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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.

PROJECT REQUIREMENTS

- 19 customer needs developed by design team & client
- Highest valued client needs:
  - Launch Vehicle Contact
  - Accessibility
  - Safety/Component Safety Factors
  - Solar, Moisture, Wind Protection

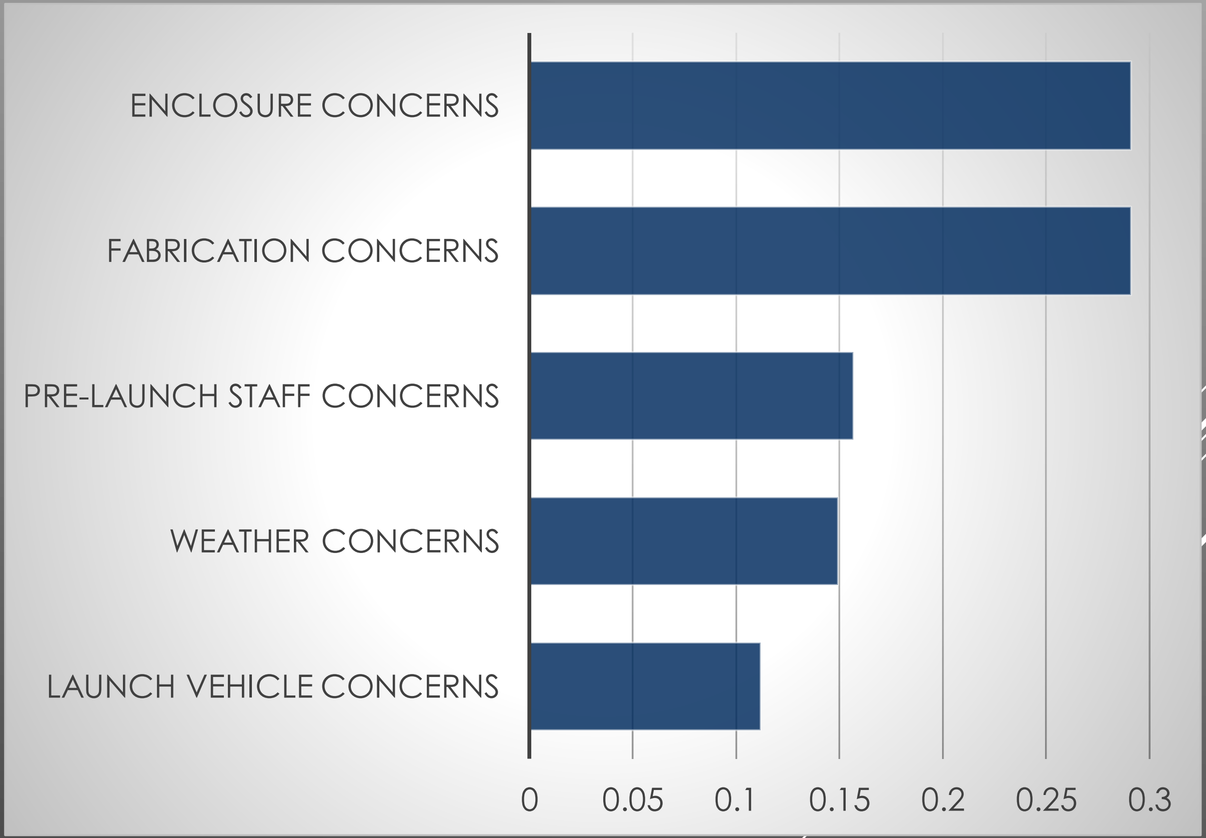


Figure 1. Weighted average of customer need groups

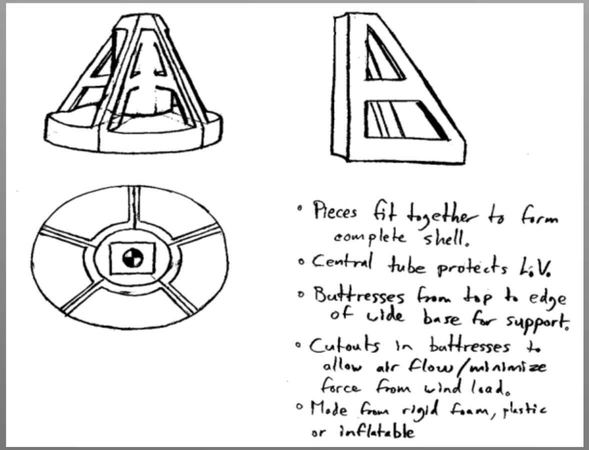
PROJECT REQUIREMENTS

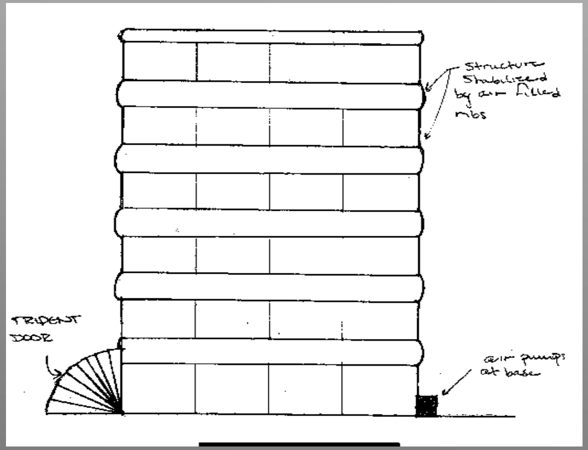
Need Group	Customer Need (CN)	Engineering Req. (ER)	Target Value
Weather Concerns	Solar Protection	Heat Flux Through Enclosure	< 354 W/m2
Enclosure Concerns	Launch Vehicle Contact	Enclosure Defelction	< 1m
Pre-Launch Staff Concerns	Accessibility	Entrance Dimensions	25 ± 5 m
Fabrication Concerns	Time of Assembly & Disassembly	Time to Assemble & Disassemble	1 ± 8 hr 0.5 ± 3 hr
Launch Vehicle Concerns	Factor of Safety	Yield FOS & Ultimate FOS	> 3.0 > 5.0

