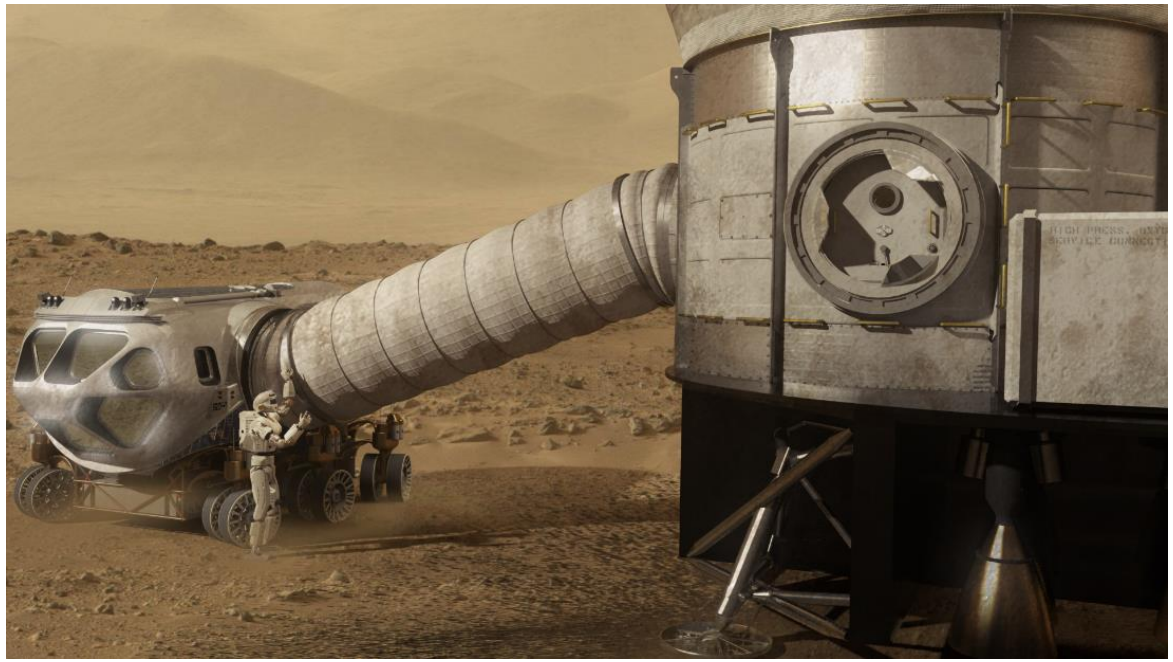
Inflatable Softgoods Design of an Articulating Crew Transfer Tunnel

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Need for Pressurized Transfer

- NASA's Moon to Mars architecture, including the Artemis Program, requires multiple elements on planetary surface
  - Landers
  - Pressurized Rovers
  - Habitats
  - Etc…
- Interoperability between those elements is required for Artemis Accords
- Shirt-sleeve transfer on the Moon can greatly extend mission life and achieve greater science objectives, by reserving EVA time for exploration instead of translation between elements
- Shirt-sleeve transfer between elements is also required for Mars missions for planetary protection
- **To enable this, a "standard" attachment system needs to be developed for surface assets, like the International Docking System Standard (IDSS) for micro-gravity**

