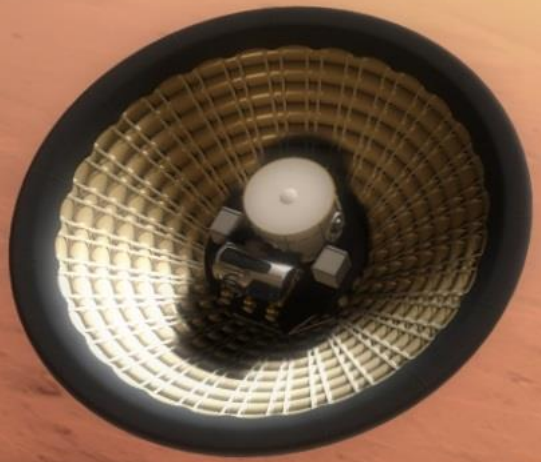
National Aeronautics and
Space Administration



Hypersonic Inflatable Aerodynamic Decelerator Ground Test Development

Joseph A. Del Corso
Stephen Hughes, Neil Cheatwood,
Keith Johnson, Anthony Calomino

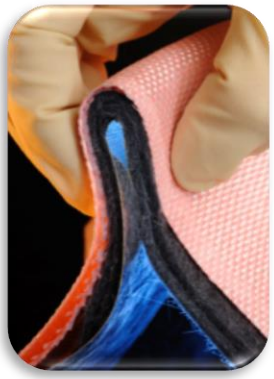
International Planetary Probe Workshop #12

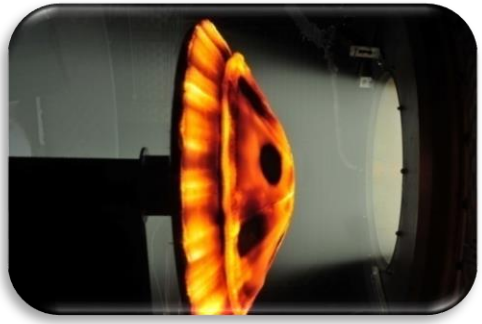
Agenda

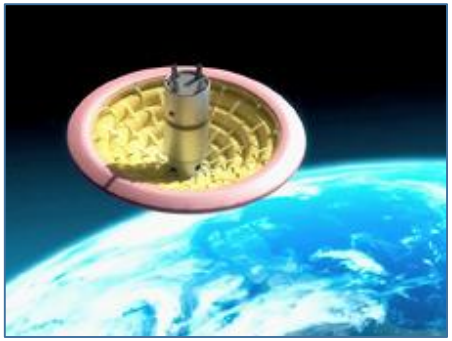
- HIAD Context
  - Technology Background (Historical Context)
  - Future Flight and Developments Path
  - Technology Requirements
- HIAD at the end of FY14
  - FTPS Accomplishments and Solutions
  - IS Accomplishments and Solutions
- HIAD-2 “Preparing for Mars”
  - Flexible Systems Development Areas
  - Inflation Systems and Aeroaffector Technology
- Closing Remarks

