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PROJECT SCOPE

This project consists of the design, manufacturing, and testing of a launch vehicle enclosure for Orbital ATK. The primary purpose of the enclosure is to provide launch vehicles protection from the elements during launch pad processing.

CUSTOMER REQUIREMENTS

Table 1. Developed engineering requirements from customer needs

Item:	Customer Need	Related Engineering Requirement	Metric	Target Value	Tolerance
1.0 Concerning Weather					
1.1	Solar Protection	Heat Flux Through Enclosure Material	*W*	354	<354
1.2	Moisture Protection	Permeability	$g/m^2/24hr$	603	<603
1.3	Wind Protection	Volumetric Flow Rate	*m3/s*	0.071	±0.005
2.0 Concerning Launch Vehicle					
2.1	Launch Vehicle Temperature	Surface Temperature Delta	*°C*	23.9	18.4 - 29.4
2.2	Launch Vehicle Contact	Enclosure Deflection	*m*	1	<1
3.0 Concerning Pre-Launch Staff					
3.1	Work Environment Temperature	Dead Space Temperature	*°C*	23.9	18.4 - 29.4
3.2	Work Space	Enclosure Footprint	m^2	200	±10
3.2.1	Accessibility	Entrance Dimensions	m^2	25	±5
4.0 Concerning Material Procurement/Manufacturing/Assembly					
4.1	Scalable Design	Cost per Enclosure Height	*$/m*	2000	<2000
4.2	Ease of Assembly	Number of Assembly Steps	*# of Steps*	10	±5
4.2.1	Time of Assembly	Time to Assemble	*min*	60	±480
4.2.2	Time of Disassembly	Time to Disassemble	*min*	30	±160
4.3	Associated Costs	Raw Material Cost	*$*	50,000	±50,000
5.0 Concerning Enclosure					
5.1	Ability to Support Items	Bearing Stress	*kPa*	1	±0.015
5.2	System Lifespan	Usage Quantities	*# Uses*	5	±20
5.3	Durability	UV Degradation	*Hrs*	5,000	>5,000
5.4	Safety	Failure Percentage Across Various Scenarios	*%*	1	±0.01
5.5	Factor of Safety	Yeild Stress / Working Stress	*FOS#*	3 yeild & 5 Ult.	>3 >5