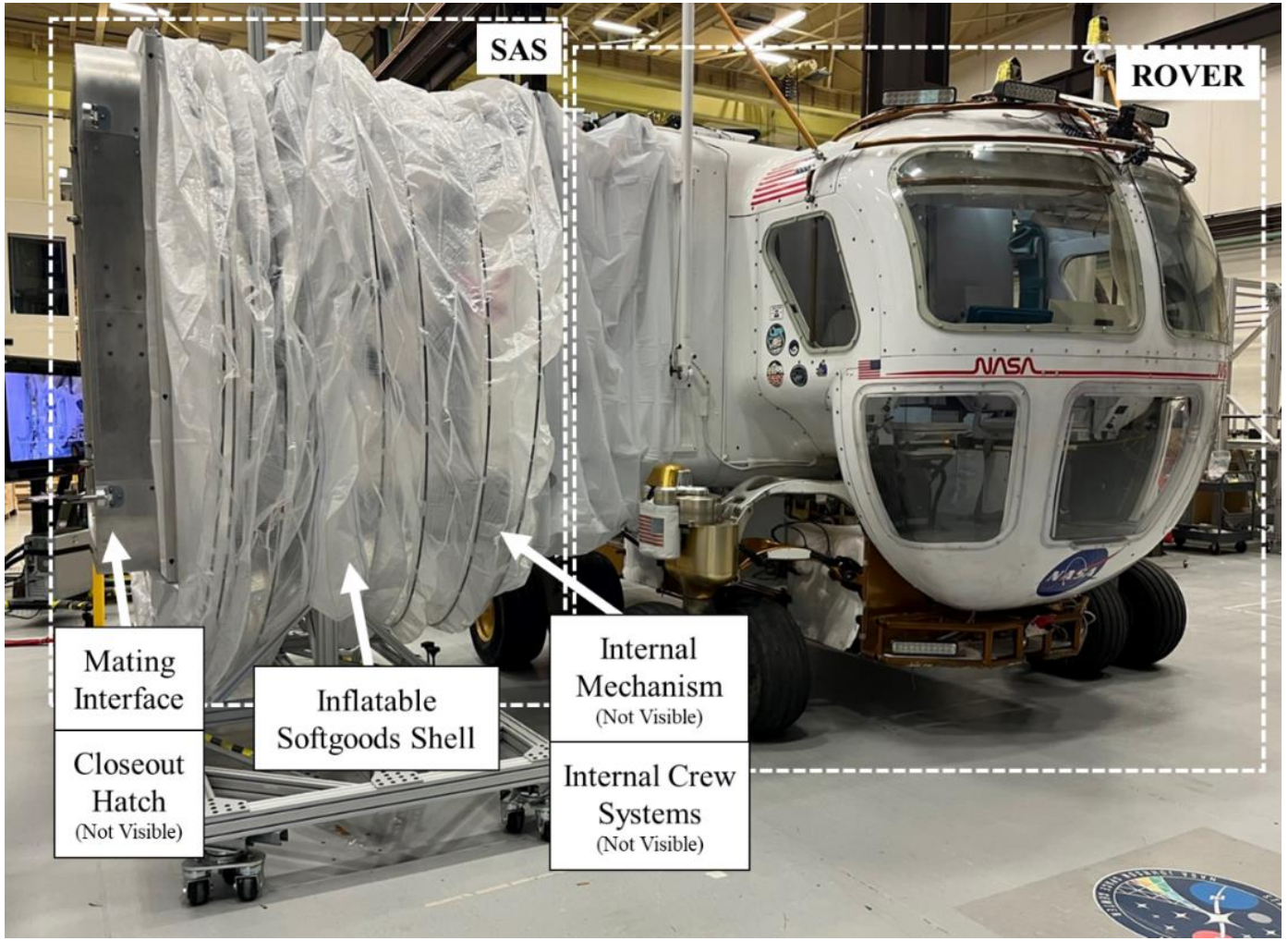


Conceptual Rendering of a Pressurized Transfer Tunnel Between a Habitat and Pressurized Rover on the Martian Surface

- A development effort to inform the new docking standard was started at NASA Johnson Space Center to develop the Surface Attachment System (SAS) – a pressurized transfer testbed to evaluate surface attachment requirements

Surface Attachment System (SAS) Overview

- **SAS design includes five major components:**
  - Internal Mechanism
  - Inflatable Softgoods Shell
  - Internal Crew Systems
  - Mating Interface
  - Closeout Hatch
- **Primary constraints:**
  - Designed for walk-through operation
  - 10.2 psig operating pressure
  - 40-inch x 60-inch rectangular opening
- **Operations:**
  - Unpressurized extension, articulation, and alignment leads to hard mate with latches
  - Pressurize internal volume of tunnel as fabric takes load, equalize pressure, crew opens hatches and translates
  - Reverse operation with tunnel retracted and packed for next use



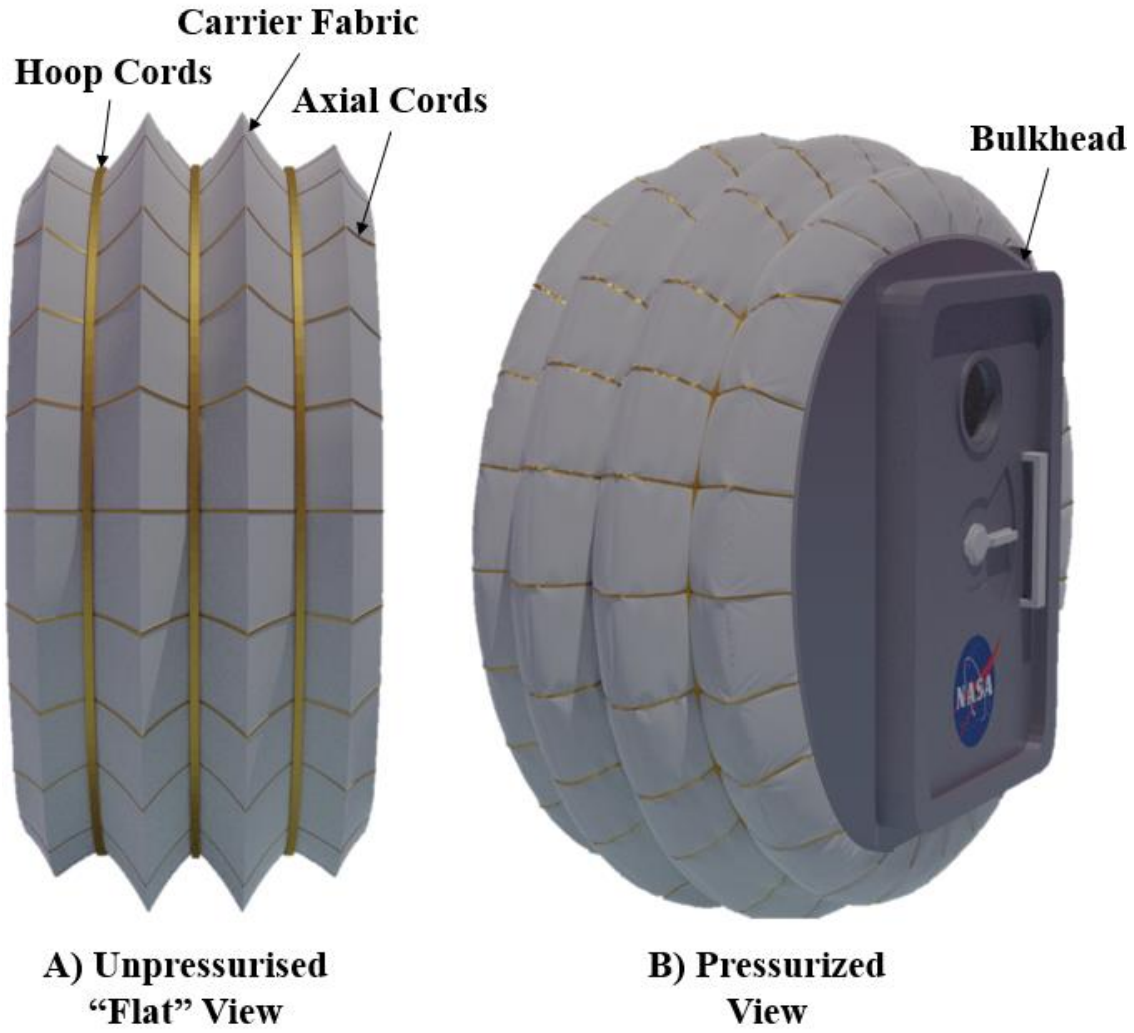
Full-scale Demonstration Test of the Surface Attachment System on a Pressurized Rover at Johnson Space Center