HIAD Technology History

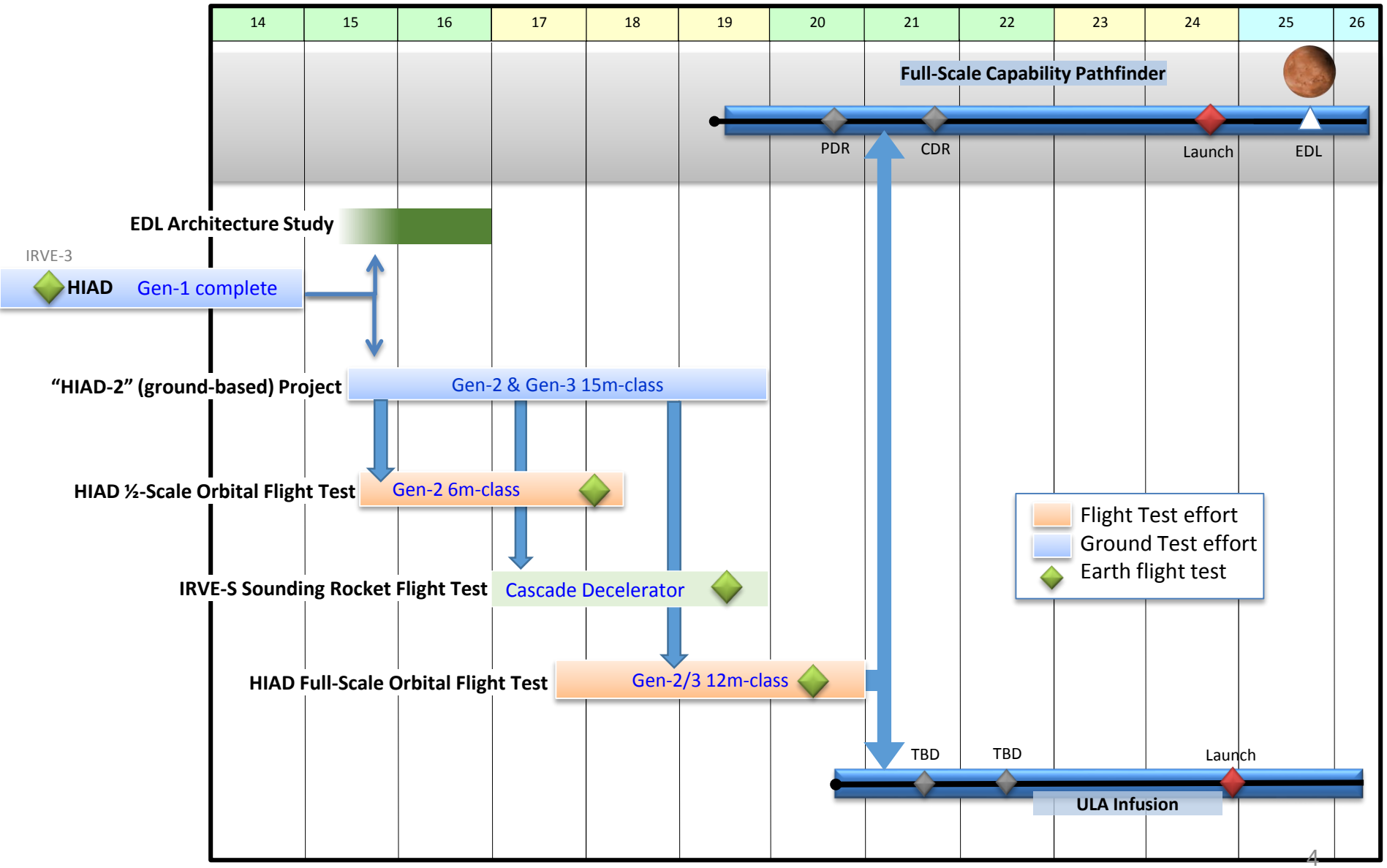
- Systematic and stepwise technology advancement
  - ✓ *Ground Test*: Project to Advance Inflatable Decelerators for Atmospheric Entry (PAI-DAE): Softgoods technology breakthrough
  - ✓ *Flight Test*: Inflatable Reentry Vehicle Experiment (IRVE), 2007: LV anomaly--no experiment
  - ✓ *Flight Test*: IRVE-II, 2009: IRVE "build-to-print" re-flight: Historic first successful HIAD flight
  - ✓ *Ground Test*: HIAD Project improving structural and thermal system performance (Gen 1 & Gen 2): Extensive work on entire aeroshell assembly
  - ✓ *Flight Test*: IRVE-3, 2012: Improved 3m IS & FTPS, higher energy reentry; first controlled lift entry
- Next Steps
  - ⇨ *Ground Effort: TRL Maturation Project improving Aeroshell capabilities, including scaling to >10m, manufacturing advancements, controllability and demonstrated staging to secondary decelerator option.* **Prepares for large scale flight test demo and readiness for Mars mission**.
  - ⇨ *Flight Test Possibilities*: *ULA Asset Recovery Demo at scale and environments relevant to Mars Human Pathfinder* .





