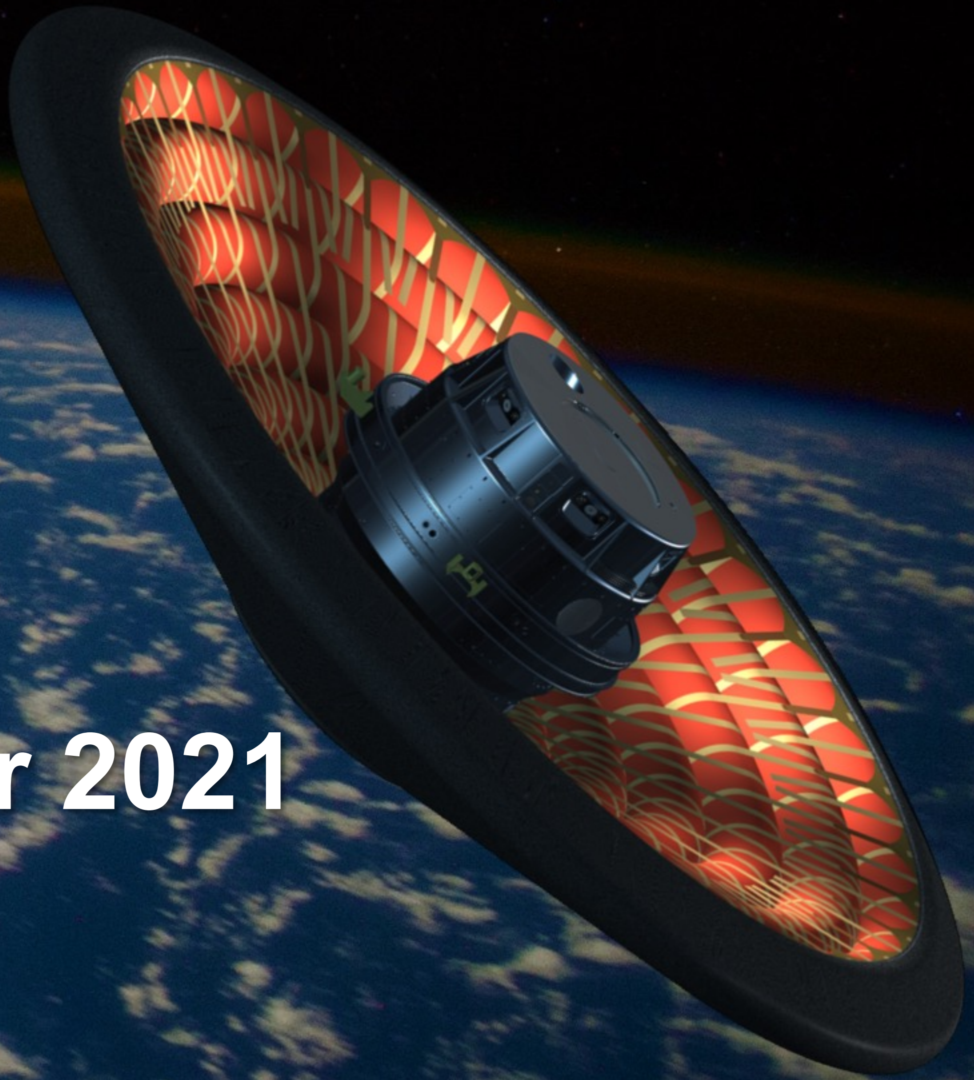
Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID)



EDL Seminar Series Summer 2021

Dr. Neil Cheatwood, Principal Investigator

Greg Swanson, Instrumentation Lead / Aeroshell Development

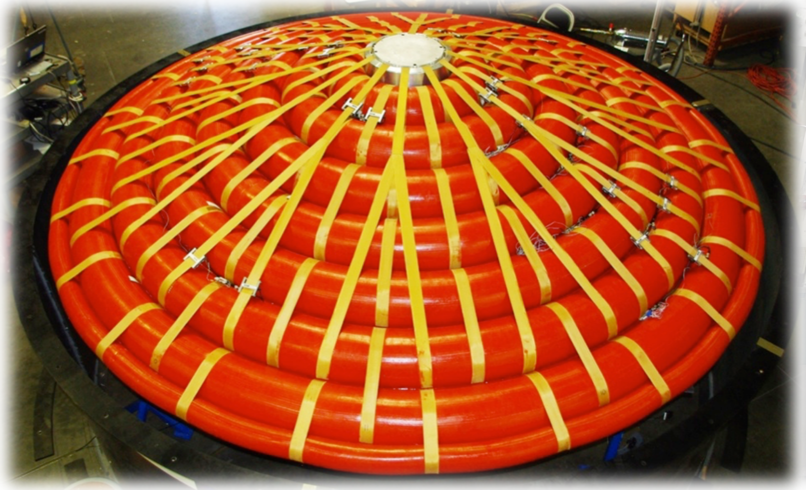
Low-Earth Orbit Flight Test
of an Inflatable Decelerator

National Aeronautics and
Space Administration

HIAD Technology

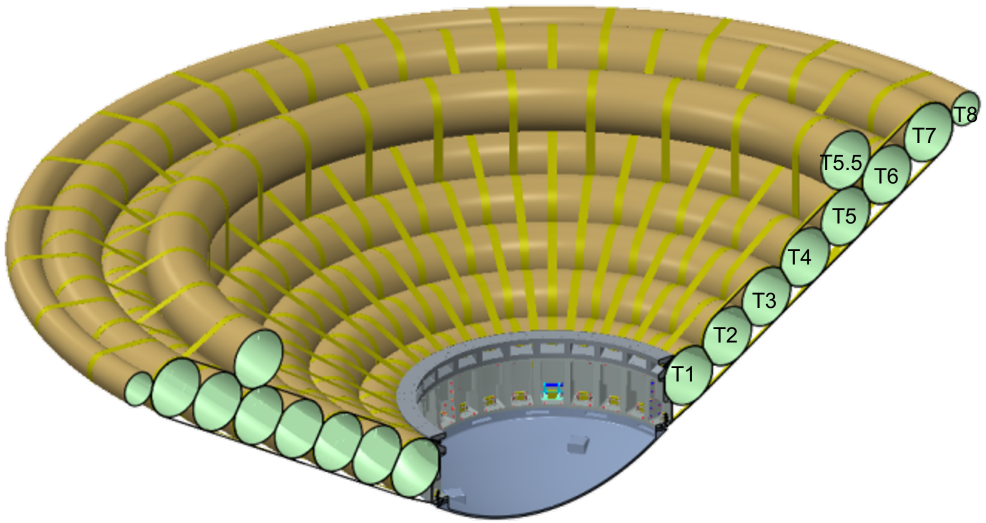
What is a HIAD?

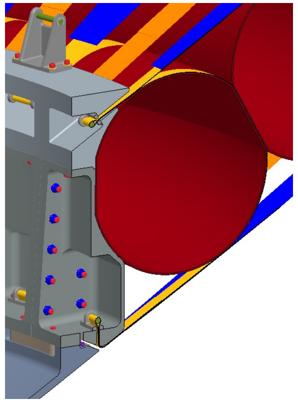
A Hypersonic Inflatable Aerodynamic Decelerator (HIAD) is a deployable aeroshell consisting of an Inflatable Structure (IS) that maintains shape during atmospheric flight, and a Flexible Thermal Protection System (FTPS) employed to protect the entry vehicle through hypersonic atmospheric entry.



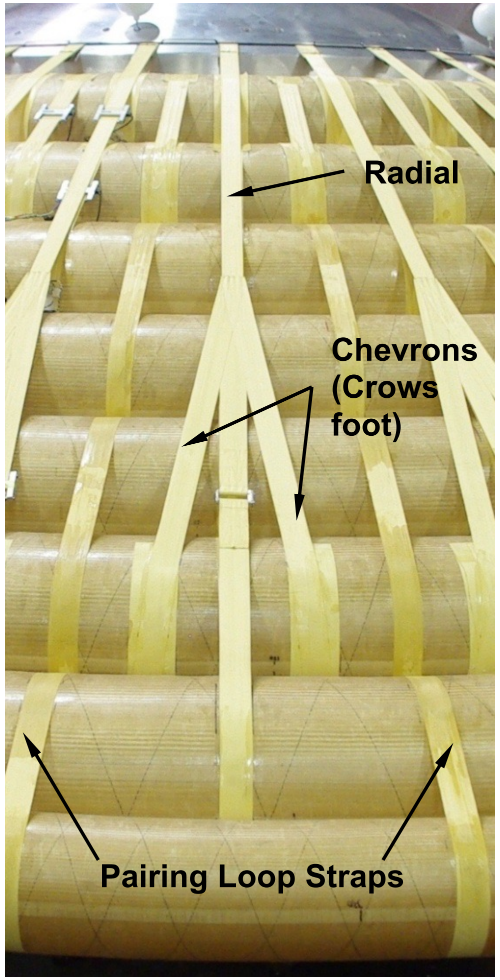
Anatomy of a HIAD

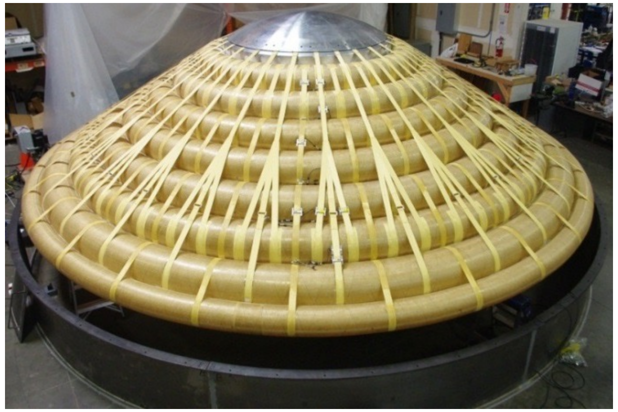
Inflatable Structure (IS): Stacked torus design with straps to establish shape and distribute loads





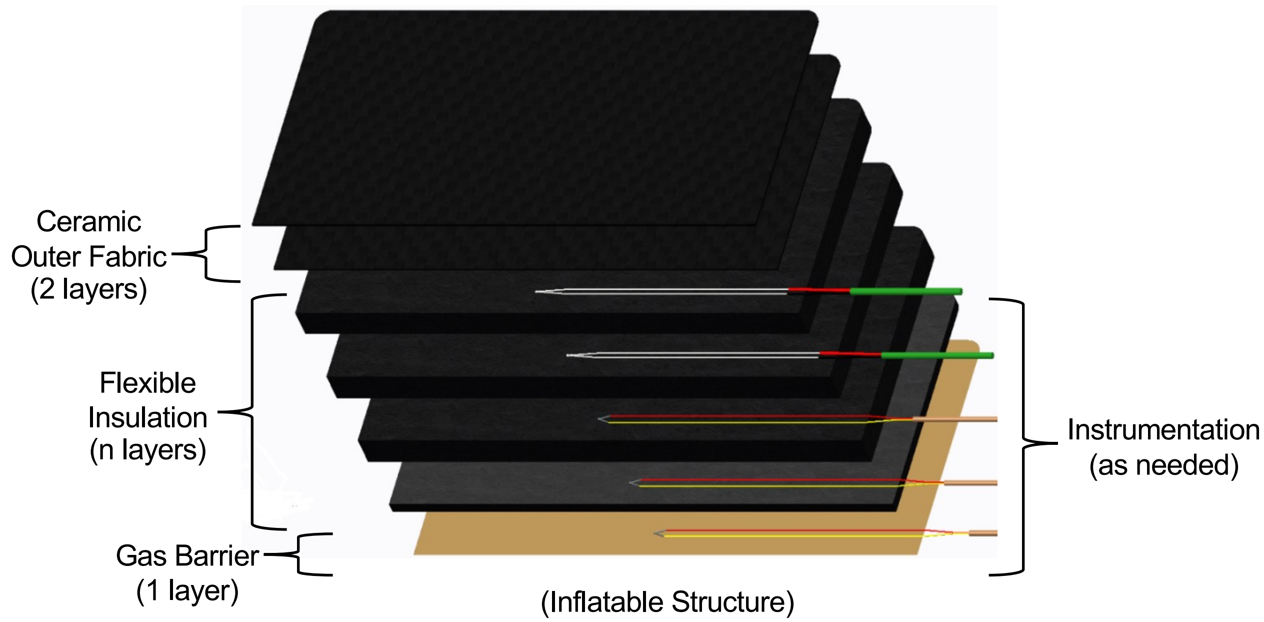
Forward and Aft straps attach IS to centerbody/vehicle