Softgoods Requirements & Design Overview

Softgoods Specific Design Constraints

1. 10.2 psig x 4.0 Factor of Safety
2. 50 pressure cycles x 4.0
3. Accommodate tunnel's full articulation envelope
4. Pressurize anywhere in docking envelope
5. Able to retract into stowed position

- These constraints make the inflatable unlike other softgoods structures that are designed with a specific inflated shape
- **Solution based on "pumpkin" lobe design (also known as Taylor surface or zero-hoop stress shape)**
- Uses carrier fabric that transfers loads into series of cords, like a parachute canopy and suspension lines
- Unique tunnel design features four "pumpkins" stacked and truncated on one another to form a single internal volume
- Flat annulus sections behave like Mylar balloons and create wrinkles when pressurized – where the axial cords are set inside
- Allows for flexibility in design that can be scaled and accommodate multiple tunnel positions



Softgoods Tunnel Design Overview

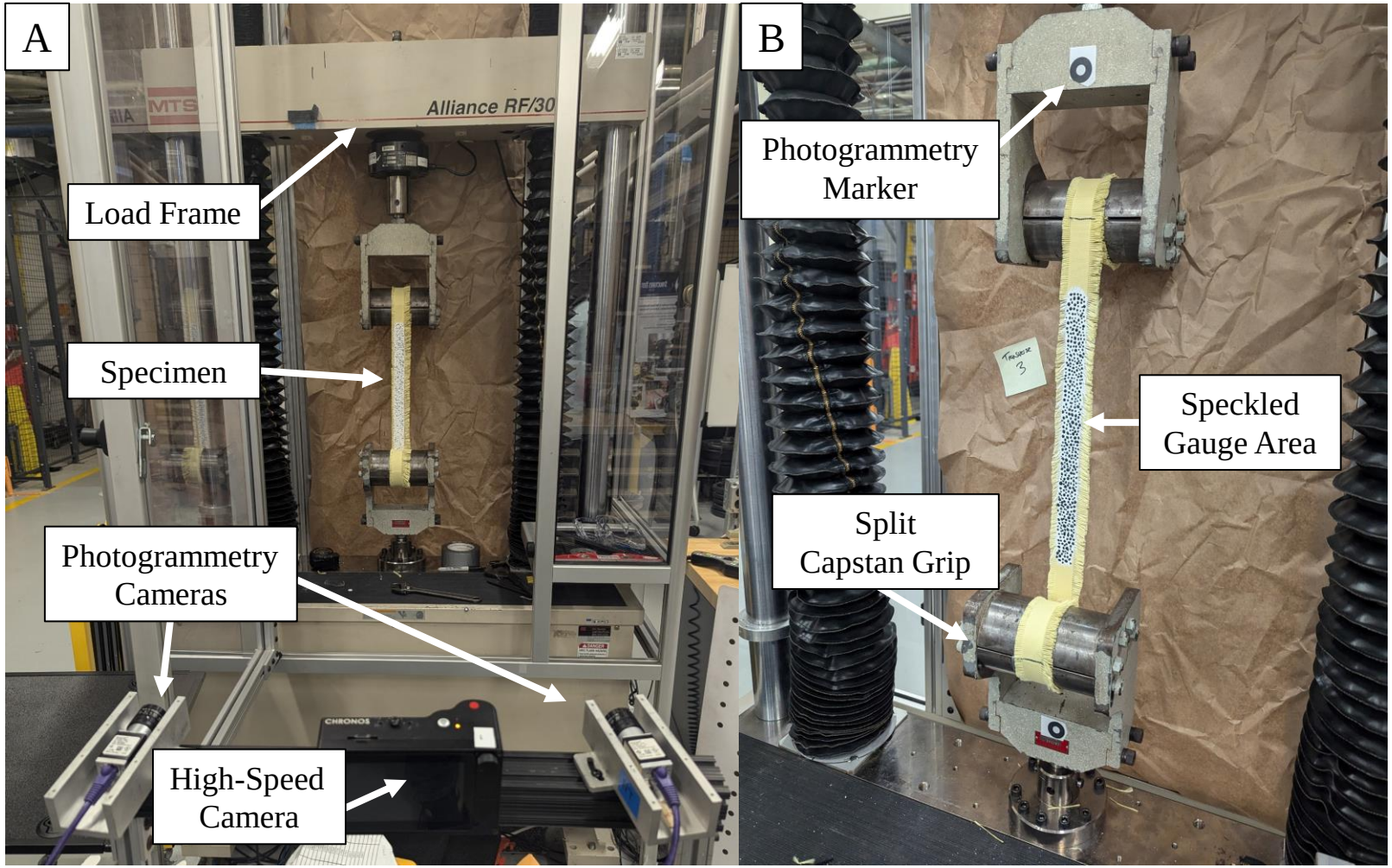
Softgoods Design Overview



MATERIAL TESTING

Material Testing – General Testing Setup

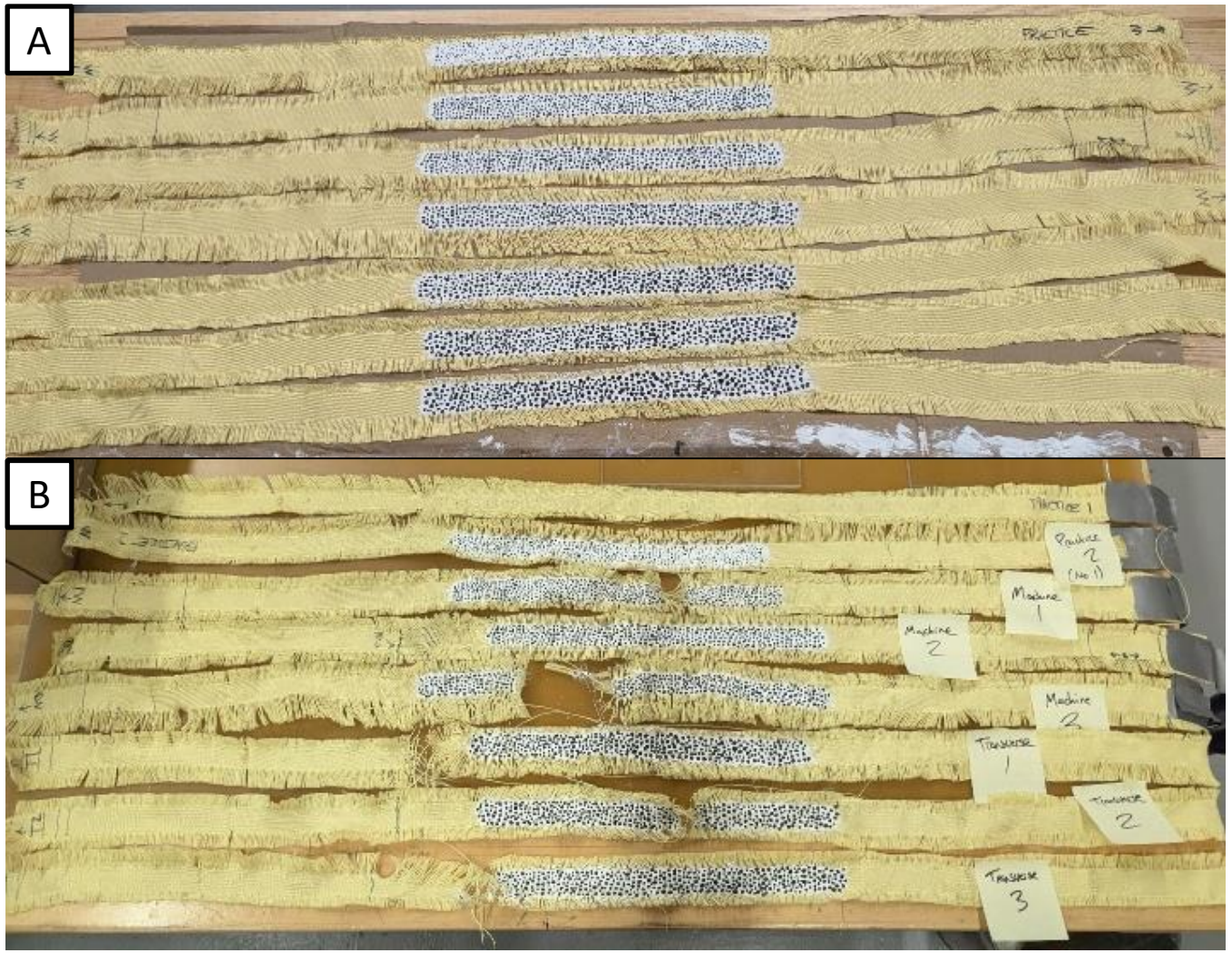
- Uniaxial tensile testing of raveled cloth strips per PIA-Test Standard 4108A, cordage per ASTM D4268
- Photogrammetry cameras used to capture material strain in gauge area by tracking painted speckles or black and white eclipse target markers
- Load frame providing time, load, and crosshead position data for comparison
- Samples pulled until failure



Tensile Testing Setup Showing A) Camera View and B) Close-Up View

Material Testing – Broadcloth

- 1500 denier, Kevlar 29 plain weave fabric
- The material was prepared in one-inch-wide raveled strips, in both the machine and transverse directions
- Split-capstan grips were used to secure the specimens



