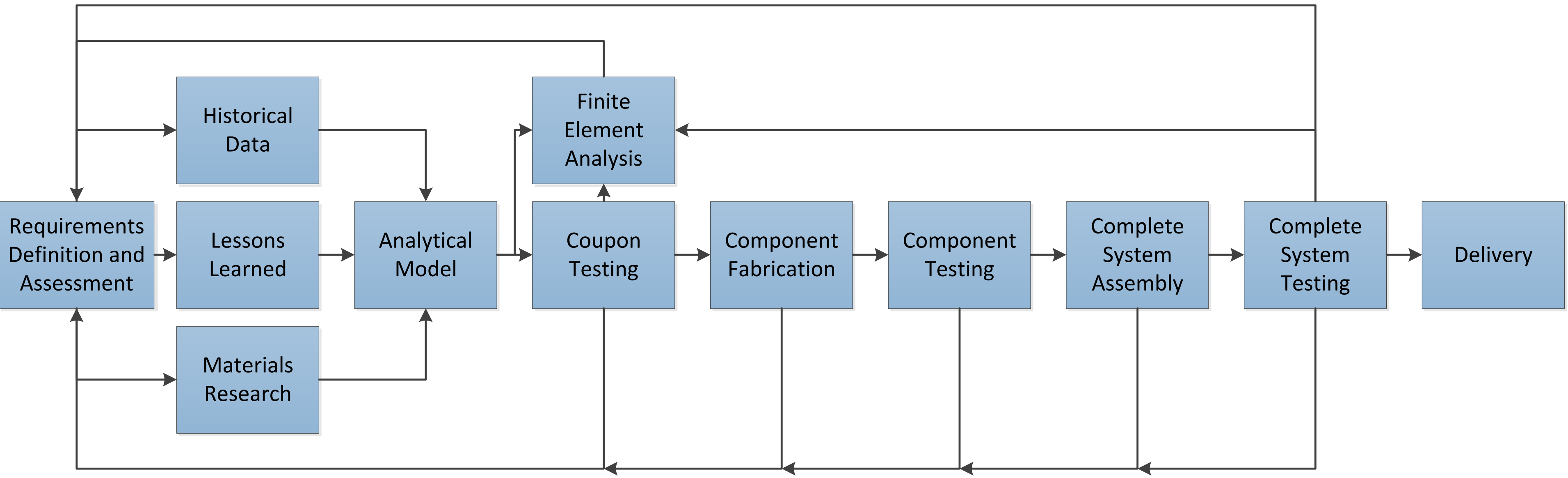
Overview



- From the engineering perspective the process of designing, fabricating, and testing is highly iterative and requires updating of requirements.

Requirements Definition

IRVE – 3 Flight Unit

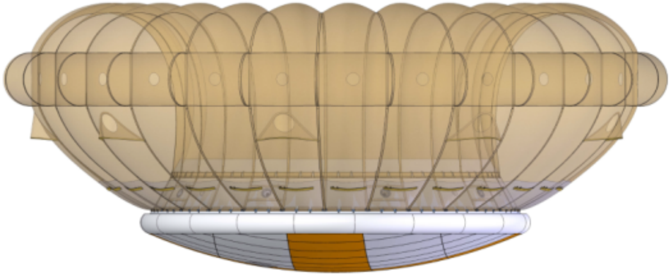
- Thermal - 250°C
- Loading - 1.2 PSI load (~13,000 Lbf)
- Pressure - <20PSI
- Leak Rate – 20 SLPMS
- Inflation Gas – Nitrogen
- Packability – High Density Pack
- Dimensional Stability – Maintain 95% of Area while loaded

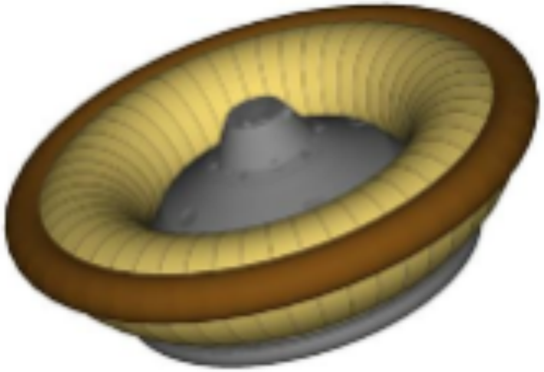
Large Scale Wind Tunnel Model

- Thermal - None
- Loading – 32,000 Lbf (Max force tunnel can handle)
- Pressure – 7 - 20PSI
- Leak Rate – None
- Inflation Gas – Air
- Packability – None
- Dimensional Stability – Maintain 95% of Area while loaded

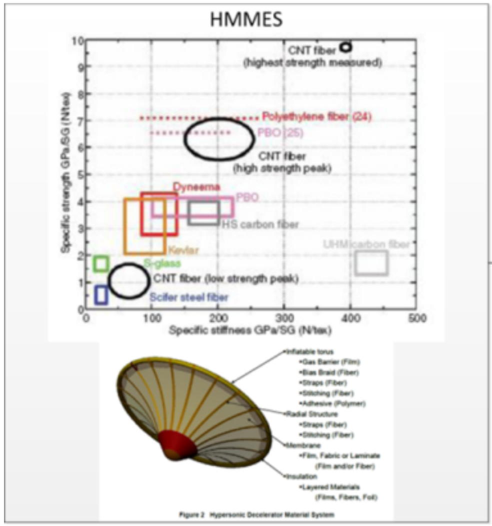
Historical Data

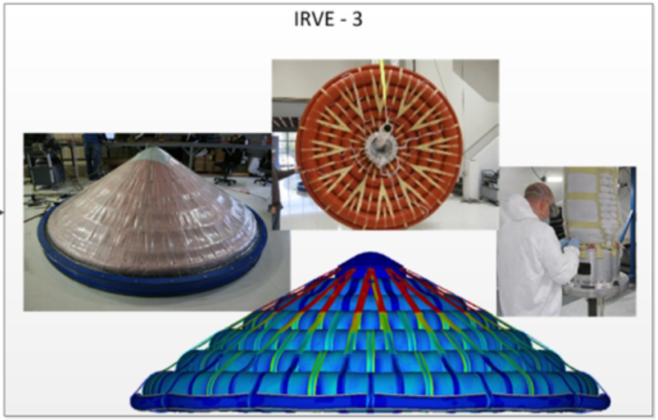
- Significant historical data from 1950’s – Today.
- Most data was for ram inflated decelerators not stacked tori and was thus not applicable.

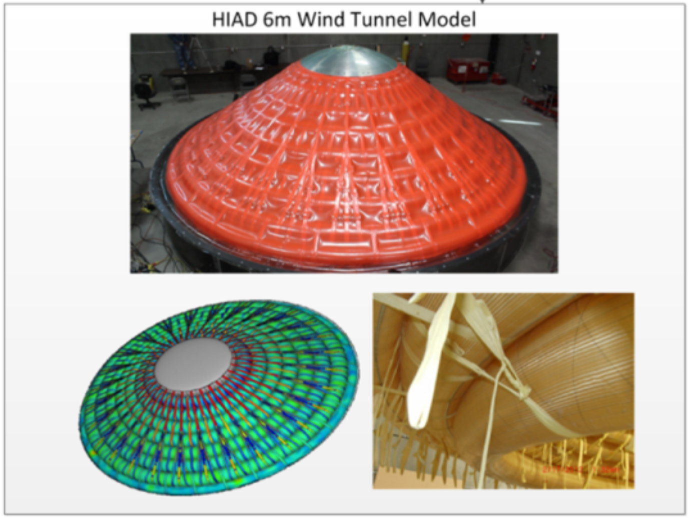




Lessons Learned







Materials Research

	IRVE-3	Large Articles
Braid	Kevlar ®	Technora ®
Liner	Silicone	Urethane
Coating	Silicone Based	Urethane Based
Adhesive	Silicone Based	Urethane Based
Straps	Kevlar ®	Kevlar ® (Higher Strength)
Aerocover	TBD	Vinyl Coated Polyester
Inflation Ports	Custom Aluminum Ports	Larger Diameter Urethane Ports

Silicone Bladder

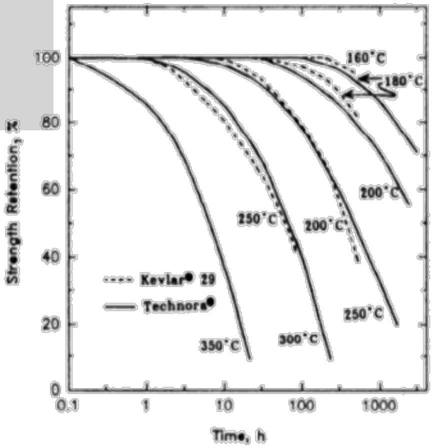
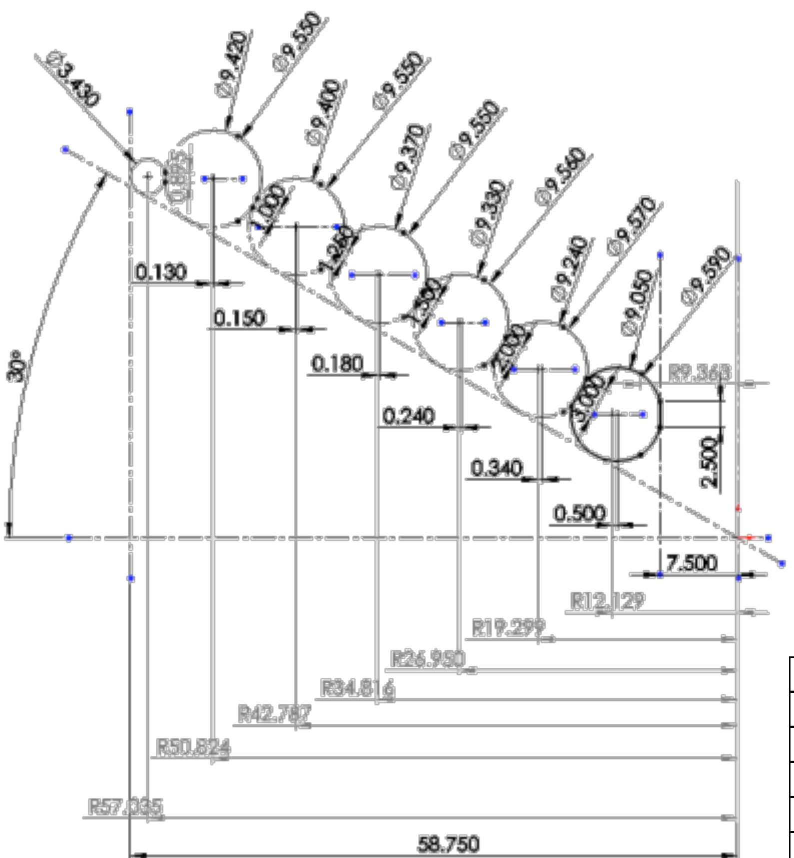


Fig. 10.3 Strength retention of Kevlar 29 and Technora fibers following elevated temperature exposure (DuPont, 1992a; Teijin, 1989).