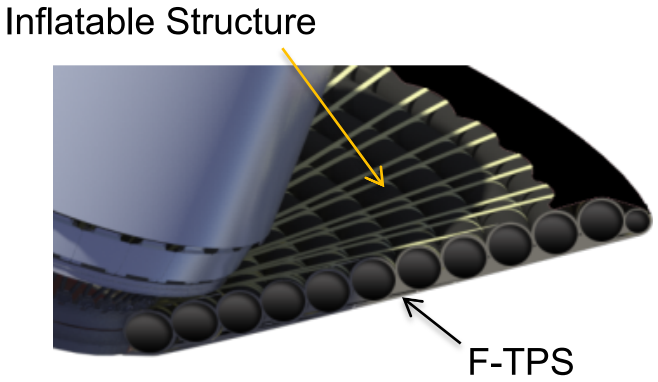


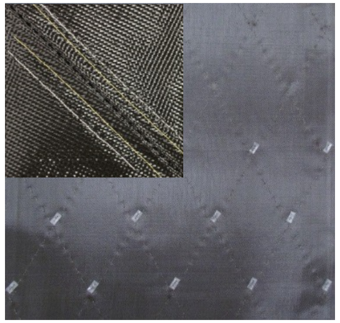


Anatomy of a HIAD

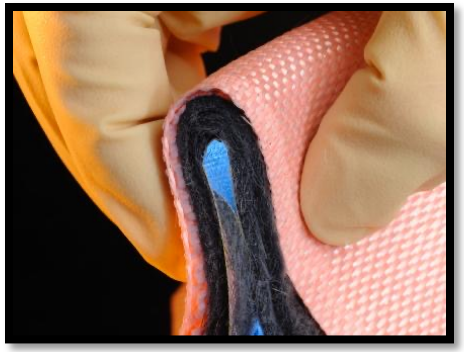
Generic F-TPS



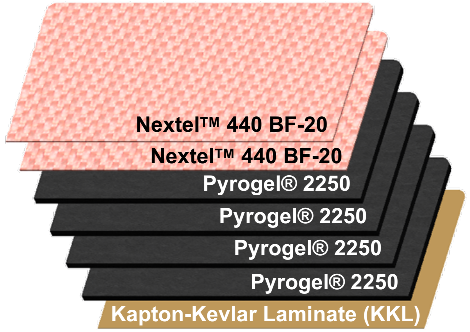




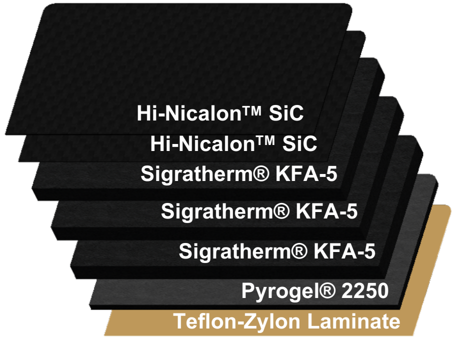
Seams, Quilting, Tacking



Gen-1

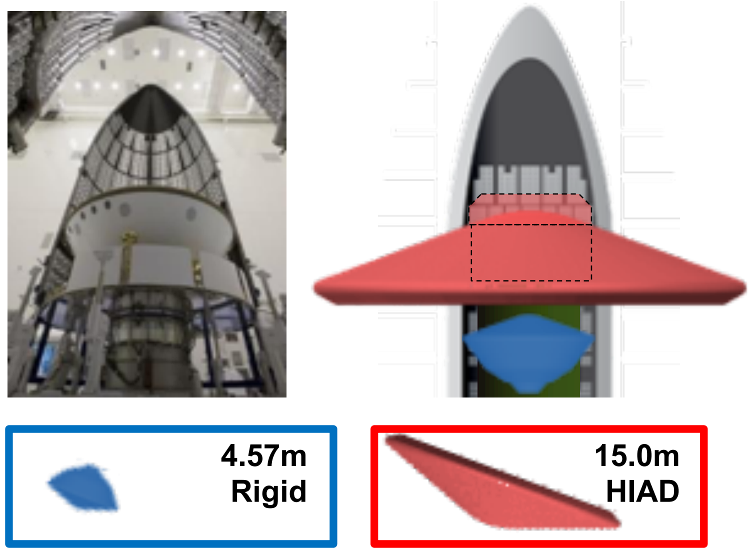


Gen-2

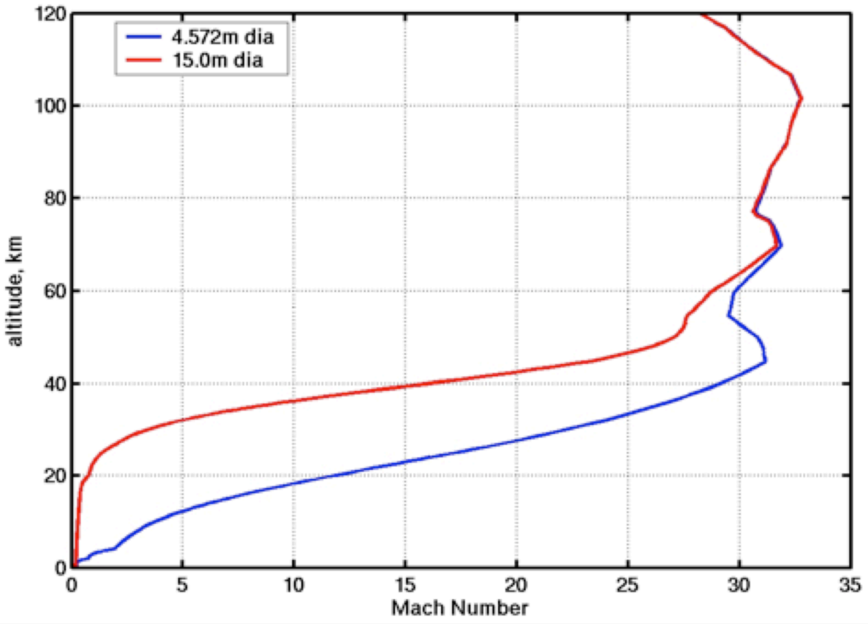


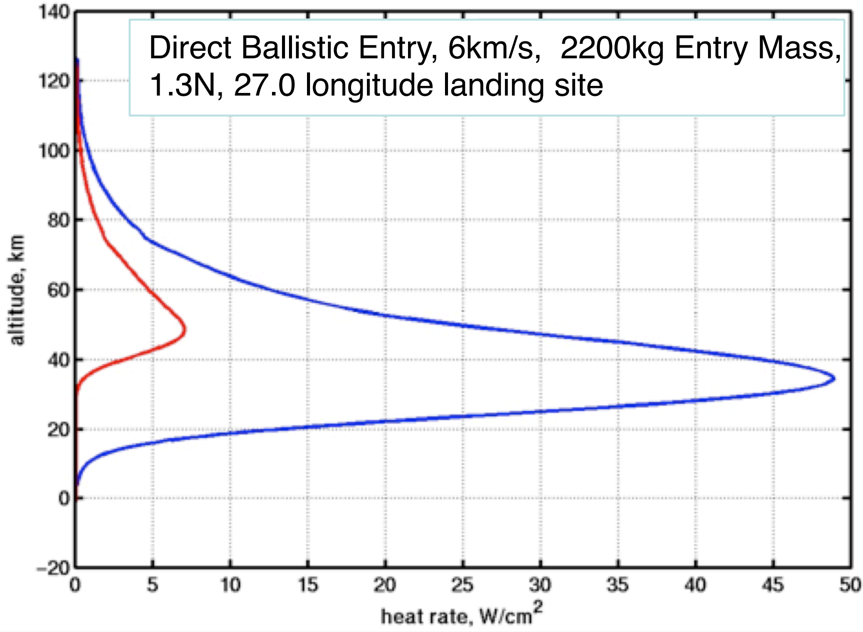
Why Inflatable?

- **Entry mass at Mars, and other destinations with atmospheres, is limited by launch vehicle fairing size**
- **Inflatable technology:**
  - Deploys a large aeroshell before atmospheric interface
  - Enables delivering more payload mass to a larger range of altitudes (including orbit via aerocapture)
  - Reduces peak heat flux by decelerating more in less dense upper reaches of the atmosphere
  - Allows payloads to use the full diameter of the launch fairing (can be stowed forward of payload)
    - Stows into customized shapes for payload attachment and integrated servicing



Entry speed: 6km/s, Entry mass: 2200kg (MSL-rover class)





HIAD Technology Investment History

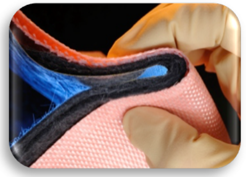
Investments in HIAD Technology

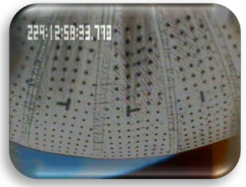
2005

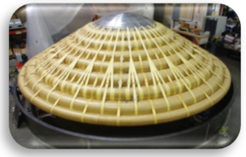
- ✓ **Ground Test**: Project to Advance Inflatable Decelerators for Atmospheric Entry (PAI-DAE)—Soft goods technology breakthrough
- ✓ **Flight Test**: Inflatable Reentry Vehicle Experiment (IRVE), 2007—
  LV anomaly; no experiment
- ✓ **Flight Test**: IRVE-II, 2009—
  IRVE “build-to-print” re-flight; 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 (Gen-1) 3m IS & FTPS, higher energy reentry; first controlled lift entry
- ✓ **Ground Test**: HIAD-2 Project improving on Gen-2 FTPS, evaluating advanced structures, packing, and manufacturability at scales >10m

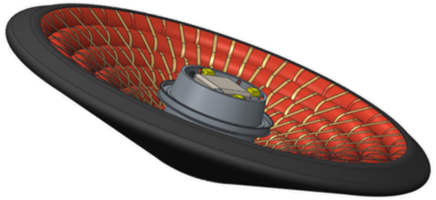
2018

⇨ **LOFTID Flight Test**: HIAD demonstration *at scales and environments relevant to Mars Human EDL Pathfinder*. Leverages 10+ years of NASA investment in HIAD technology development, across ground and flight projects.









Inflatable Structure

Manufacturing

- Define large-scale fabrication methods
- Optimize packed volume and density requirements
- Establish manufacturing processes and quality control standards

Torus Stacking and Alignment

Testing

- Quantify aerodynamic structural response
- Verify load reaction and structural integrity
- Establish structural performance limits

Torus Compression/ Torsion Tests

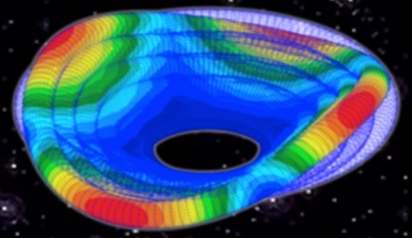
Performance

- Qualify structural materials performance capability
- Establish handling and stowage requirement
- Define design methods and safety margins

Static Loading

Modeling

- Validate non-linear structural modeling capability
- Establish structural design procedures and standards
- Define system weight, stiffness, and strength options



Dynamic Response

Flexible TPS

Manufacturing

- Establish large-scale fabrication methods
- Define manufacturing processes and quality control standards
- Determine handling and stowage requirements

Fabrication

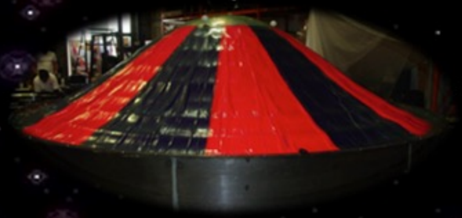
Testing

- Characterize mechanical and thermal physical properties
- Define mission-cycle performance capability
- Establish F-TPS material performance limits

Stagnation

Performance

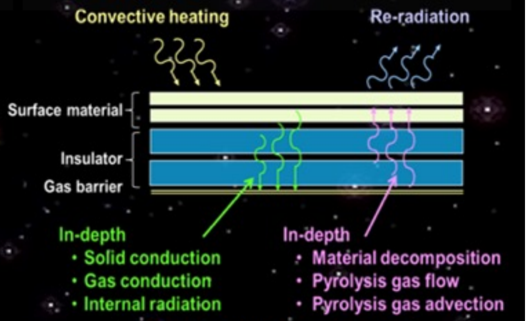
- Extend F-TPS materials performance capability
- Qualify thermal and aero-elastic response
- Define system integration metrics and requirements



Structural Contribution

Modeling

- Validate a multi-physics thermal response model
- Establish design requirements and safety margins
- Verify integrated system load response