Broadcloth Tensile Specimens A) Pre-Test with Speckle Pattern and B) Post-Test

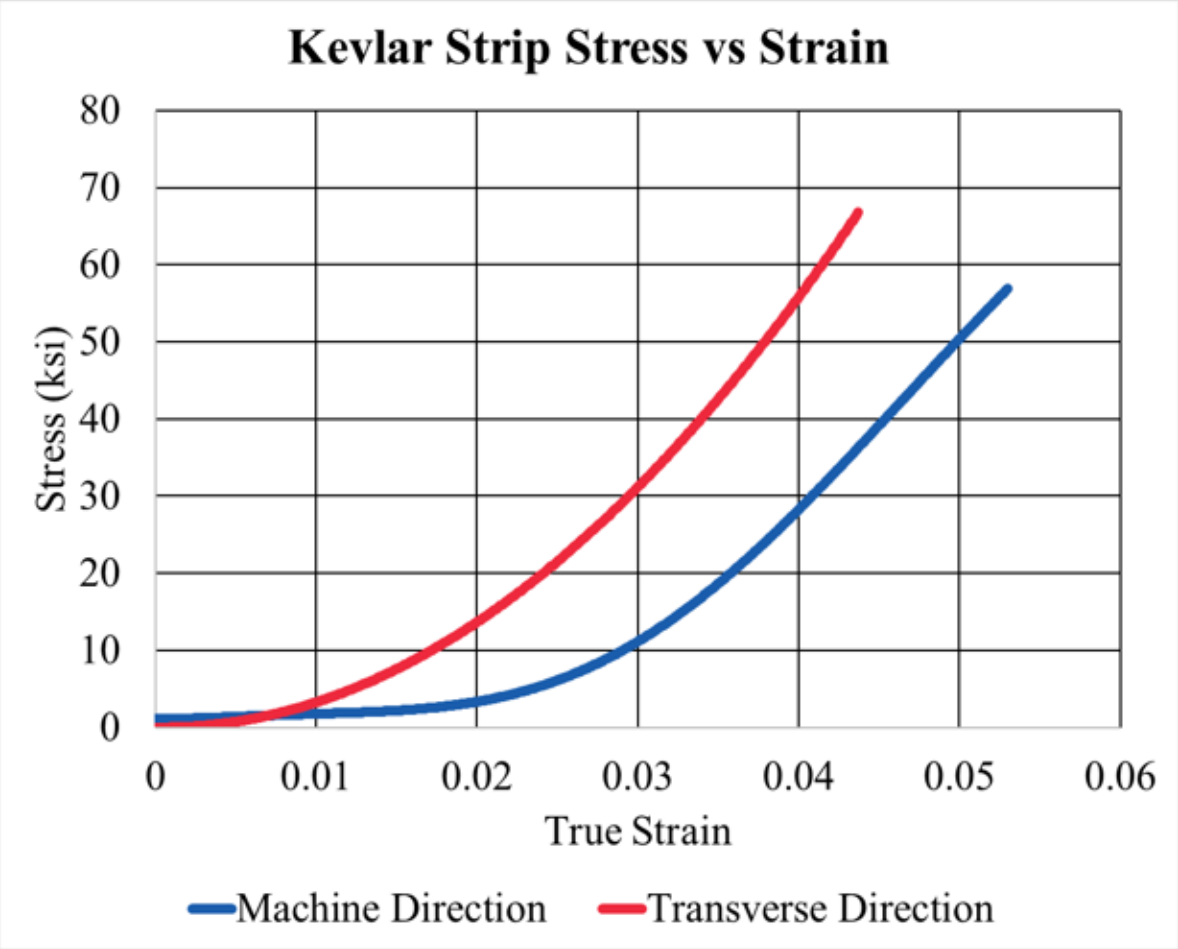
Material Testing – Cordage

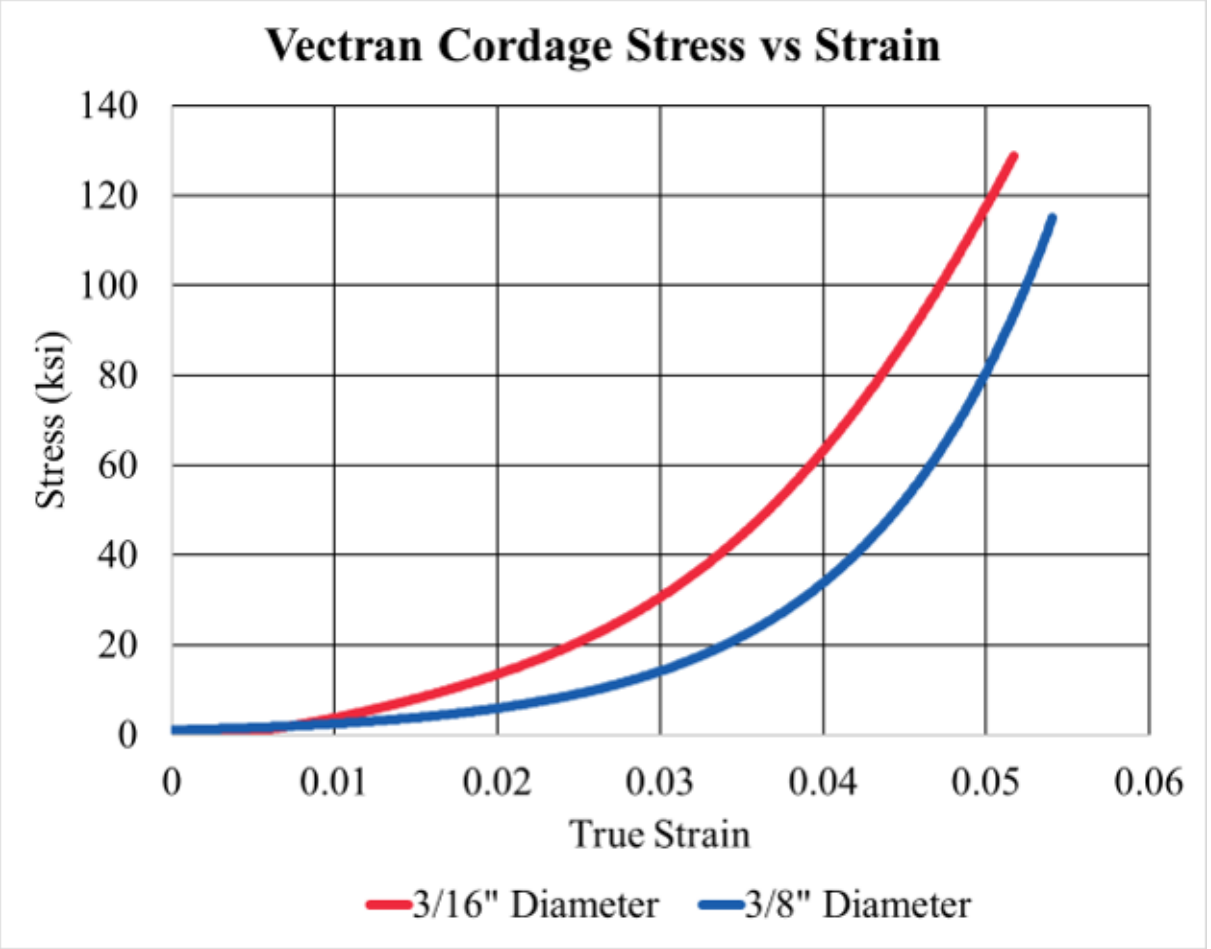
- Vectran 12 strand braided cord in black color
- Initially prepared in same fashion as the constructed cords in the test article
- 3/8” diameter axial cords used Samson Class-II Eye Splices as on both ends, tensioned by pin connections
- 3/16” diameter hoop cords used Class-II End-for-End splices but were disassembled and wrapped around two high strength cordage capstan grips, due to a lack of range of motion on available load frames.