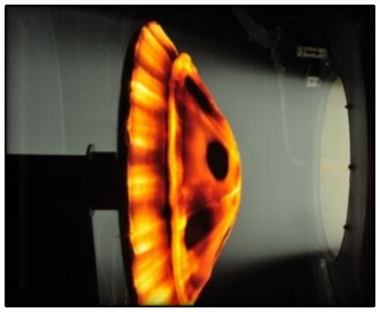


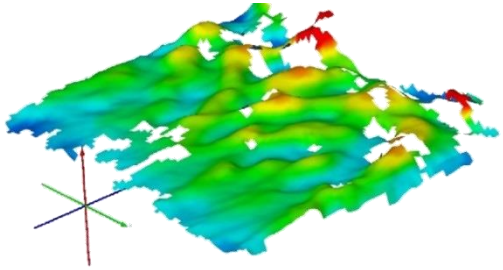
Development Timeline for 2024 Mars Demo, Utilizing ULA

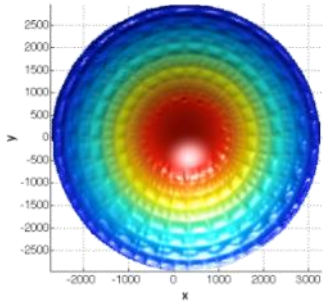


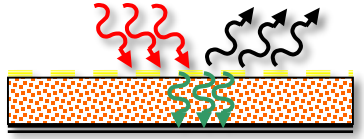
HIAD Technology Requirements

- Manufacturability of full aeroshell system at scale
- Demonstrate performance margin at entry aerothermal environments
- Pack aeroshell to high densities (~300 kg/m^3 [20lb/ft^3] packed, ~40 kg/m^3 deployed)
- Fold materials to a hard crease (near-zero bend radius) without degrading aeroshell performance
- Withstand long duration exposure to in-situ exo-atmospheric environments, without degrading materials capability.
- Deploy and inflate aeroshell after long duration storage at high packing densities without significantly changing thermophysical characteristics of TPS, leak rate of IS, or inflation capability
- Model and reliably calculate material and system performance in order to size TPS for desired trajectory

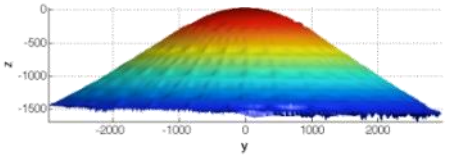


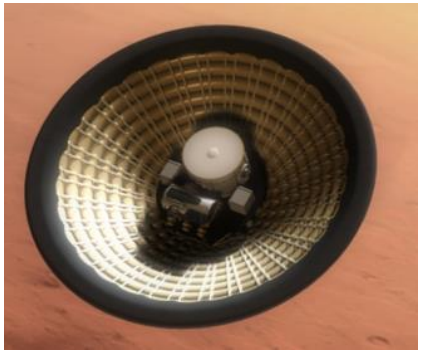






$$\rho C_p \frac{\partial T}{\partial t} - \frac{\partial}{\partial x}\left(K \frac{\partial T}{\partial x}\right) = 0$$

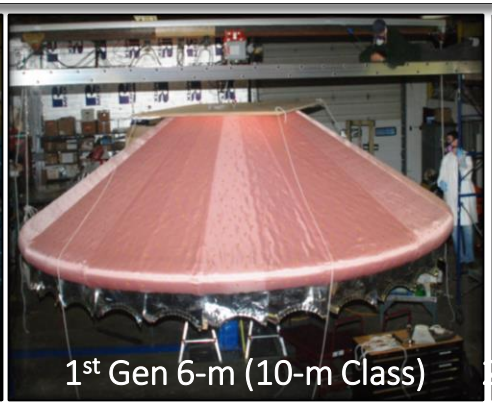




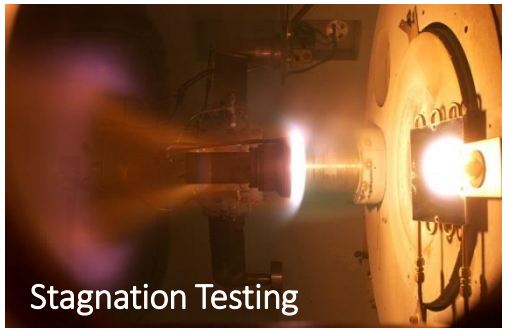
HIAD F-TPS Accomplishments


IRVE-3 Nosecap Skirt

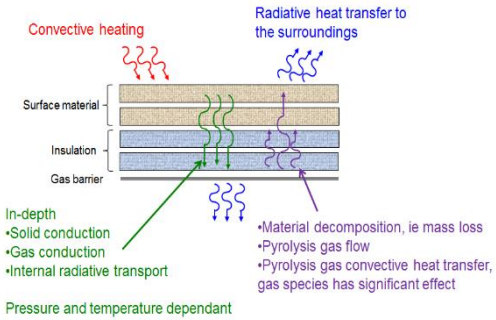

Plan "B" 3-m (IRVE-3 Clone)