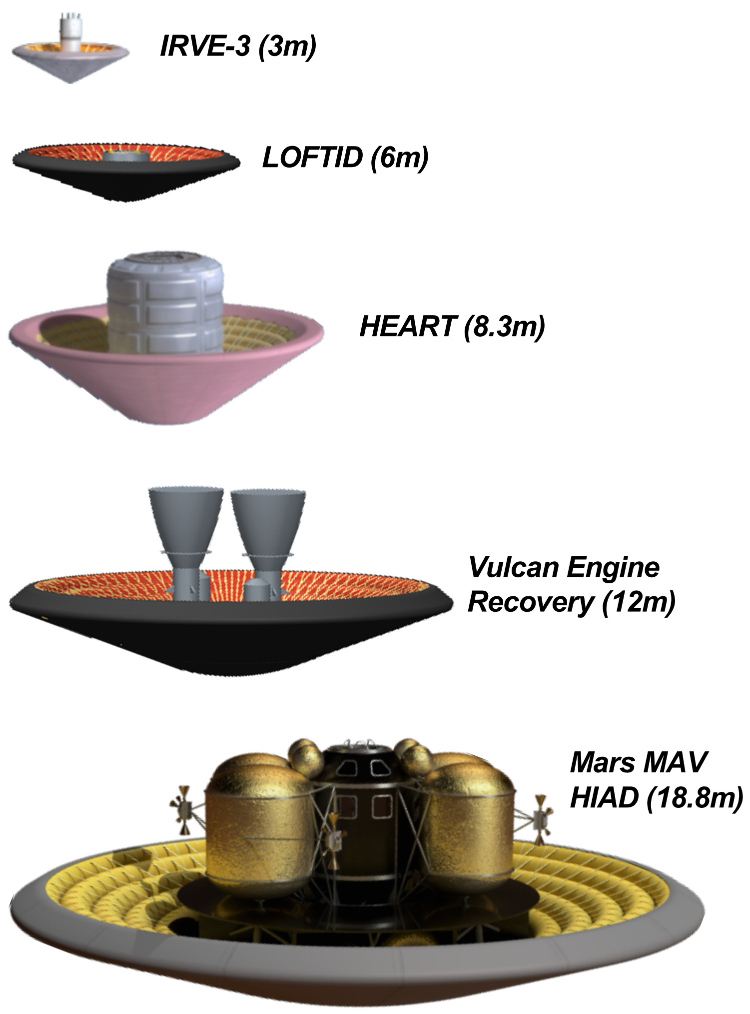


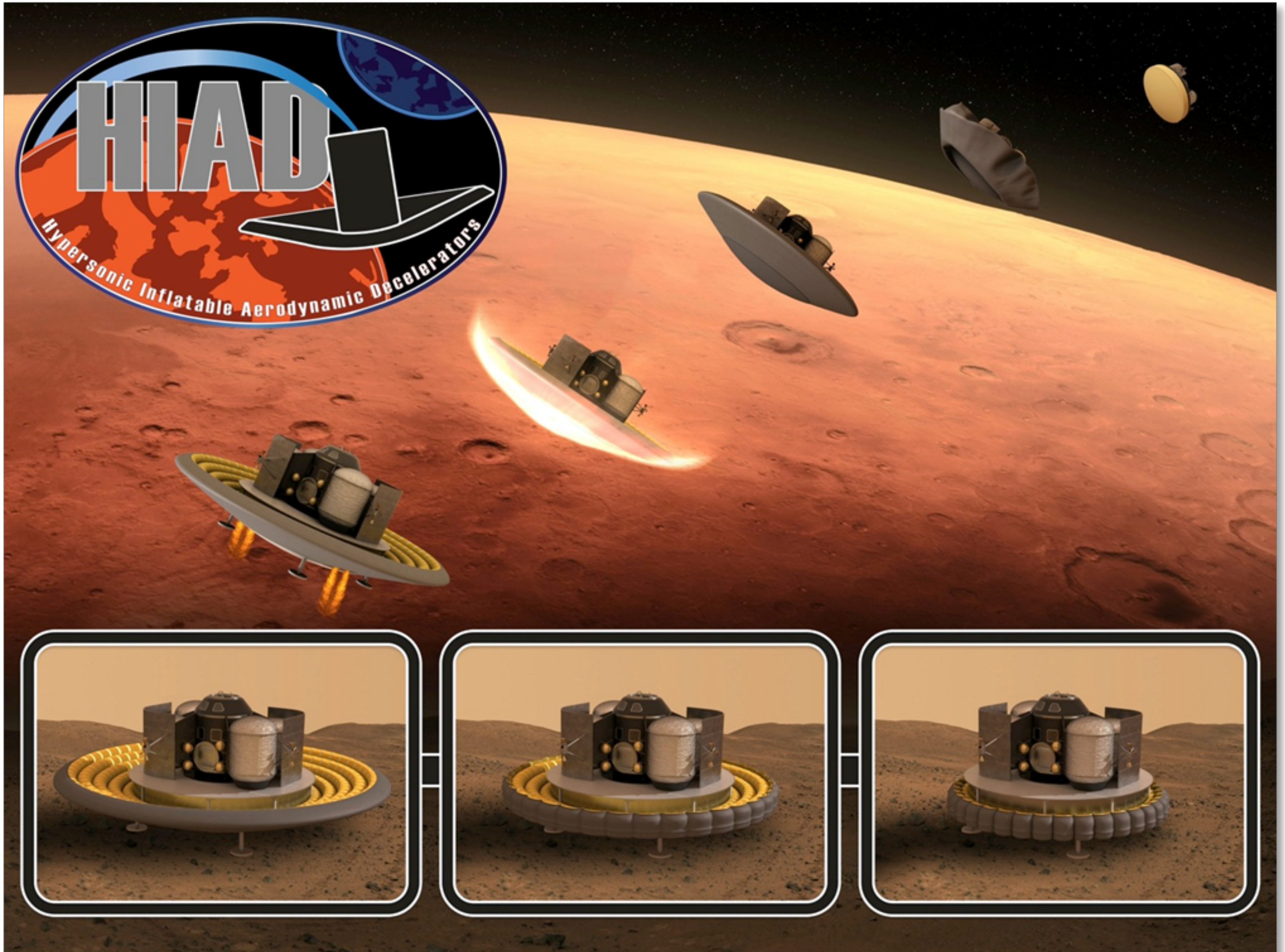
Multi-Physics Model

HIAD Applications

- Robotic missions to any destination with an atmosphere (including sample return to Earth)
- ISS down mass (without Shuttle, the U.S. has no large-scale down mass capability)
- Lower cost access to space through launch vehicle asset recovery (for example, ULA's booster module)
- High mass delivery to high altitudes at Mars (including humans to Mars)

Relative Scales of HIAD Missions

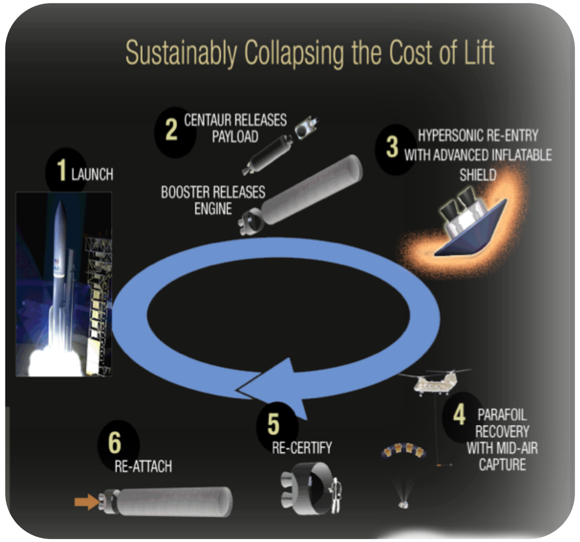


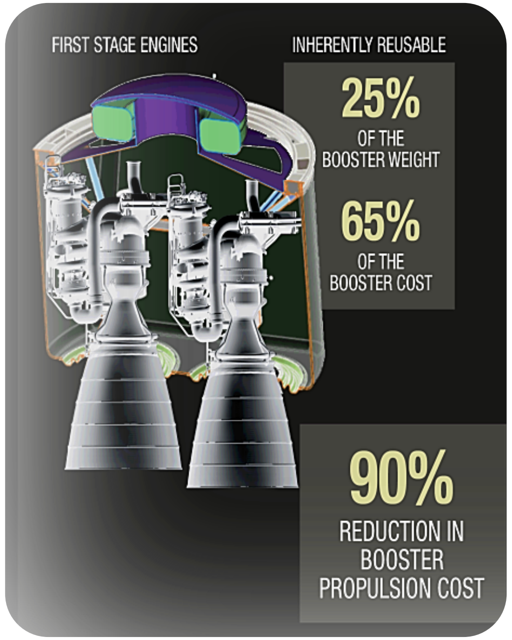

HIAD
Hypersonic Inflatable Aerodynamic Decelerators

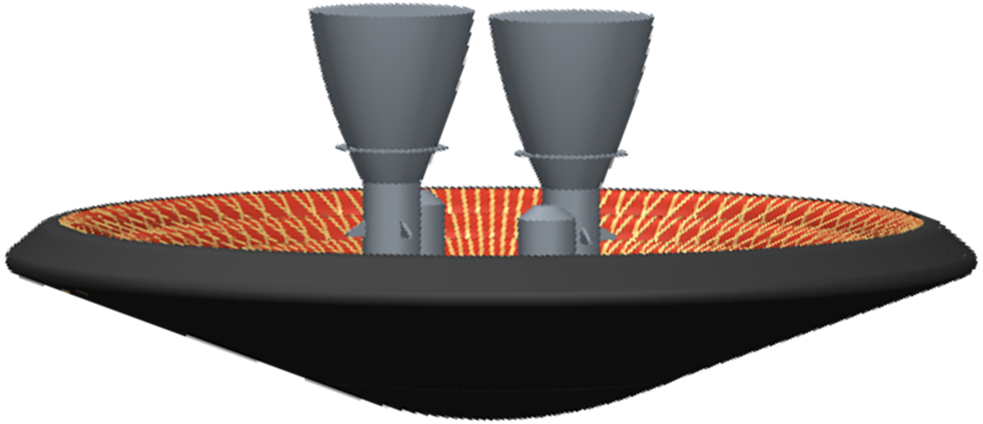
ULA Smart Reuse:
Vulcan First-Stage Engine Recovery

ULA initiated discussions with HIAD with potential flight opportunity and technology infusion path.

- Looking to utilize HIAD technology for SMART Reuse capability; they would like to bring back the first stage engines (only the engines) via Mid-Air Recovery (MAR).
- Went public with SMART Reuse option in March 2015, <u>and explicitly identified HIAD as key enabling technology.</u>
- First-stage engine recovery would require 10-12m HIAD; significant step for HIAD technology.
- For risk reduction, 6m HIAD flight test from LEO has been proposed.
- In addition, NASA intends to collect HIAD performance data from multiple engine recoveries, to improve HIAD design/model correlation.