PERMEABILITY ANALYSIS

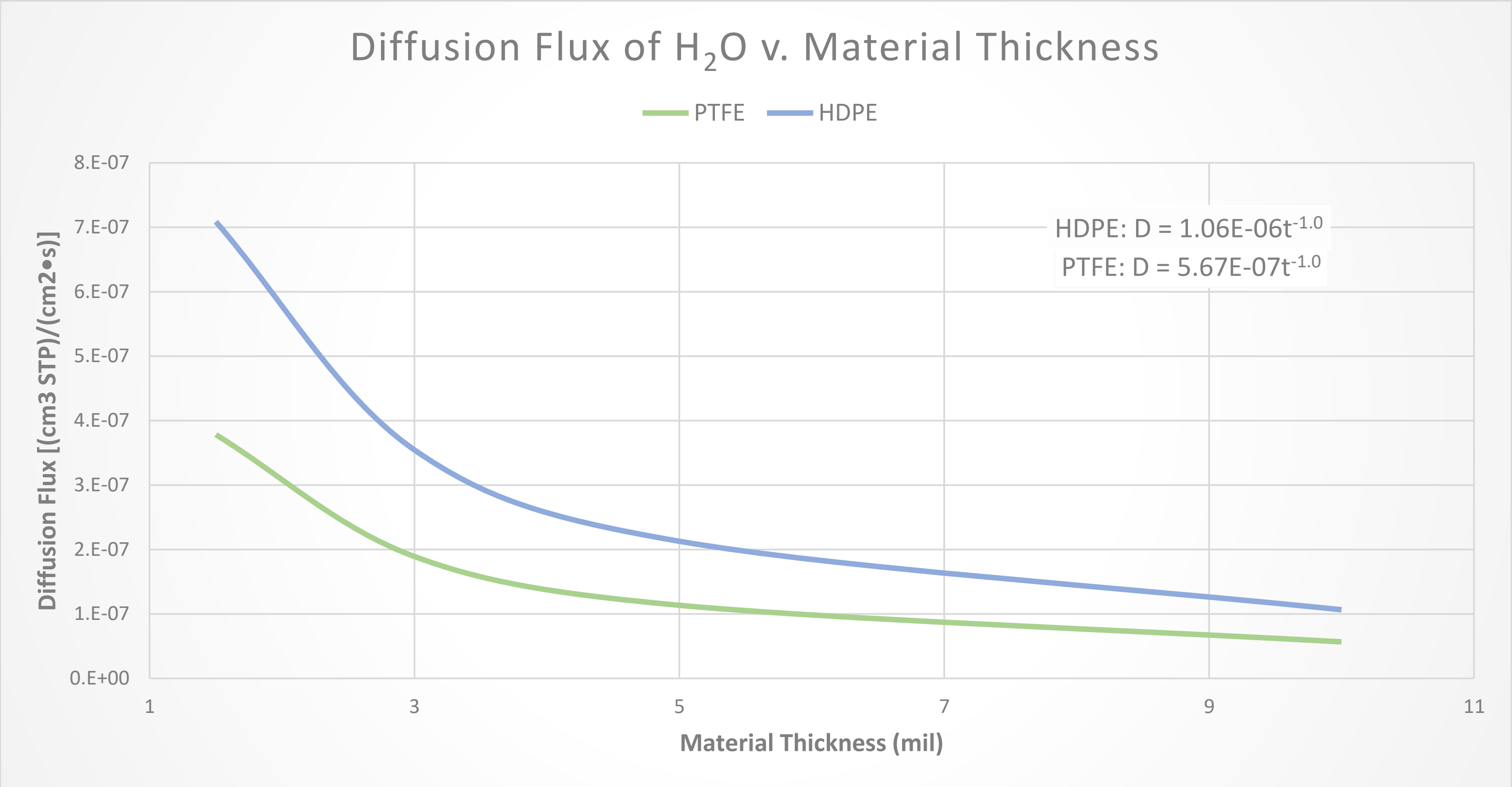


Figure 1. Except of permeability analysis conduct on various fabric materials

HEAT TRANSFER ANALYSIS

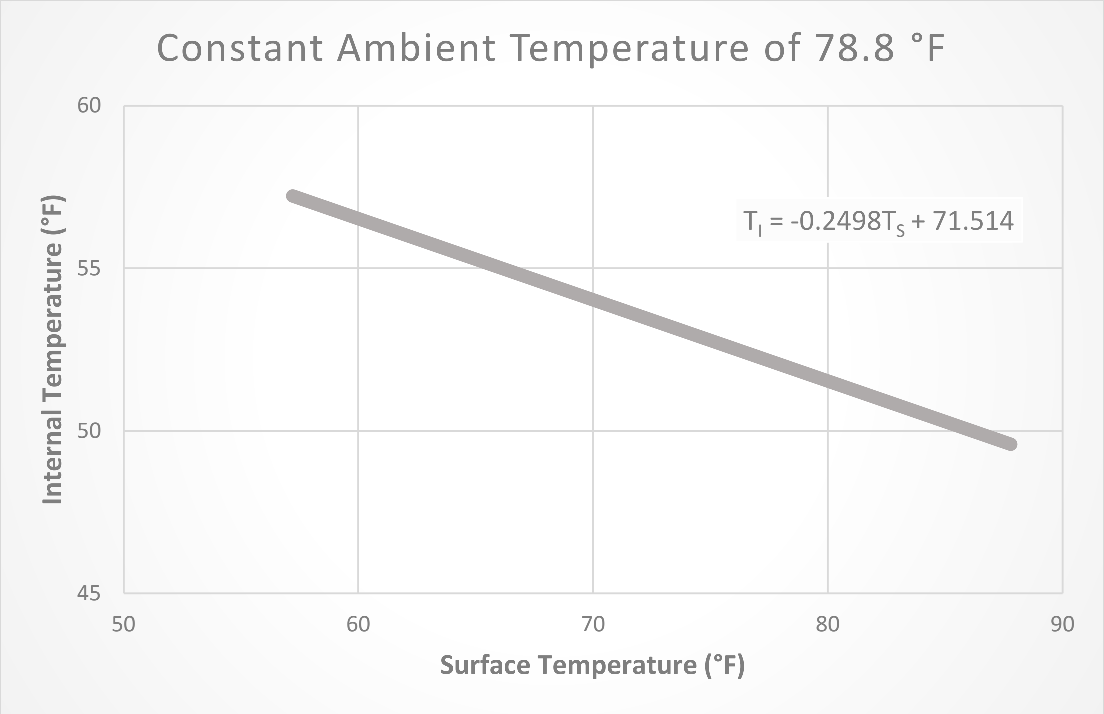


Figure 2. Temperature trends while ambient air temperature is held constant

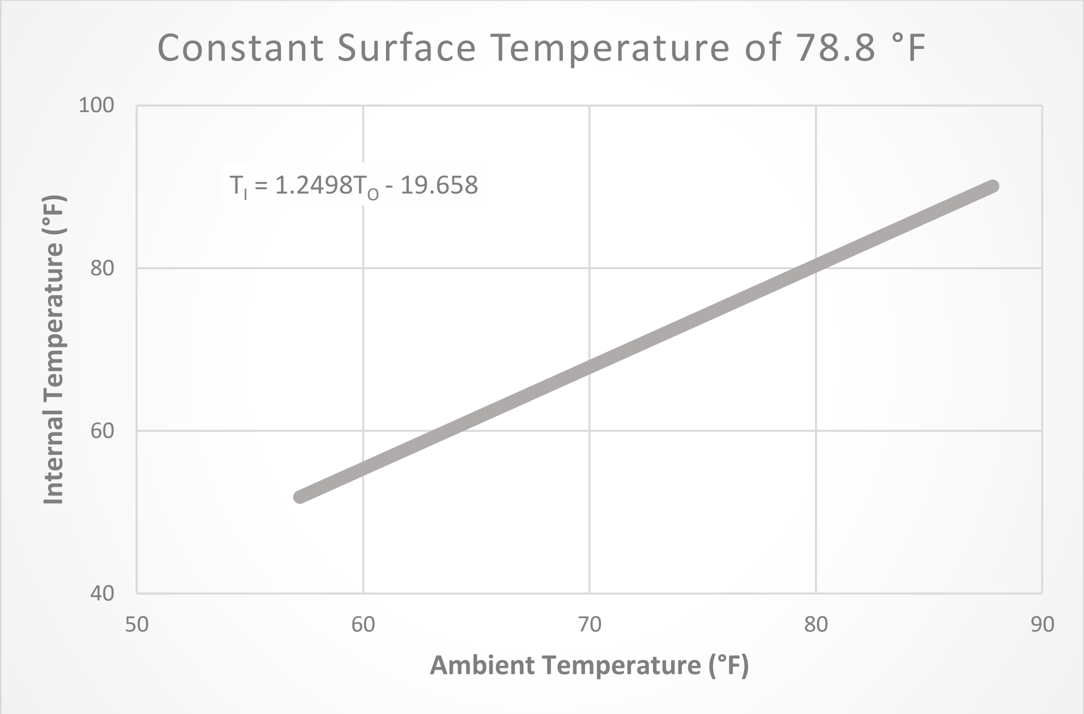


Figure 3. Temperature trends while enclosure surface temperature is held constant

DEGRADATION ANALYSIS

- Cut-off wavelength of 180nm [2]
- Spectral Sensitivity Range of 260nm-360nm [2]
- Measured a 4.0 for stability [2]
- Altered PE with UV stabilizer results in HDPE
  - Approximated lifetime of 20 year [3]

FLEXURAL STRENGTH ANALYSIS

- Double Integration Method: $\theta(x) = \int \frac{M(x)}{EI} dx$ & $\Delta = \iint \frac{M(x)}{EI} dx$
- Fibers will snap prior to major deflection