Kapton Film

Kevlar Tape

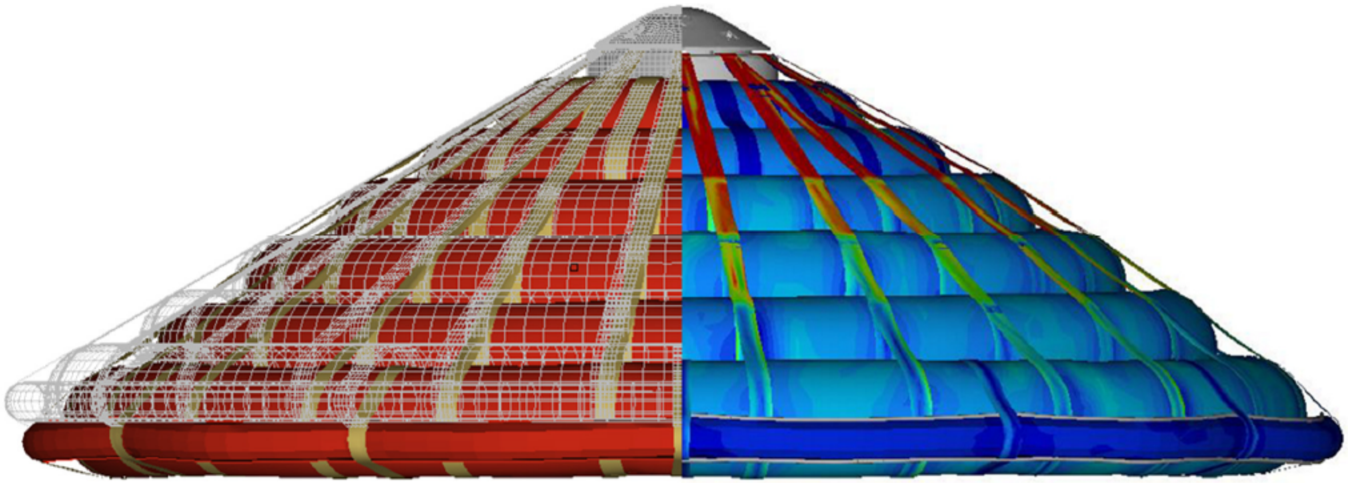
Analytical Model



Input Braid Geometry	***Braid:***	***HDT8040 with HDT8011 Axial Cords***					
Braid Constructed diameter	d =	9.67	in				
Braid Constructed (*Helix*) Angle	β =	70.0	°	*straight tube*			
Angle between Axial Cords	α_{cord} =	112.6	°				
Input Axial Cord Data							
Axial Cord:		HDT8011 Axial Cords					
		Cord Data in Sheet "*Braid & Cord Design*"					
Axial Cord Layout Length	L_L =	57.500	in	with 100	lb Tension		
Resulting Torus Geometry							
		Design Values		***Target Values***		***Measured Values***	
Axial Cord Loaded Circumferential Length	C_{cord} =	57.607	in	57.607	in	57.6	in
Axial Cord Radius from Torus Center	R_{cord} =	9.17	in	9.17	in	9.15	in
Resulting Torus Reference Radius	R_T =	11.85	in				
Resulting Torus Inside Radius	R_I =	6.88	in	6.88	in	7.03	in
Resulting Torus Outside Diameter	D_O =	32.05	in	32.05	in	32.07	in
Torus Outside Circumference	C_O =	100.70	in	100.70	in	100.75	in
Section Width	w =	9.14	in		in	9.00	in
Section Height	h =	9.25	in		in	9.30	in
Section Circumference	c =	28.90	in		in	29.06	in
Torus Volume	V_T =	4801	in^3		in^3		in^3

Torus	Design Circumference	EDU-2 As-Built	EDU-2 %
1	100.71	102.0	101%
2	147.13	147.1	100%
3	196.13	197.1	100%
4	246.18	247.0	100%
5	296.72	296.8	100%
6	347.64	348.0	100%
7	369.14	368.3	100%

Finite Element Analysis

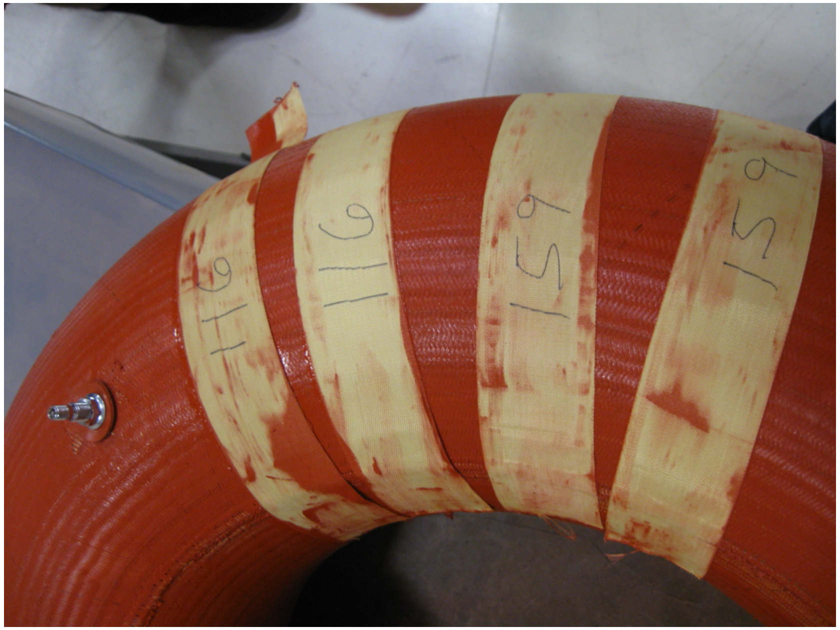


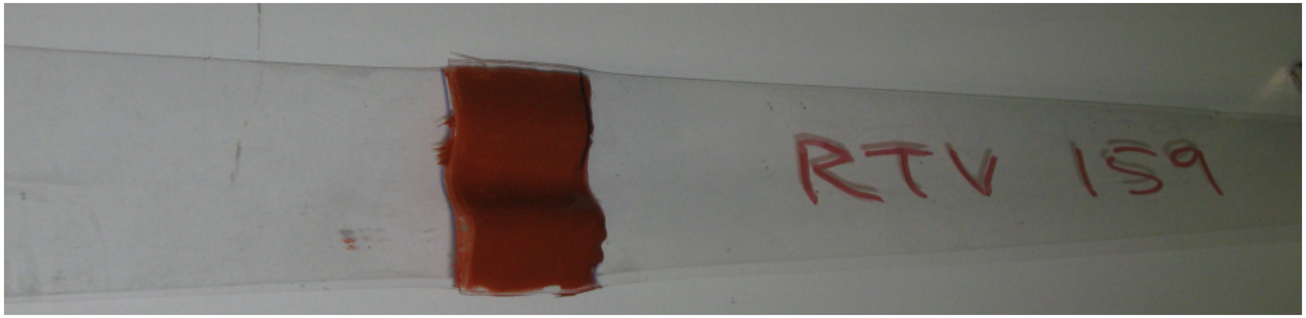
FEA Results, Deflections Left, Stresses Right

- LS-DYNA FEA used to model the inflatable
- Models non-orthogonal braided tori
- Complex interaction between webbing and inflatable
- Detailed comparisons with test data is still in work