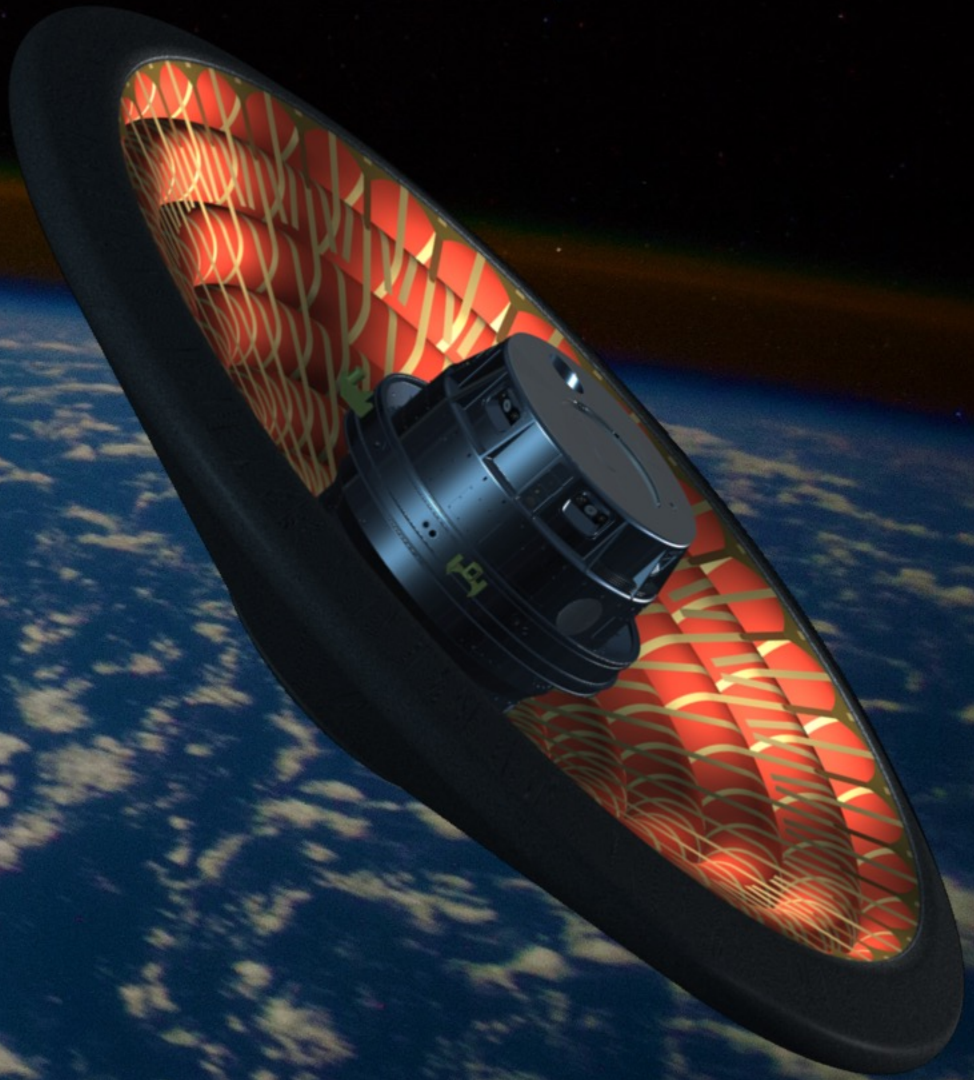




Rocket Lab: Electron First-Stage Recovery

- Currently averaging one launch per month.
- Factory for manufacturing Electron first stage is at capacity.
- Increasing launch frequency would require either significant infrastructure investment OR recovery for reuse.
- Recovering first stage and reusing just once on average doubles their capacity without building a new factory.
- RL conducted in-house trade of recovery options, concluding an inflatable hypersonic decelerator (HD) was best option.
- NASA is currently collaborating with Rocket Lab (RL) in the following ways:
  - Providing V&V of RL aero, aeroheating, and flight dynamics analyses
  - Assessing RL in-house HD design
  - Consulting on instrumentation
  - Advising on high-temperature material selection
  - Trading RL HD against HIAD

IRVE3 YouTube Video



Why LOFTID?

Shortcomings of Ground-Based Testing Alone

- **F-TPS: Inability to match all environments simultaneously. Those environments are achievable only at coupon scale. Running-length build-up of shear is not captured.**

- **IS: Inability to test at scale with flight-like pressure distributions at elevated temperature**

- **Earth orbital reentry introduces HIAD technology to a design-reference atmospheric entry environment**
  - Similar aeroheating to potential Mars and LEO HIAD entry missions
  - Opportunity to exercise HIAD at temperature with aerodynamic forces
    - F-TPS with shear loading and turbulent heating augmentation
    - Inflatable Structure at temperature with drag loading

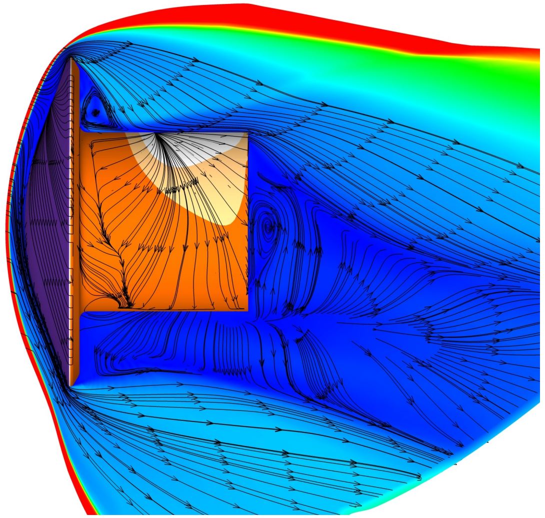
Motivation for LOFTID

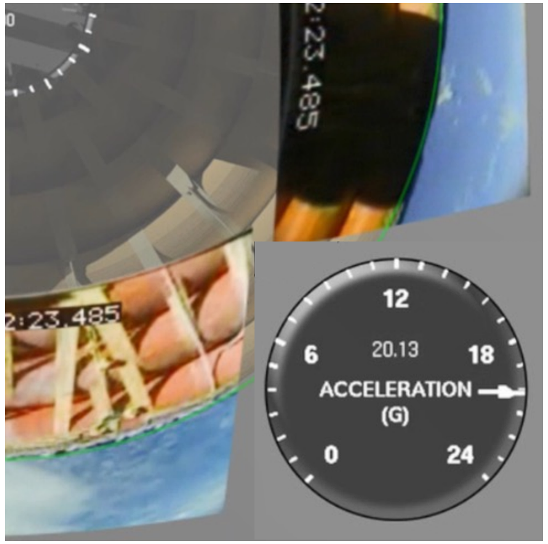
LeO Flight Test of an Inflatable Decelerator (LOFTID) Objective: Perform an orbital energy reentry experiment of a scaled-up HIAD

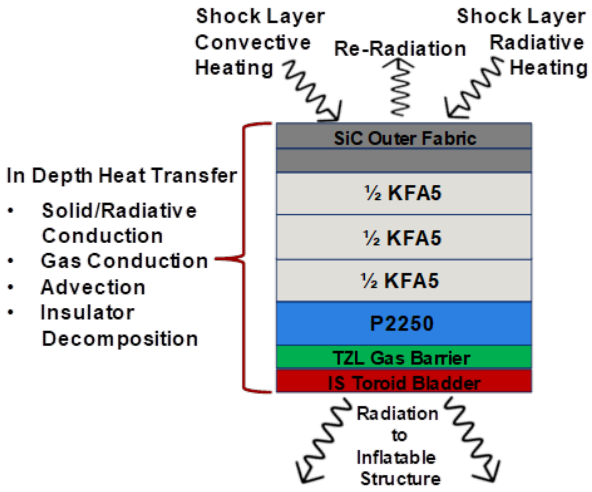
- **Earth orbital reentry introduces HIAD technology to a mission-relevant atmospheric entry environment**
  - Similar aeroheating to Mars and LEO HIAD entry missions
  - Opportunity to exercise heat-affected HIAD with aerodynamic forces in real time
    - F-TPS with shear loading and turbulent heating augmentation
    - Inflatable Structure with drag loading that exceeds Mars HIAD entry
- **6m scale largest achievable within mass and volume constraints, while targeting a ballistic coefficient that yields a relevant heat pulse**
- **Builds upon IRVE-3's success from a suborbital trajectory**
  - Triple the expected peak heat flux (from 15 to ~45 W/cm^2)
  - Order of magnitude increase of the total heat load (from 0.2 to ~2 kJ/cm^2)
- **Controls costs by simplifying test vehicle (compared to IRVE-3/THOR)**
  - ULA Centaur provides reliable and simplified reentry experiment setup
  - Spin stabilized ballistic entry with no deorbit, attitude control, or lift generation systems required
- **Opportunity for largest diameter blunt body aeroshell reentry**

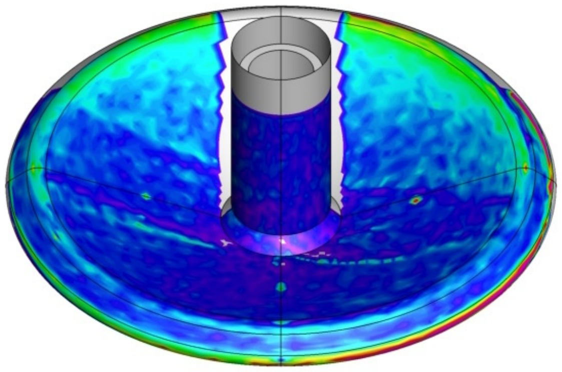
Aeroshell Design Drivers are Mission Dependent

- Avoiding payload impingement dictates aeroshell diameter and/or payload aspect ratio.
- RV mass and peak g-load informs HIAD structure design.
- Heat flux defines outer surface material. Heat load governs thickness/composition of insulators.
- Convective heating down in bowl dictates aftbody inflatable structure temperature (Zylon™ cords & bladder).









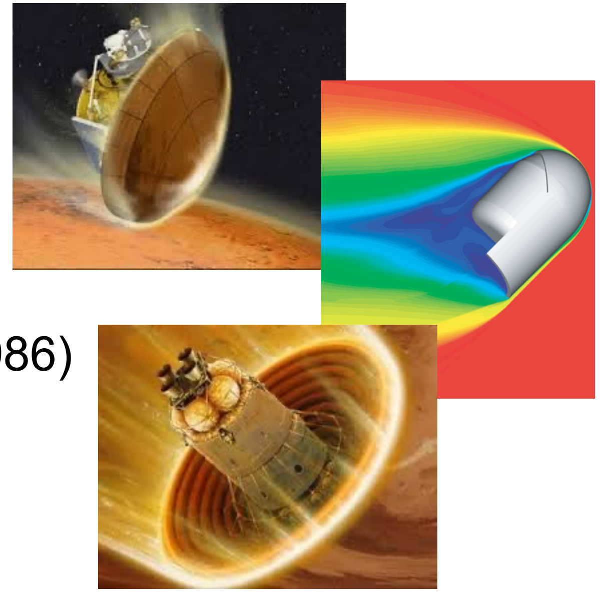
Science Mission vs Tech Demo

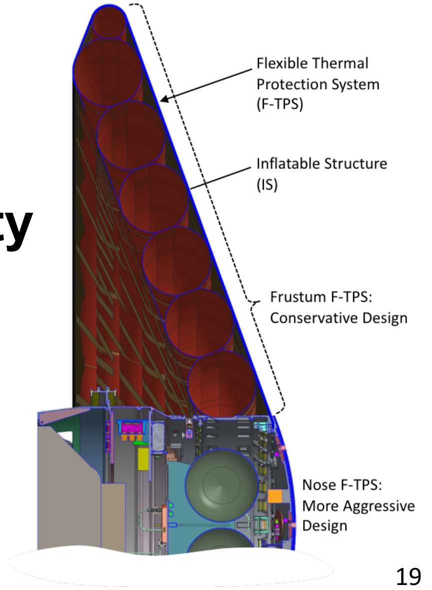
- **Design Philosophy:**
  - Science Mission: Add margin to aeroshell design to ensure mission success
  - Tech Demo: Don’t just fly a new technology, exercise it
- **Design Considerations:**
  - When aeroshell technology is the science, trim margin to insure aeroshell (layup thermally stressed) performance is demonstrated.
  - Higher altitude deceleration means lower velocity at a given atmospheric density (lower heat flux)—lower absolute error in heating environment
  - Soft goods are not as precise as metal, and the surface is not impermeable (the gas barrier provides a deadhead)

The LOFTID Approach

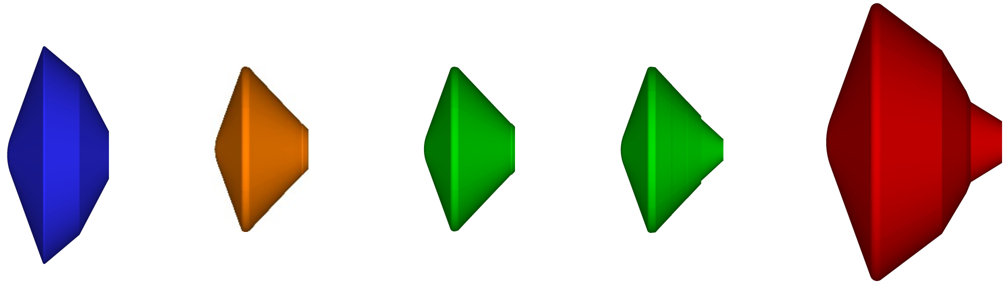
- **Energy to be managed (LEO vs suborbital)**
  - Opportunity to get simultaneous aero/aeroheating/shear environments at scale
  - Historically, those flight environments then become “heritage” use.
- **No backshell—reduces mass, improves CG**
  - Aeroassist Orbit Transfer Vehicle (AOTV) for GEO to LEO transfer (circa 1982)
  - Aeroassist Flight Experiment (AFE)-–AOTV demo prototype for Shuttle (circa 1986)
  - AFE adopted by CNES for 2005 Mars Sample Return Orbiter (circa 1996)
  - Ellipsled (Circa 1998)
- **Nose heatshield tailored to needs (singularities)**
  - For sciences missions: radar, lidar, landing gear, etc.
  - For tech demo: Experiment within experiment
    - Metallic structure provides fixed reference and thermal sink
    - Insulative “isolation” layers prevent exceeding F-TPS margins
- **HIAD Gen-2 F-TPS should see environments that exceeds HIAD Gen-1 capability**
  - Long duration heat pulse provides in-depth temperature rise in insulators
  - Elevated gas barrier temperatures (> 250) exceeds traditional rigid structure/TPS design
- **Monte-Carlo-based structure and heatshield thermal performance assessment**