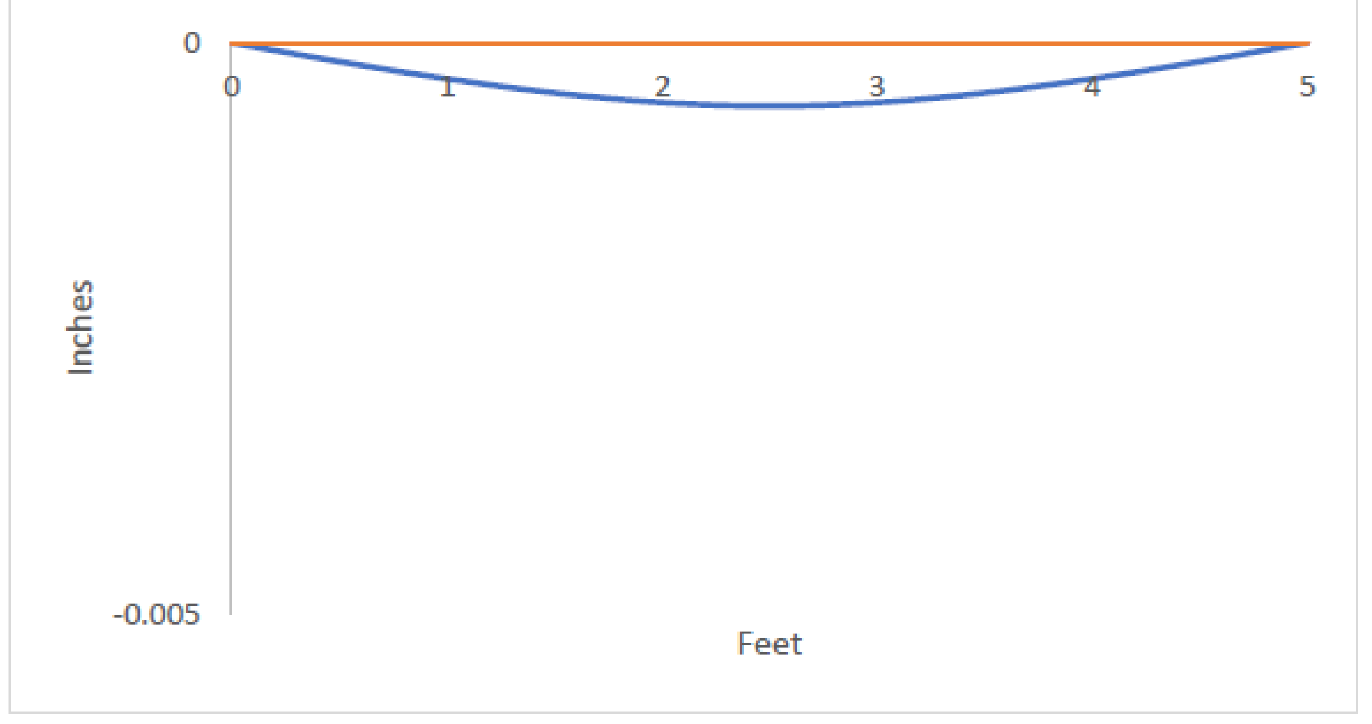


Figure 4. RISA 3D results of a 3 point bend test with a load of XXX

WIND LOAD ANALYSIS

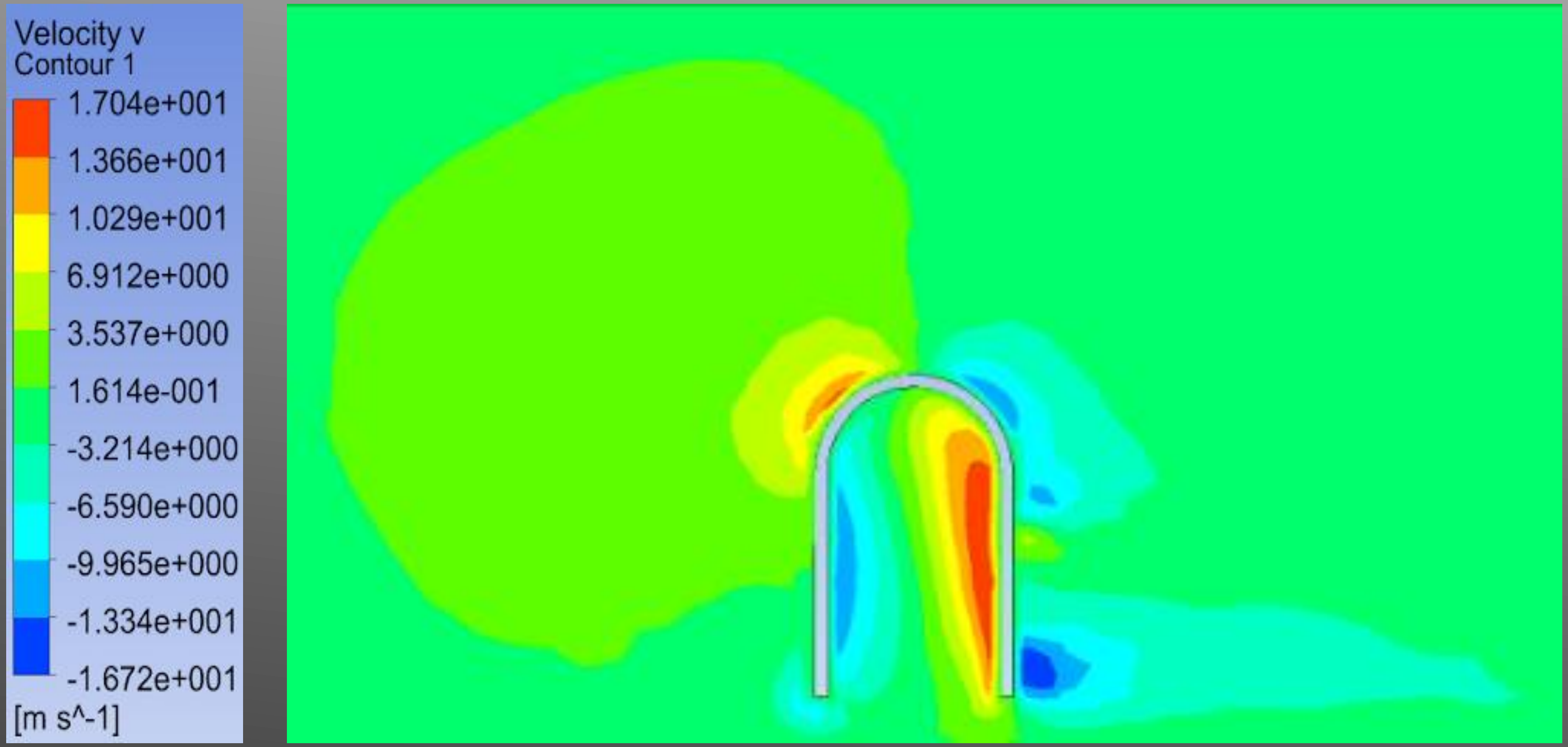


Figure 7. Wind speeds in & around the enclosure while at a freestream velocity of 50 mph

DEFLECTION ANALYSIS

- Risa 2D
- Construction Materials
  - Laminated Veneered Wood
  - Aluminum 6061
  - 1006 Steel
  - Carbon Fiber
- Column Cross-Section
  - Square rod and tubing
  - Circular rod and tubing
  - I-beam
- Material with least deflection: Carbon Fiber
- Cross-section with the least deflect: Square Rod