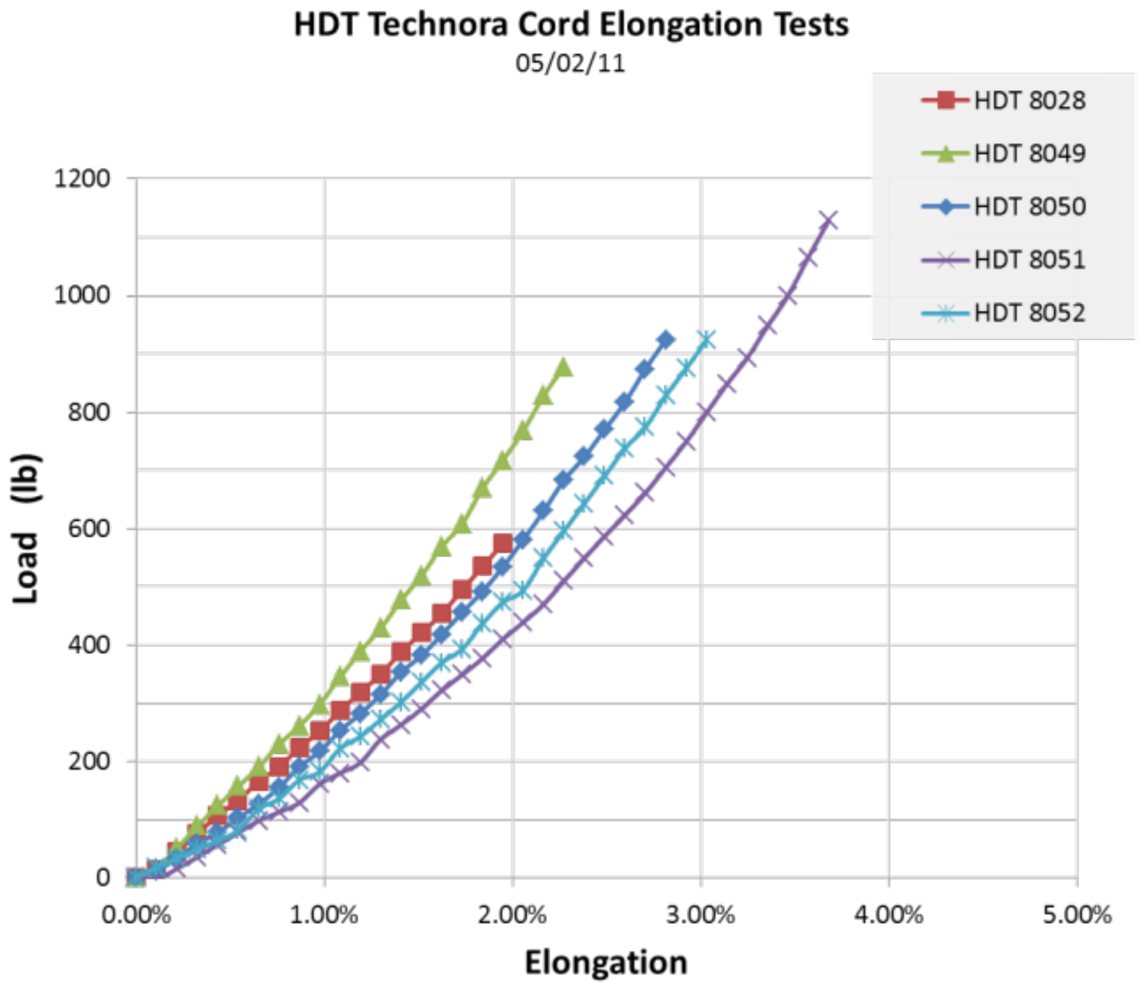
Coupon Testing

- Cord Testing
- Strap Testing
- Coating Testing
- Adhesives
- Braid Testing





Cord Elongation Curves



- Most elongation was due to material crimp and not the base fibers
- Cords with minimal crimp were chosen to provide dimensional stability

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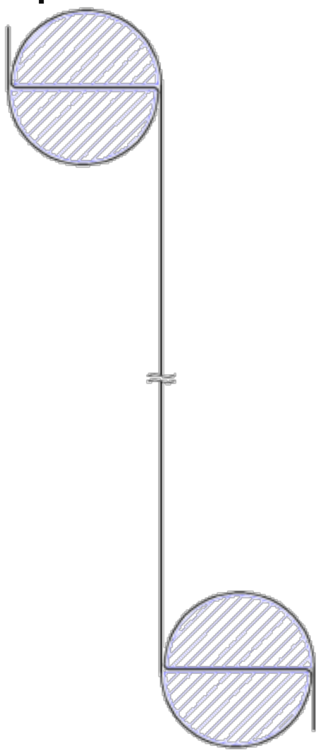
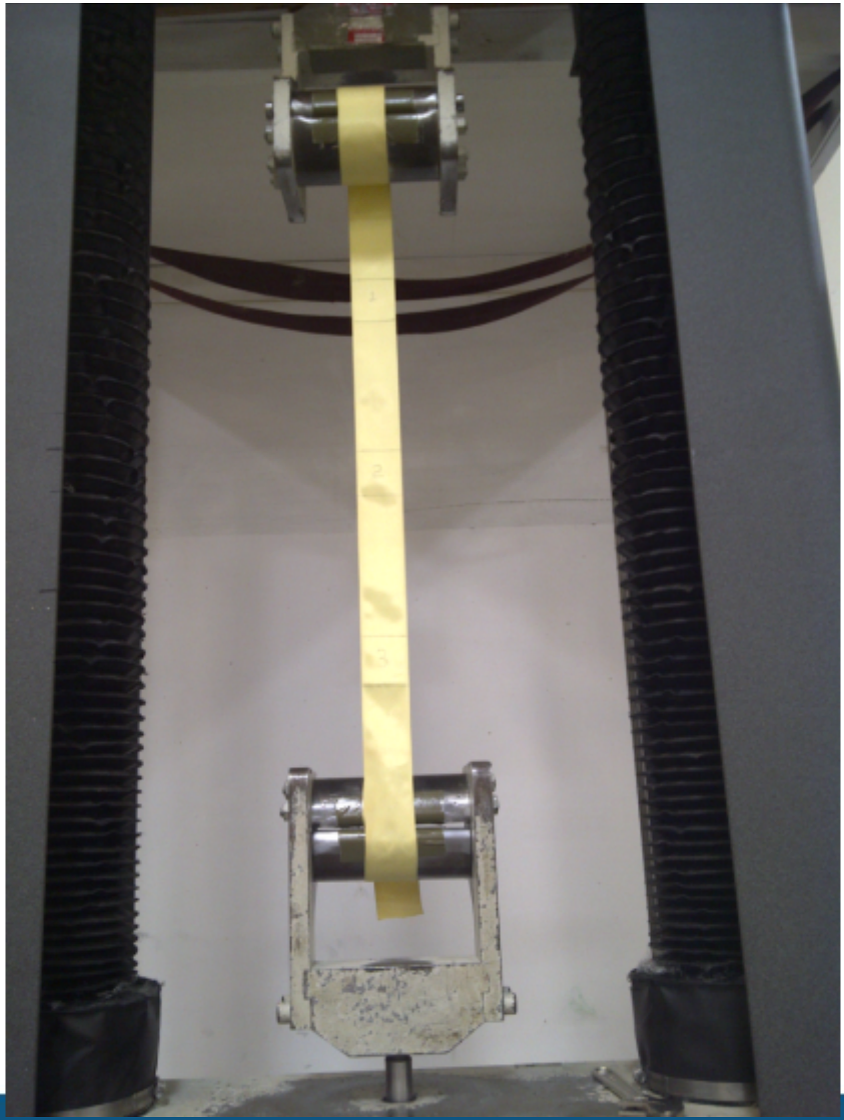
Strap Testing

- Material is wrapped around drums to reduce end effects as much as possible



- Testing is used to verify the straps meet the required loading.