  Applicable beyond HIAD



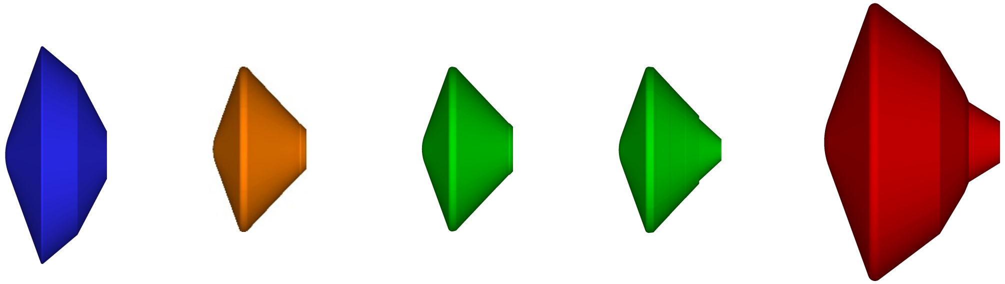


Project Viking



	Viking 1/2	Pathfinder	MER A/B	Phoenix	MSL
Diameter (m)	3.5	2.65	2.65	2.65	4.56
Forebody Geometry (deg)	70	70	70	70	70
Entry Mass (kg)	930	585	840	602	3150
Entry Velocity (km/s)	4.5	7.6	5.5	5.9	5.9
Peak Heat Rate (W/cm2)	24	106	48	56	225

Analogies Between Project Viking and LOFTID



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	IRVE-3	LOFTID	LEO Return	ISS Down Mass	ULA Engine Recovery	Humans to Mars
Diameter (m)	3	6	<6	8-12	12	18.8
Forebody Geometry (deg)	60	70	60-70	60-70	60-70	70
Entry Mass (kg)	330	1700	<1500	<5000	12000	56000
Entry Velocity (km/s)	2.7	7.1	7-7.5	7-7.5	4-6.5	6.2
Peak Heat Rate (W/cm2)	15	60	<50	30-40	<30	40

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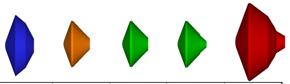

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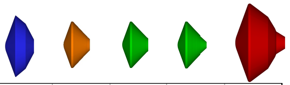

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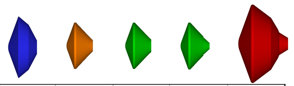

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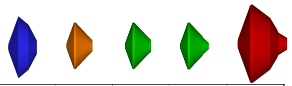
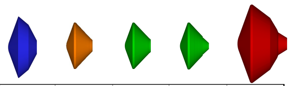


	Viking 1/2	Pathfinder	MER A/B	Phoenix	MSL
Diameter (m)	3.5	2.65	2.65	2.65	4.56
Forebody Geometry (deg)	70	70	70	70	70
Entry Mass (kg)	930	585	840	602	3150
Entry Velocity (km/s)	4.5	7.6	5.5	5.9	5.9
Peak Heat Rate (W/cm2)	24	106	48	56	225

	IRVE-3	LOFTID	LEO Return	ISS Down Mass	ULA Engine Recovery	Humans to Mars
Diameter (m)	3	6	<6	8-12	12	18.8
Forebody Geometry (deg)	60	70	60-70	60-70	60-70	70
Entry Mass (kg)	330	1700	<1500	<5000	12000	56000
Entry Velocity (km/s)	2.7	7.1	7-7.5	7-7.5	4-6.5	6.2
Peak Heat Rate (W/cm2)	15	60	<50	30-40	<30	40

Analogies Between Project Viking and LOFTID



	Viking 1/2	Pathfinder	MER A/B	Phoenix	MSL
Diameter (m)	3.5	2.65	2.65	2.65	4.56
Forebody Geometry (deg)	70	70	70	70	70
Entry Mass (kg)	930	585	840	602	3150
Entry Velocity (km/s)	4.5	7.6	5.5	5.9	5.9
Peak Heat Rate (W/cm2)	24	106	48	56	225

	IRVE-3	LOFTID	LEO Return	ISS Down Mass	ULA Engine Recovery	Humans to Mars
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Peak Heat Rate (W/cm2)	15	60	<50	30-40	<30	40

Low-Earth Orbit Flight Test
of an Inflatable Decelerator

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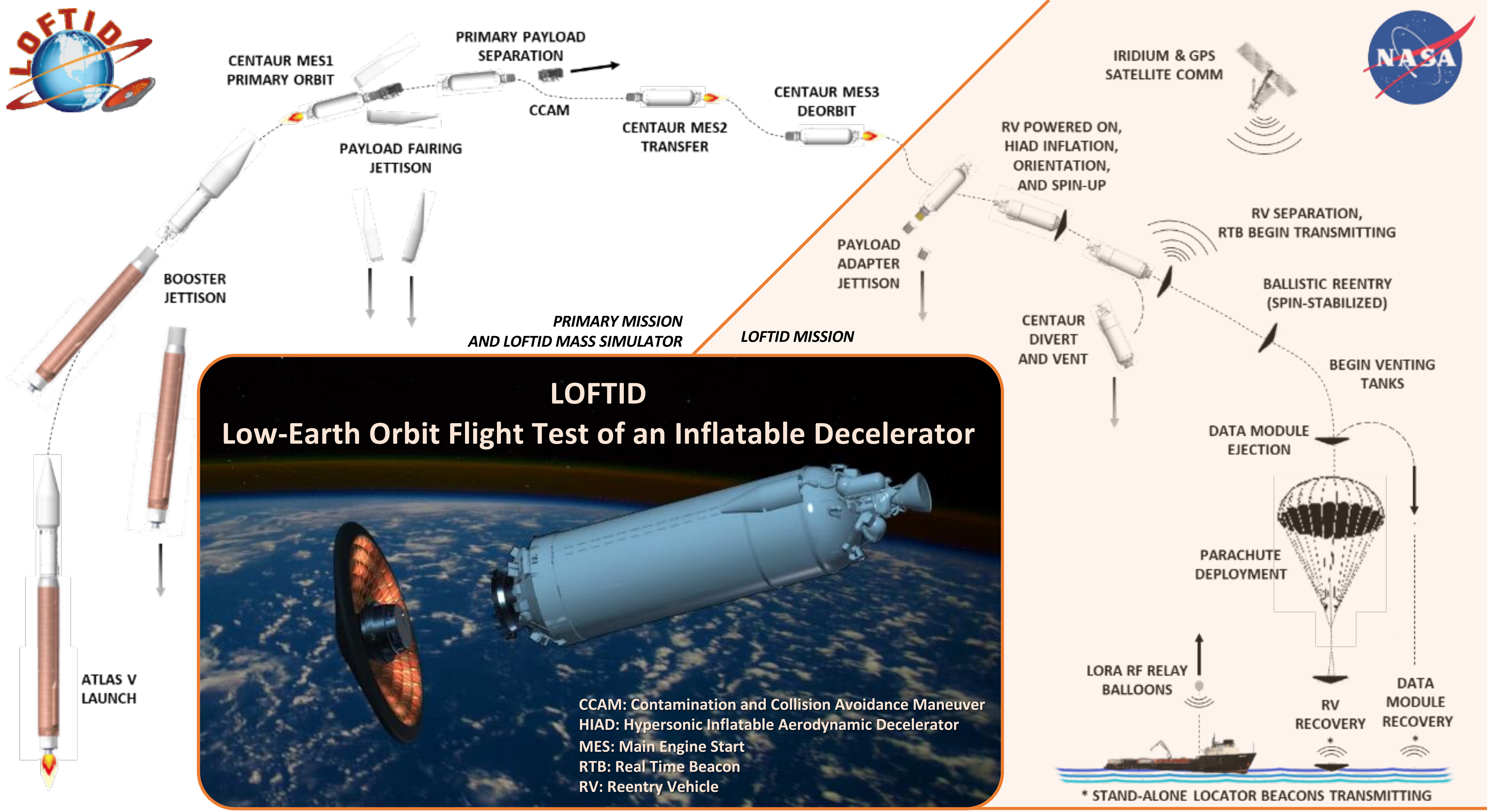
LOFTID Overview

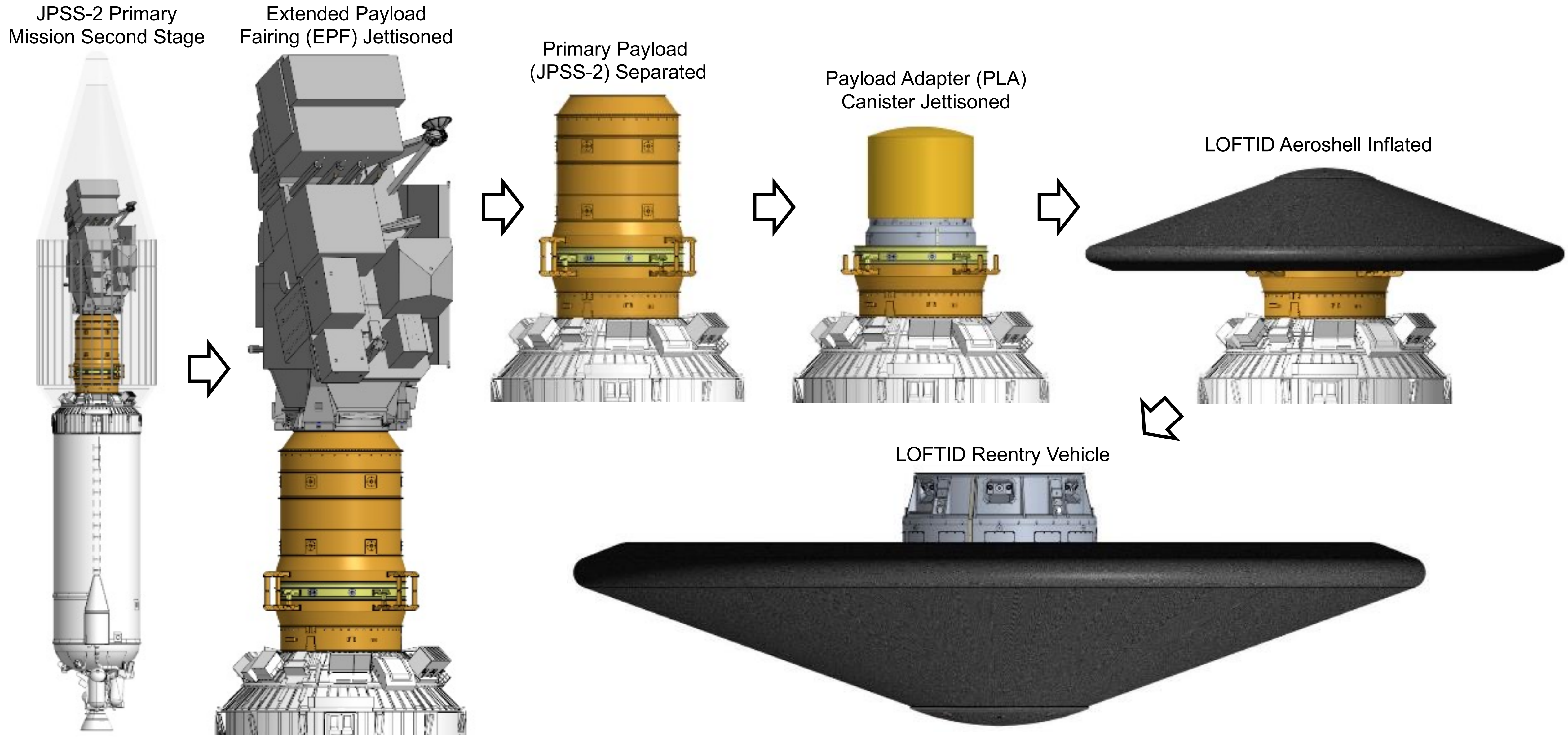

LOFTID
Low-Earth Orbit Flight Test of an Inflatable Decelerator
NASA
ATLAS V LAUNCH
BOOSTER JETTISON
CENTAUR MES1 PRIMARY ORBIT
PAYLOAD FAIRING JETTISON
PRIMARY PAYLOAD SEPARATION
CCAM
CENTAUR MES2 TRANSFER
CENTAUR MES3 DEORBIT
PRIMARY MISSION AND LOFTID MASS SIMULATOR
LOFTID MISSION
PAYLOAD ADAPTER JETTISON
RV POWERED ON, HIAD INFLATION, ORIENTATION, AND SPIN-UP
IRIDIUM & GPS SATELLITE COMM
RV SEPARATION, RTB BEGIN TRANSMITTING
BALLISTIC REENTRY (SPIN-STABILIZED)
CENTAUR DIVERT AND VENT
BEGIN VENTING TANKS
DATA MODULE EJECTION
PARACHUTE DEPLOYMENT
LORA RF RELAY BALLOONS
RV RECOVERY
DATA MODULE RECOVERY
* STAND-ALONE LOCATOR BEACONS TRANSMITTING
CCAM: Contamination and Collision Avoidance Maneuver
HIAD: Hypersonic Inflatable Aerodynamic Decelerator
MES: Main Engine Start
RTB: Real Time Beacon
RV: Reentry Vehicle