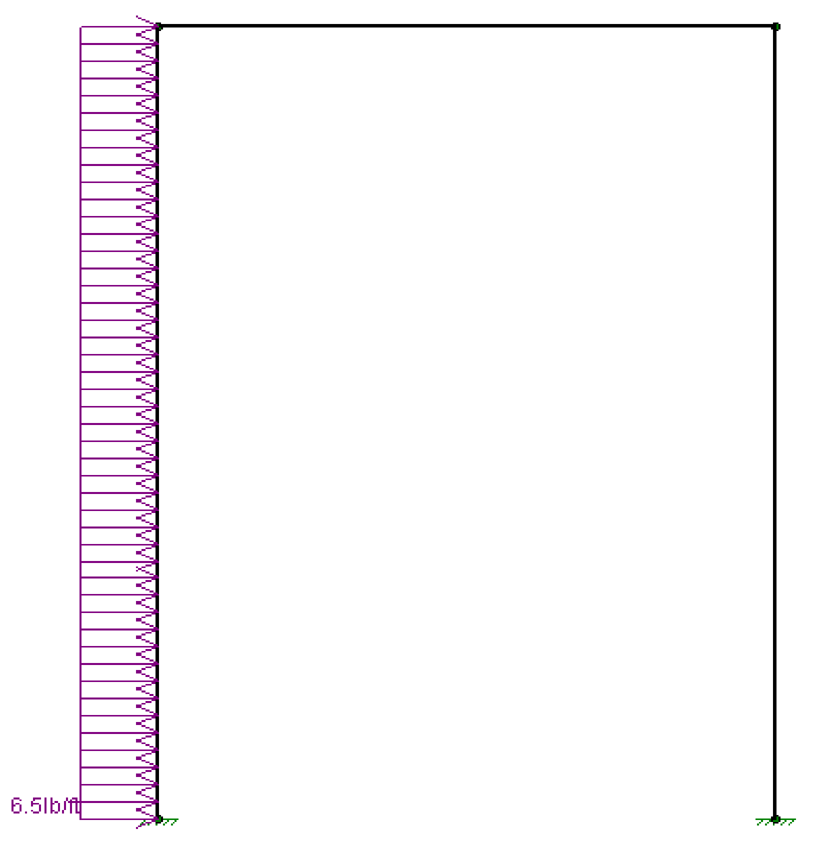


Figure 5. RISA 2D analysis performed to aid in structural material selection

STRESS (FOS) ANALYSIS

- RISA 3D used for getting reaction forces
- Reaction forces used to calculate shear and bearing stress
- Ultimate shear and tensile strength used to get factor of safety

Table 2. Factor of safety for individual components determined from RISA 3D analysis

Part	Yeild Factor of Safety	Failure Facture of Safety
Hinge Bolt		15.2
Hinge Plates	3.56	6
5/8" Base Plate Pin		3.24
Base Plates 5/8" Hole	2.82	4.75
Base Adaptor Plate 5/8" Hole	5.17	8.71
3/4" Base Plate Pin		4.67
Base Plates 3/4" Hole	3.39	5.7
Base Adaptor Plate 3/4" Hole	6.21	10.45