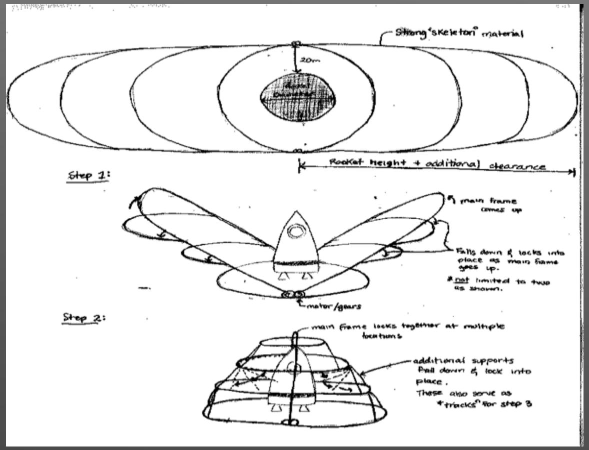
→ Final Design

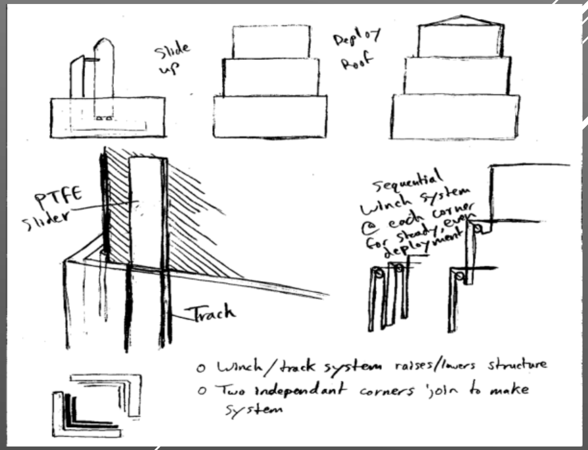
EARLY DESIGN GENERATION

- Current solutions were researched for this design problem
- 10 preliminary design concepts developed
  - Each concept had multiple variations
- Untraditional solution preferred by client
- Feasibility was questionable for multiple designs









Figures 2-5. Preliminary concept sketches

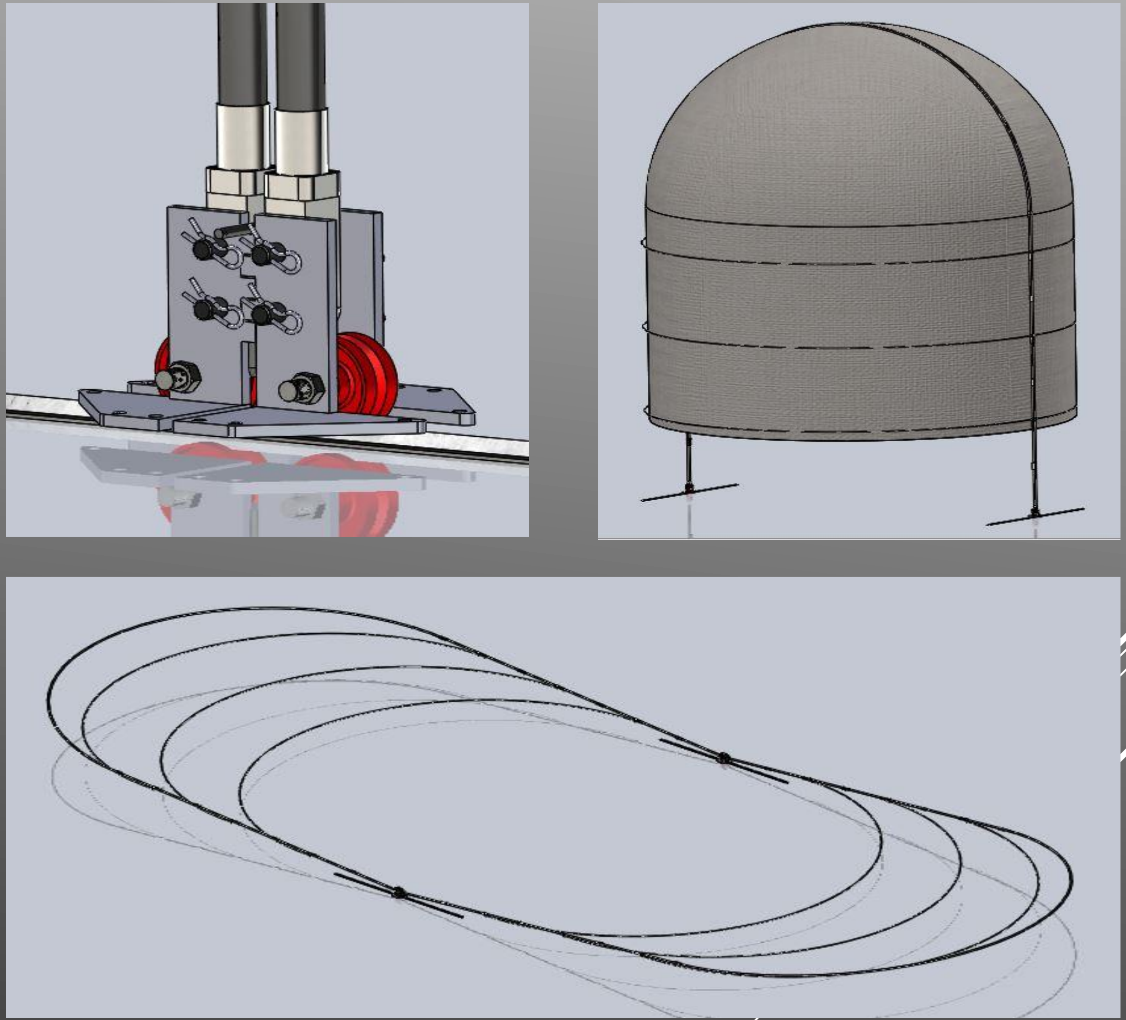
DESIGN SELECTION

Table 1. Quantitative design selection method

		Design: The Curtain		Design: The Bear Trap		Design: The Cone		Design: Rocket Awning	
Criteria	Criteria Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Solar Protection	0.10	8.00	0.80	7.00	0.70	9.00	0.90	7.00	0.70
Moisture Protection	0.10	4.00	0.40	6.00	0.60	6.25	0.63	5.00	0.50
Debris Protection	0.01	3.50	0.04	4.00	0.04	8.00	0.08	4.50	0.05
Lightning Protection	0.06	5.00	0.30	5.00	0.30	5.00	0.30	5.00	0.30
Vehicle Temperature	0.05	7.00	0.35	6.00	0.30	7.50	0.38	7.00	0.35
Vehicle Contact	0.12	8.00	0.96	7.50	0.90	6.75	0.81	7.50	0.90
Environment Temperature	0.02	4.00	0.08	6.00	0.12	7.50	0.15	7.50	0.15
Work Space	0.04	8.00	0.32	7.00	0.28	3.50	0.14	6.00	0.24
Accessibility	0.11	9.00	0.99	9.00	0.99	5.50	0.61	8.50	0.94
Scalability	0.06	8.50	0.51	4.00	0.24	7.00	0.42	6.50	0.39
Ease of Assembly	0.02	8.00	0.16	7.00	0.14	8.00	0.16	5.00	0.10
Time of Assembly	0.02	6.00	0.12	7.00	0.14	6.00	0.12	3.50	0.07
Time of Disassembly	0.02	6.00	0.12	3.00	0.06	9.00	0.18	4.00	0.08
Associated Costs	0.03	4.00	0.12	5.00	0.15	4.50	0.14	7.00	0.21
Support Ability	0.01	5.00	0.03	0.00	0.00	4.00	0.02	7.00	0.04
Lifespan	0.05	4.00	0.20	5.00	0.25	7.00	0.35	6.50	0.33
Durability	0.06	5.00	0.28	6.00	0.33	7.75	0.43	6.50	0.36
Safety	0.13	6.50	0.85	3.00	0.39	8.00	1.04	5.00	0.65
			6.61		5.93		6.84		6.34