LOFTID Mission Requirements

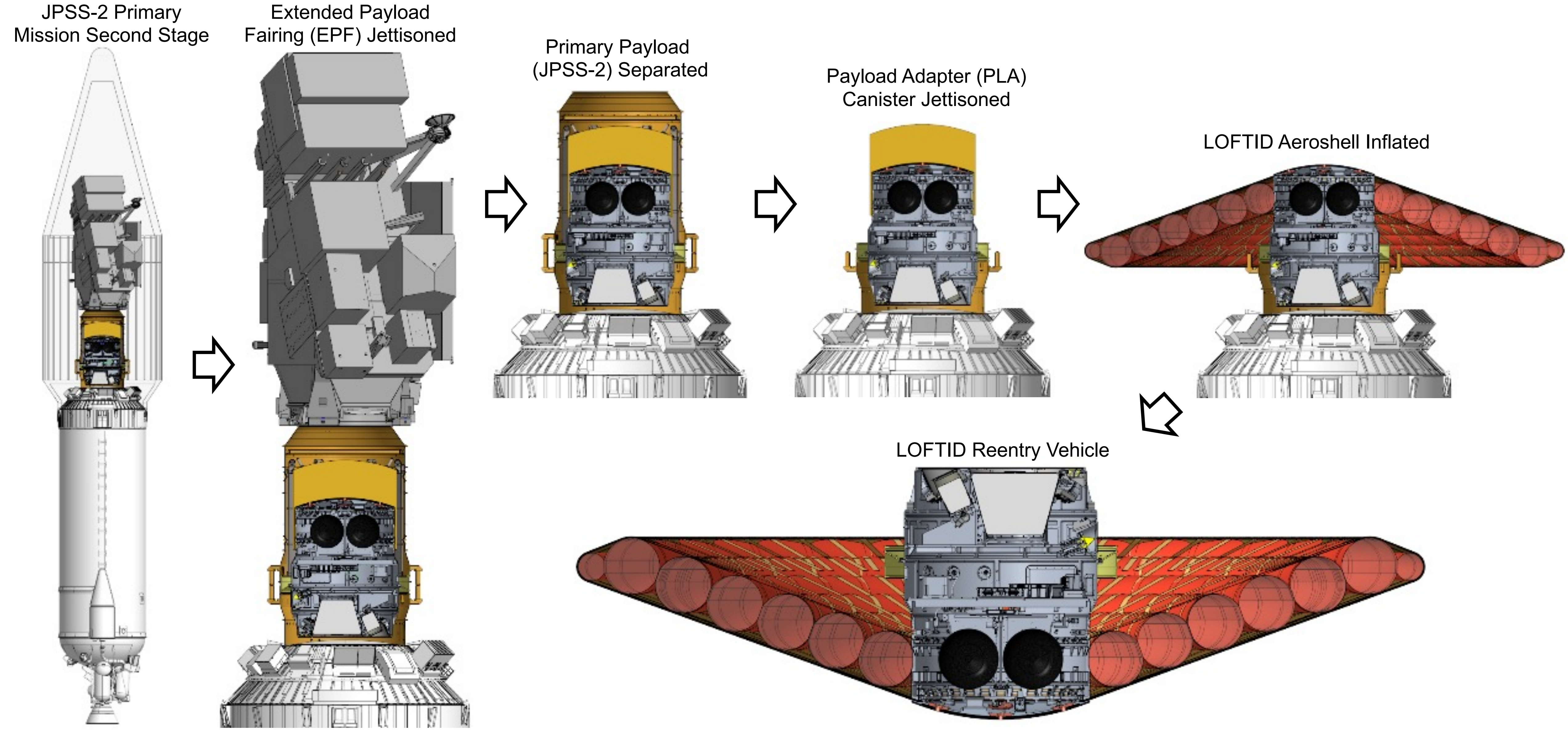
Name	Requirement
Exo-Atmospheric Deployment	LOFTID shall demonstrate the exo-atmospheric deployment of a 6 meter (nominal diameter) Hypersonic Inflatable Aerodynamic Decelerator (HIAD).
Reentry Heat Flux	LOFTID shall perform an atmospheric reentry which yields a minimum peak heat flux of 30 W/cm^2.
Experimental Data	LOFTID shall obtain flight data to measure HIAD atmospheric flight performance.
Reentry Heat Load	LOFTID shall perform an atmospheric reentry which yields a predicted peak heat load of at least 2 kJ/cm^2.
Launch Vehicle	LOFTID shall be constrained to use the launch vehicle provided under the terms of the Space Act Agreement with United Launch Alliance.

- Requirement Levels
  - Level 1 requirements (Mission)
  - Level 2 requirements (System)
  - Level 3+ requirements (Subsystems)
- Over 550 requirements specified for LOFTID, over 600 total including ULA specific requirements
- All but 3 requirements must be verified before the PSR. This is done either through test, analysis, demonstration, and inspection.

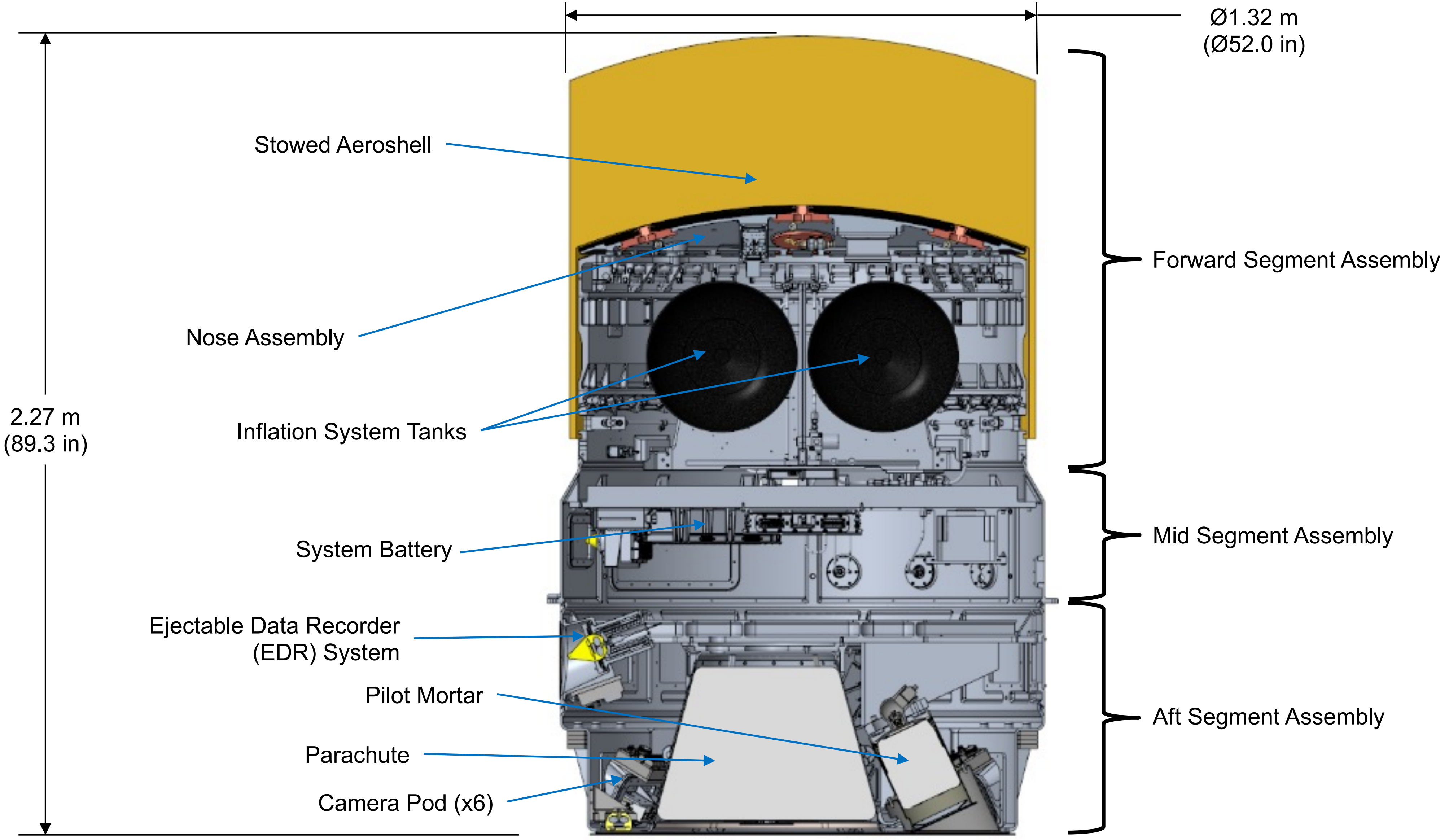
Mission Architecture



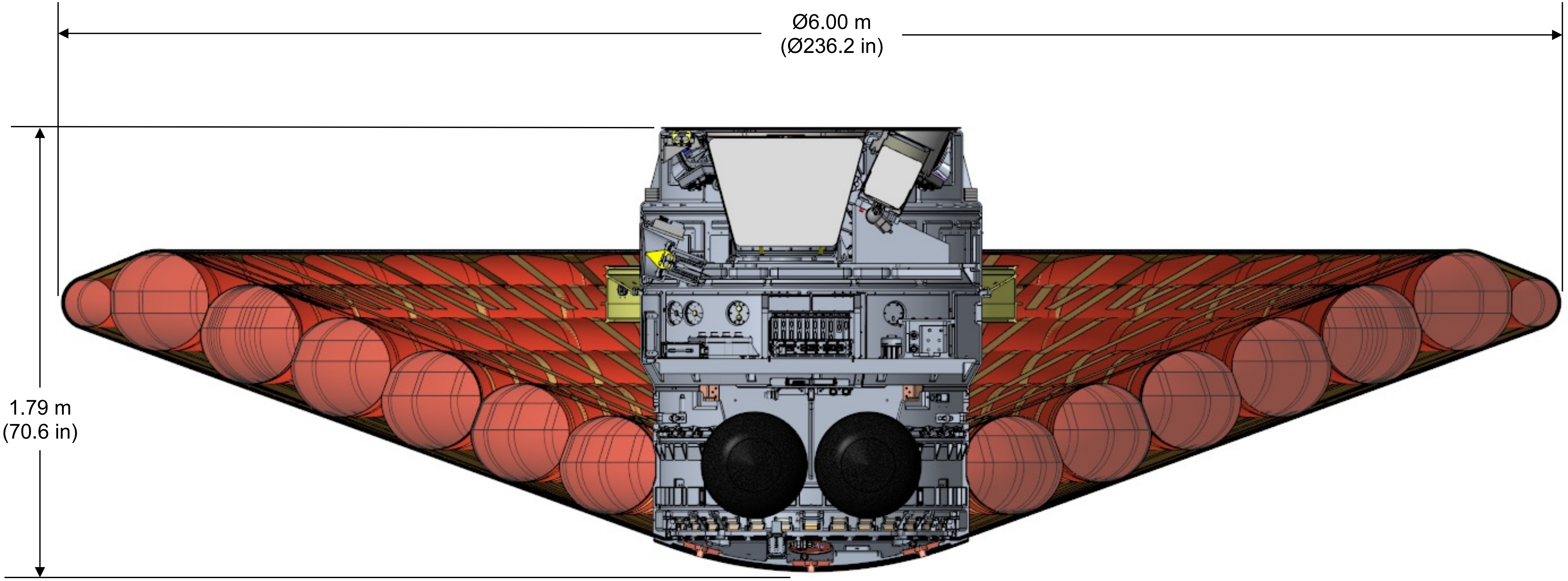
Mission Architecture Cross Section Views