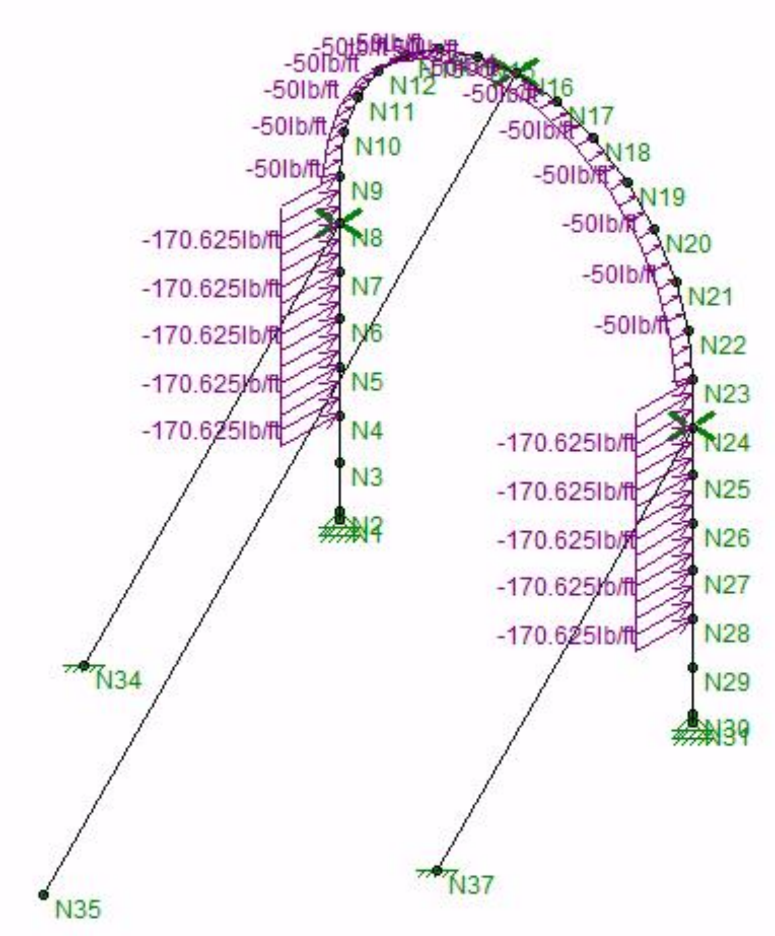
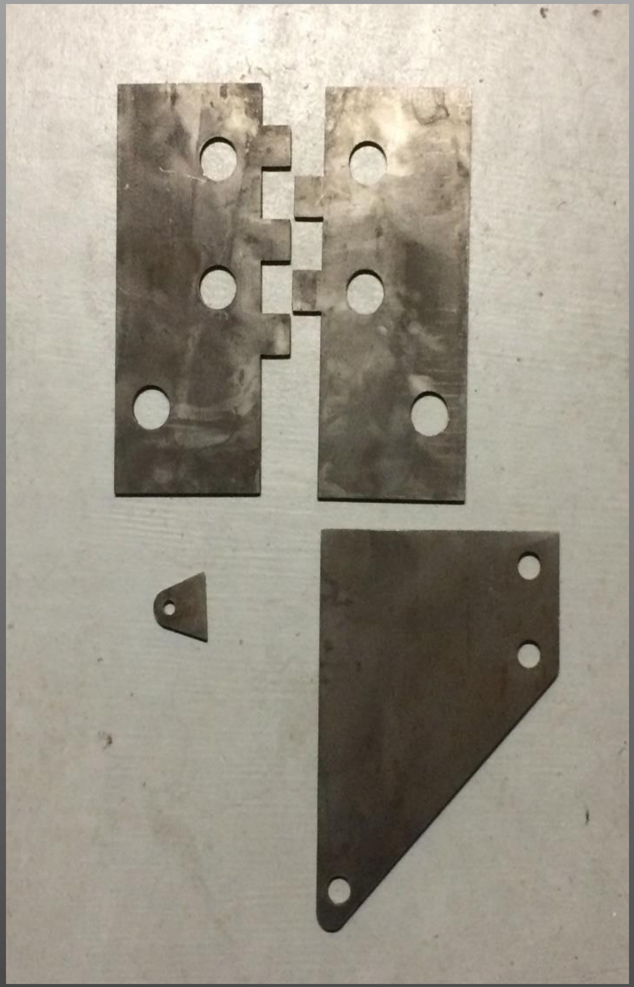


Figure 6. RISA 3D model with distributed loads representing a 50 mph wind load

MANUFACTURING

- Steel:
  - Laser Cut – Valley Steel Supply
  - MIG Welding
  - Drill Press
- Carbon Fiber:
  - Miter Saw
- HDPE
  - Sewing Machine
- Connections:
  - Couplers
  - Fasteners
  - Epoxy
  - Compression Fittings



Figures 8 -10. Major components of selected design which required additional fabrication

SUB-SCALE PROTOTYPE

Figures 11-14. Major components of launch vehicle enclosure for the 1/6th scale prototype

SUB-SCALE PROTOTYPE

Figures 15-16. Final 1/6th scale prototype in undeployed & deployed positions, respectively

TESTING

- 9 physical tests conducted
  - 6 supported analysis
  - 2 were inconclusive
  - 1 did not support analysis data
- Wind Load
  - Design team did not anticipate testing this ER
  - Withstood 50 mph gusts, meeting CN
  - April 12, 2018: Wind gusts recorded over 60 mph in testing area [1]