1st Gen 6-m (10-m Class)


2nd Gen 3.7-m (5-m Class


Stagnation Testing

Shear Testing



8'HTT test of 2'x2' sample

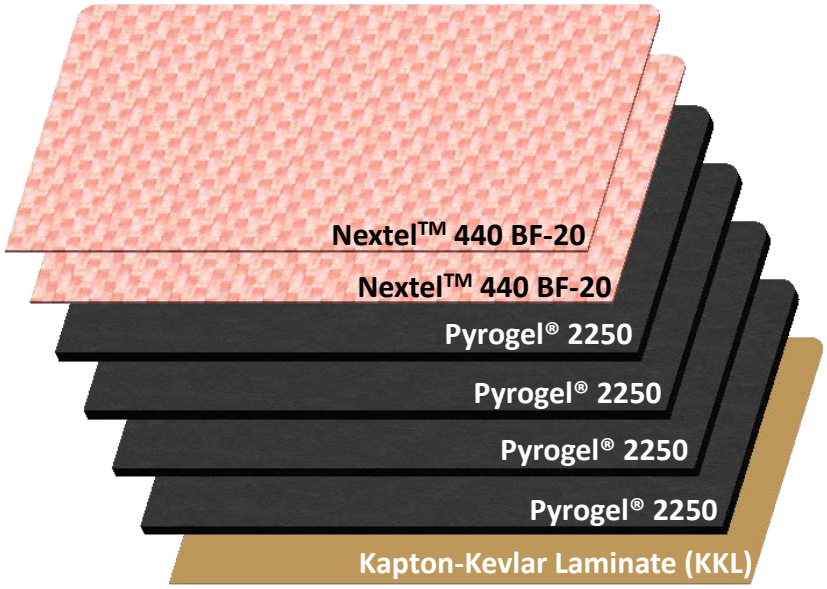
F-TPS Development (FY12-14)

- **Fabricated 6-m hybrid 1st Gen/2nd Gen F-TPS and a 3.7-m 2nd Gen F-TPS, and successfully load tested integrated 6-m F-TPS and inflatable structure**
- **Developed new test methodology used to create aerothermal performance data sets of 1st and 2nd Generation layups and conducted 302 stagnation and 33 shear tests during 3 years**
- **Developed F-TPS multi-physics thermal model which incorporated measured material properties and physical phenomena; and performed initial validation of model to ground and flight test data**
- **Developed analysis framework which incorporates the F-TPS multi-physics thermal model and uses probabilistic tools which is being used to reduce margined mass while preventing bondline over-temperature**