RV at LV Integration



RV at Reentry



Aeroshell Design

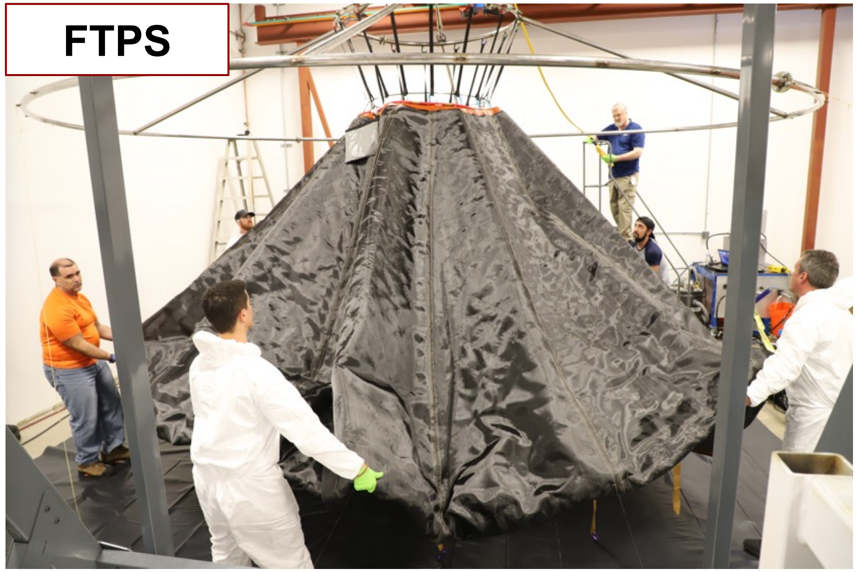
6m Diameter, 70-deg Sphere-Cone Stacked Torus Design

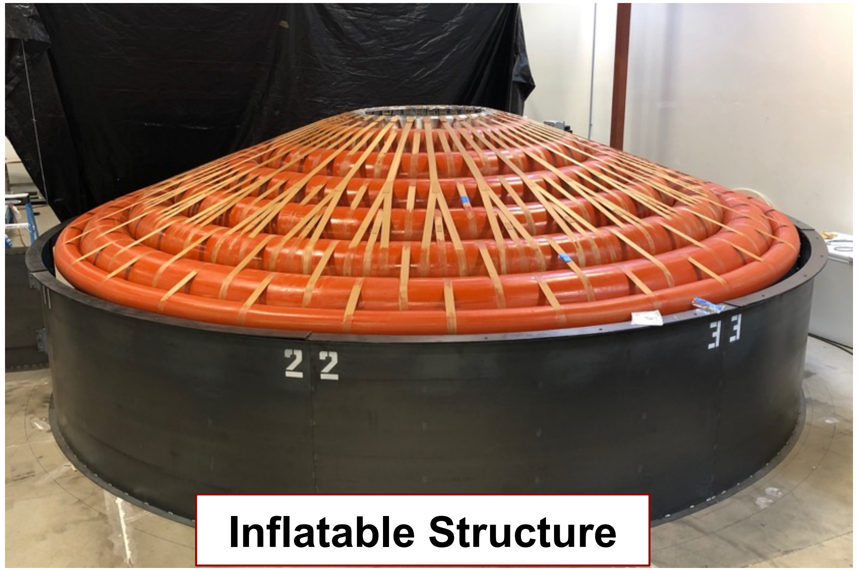
Flexible Thermal Protection System (FTPS)

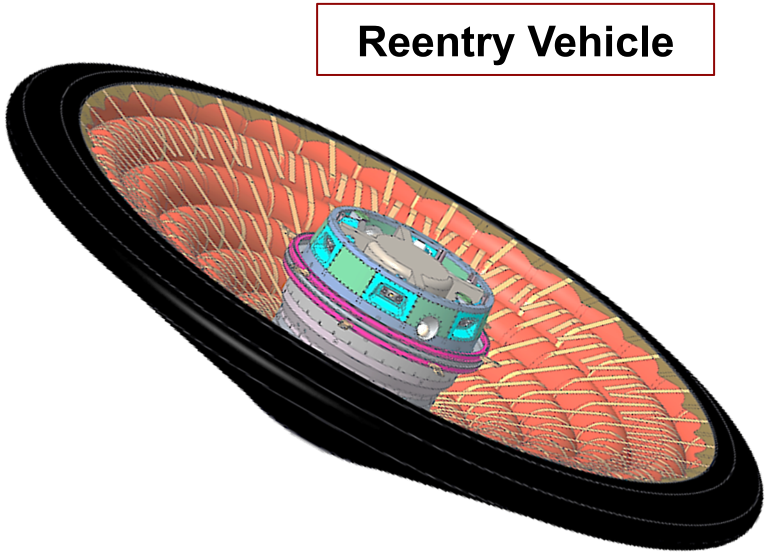
- 2nd Generation Materials
  - Silicon Carbide Outer Layer, Carbon Felt/Pyrogel Insulation, PTFE/Zylon Laminate Gas Barrier
- Successfully Tested to 80 W/cm^2
- 50 W/cm^2 Cold Wall Limit for LOFTID
- 30 W/cm^2 Minimum Requirement for LOFTID

Inflatable Structure (IS)

- 2nd Generation Materials
  - Zylon Structural Elements with PTFE Bladder
- 400 deg C Temperature Capability
- 250 deg C Minimum Requirement, Expected 350 deg C
- 20 PSI Maximum Expected Operating Pressure (MEOP)







HIAD Flight Test Data Suite

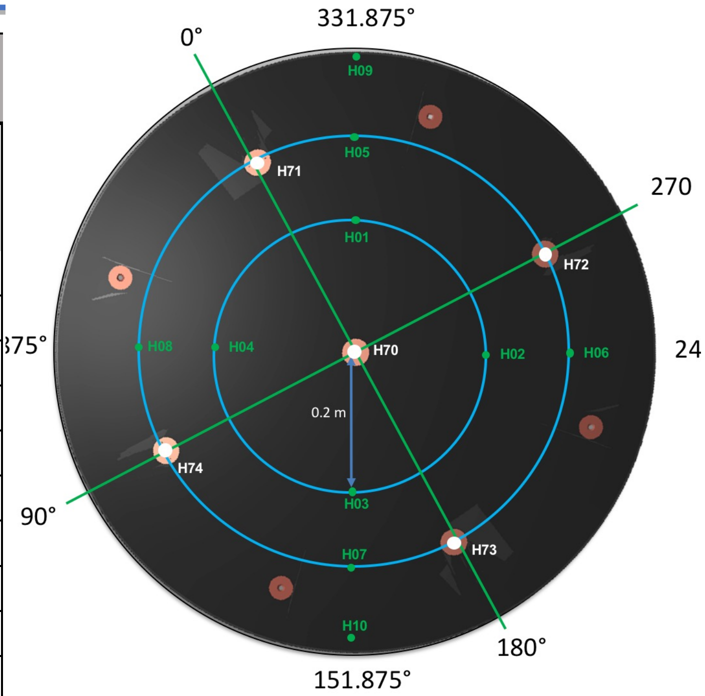
LOFTID is a demonstration flight project that will be used to validate computational models, and advance understanding of the HIAD technology

- **Nose and aeroshell instrumentation**
  - Pressure transducers, surface and in-depth thermocouples (including aftbody), total heat flux gages, and radiometer
  - Loadcell clevis pins on IS straps
  - Fiber Optic Sensing System (FOSS)
- **Internal instrumentation**
  - Inertial measurement unit (IMU)
  - Global positioning system (GPS) unit
  - Inflation system instrumentation
- **Video/Imaging**
  - Video (360-deg coverage) for context, structural response, diagnostics
  - Infrared (IR) imaging (360-deg) for aft-side temperature distribution on aeroshell
  - Up-Look HD Camera
- **Data recovery**
  - Comprehensive set to ejectable recorder, for primary recovery path
  - Second comprehensive data set to on-board recorder—recovered with HIAD entry vehicle
  - Beacon utilizes Iridium network to relay minimal “real-time” data set (orientation/status/high priority measurements)
  - RV recovery (inspection of HIAD post heat pulse)

Master Measurements List
(Example Excerpt for Nose)

LOFTID Nose Measurement Requirements

Science Measurement POC	Measurement ID	Analysis Discipline	Priority	Prioritization Comments	Measurement Function Description	Sensor Type	Sensor Description	Sample Rate (SPS)	Units	EU Range	Resolution	Accuracy
Steven Tobin	LTH10-6	F-TPS	2	Nose F-TPS performance	F-TPS TC 17	Thermocouple	Type K	10	Celsius (°C)	-100 to 250°C	1°C	±5°C
Steven Tobin	LTH08-1	F-TPS	2	Nose F-TPS performance	F-TPS TC 18	Thermocouple	Type R	10	Celsius (°C)	0 to 1600°C	2°C	±20°C*
Steven Tobin	LTH09-1	F-TPS	2	Nose F-TPS performance	F-TPS TC 19	Thermocouple	Type R	10	Celsius (°C)	0 to 1600°C	2°C	±20°C*
Steven Tobin	LTH09-2	F-TPS	2	Nose F-TPS performance	F-TPS TC 20	Thermocouple	Type K	10	Celsius (°C)	-100 to 800°C	2°C	±15°C
Steven Tobin	LTH10-1	F-TPS	2	Nose F-TPS performance	F-TPS TC 21	Thermocouple	Type R	10	Celsius (°C)	0 to 1600°C	2°C	±20°C*
Steven Tobin	LTH10-2	F-TPS	2	Nose F-TPS performance	F-TPS TC 22	Thermocouple	Type K	10	Celsius (°C)	-100 to 800°C	2°C	±15°C
Chris Karlgaard	LPH70-U	Aerodynamics/ Flight Mechanics	1.5	Candidate for beacon	Aero PT 01	Pressure Tranducer	Absolute	10	psi	1.5 psia	0.0004 psia	±0.005 psia
Chris Karlgaard	LPH71-U	Aerodynamics/ Flight Mechanics	1.5	Candidate for beacon	Aero PT 02	Pressure Tranducer	Absolute	10	psi	1.5 psia	0.0004 psia	±0.005 psia
Chris Karlgaard	LPH72-U	Aerodynamics/ Flight Mechanics	1.5	Candidate for beacon	Aero PT 03	Pressure Tranducer	Absolute	10	psi	1.5 psia	0.0004 psia	±0.005 psia
Chris Karlgaard	LPH73-U	Aerodynamics/ Flight Mechanics	1.5	Candidate for beacon	Aero PT 04	Pressure Tranducer	Absolute	10	psi	1.5 psia	0.0004 psia	±0.005 psia
Chris Karlgaard	LPH74-U	Aerodynamics/ Flight Mechanics	1.5	Candidate for beacon	Aero PT 05	Pressure Tranducer	Absolute	10	psi	1.5 psia	0.0004 psia	±0.005 psia
Chris Karlgaard	LTH70-B	Aerodynamics/ Flight Mechanics	2	Reference for PT to obtain resolution	Aero PT TC 01	Thermocouple	Type K	10	Celsius (°C)	-100 to 250°C	1°C	±5°C
Chris Karlgaard	LTH71-B	Aerodynamics/ Flight Mechanics	2	Reference for PT to obtain resolution	Aero PT TC 02	Thermocouple	Type K	10	Celsius (°C)	-100 to 250°C	1°C	±5°C
Chris Karlgaard	LTH72-B	Aerodynamics/ Flight Mechanics	2	Reference for PT to obtain resolution	Aero PT TC 03	Thermocouple	Type K	10	Celsius (°C)	-100 to 250°C	1°C	±5°C
Chris Karlgaard	LTH73-B	Aerodynamics/ Flight Mechanics	2	Reference for PT to obtain resolution	Aero PT TC 04	Thermocouple	Type K	10	Celsius (°C)	-100 to 250°C	1°C	±5°C
Chris Karlgaard	LTH74-B	Aerodynamics/ Flight Mechanics	2	Reference for PT to obtain resolution	Aero PT TC 05	Thermocouple	Type K	10	Celsius (°C)	-100 to 250°C	1°C	±5°C
Brian Hollis	LTH70-R	Aeroheating	2		Radiation 01	Heat Flux Gage	Radiometer	10	W/cm^2	0 - $3W/cm^2$	$0.05W/cm^2$	$\pm 0.2W/cm^2$
Brian Hollis	LTH71-G	Aeroheating	1.5	Candidate for beacon	Heat Flux 01	Heat Flux Gage	Total Heat Flux	10	W/cm^2	0 - $70W/cm^2$	$1W/cm^2$	$\pm 3.5W/cm^2$
Brian Hollis	LTH72-G	Aeroheating	1.5	Candidate for beacon	Heat Flux 02	Heat Flux Gage	Total Heat Flux	10	W/cm^2	0 - $70W/cm^2$	$1W/cm^2$	$\pm 3.5W/cm^2$
Brian Hollis	LTH73-G	Aeroheating	1.5	Candidate for beacon	Heat Flux 03	Heat Flux Gage	Total Heat Flux	10	W/cm^2	0 - $70W/cm^2$	$1W/cm^2$	$\pm 3.5W/cm^2$
Brian Hollis	LTH74-G	Aeroheating	1.5	Candidate for beacon	Heat Flux 04	Heat Flux Gage	Total Heat Flux	10	W/cm^2	0 - $70W/cm^2$	$1W/cm^2$	$\pm 3.5W/cm^2$