DESIGN ACCEPTANCE

- Preliminary & critical design reviews with Orbital ATK
- The Bear Trap concept was highly favored by Orbital ATK & design team
  - This design focused on rapid deployment and lightweight materials
- Features of 3 preliminary designs incorporated
- Approval for use of carbon fiber was provided



Figures 6-8. CAD images of proposed design selection

DESIGN ANALYSES

- Analyses conducted:
  - Deflection
  - Degradation
  - Flexural Strength
  - Heat Transfer
  - Permeability
  - Stresses (FOS)
  - Wind Loads (Two approaches taken)
- Used in material selection & component design
- Each analysis conducted analytically
  - Testing verified results

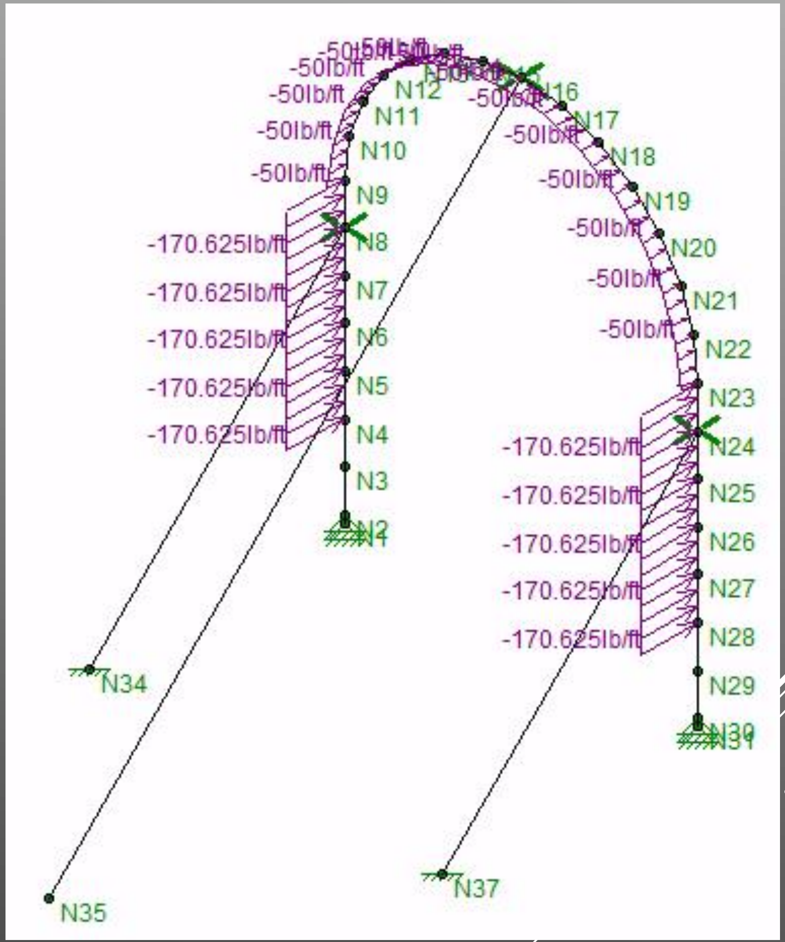
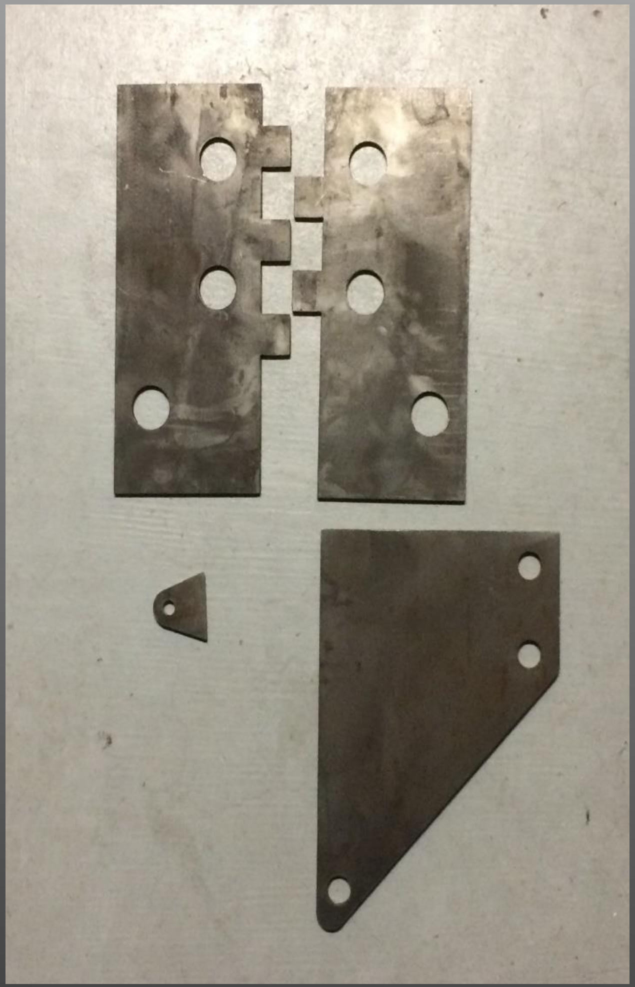


Figure 9. RISA 3D model used to predict experienced stresses

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 10-12. Major components of selected design which required additional fabrication

SUB-SCALE PROTOTYPE

Figures 13-16. Major components of launch vehicle enclosure for the 1/6th scale prototype

SUB-SCALE PROTOTYPE

Figures 17-18. 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 19. Permeability testing on a test section of HDPE fabric

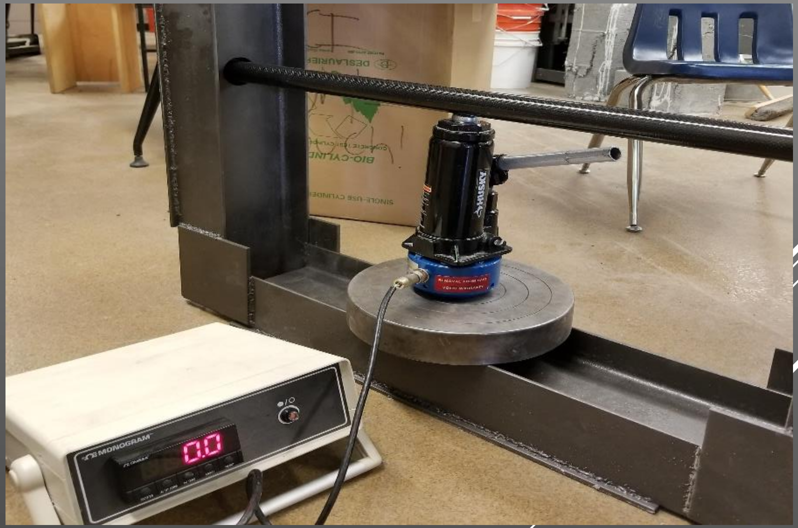


Figure 20. Flexural testing on a test section of HM carbon fiber

TESTING RESULTS

Table 2. 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;	Record Temperature Data From System	~80°F	65.1 – 84.9°F
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**