Figure 17. Permeability testing on a test section of HDPE fabric

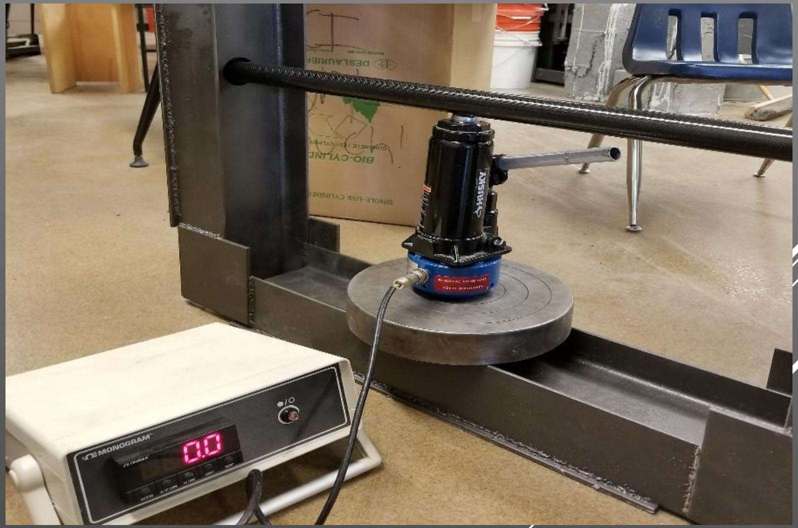


Figure 18. Flexural testing on a test section of HM carbon fiber

TESTING RESULTS

Table 3. Results of 9 physical tests preformed on launch vehicle enclosure

Testing Conducted	Engineering Requirement(s)	Procedure	Results	Target
Accessibility	Footprint; Entrance Dimensions	Measure Enclosure Opening	208.85 m^2*; 286.92 m^2*	200 m^2; 25 m^2
Assembly	Assembly/Disassembly time; Assembly steps	Time Design Team During Assembly/Disassembly	3 hr*; 2hr*; 7	8 hr; 3.5 hr; 10
Cost Analysis	Cost Per Height	Record All Material Costs	$923/m	$2000/m
Flow Visualization	Airflow Through Structure; Ventilation	Force Smoke Through System	Inconclusive	0.071 m3/s
Material Endurance	Usage Quantities; Life Span	Fully Assemble/Disassemble Repeatedly	7	5
Operational Testing	Component Functionality	Assemble/Disassemble While Visually Inspecting Components	Fully functional	N/A
Permeability	Flow Rate Through Material	Bucket/Timer Method On A Sample Piece of Fabric	212,000 g/m^2/24hr**	603g/m^2/24hr
Temperature Effects	Workspace Temperature; Vehicle Temperature; Heat Flux	Record Temperature Data From System	~80°F, 174.9W	65.1 – 84.9°F, 354W
Three Point Bend	Strength; Stress; FOS	Hydraulic Ram With Force Readings	~1.11 Msi***	57 Msi

***Testing result has been scaled to full scale enclosure**
****Specified HDPE material could not be acquired**
***** Failure occurred due to hydraulic ram puncture**