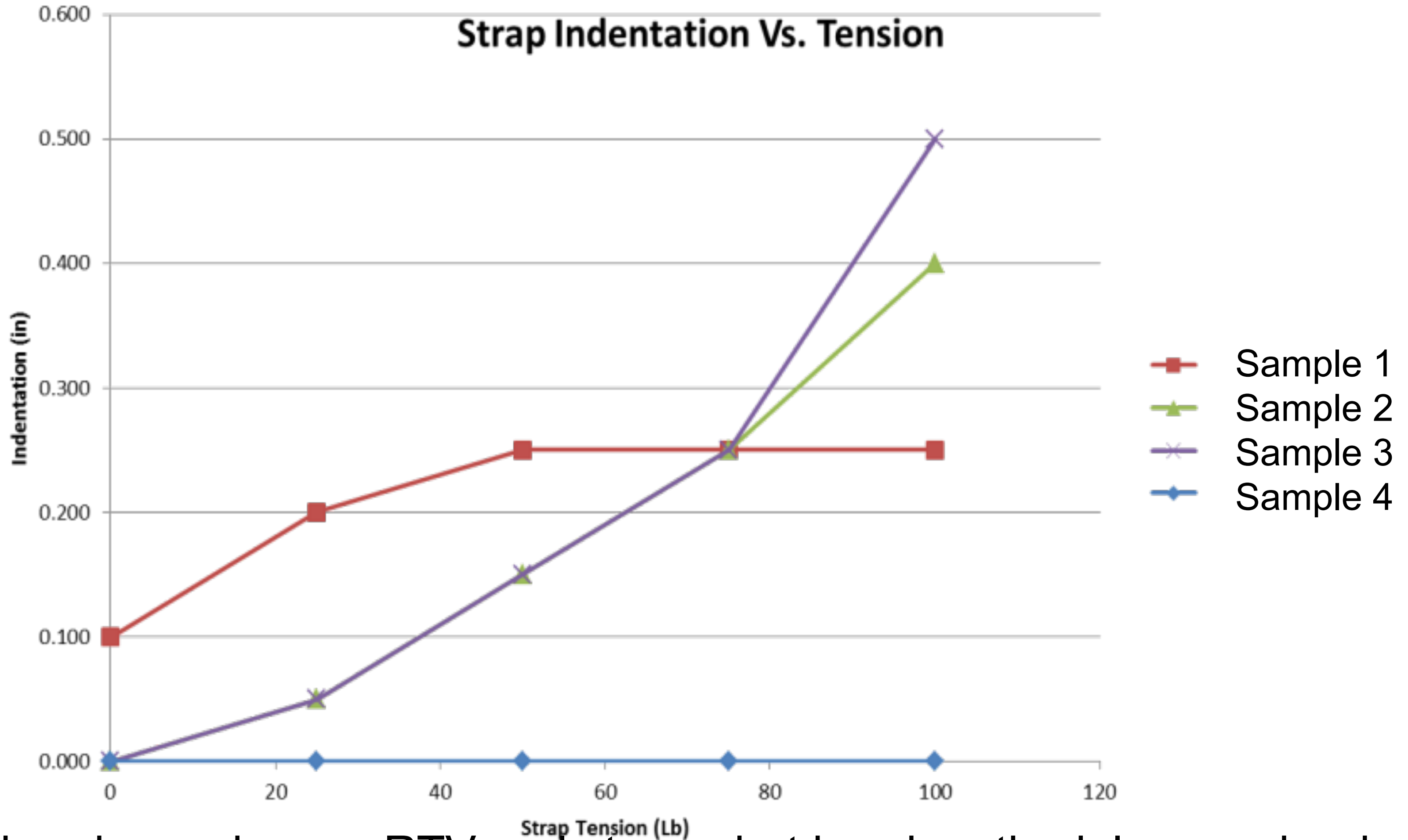
Component Fabrication

- All tori are fabricated independently prior to any joining

Component Testing

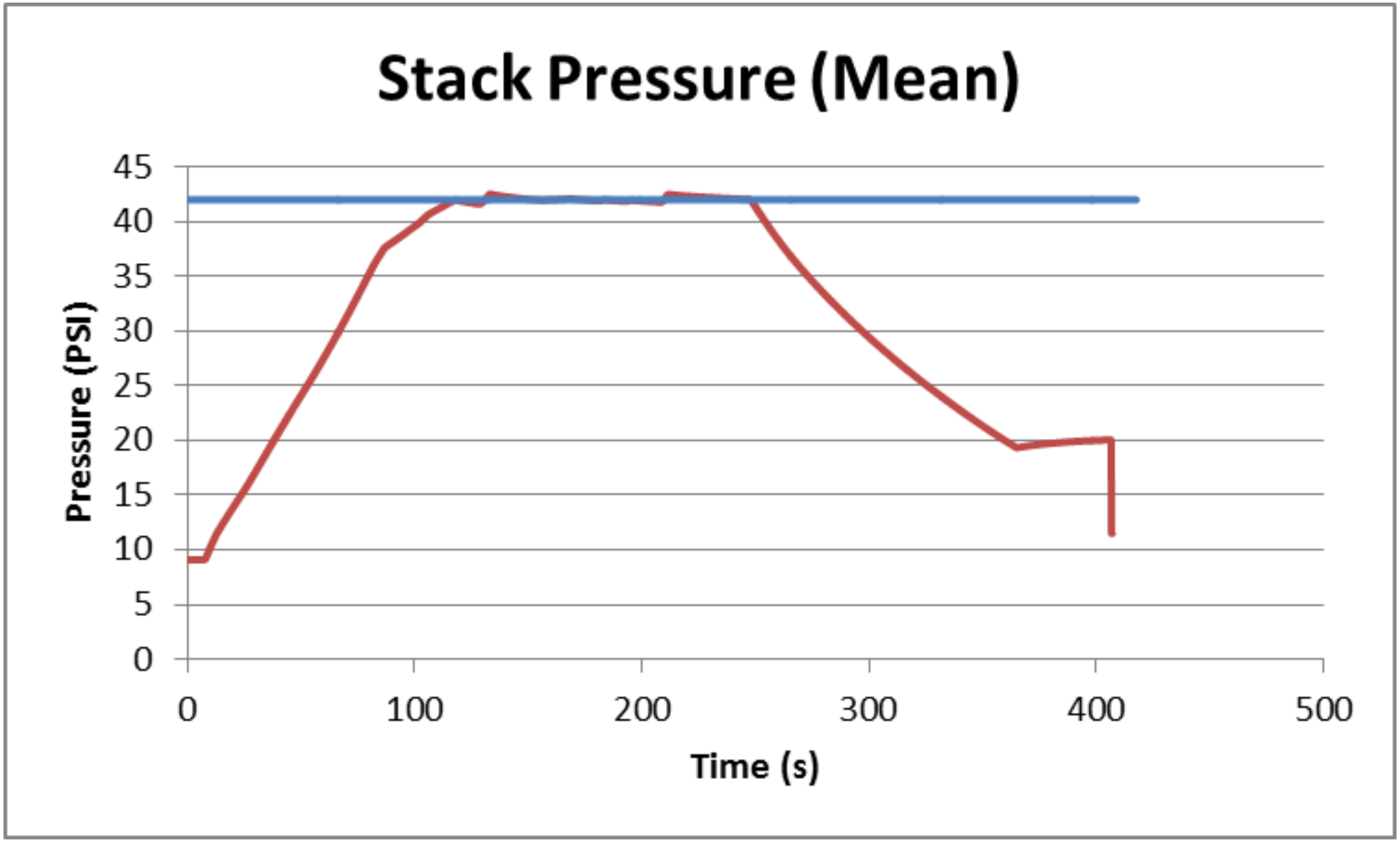
- Single Component
  - Indentation
  - Burst
- Acceptance Testing
  - Proof
  - Mass Check
  - Dimensional Checks

Strap Indentation Results Summary



- All bonds used same RTV and straps, but bond methodology and order drastically alters the stiffness of the structure

Small Tori Burst Test

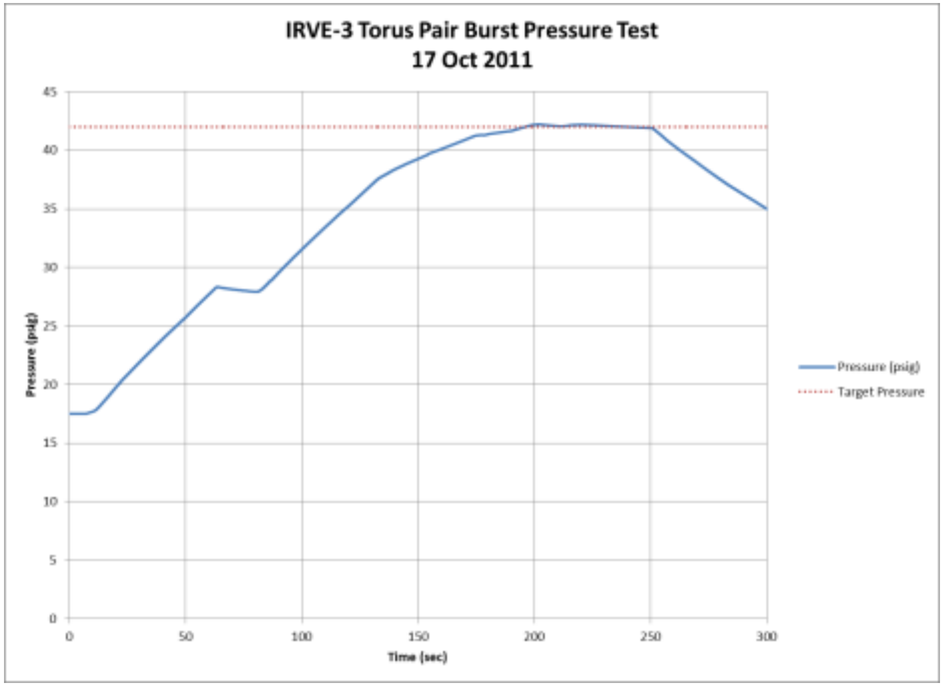


- Full stack taken to 2x Max Expected Operating Pressure

Video

- Torus 1-2 stack was burst tested to as first boundary condition with torus 1 braid coverage as limiting factor.

Torus 5/6 Burst Test



- Additional torus 5-6 pair was fabricated and burst tested to ensure that the interface loads at max pressure were not the limiting factor.