CLOSING REMARKS

- Next Steps:
  - Continued material testing using specified manufacturers
  - Further development of seal between system halves
- Takeaways:
  - Importance of iterating
  - Communication
  - Scheduling
  - Gaps between theoretical analysis & physical testing
- Final Delivery to Orbital ATK
  - May 3, 2018

Figure 21. Final 1/6th CAD model for launch vehicle enclosure

QUESTIONS?

CUSTOMER REQUIREMENTS

Table 3. Developed engineering requirements from customer needs

Item:	Customer Need	Description	Related Engineering Requirement	Metric	Target Value	Tolerance	Customer Rank
1.0 Concerning Weather							
1.1	Solar Protection	Ability to limit temperature variance within the enclosure	Heat Flux Through Enclosure Material	W/m^2	354	<354	90
1.2	Moisture Protection	Ability to limit entrance of moisture into the enclosure	Permeability	$g/m^2/24hr$	603	<603	90
1.3	Debris Protection	Ability to shroud launch vehicles from airborne debris	Tensile Strength	kPa	1	±.015	10
1.4	Wind Protection	Ability to restrict/allow airflows into the enclosure	Volumetric Flow Rate	m^3/s	0.071	±.005	10
2.0 Concerning Launch Vehicle							
2.1	Launch Vehicle Temperature	External vehicle temperature must remain within provided temperature ranges during pre-launch processing	Surface Temperature Delta	°C	23.9	18.4 - 29.4	50
2.2	Launch Vehicle Contact	Enclosure must not contact at any point (high wind/rain conditions	Enclosure Deflection	m	1	<1	100
3.0 Concerning Pre-Launch Staff							
3.1	Work Environment Temperature	Launch vehicle enclosure must remain within a workable temperature range	Dead Space Temperature	°C	23.9	18.4 - 29.4	30
3.2	Work Space	Suitable space between launch vehicle and enclosure wall to perform necessary pre-launch operations	Enclosure Footprint	m^2	200	±10	80
3.2.1	Accessibility	Ability for employee/truck/scissor lift to enter enclosure	Entrance Dimensions	m^2	25	±5	100
4.0 Concerning Material Procurement/Manufacturing/Assembly							
4.1	Scalable Design	Ability for final design to be adapted to full range of launch vehicles	Cost per Enclosure Height	$/m	2000	<2000	90
4.2	Ease of Assembly	Simplicity of enclosure construction at launch site. Minimizing the amount of steps.	Number of Assembly Steps	# of Steps	10	±5	80
4.2.1	Time of Assembly	Time required to construct enclosure at launch site	Time to Assemble	min	60	±480	80
4.2.2	Time of Disassembly	Time required to remove enclosure from launch site	Time to Disassemble	min	30	±160	80
4.3	Associated Costs	Costs involved in the production, ownership, and operation of the system	Raw Material Cost	$	$50,000	±$50,000	60
5.0 Concerning Enclosure							
5.1	Ability to Support Items	Ability for the enclosure to support auxiliary items	Bearing Stress	kPa	1	±.015	30
5.2	System Lifespan	Ability for the enclosure to be deployed multiple times without failure. *Unless a single use system is determined to be more cost effective	Usage Quantities	# Uses	5	±20	80
5.3	Durability	Ability for enclosure to resist exposure and typical wear	UV Degradation	Hrs	5000	>5000	80
5.4	Safety	Ability for safety hazards to be minimized during extreme weather events and/or failure	Failure Percentage Across Various Scenarios	%	1	±0.01	100
5.5	Factor of Safety	Ability for a much stronger system than needed to minimize safety hazards	Yeild Stress / Working Stress	FOS#	3yeild & 5Ult	>3yeild & >5Ult	100
					Total Points Assigned		1340

HOUSE OF QUALITY

Table 4. House of quality except used to determine relationships between customer needs & engineering requirements

		1	2	3	4	6
1	Heat Flux Through Enclosure Material, TP 2.3.1					
2	Permeability, TP 2.3.3	+				
3	Tensile Strength, TP 2.3.2	-				
4	Volumetric Flow Rate, TP 2.3.3		+			
6	Surface Temperature Delta, TP 2.3.1	+	+		+	

Legend	
A	Alaska Tent & Tarp: Arctic Oven
B	Rubb: CAE EFASS
C	Losberger: TMM Inflatable Shelter

			Technical Requirements					Benchmarking				
	Customer Needs	Customer Weights	Heat Flux Through Enclosure Material, TP 2.3.1	Permeability, TP 2.3.3	Tensile Strength, TP 2.3.2	Volumetric Flow Rate, TP 2.3.3	Surface Temperature Delta, TP 2.3.1	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
		↑↓	↓	↓	↑	↓	↓					
1	Solar Protection	9	9	1			3			A	BCD	
2	Moisture Protection	9		9		3					ACD	B
3	Debris Protection	1		3	3	3				ACD	B	
4	Wind Protection	1		3	9	9			C	A	D	B
5	Lightning Protection	9						AD	C		B	
	Relative Technical Importance		15	16	9	19	18					