TEMPERATURE TESTING

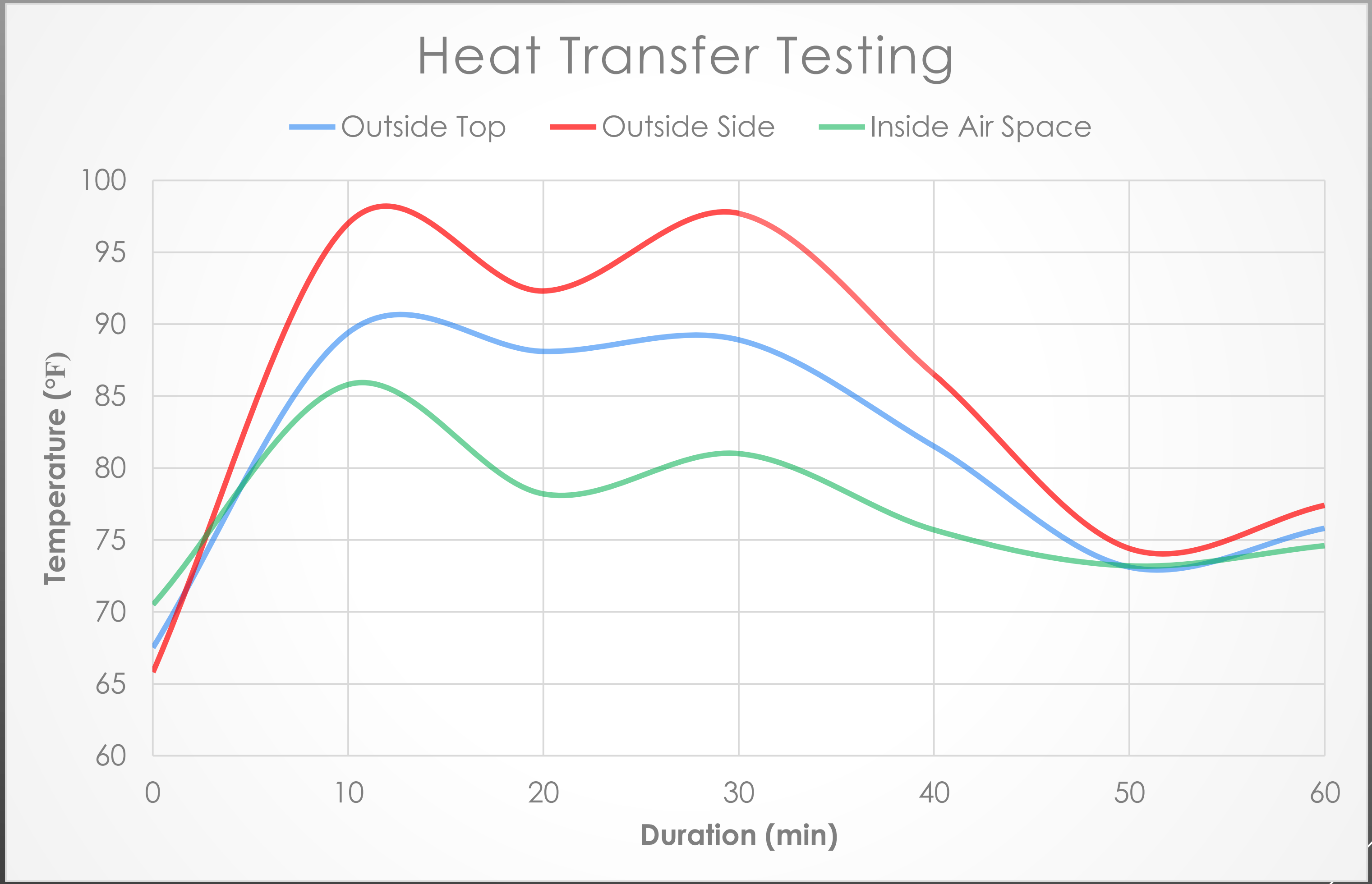


Figure 19. Results of heat transfer testing at three critical locations of the system

FLEXURAL TESTING

Figure 20. Results from bending tests conducted on high modulus carbon fiber

DESIGN CHANGES

- Changes occurred only on the sub-scale prototype
- Dodecagon replaced semicircle
  - Top arch
- Eye bolts replaced pulleys
  - System deployment
- Paracord replaced steel cable
  - System deployment

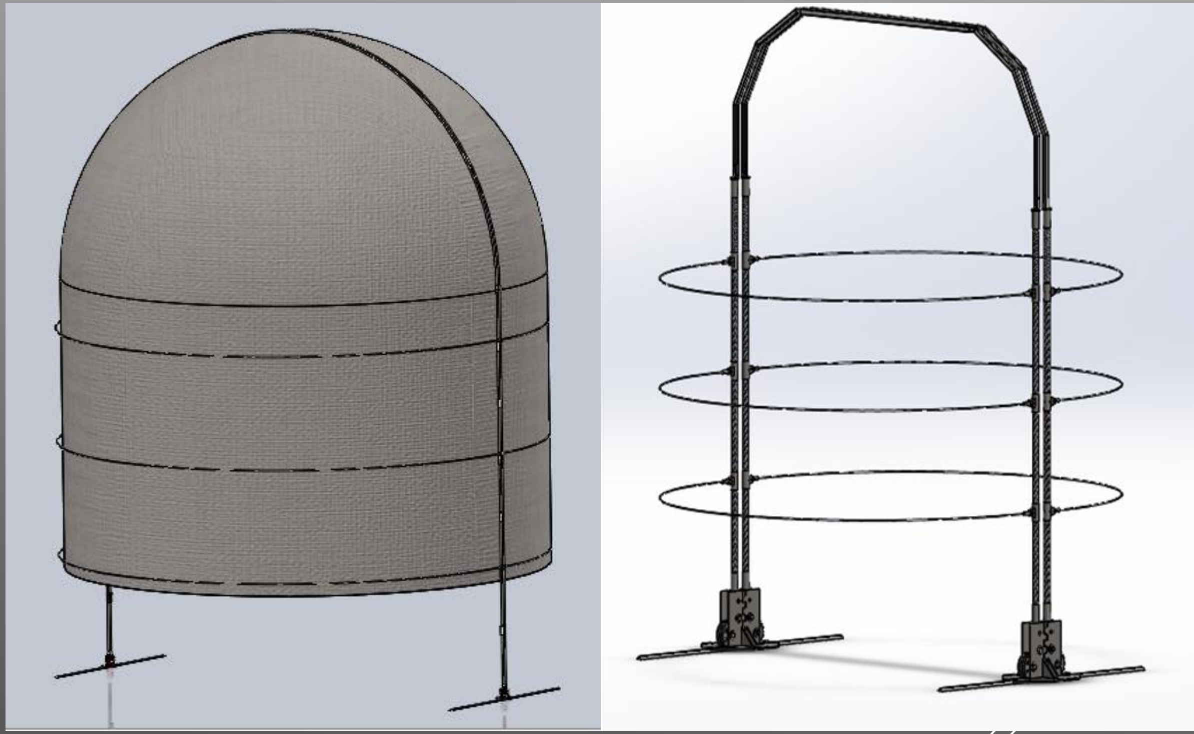


Figure 21. Visualization of the design changes made from original design to final prototype

CLOSING REMARKS

- Recommendations due to time constraints:
  - Further development of seal between system halves
  - Additional testing:
    - Flow visualization
      - Wind tunnel with smoke streams
    - Factor of Safety
      - Yield/fracture testing on steel samples
    - Enclosure temperature
      - Testing in launch environments
    - Material Testing
      - Carbon fiber for strength properties
      - HDPE material for permeability & degradation

Figure 22. Final 1/6th CAD model for launch vehicle enclosure

QUESTIONS?

REFERENCES

[1]National Weather Service, 2018. [Online]. Available: www.twitter.com
[2] J. E. Mark, Physical Properties of Polymers Handbook, Woodbury: American Institute of Physics, 1996, ch. 40.
[3] Layfield, UV Light Resistance [Online]. Available: https://www.layfieldgroup.com/Geosynthetics/Tech-Notes/UV-Resistance.aspx.