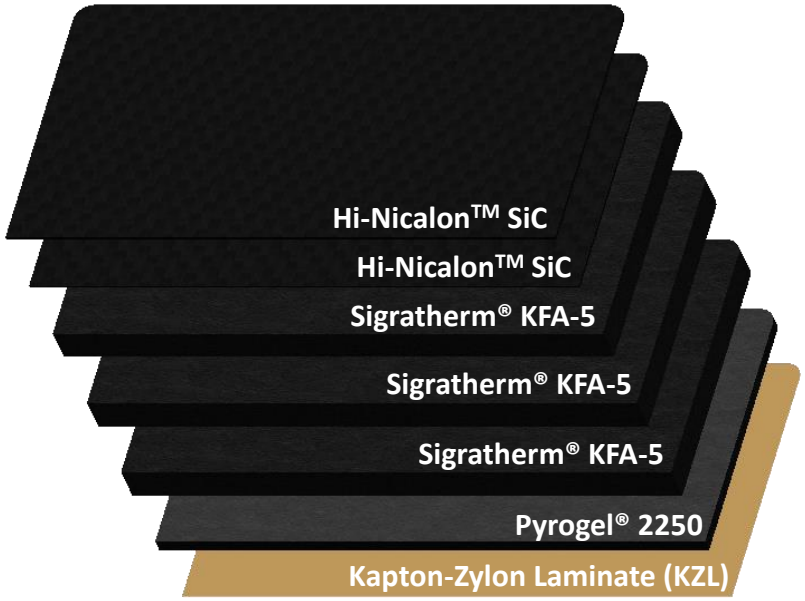
HIAD F-TPS Framework

F-TPS Components	1st Gen (30 Watts/cm²)	2nd Gen (50 Watts/cm²)
Outer Fabric	Nextel™ 440 BF-20	Hi-Nicalon™ SiC
Primary Insulator	Pyrogel® 2250	Sigratherm® KFA-5
Secondary Insulator	Pyrogel® 2250	Pyrogrel® 2250
Gas Barrier	Kapton-Kevlar Laminate (KKL)	Kapton-Zylon Laminate (KZL)
Inflatable Structure Temperature Limit	***250°C***	***400°C***