PERMEABILITY ANALYSIS

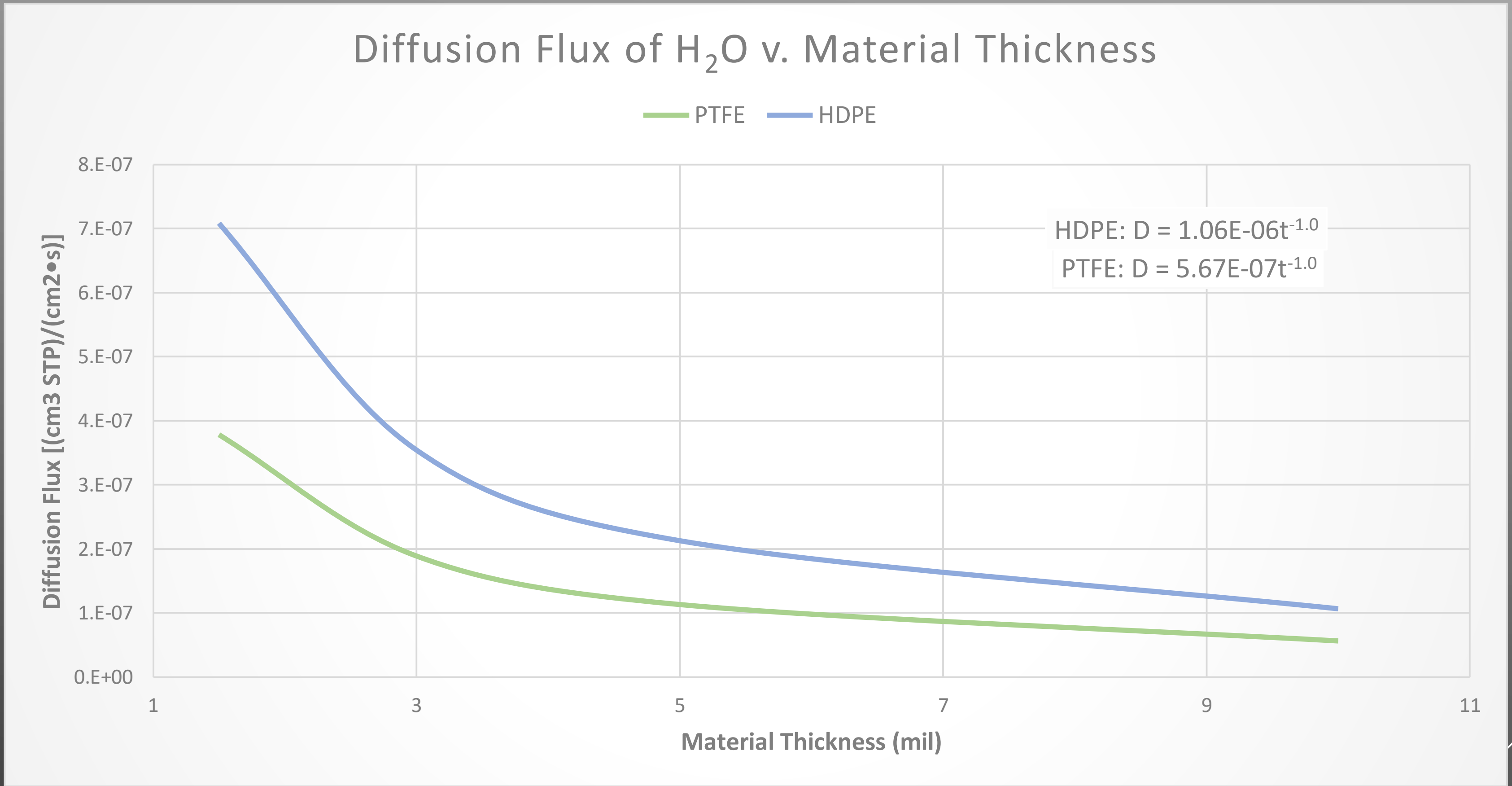


Figure 22. Except of permeability analysis conduct on various fabric materials

HEAT TRANSFER ANALYSIS

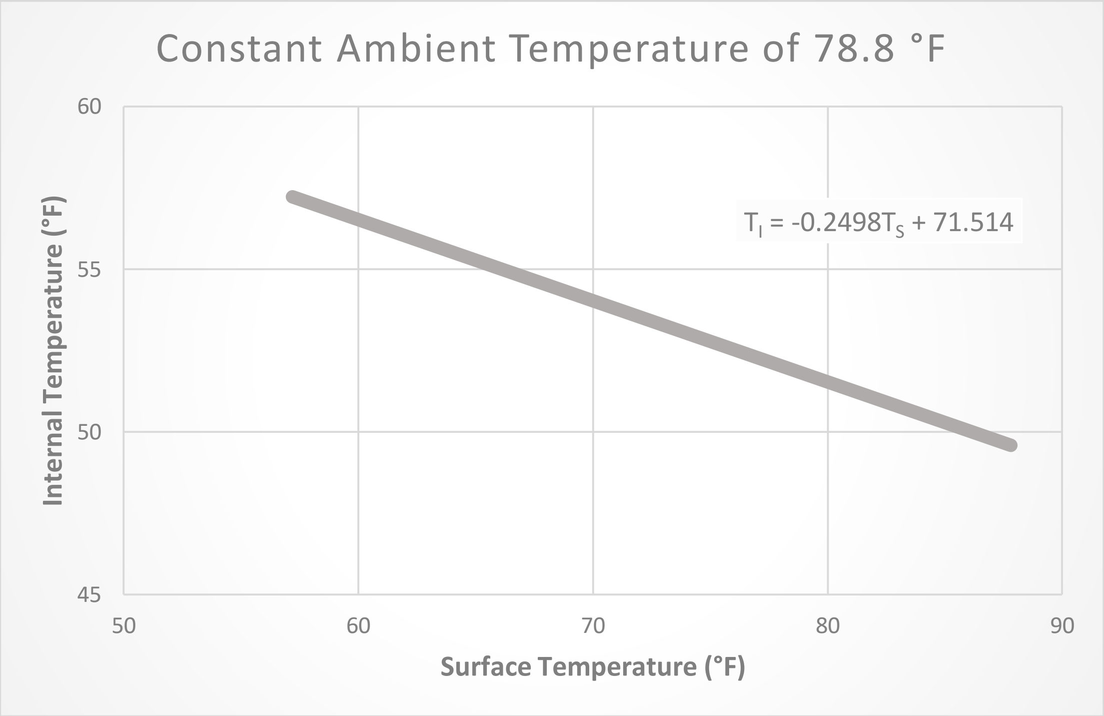


Figure 23. Temperature trends while ambient air temperature is held constant

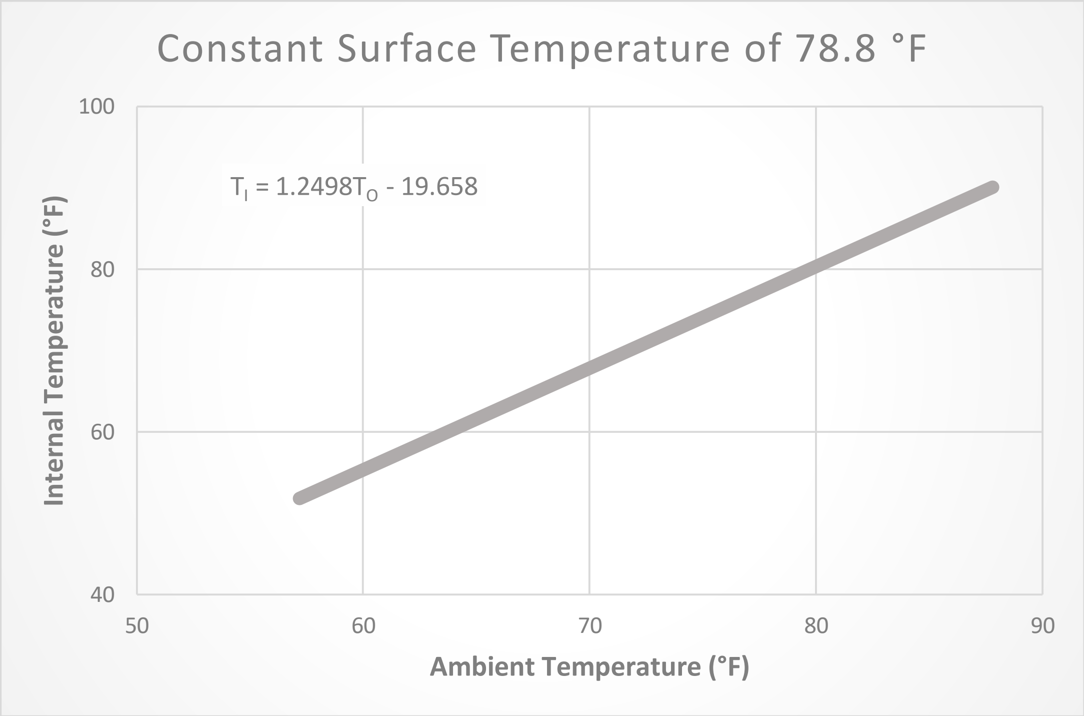