Cordage Tensile Specimens A) Pre-Test With Marker Targets and B) Post-Test

Material Testing – Results



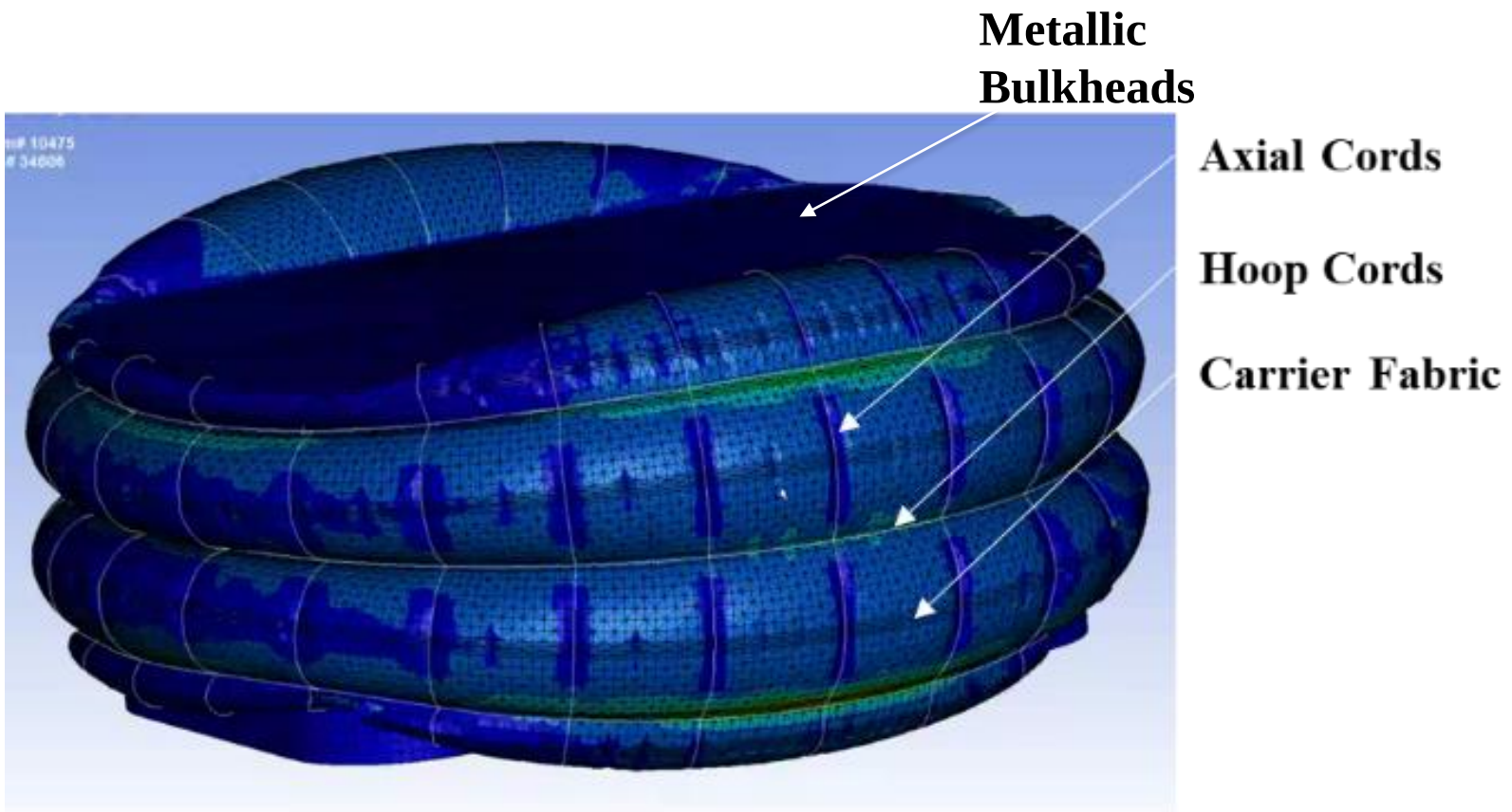


Stress vs Strain Curves for (LEFT) Kevlar Broadcloth Strips and (RIGHT) Vectran Cordage