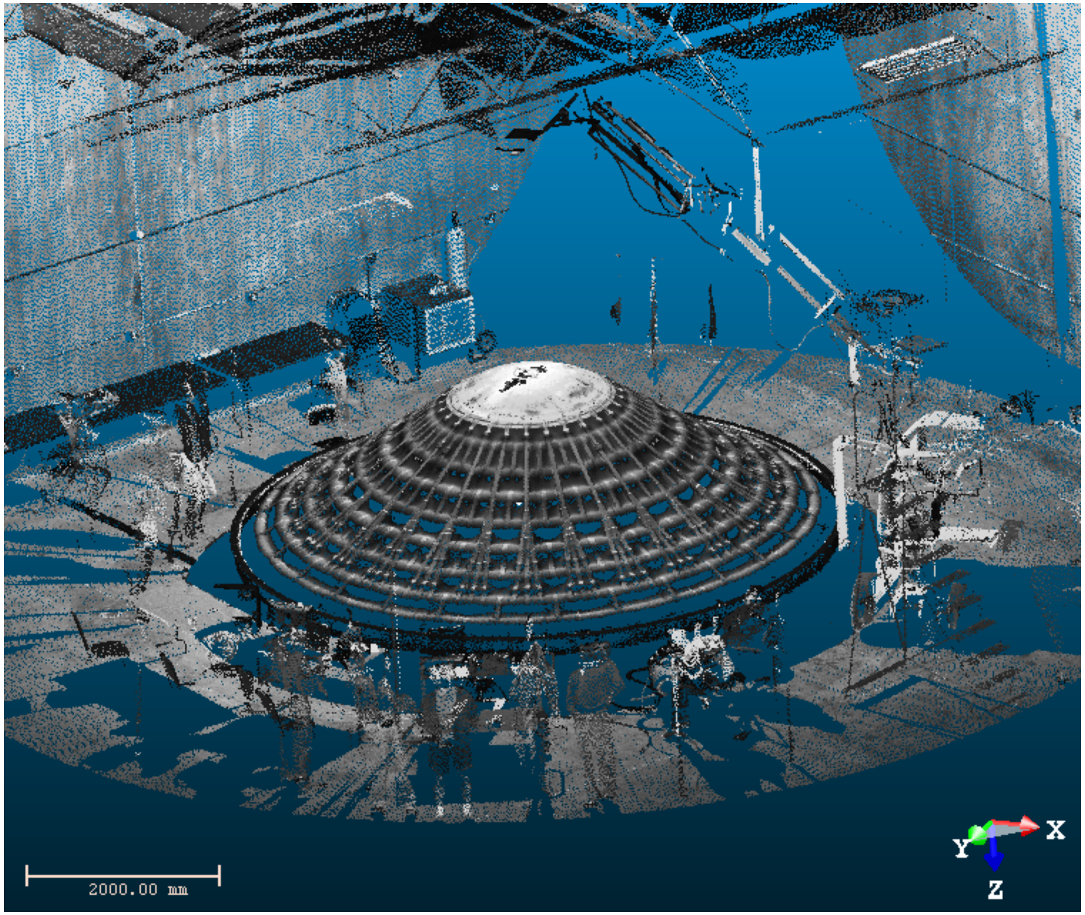
Complete System Assembly

Complete System Assembly

Complete System Assembly

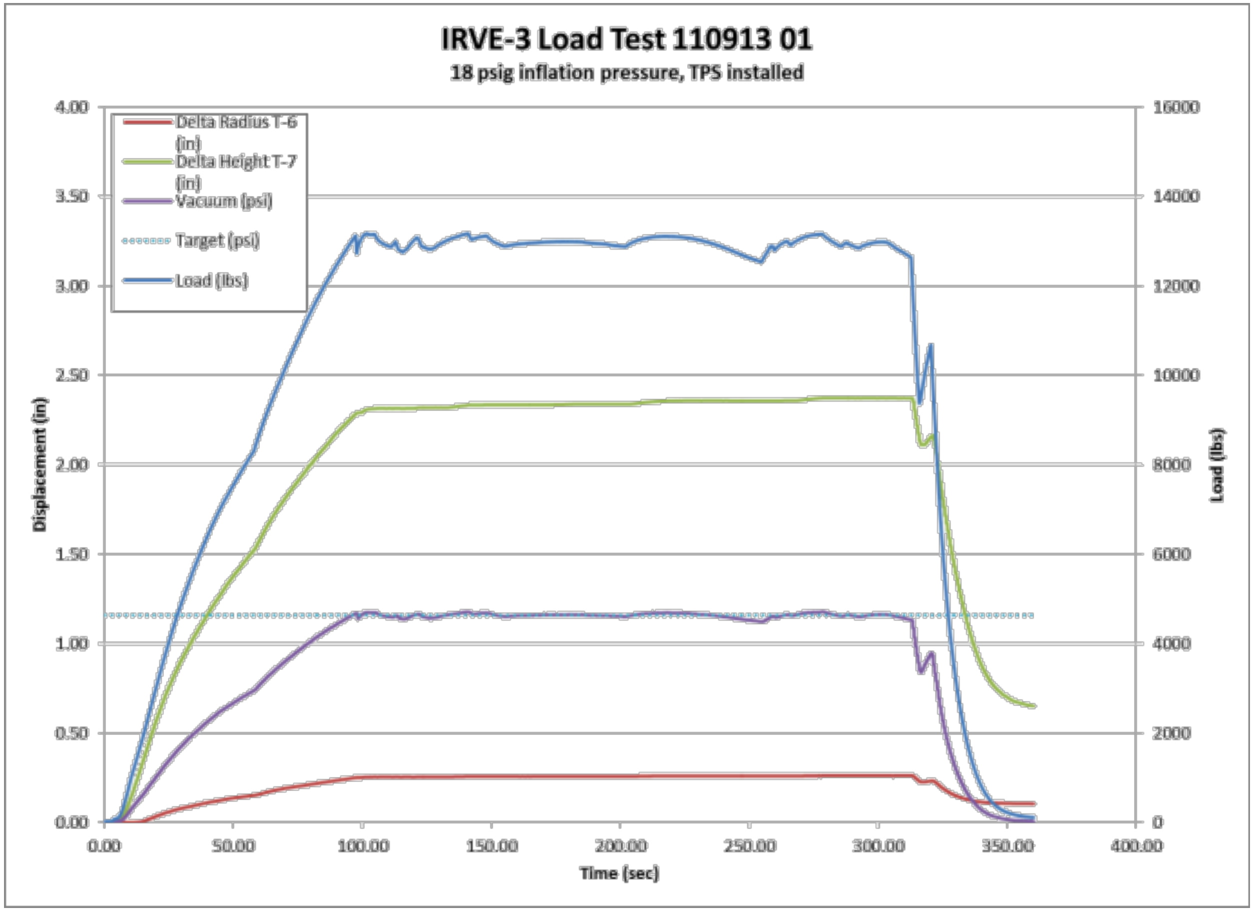
Complete System Testing

- HDT Airborne Systems Testing
  - Load Testing
  - Leak Testing
  - Proof Testing
  - TPS Integration Testing
  - Packing Testing
  - Deployment Testing



- NASA Testing
  - Modal Testing
  - Wind Tunnel Testing
  - Flight Testing

IRVE-3 18 PSI Load Test Results



Full stack was taken to 13,000 Lbs. and experienced minimal change in drag area and less then 2.5 inches of aft deflection.

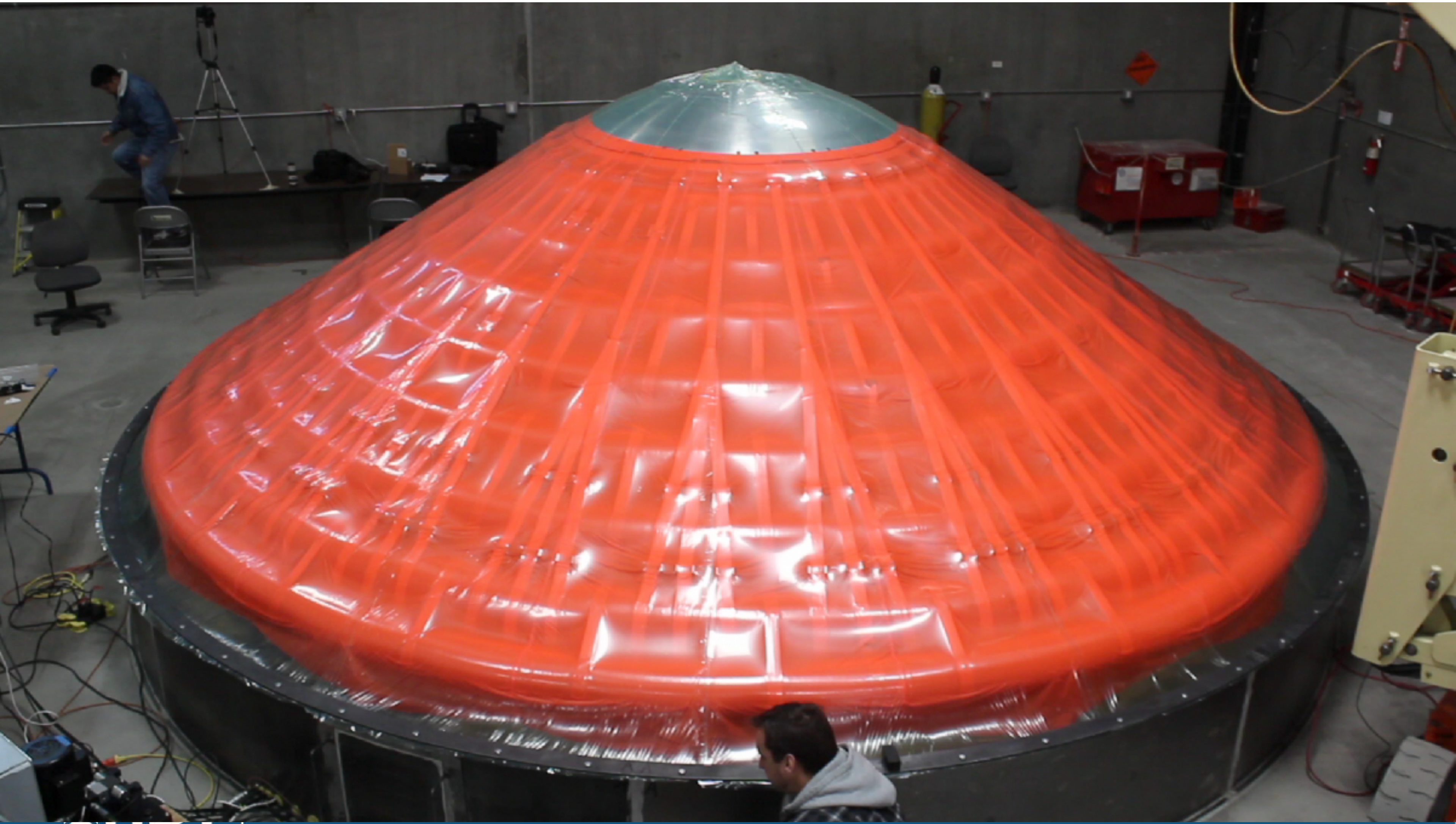
IRVE – 3 18 PSI No TPS

BASELINE

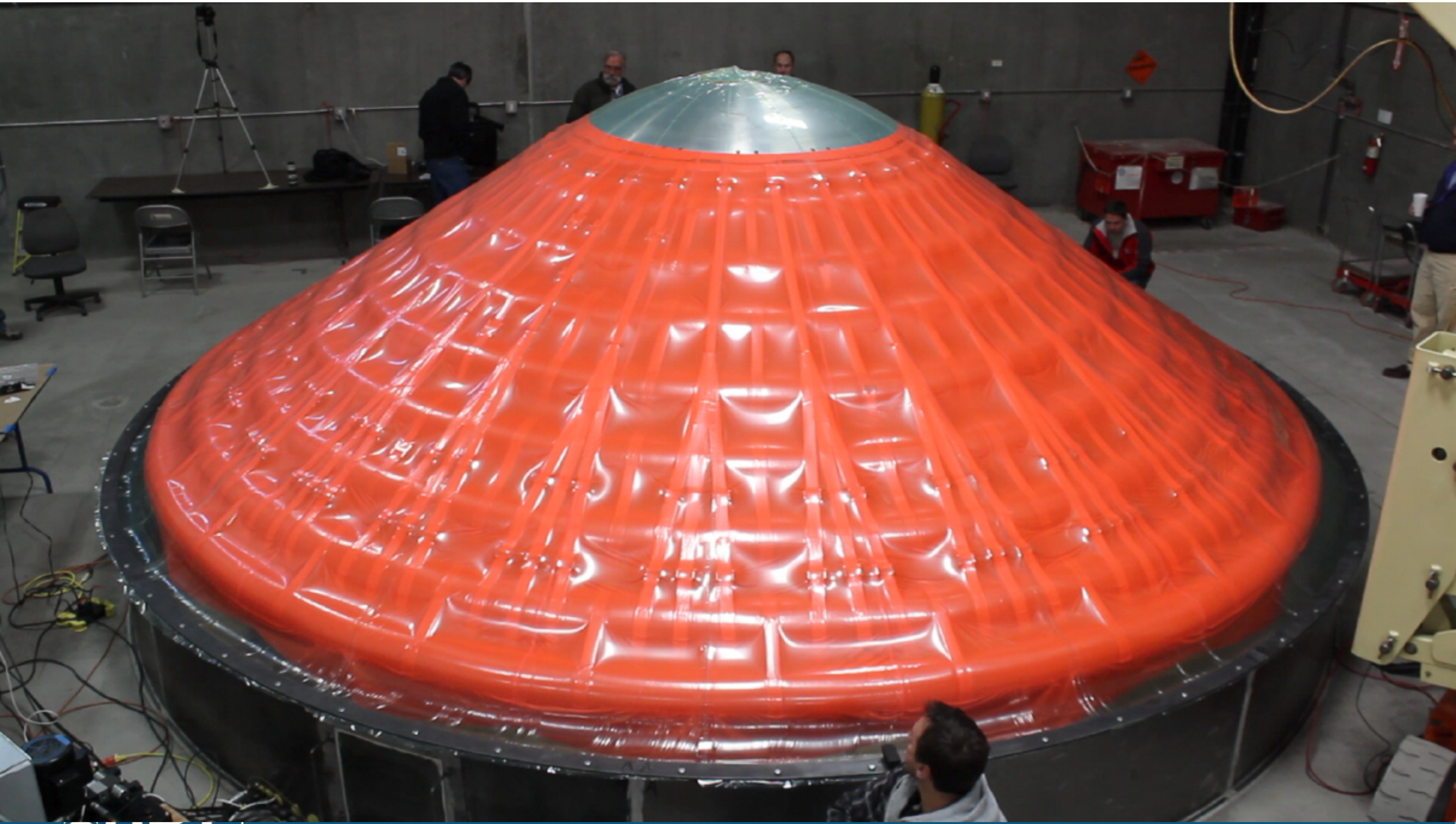
Full Load

All tests were laser scanned at load to validate loaded shape.