Figure 24. Temperature trends while enclosure surface temperature is held constant

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]

WIND LOAD ANALYSIS

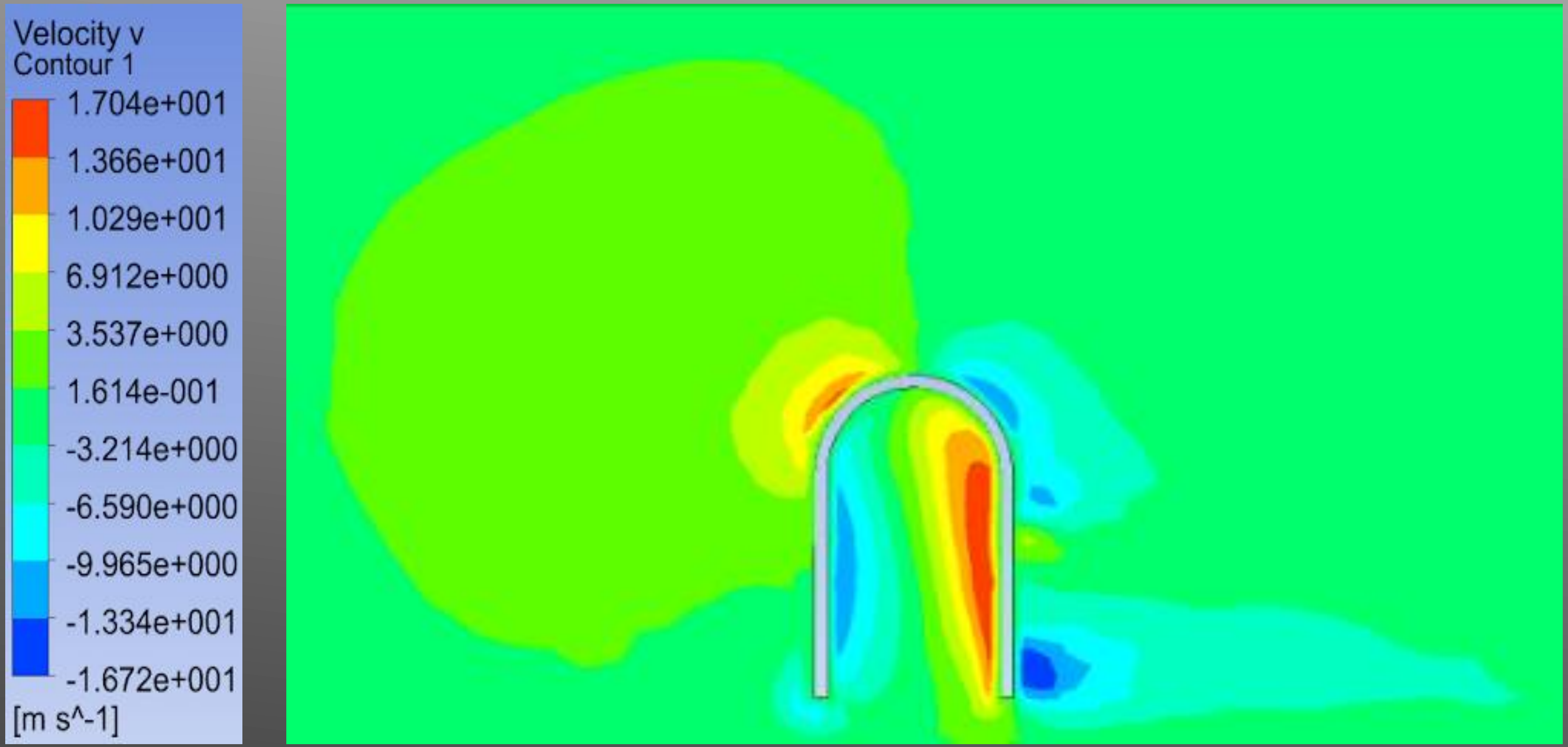


Figure 25. Wind speeds in & around the enclosure while at a freestream velocity of 50 mph