MODELS & SIMULATION

LS-DYNA Model

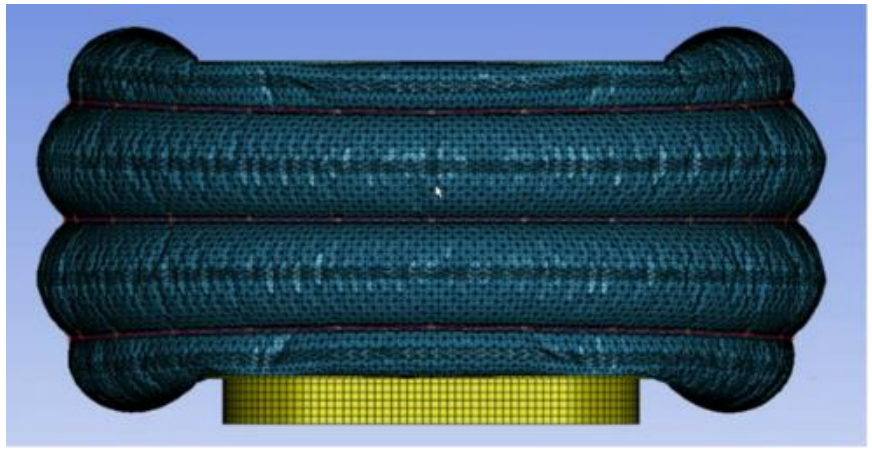
- Shell & cable element model of softgoods structure & metallic bulkheads
- Non-linear properties derived from material testing
- Cord-fabric & fabric-fabric contacts modeled
- Model was used to evaluate the structural softgoods design and feed requirements to the internal mechanism



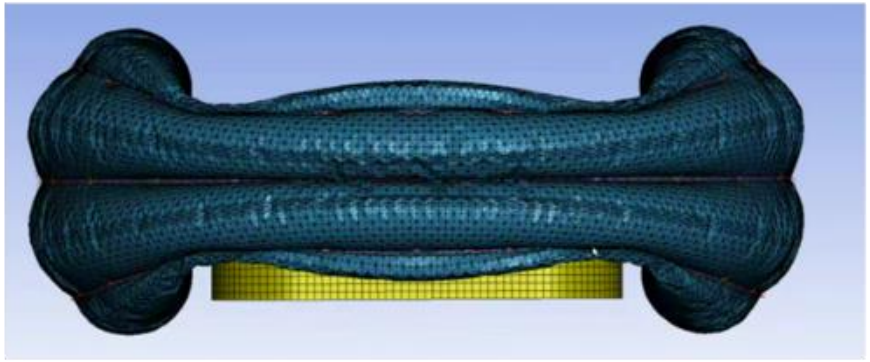
Components of the SAS LS-DYNA Model

Model Cases

- Model cases were completed for tunnel positions at the extremes of the docking envelope
- Loads on the internal mechanism and softgoods stresses were analyzed for each case