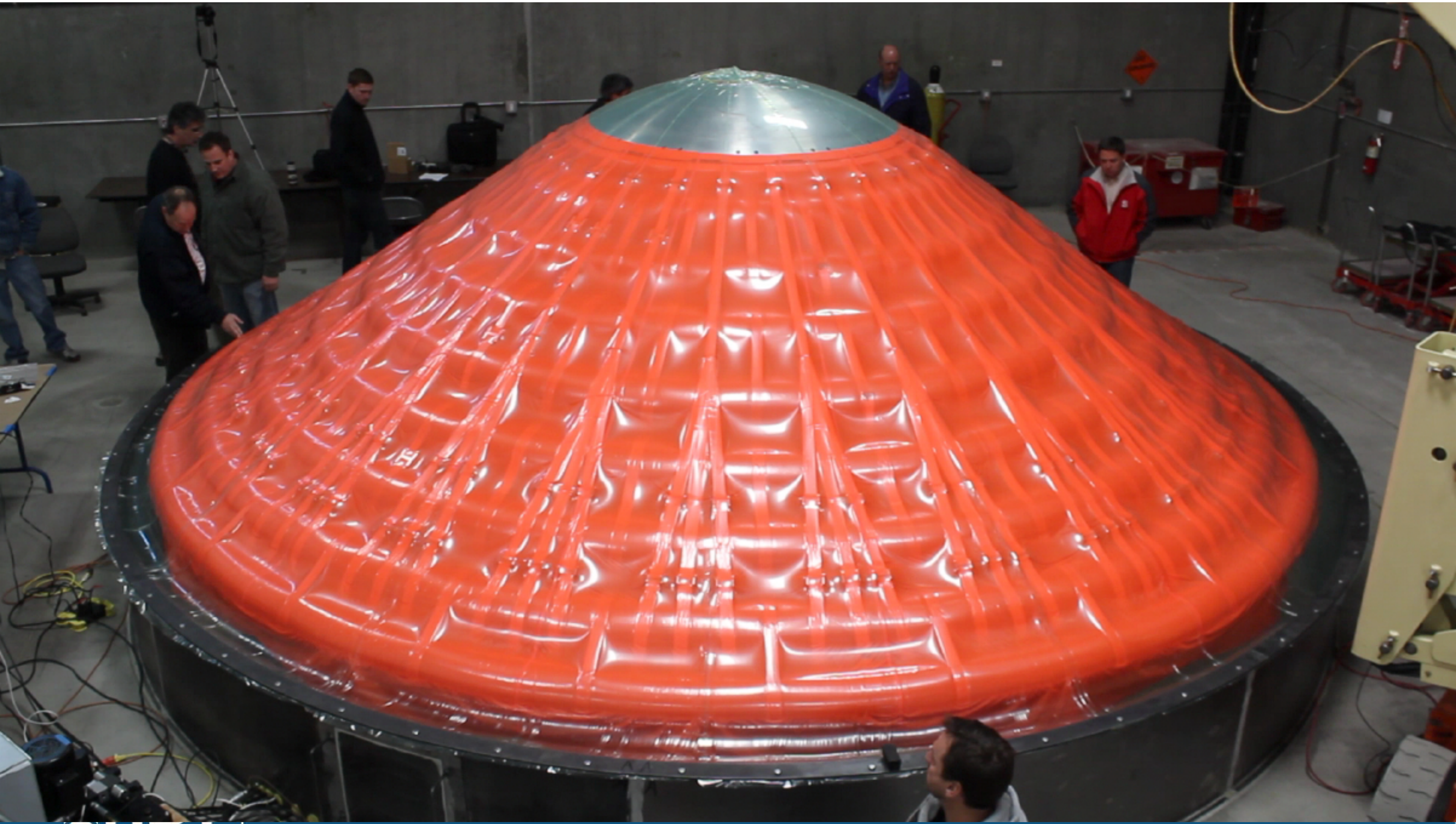
HIAD Static Load Test- No Load



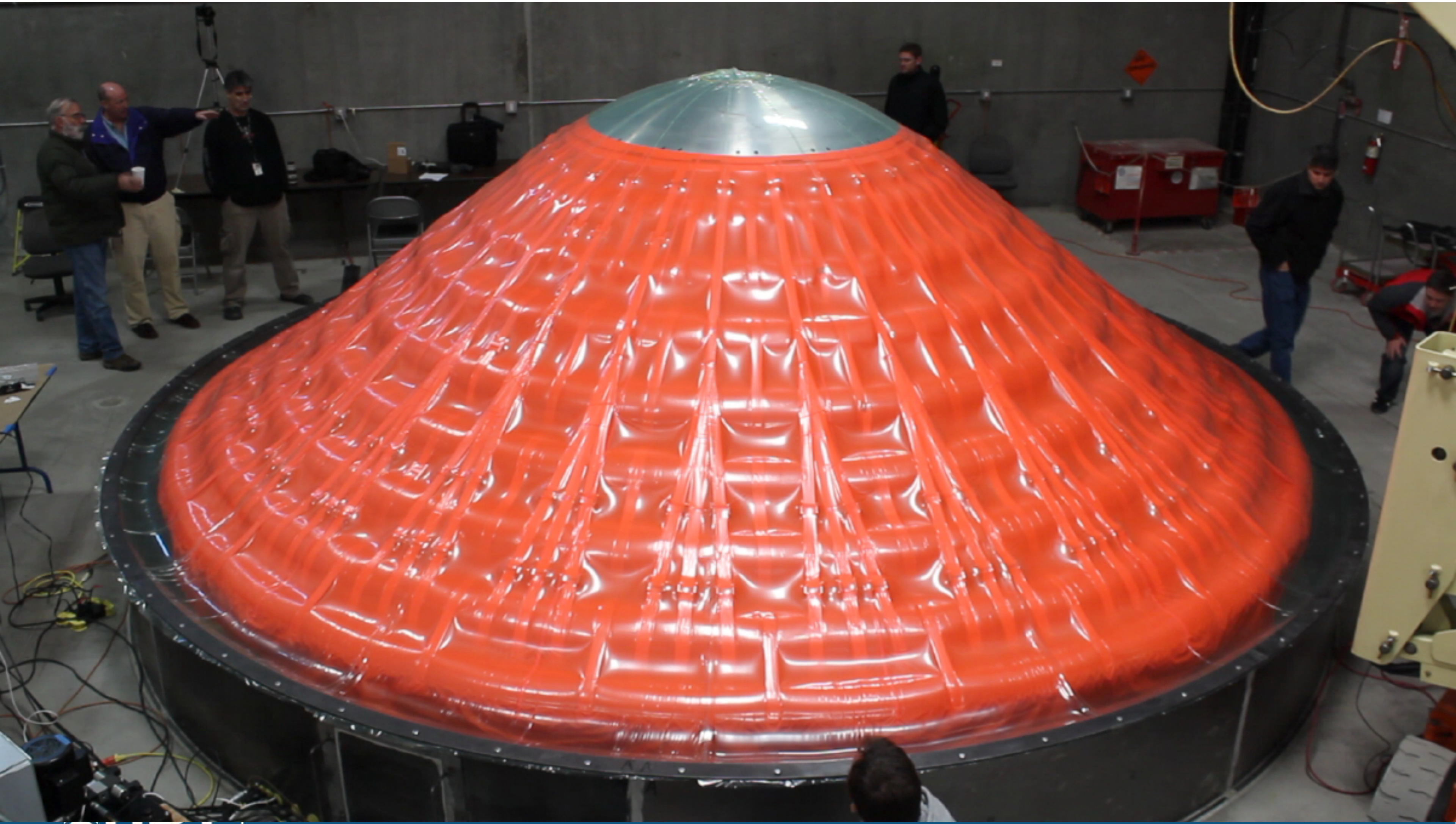
HIAD Static Load Test- ½ Load



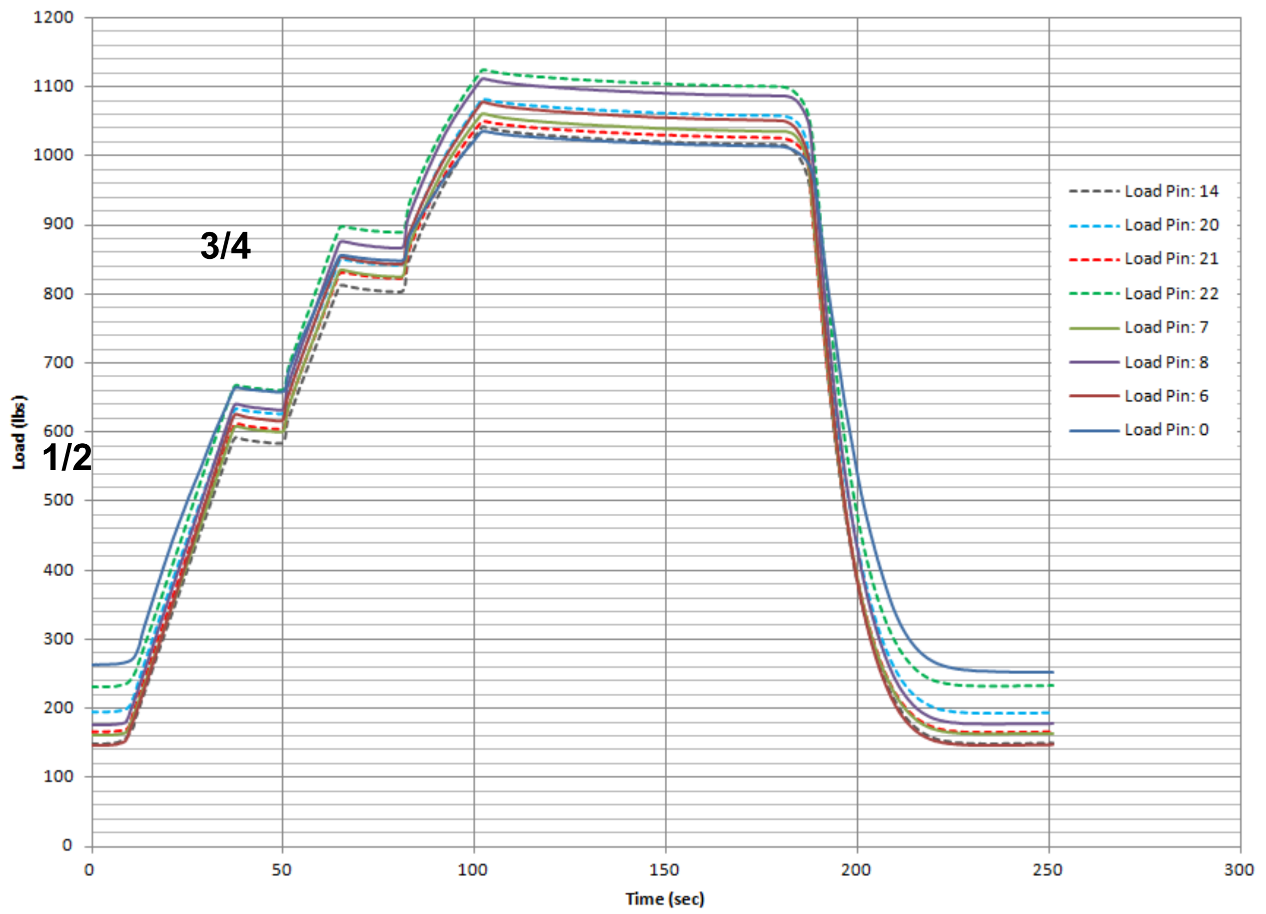
HIAD Static Load Test- ¾ Load



HIAD Static Load Test- Full Load



15 PSI 6m Strap Load Pin Data



Load pins and strap load cells were in place during testing for real time load data and correlation.

TPS Integration Testing

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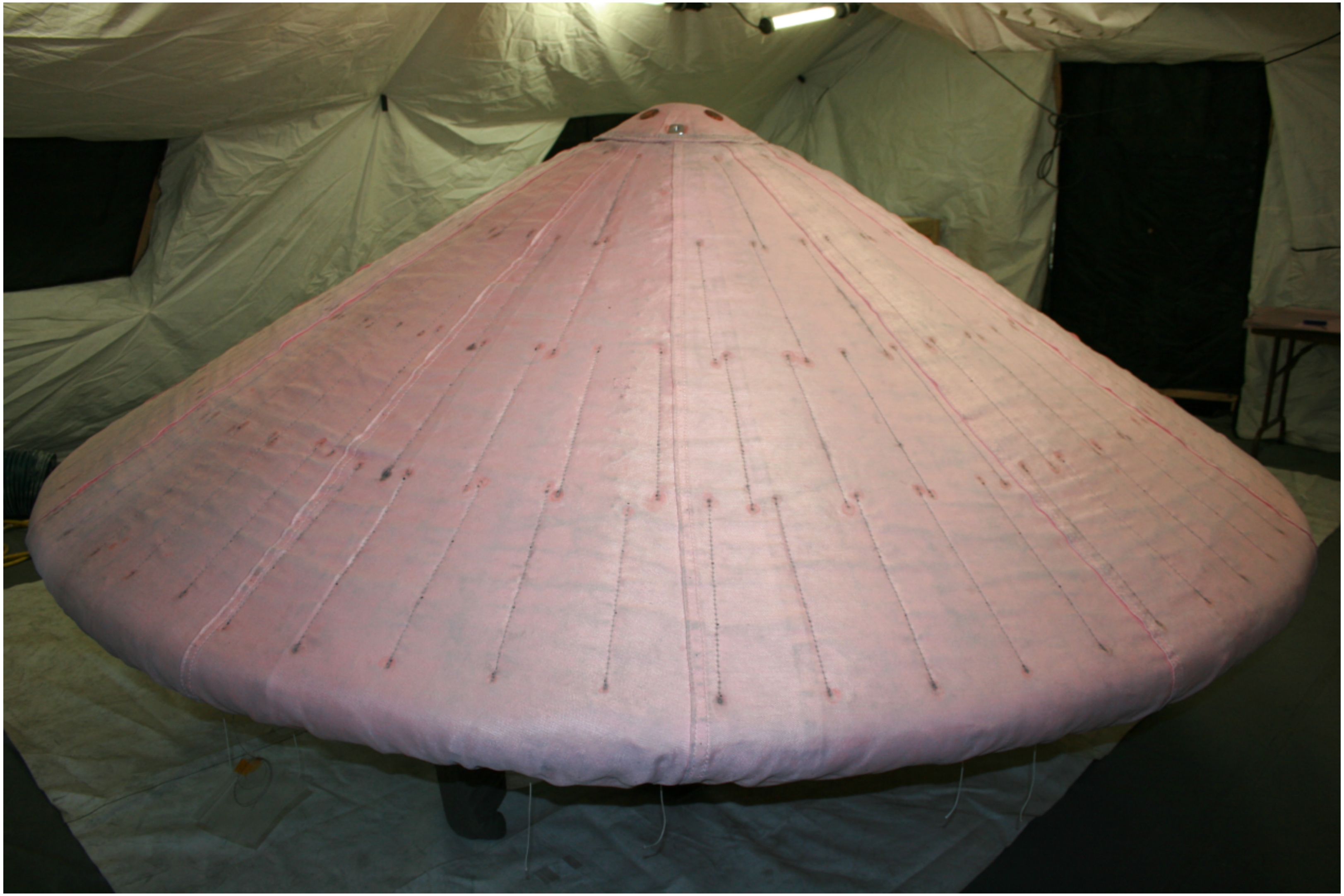

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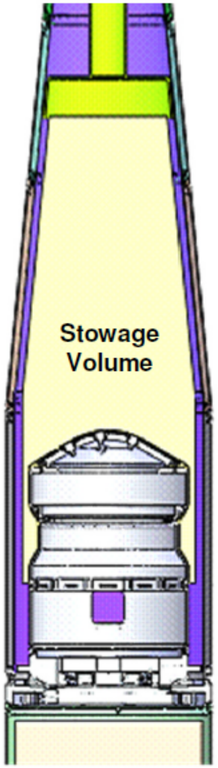
Restraint Testing

- Kevlar panel developed to restrain packaged aeroshell during launch
- Article stows forward of the centerbody in the nosecone region
- Pyro released “Dutch” lacing provides release capability
- Lacing releases with only the material strain energy
- Girdle provides uniform tension in the panel
- Inflation commences after the panel has released