1st Generation



2nd Generation



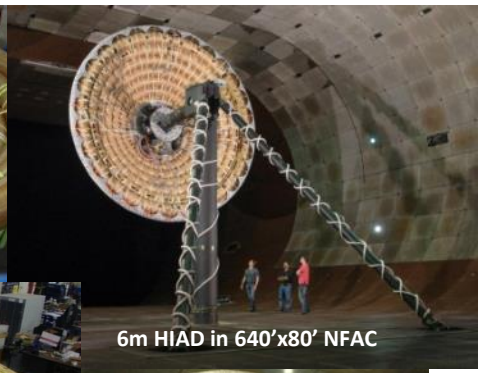
HIAD IS Accomplishments


Torus Fabrication

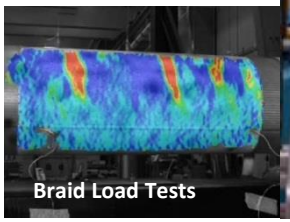

Braid Mechanical Property Tests


Torus Compression/Torsion Test

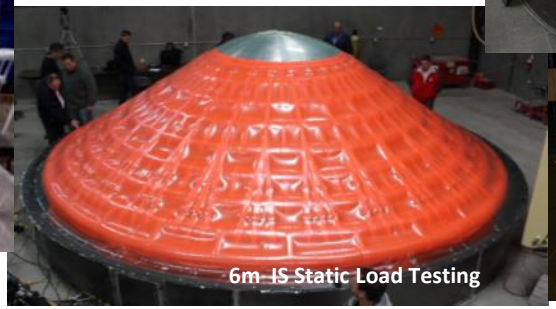

6m Fabrication


6m HIAD in 640'x80' NFAC

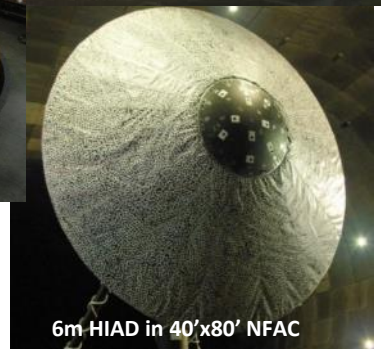

6m IS Test Article

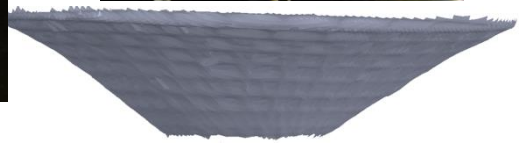

Braid Load Tests


Thermal Testing


6m IS Static Load Testing


6m HIAD Packing


6m HIAD in 40'x80' NFAC

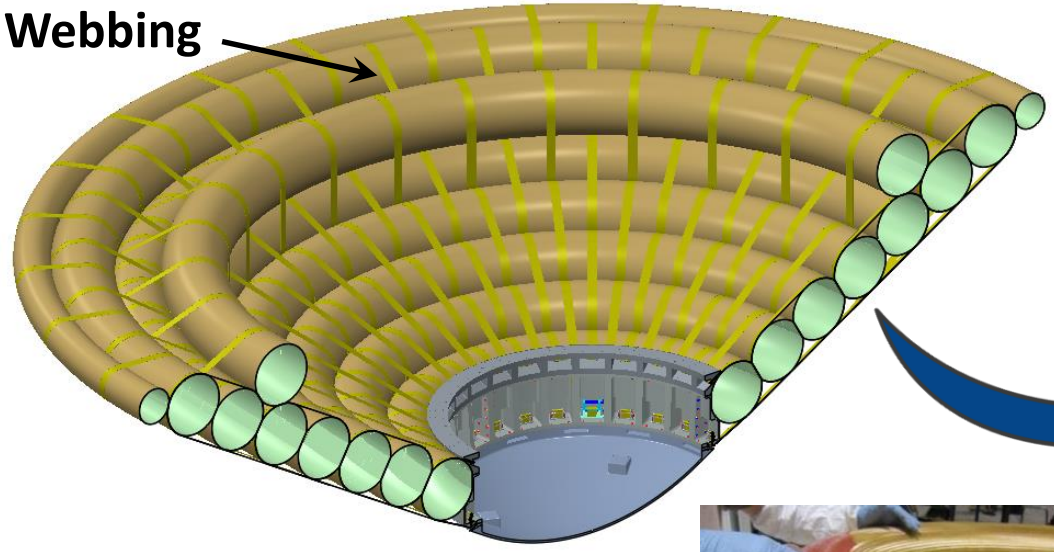

Aero loading at Angle of Attack in NFAC

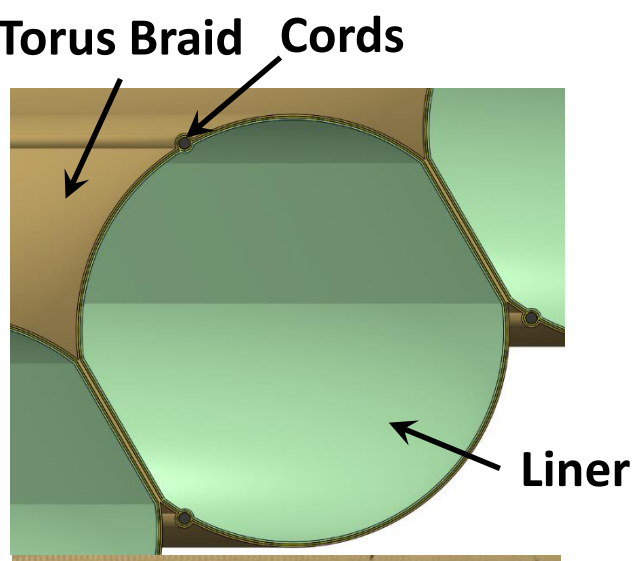
IS Development (FY12-14)

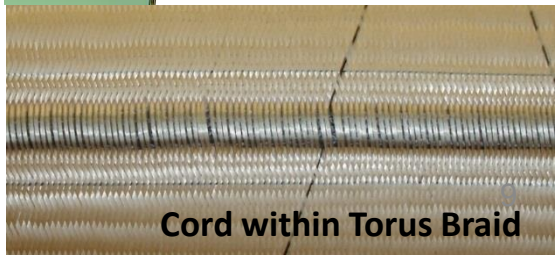
- **Material and Component Characterization Tests:** Verify material strengths and properties for design margin analysis and structural modeling
- **Modeling and Analysis:** Models correlated to test data to evaluate component loads, response to aerodynamic loading, and performance for mission application
- **Fabrication Demonstrations:** 3m and 6m (Gen 1 - 250°C) and 3.7m (Gen 2 - 400°C)
- **Performance Demonstrations:** Static Load Tests, Aero Load Tests (NFAC), Modal Tests
- **Packing:** Folding and Packing to meet stowage volume constraints and packing densities

HIAD IS Framework

IS Components	1st Gen (250°C)	2nd Gen (400°C)
Webbing	Kevlar, Technora	Zylon
Torus Braid	Kevlar, Technora	Zylon
Cords	Kevlar, Technora	Zylon
Liner	Silicone film	PTFE film
Coatings and Adhesives	Silicone	Silicone

