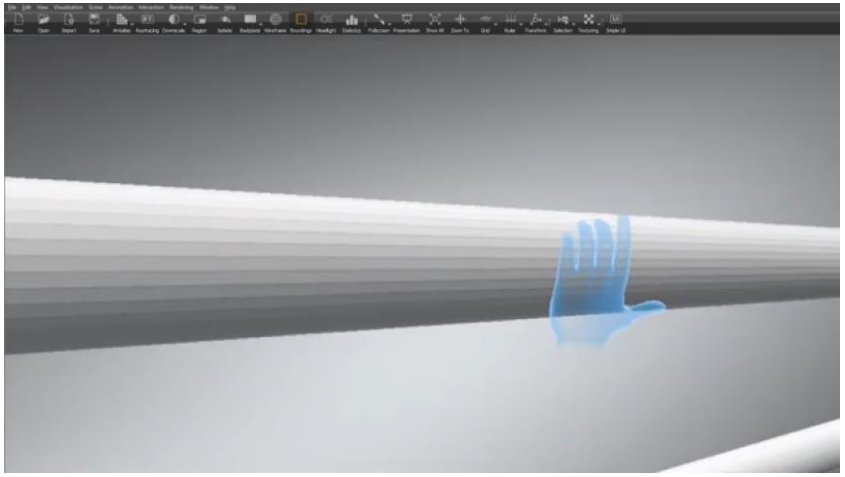
Post-CDR Schedule Timeline



- **Task 5**
  - *Final Engineering Model Construction*
- **Task 6**
  - *Testing, Technology Maturation and Implementation*
- **Task 7**
  - *Documentation Development, Validation, Delivery*

Post-CDR Schedule
Outreach

- **Potential Outreach**
  - Stillwater Public Schools
  - Public Schools in surrounding counties
- **Outreach topics**
  - Perspective as STEM students
  - Use of inflatable structures
  - Future of inflatables in
  - Space Applications
- **Outreach Tools**
  - VR models
  - Scale Models
  - Inflatables



Review & Questions

- **Administrative Overview**
  - CDR POC: Justin Duewall
- **Analog System Design Solution**
  - CDR POC: Austin Bennett
- **Research and Development**
  - CDR POC: Madison Whiteley
- **System Operations and Interfacing**
  - CDR POC: Josh Pankratz
- **Administrative Review**
  - CDR POC: Michael Raymer