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

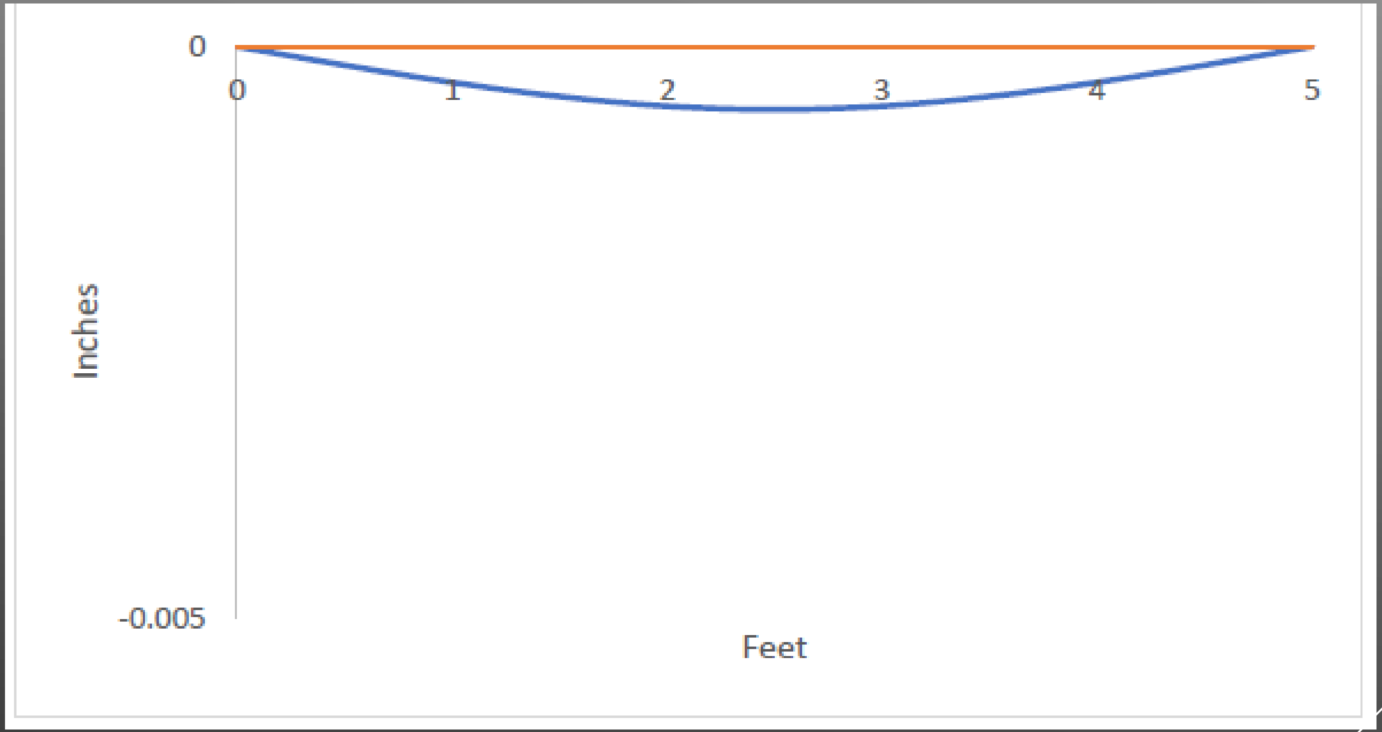


Figure 26. RISA 3D results of a 3 point bend test with a load of XXX

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 5. 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