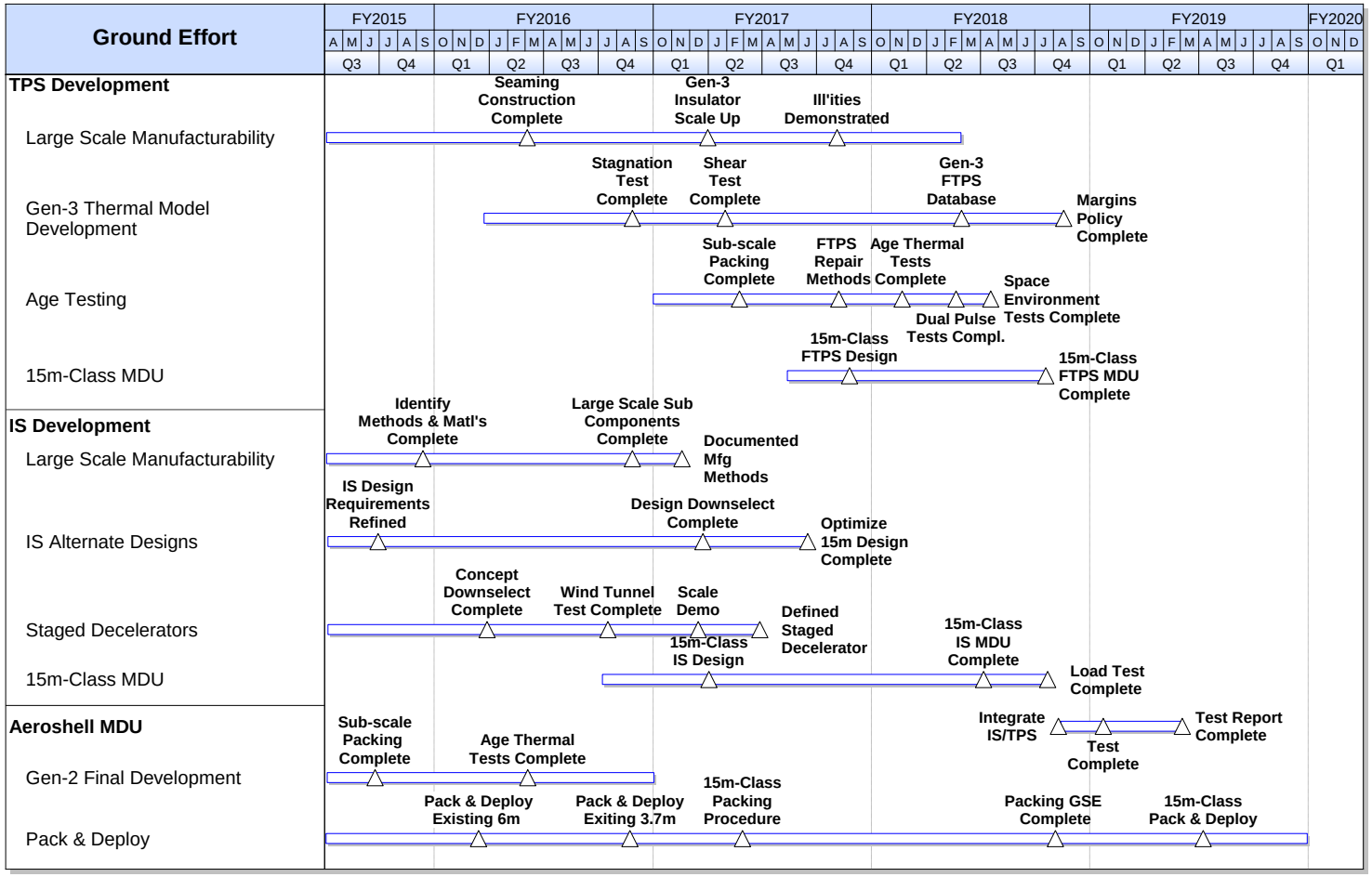






HIAD-2 Flexible System Development

Developments for FTPS	Developments for IS	Developments for Aeroshell
• Improve TRL of 3rd Gen F-TPS (75W/cm2 @ 400˚C) • 15-m class manufacturability of 3rd Gen TPS	• Investigate alternate inflatable structure concepts • 15-m class manufacturability • Develop cascading decelerator option	• Complete 2nd Gen FTPS • Develop packing techniques • Investigate scaling ramifications for 15-m class aeroshell