Nosecone Schematic

De-lacing System

Girdle System

Deployment Testing

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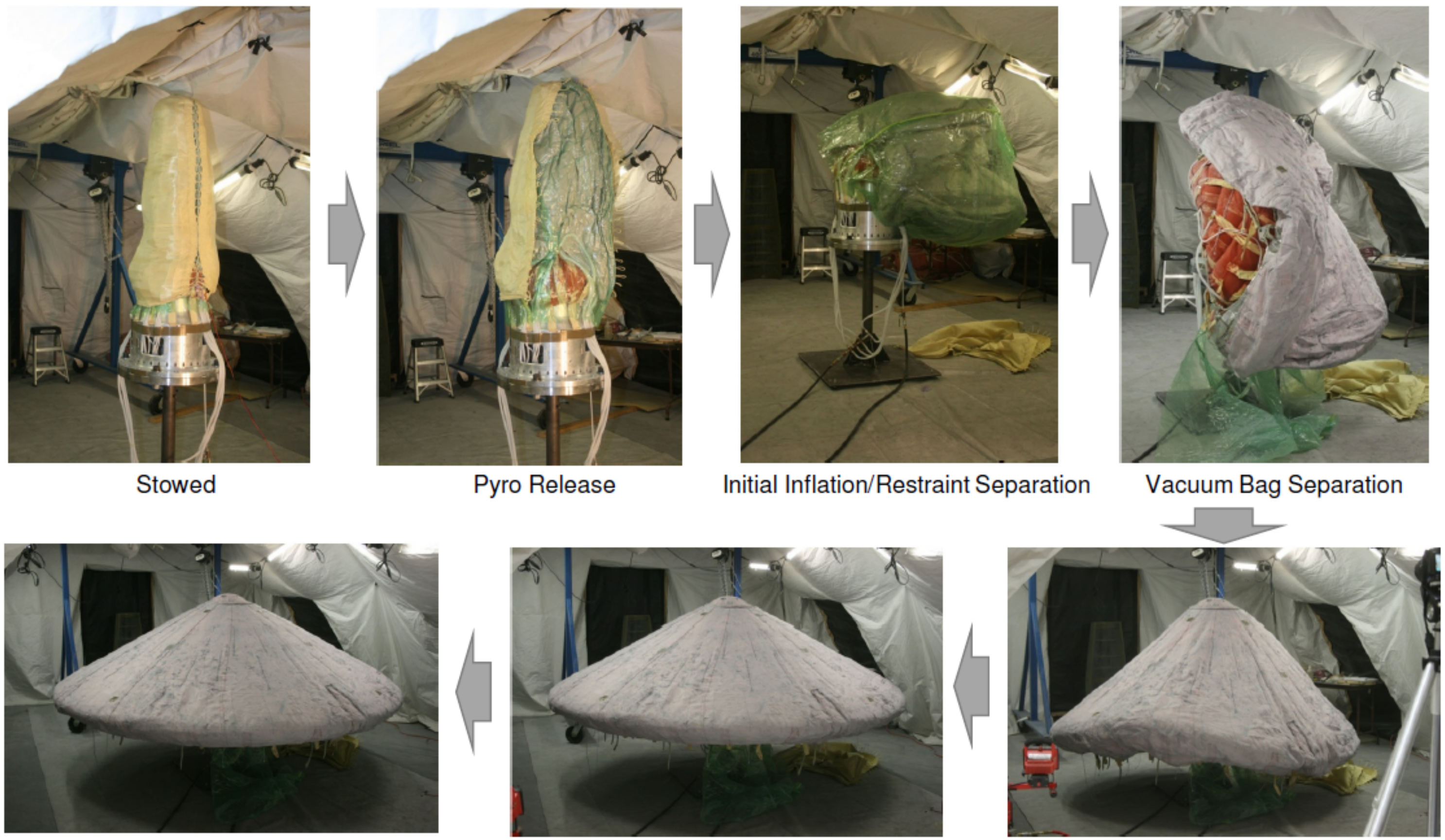
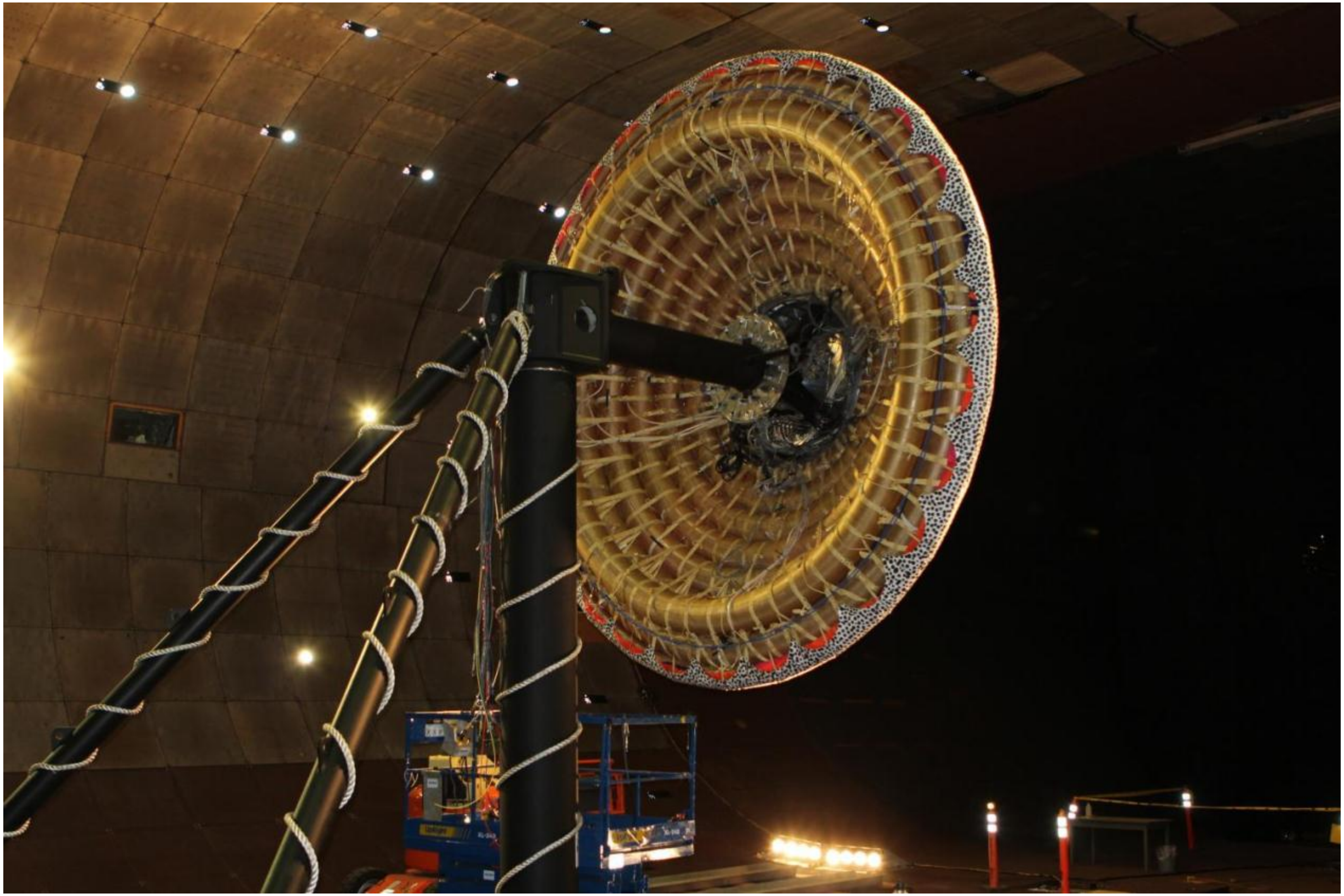


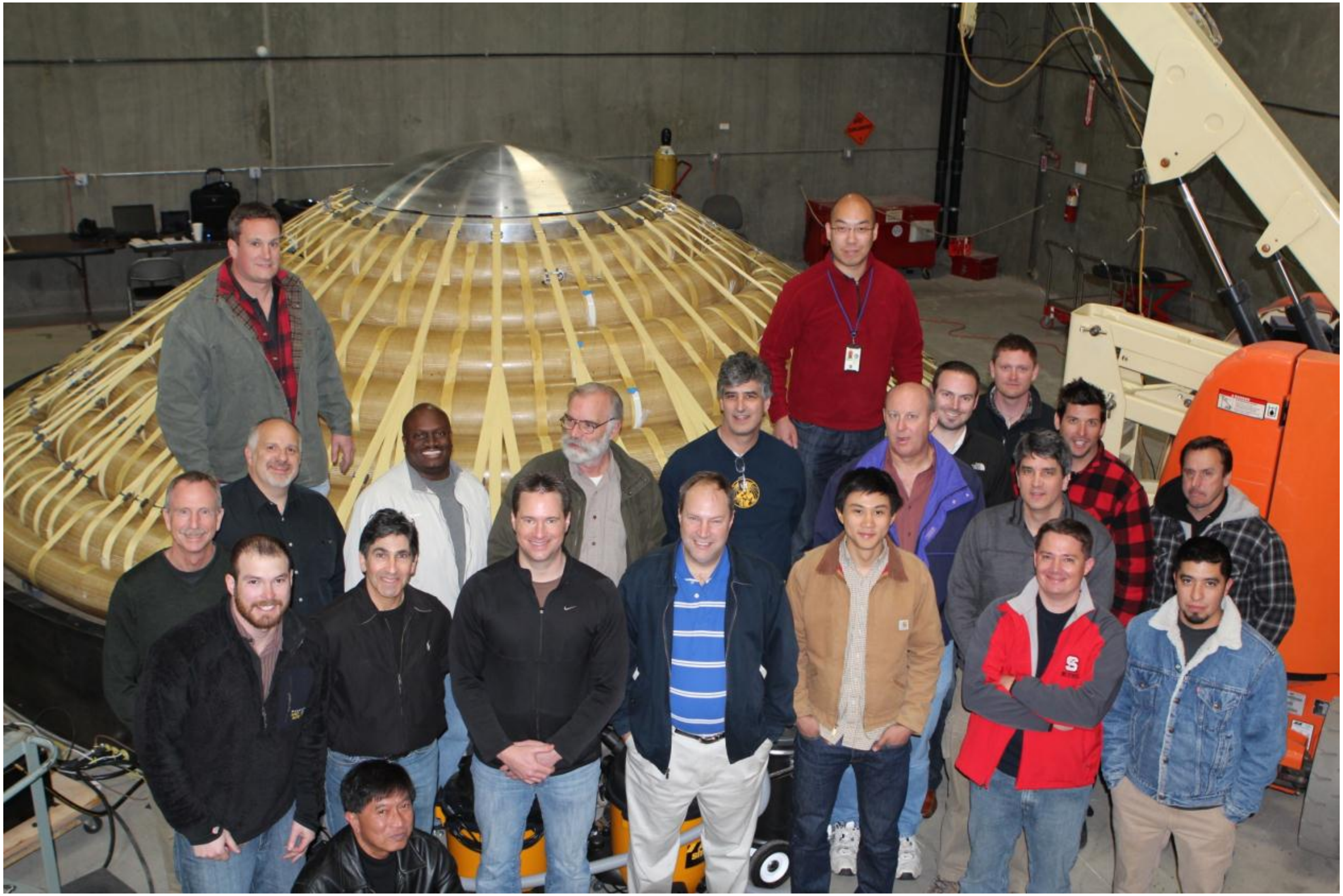
NASA Wind Tunnel Testing



Delivery and Conclusions

- Developing Hypersonic IADs is a very complex and iterative process that relies heavily on component and system testing.
- Look forward to Launch of IRVE-3 in July and WT Testing

Large Scale Article Team



HIAD After Hours

References and Acknowledgements

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- References

1. Zang, T. A. (Editor), “Entry, Descent and Landing Systems Analysis Study: Phase 1 Report,” EDL Systems Analysis Team, NASA TM-2010-0000002009, May 2010.
2. Lichodziejewski, Leo, Christopher Kelly, Ben Tutt, David Jurewicz, Glen Brown, Brian Gilles, Dennis Barber, Charles Player, and Robert Dillman. "Design and Testing of the Inflatable Aeroshell for the IRVE-3 Flight Experiment." 13th AIAA Gossamer Systems Forum. Honolulu, Hi. Apr. 2012. Lecture.

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- Photos By: Mike Quinn, Paul Anderson, Alan Cassell, Leo Lichodziejewski