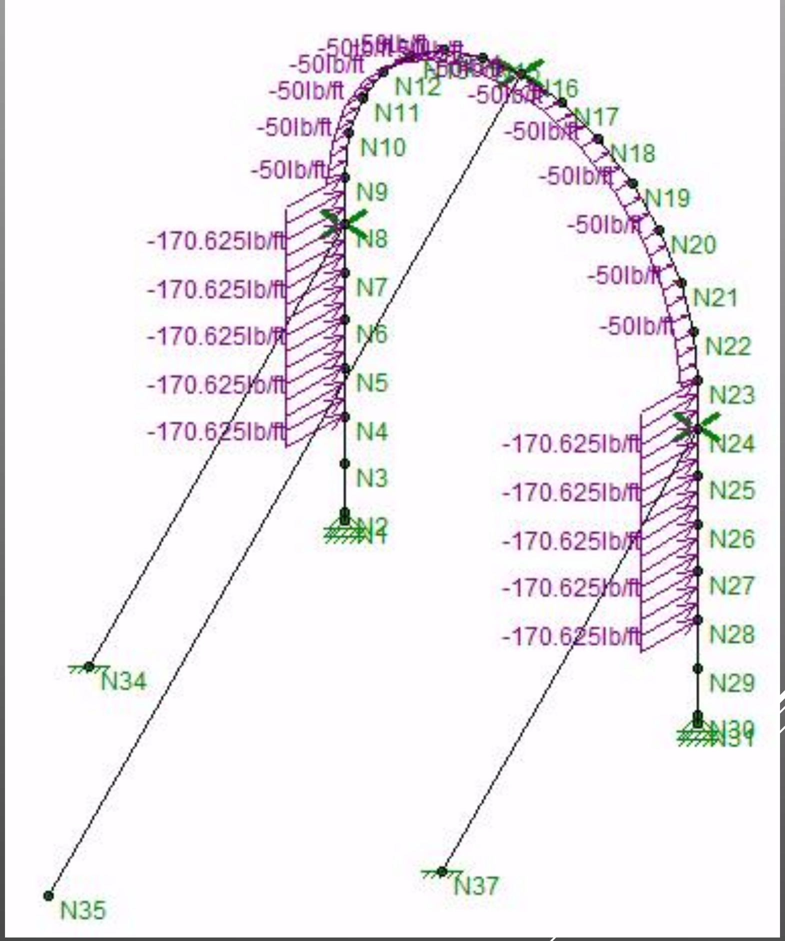


Figure 27. RISA 3D model with distributed loads representing a 50 mph wind load

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

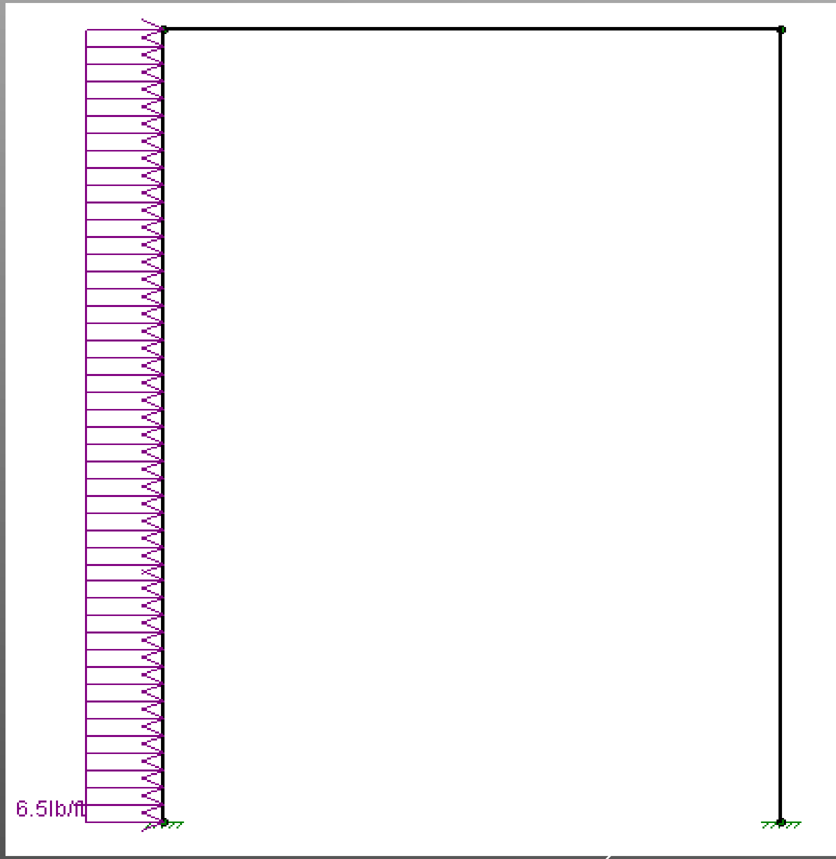


Figure 28. RISA 2D analysis performed to aid in structural material selection

TEMPERATURE TESTING

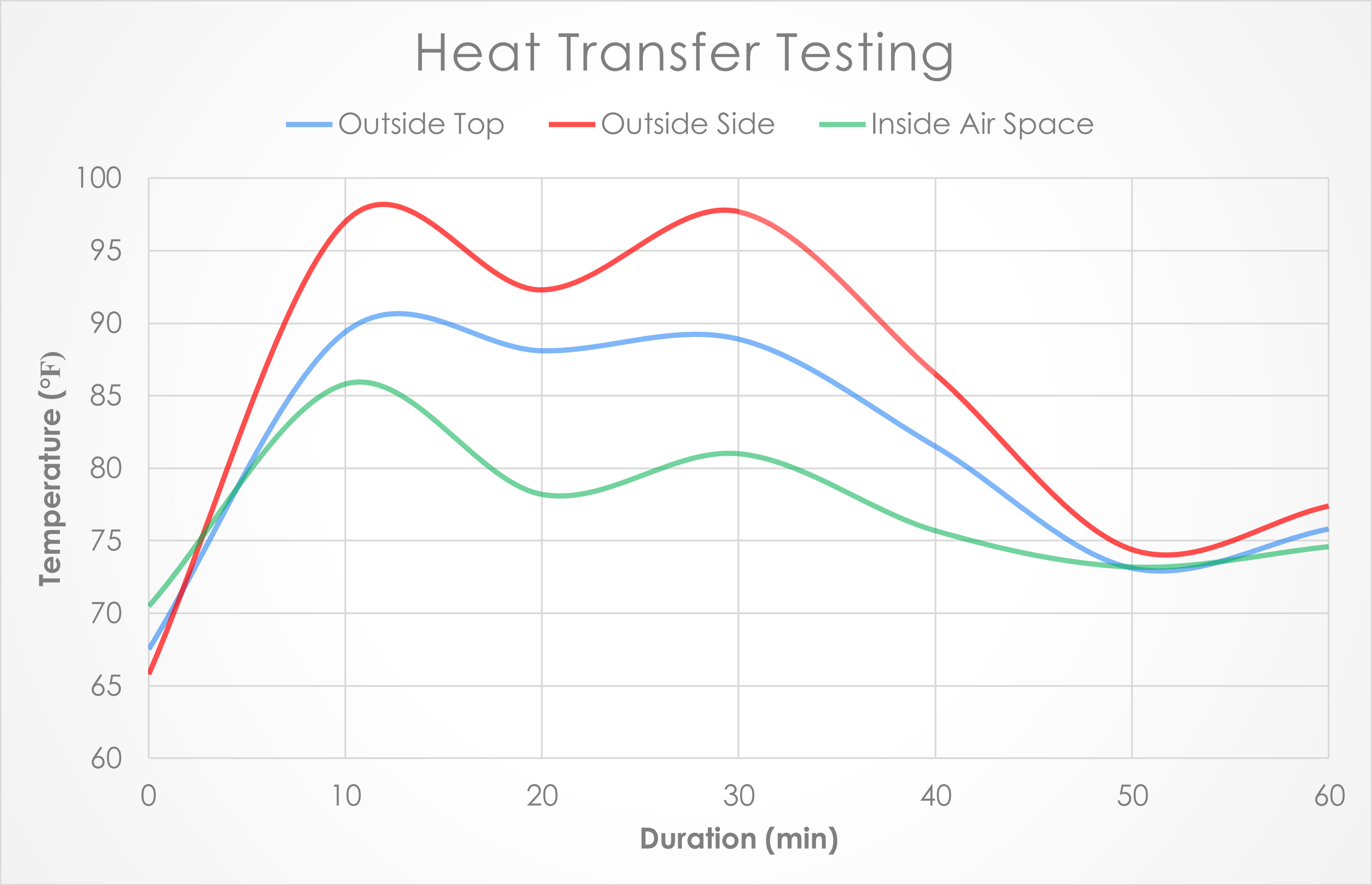


Figure 29. Results of heat transfer testing at three critical locations of the system

FLEXURAL TESTING

Figure 30. 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

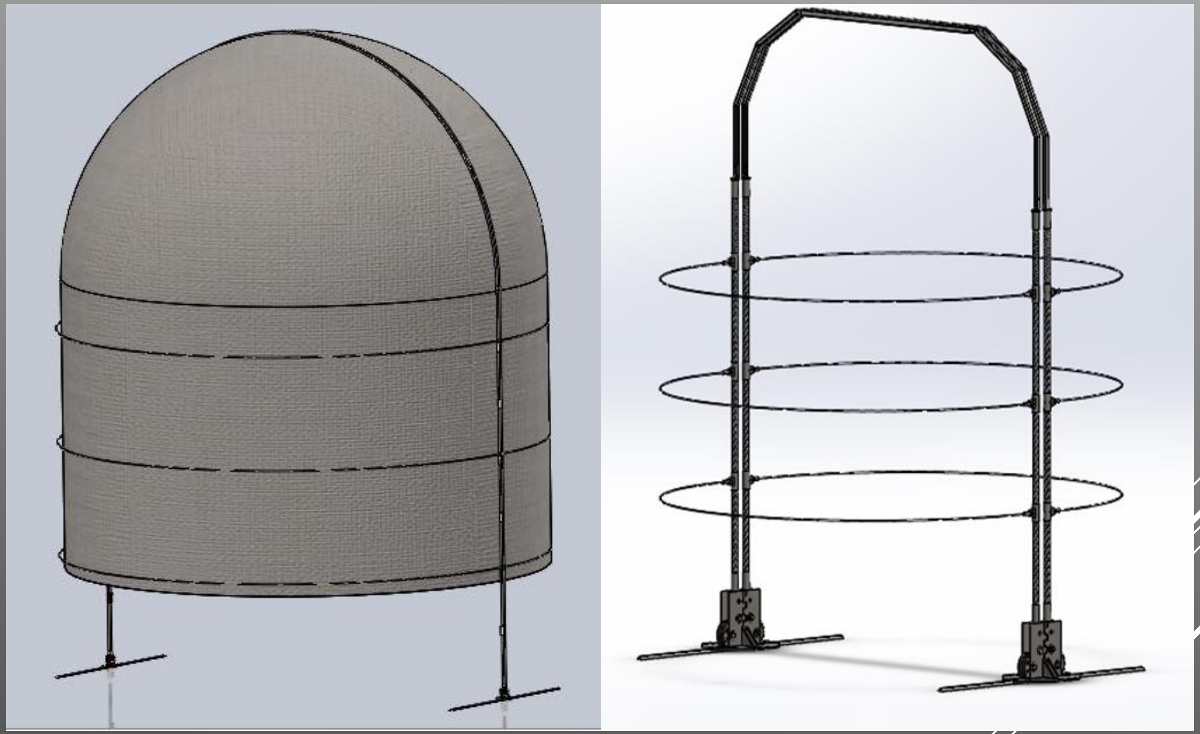


Figure 31. Visualization of the design changes made from original design to final prototype

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.