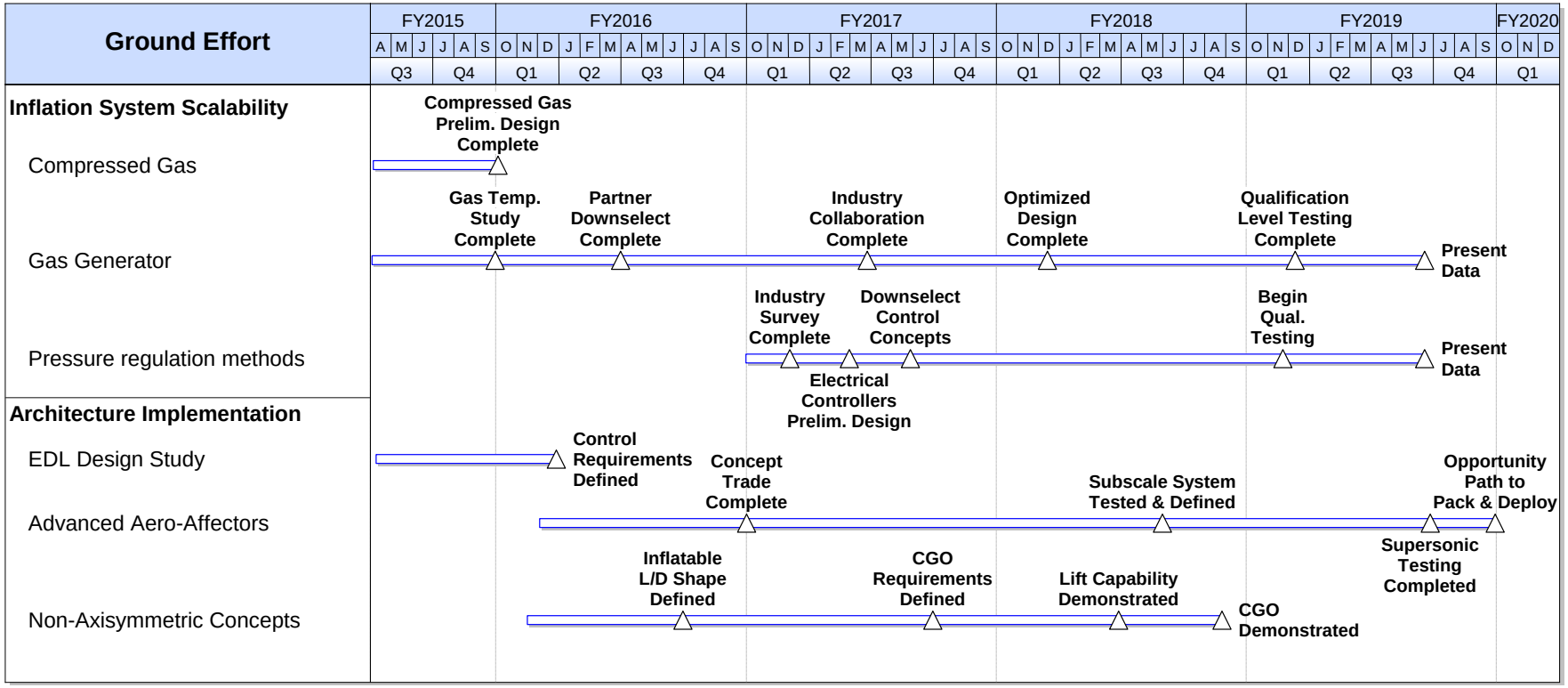
HIAD-2 Inflation System and Aeroeffectors Development

Developments for Inflation System

- Define logical limitations of compressed gas systems
- Comprehensive study to identify candidate gas generation systems (solids & liquids)

Developments for Aeroeffectors

- Design approaches for lift generation via trim tabs and morphing structures
- Analyze performance of non-axisymmetric shapes
- Evaluate each with respect to controllability



Closing Remarks

- HIAD Technology has been actively developed for nearly a decade.
- Significant work has gone into developing test techniques, manufacturing advancements, understanding and characterizing material systems.
- Successful IRVE flights have verified the technology at subscale.
- Future development to focus on scaling to 15-m class systems, targeting the proposed EDL Pathfinder demonstration, and ultimate use for human exploration of Mars.

Questions?