Max Extension



Min Extension

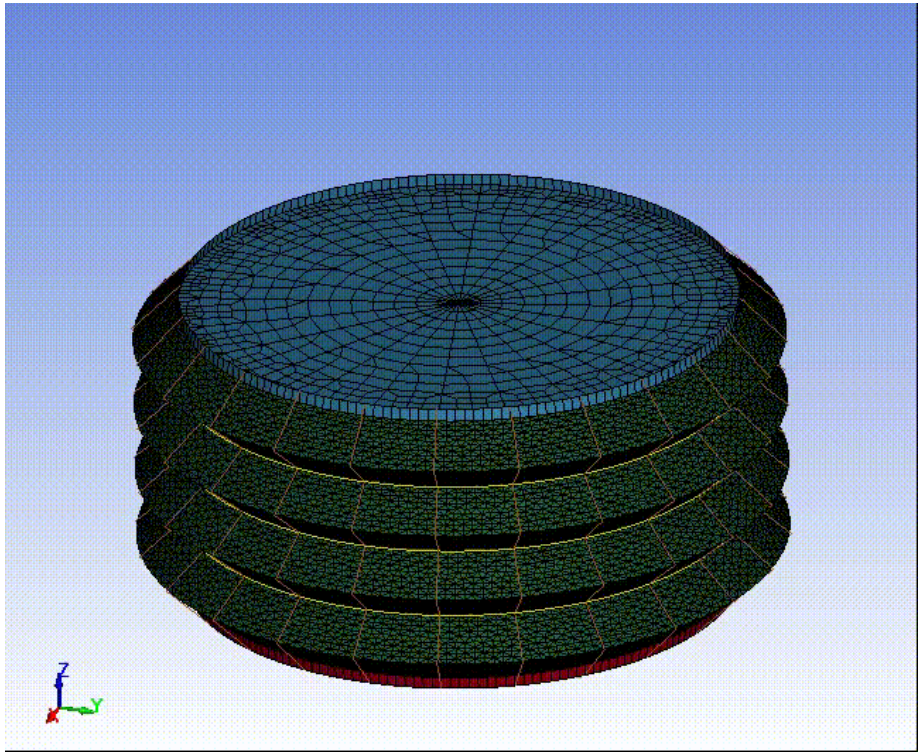


Roll

SAS Model pressurized in bounding articulation cases

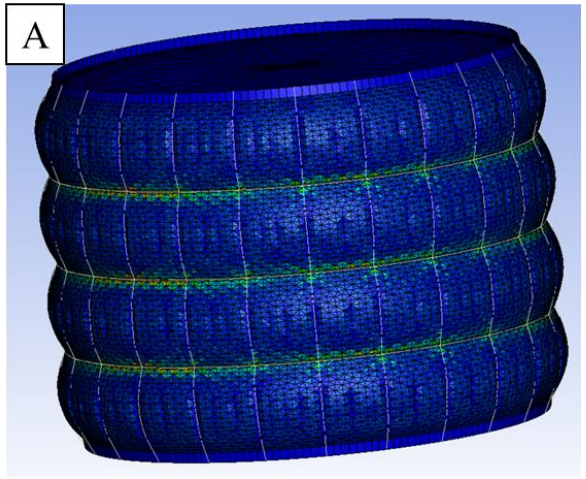
Modeling Results

- Further modeling was completed for upcoming 1/3 scale testing to ensure safe pressurization
- All softgoods components showed positive margins at 4.0 FOS over MDP



1/3 scale SAS Model moving to max extension and pressurizing

A



B **Margin of Safety Summary Table**

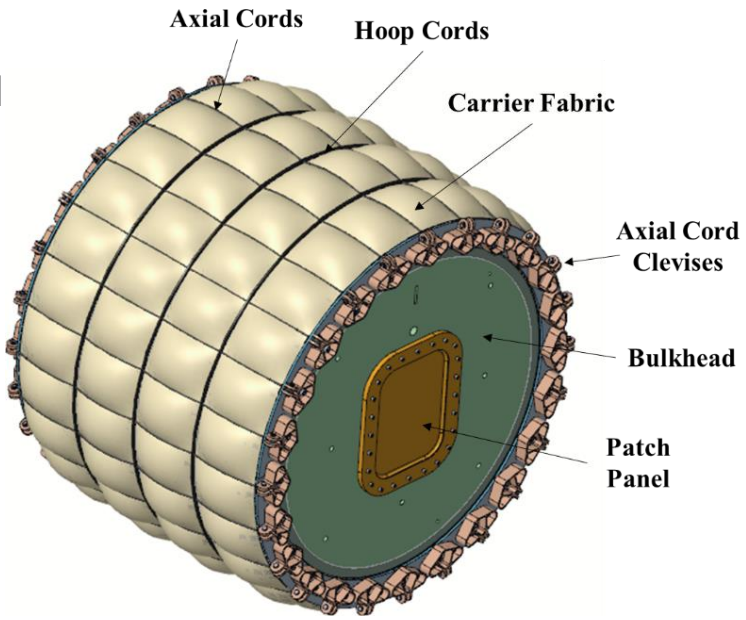
	Factory of Safety	Margin of Safety
Axial Cords	4.0	+2.44
Hoop Cords	4.0	+2.65
Broadcloth	4.0	+0.02

A) Stress results of 1/3 scale SAS model at max extension
B) Margins of safety for each 1/3 scale component

CONCLUSIONS & FORWARD WORK

Subscale Testing

- A 1/3 scale tunnel will be tested early this year
- The internal mechanism will articulate the tunnel to extreme positions, then pressurize to operational pressure
- This testing will provide model validation for the LS-DYNA model and the mechanism will be instrumented to determine internal loads
- Future work includes further analytical modeling & testing of a full-scale tunnel

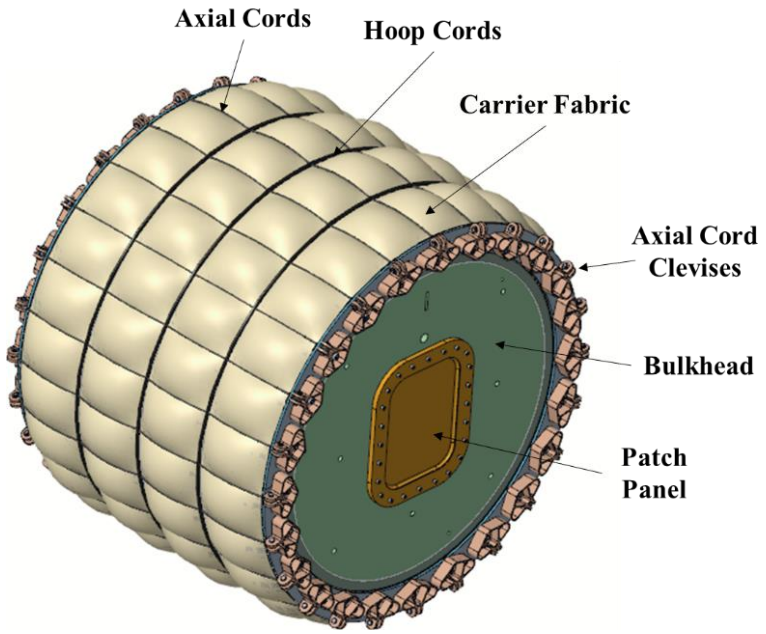


1/3 scale SAS test article components



1/3 scale SAS test article buildup

QUESTIONS?



INFLATABLE SOFTGOODS DESIGN OF AN ARTICULATING CREW TRANSFER TUNNEL

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