Real-Time Beacon Data Set

- **Data:**
  - Position, orientation, velocity
  - Deceleration, angular rates
  - Power status
  - Pyrotechnic status
  - 5 nose pressure transducers (FADS: dynamic pressure, orientation)
  - 4 total heat flux gages (stagnation region heating)
  - Radiometer (shock layer radiation component of heating)
  - TCs (FTPS, surface & in-depth; IS, cord & wake side; centerbody)
  - 3 inflation system pressure transducers (tanks and manifolds)
  - 7 toroid pressures
  - 3 load cell pins (strap load)
- **Transmitted every 20 sec to Iridium, data emailed**
- **Viewed "real-time" on computer consoles**

Number	Measurement	Priority	Sensor Type
GPS Position & Time			
1	Time of week		GPS
2	Latitude		GPS
3	Longitude		GPS
4	Altitude		GPS
5	Number of GPS satellites tracked during fix		GPS
6	Index of Last executed Timeline Event		MACH
7	Flight time (internal timer)		MACH
NAV Information			
8	Nav Yaw		IMU
9	Nav Pitch		IMU
10	Nav Roll		IMU
11	IMU Only Yaw		IMU
12	IMU Only Pitch		IMU
13	IMU Only Roll		IMU
14	Velocity, X-Axis		IMU
15	Velocity, Y-Axis		IMU
16	Velocity, Z-Axis		IMU
17	Position X-Axis		IMU
18	Position Y-Axis		IMU
19	Position Z-Axis		IMU
20	Angular Rotational Rate, X-Axis		IMU
21	Angular Rotational Rate, Y-Axis		IMU
22	Angular Rotational Rate, Z-Axis		IMU
23	Acceleration, X-Axis, IMU rate in m/s^2		IMU
24	Acceleration, Y-Axis, IMU rate in m/s^2		IMU
25	Acceleration, Z-Axis, IMU rate in m/s^2		IMU
Power Status			
26	Avionics Power Status		MACH
27	MACH PTM Card 0 Bus A Voltage (LEM50-V)		MACH
28	Pyro Battery Voltage (LEM74-V)		MACH
29	EDM Battery Voltage (?)		MACH
Pyrotechnic Status			
30	Bag Cutter Count		MACH
31	EDR Eject		MACH
32	Parachute Count		MACH
33	Inflation Vent		MACH
Science Measurements			
34	Aero PT 01 (LPH70-U)		Pressure Transducer
35	Aero PT 02 (LPH71-U)		Pressure Transducer
36	Aero PT TC 01 (LTH70-B)		Thermocouple
37	Aero PT TC 02 (LTH71-B)		Thermocouple
38	Heat Flux 01 (LTH71-G)		Total Heat Flux Gage
39	Heat Flux 02 (LTH72-G)		Total Heat Flux Gage
40	Heat Flux Gage Surface TC 01 (LTH71-X)		Thermocouple
41	Heat Flux Gage Surface TC 02 (LTH72-X)		Thermocouple
42	Tank Pressure (LPF30-U)		Pressure Transducer
43	Manifold 1 Pressure (LPF33-U)		Pressure Transducer
44	Manifold 2 Pressure (LPF34-U)		Pressure Transducer
45	Nose TC (LTH09-1)		Thermocouple
46	Nose TC (LTH09-2)		Thermocouple
47	Aeroshell TC (LTH11-1)		Thermocouple
48	Aeroshell TC (LTH11-2)		Thermocouple
49	Aeroshell TC (LTH11-3)		Thermocouple
50	Aeroshell TC (LTH17-1)		Thermocouple
51	Aeroshell TC (LTH17-2)		Thermocouple
52	Aeroshell TC (LTH17-3)		Thermocouple
53	Aeroshell Aft TC (LTH33-7)		Thermocouple
54	Aeroshell TC (LTH13-1)		Thermocouple
55	Aeroshell TC (LTH14-1)		Thermocouple
56	Aeroshell TC (LTH14-2)		Thermocouple
57	Aeroshell TC (LTH14-3)		Thermocouple
58	Aeroshell TC (LTH15-1)		Thermocouple
59	Heat Flux 03 (LTH73-G)		Total Heat Flux Gage
60	Heat Flux 04 (LTH74-G)		Total Heat Flux Gage
61	Radiometer (LTH70-R)		Radiometer
62	Reference TC for HFG 03 (LTH73-X)		Thermocouple
63	Reference TC for HFG 04 (LTH74-X)		Thermocouple
64	Reference TC for Radiometer (LTH70-Y)		Thermocouple
65	Backface TC for HFG 01 (LTH70-6)		Thermocouple
66	Loadcell Pin Fwd (TBD)		Loadcell
67	Loadcell Pin Aft (TBD)		Loadcell
68	Loadcell Pin Radial (TBD)		Loadcell
69	Aero PT 04 (LPH73-U)		Pressure Transducer
70	Aero PT 05 (LPH74-U)		Pressure Transducer
71	Aero PT TC 04 (LTH73-B)		Thermocouple
72	Aero PT TC 05 (LTH74-B)		Thermocouple
73	Torus PT 1 (LPF20-U)		Pressure Transducer
74	Torus PT 2 (LPF21-U)		Pressure Transducer
75	Torus PT 3 (LPF22-U)		Pressure Transducer
76	Torus PT 4 (LPF23-U)		Pressure Transducer
77	Torus PT 5 (LPF24-U)		Pressure Transducer
78	Torus PT 6 (LPF25-U)		Pressure Transducer
79	Torus PT 7 (LPF26-U)		Pressure Transducer
80	Aeroshell Aft TC (LTH34-7)		Thermocouple
81	Aeroshell Aft TC (LTH39-7)		Thermocouple
82	Aeroshell Aft TC (LTH40-7)		Thermocouple
83	Aeroshell Fwd Cord TC (LTH62-5)		Thermocouple
84	Aeroshell Fwd Cord TC (LTH61-5)		Thermocouple
85	Aeroshell Aft Cord TC (LTH65-5)		Thermocouple
86	Nose TC (LTH01-1)		Thermocouple
87	Nose TC (LTH01-2)		Thermocouple
88	Nose TC (LTH01-3)		Thermocouple
89	Nose TC (LTH03-1)		Thermocouple
90	Nose TC (LTH03-2)		Thermocouple
91	Nose TC (LTH03-3)		Thermocouple
92	Mid Segment TC (LTM01-6)		Thermocouple
93	Aeroshell TC (LTH12-1)		Thermocouple
94	Aft Segment TC (LTA01-6)		Thermocouple
95	Aft Segment TC (LTA02-6)		Thermocouple
96	Aero PT 03 (LPH72-U)		Pressure Transducer
97	Aero PT TC 03 (LPH72-B)		Thermocouple
98	Aeroshell TC (LTH12-2)		Thermocouple
99	Aeroshell TC (LTH12-3)		Thermocouple

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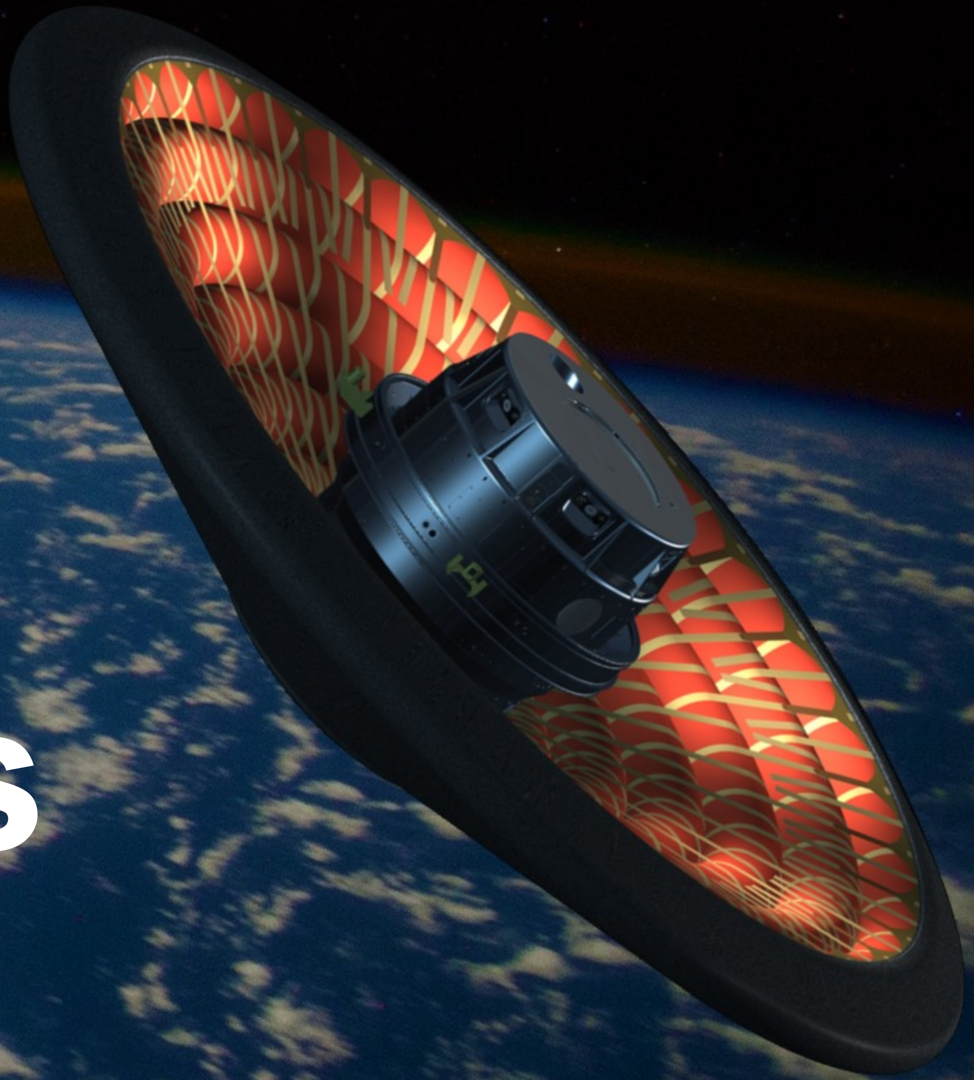


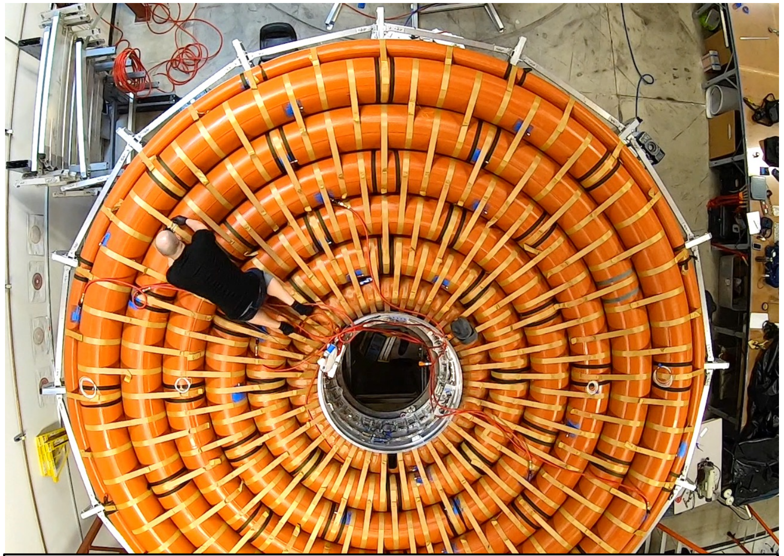
LOFTID Status

Aeroshell Fabrication

Liner Fabrication

Braid Layout

Torus Coating

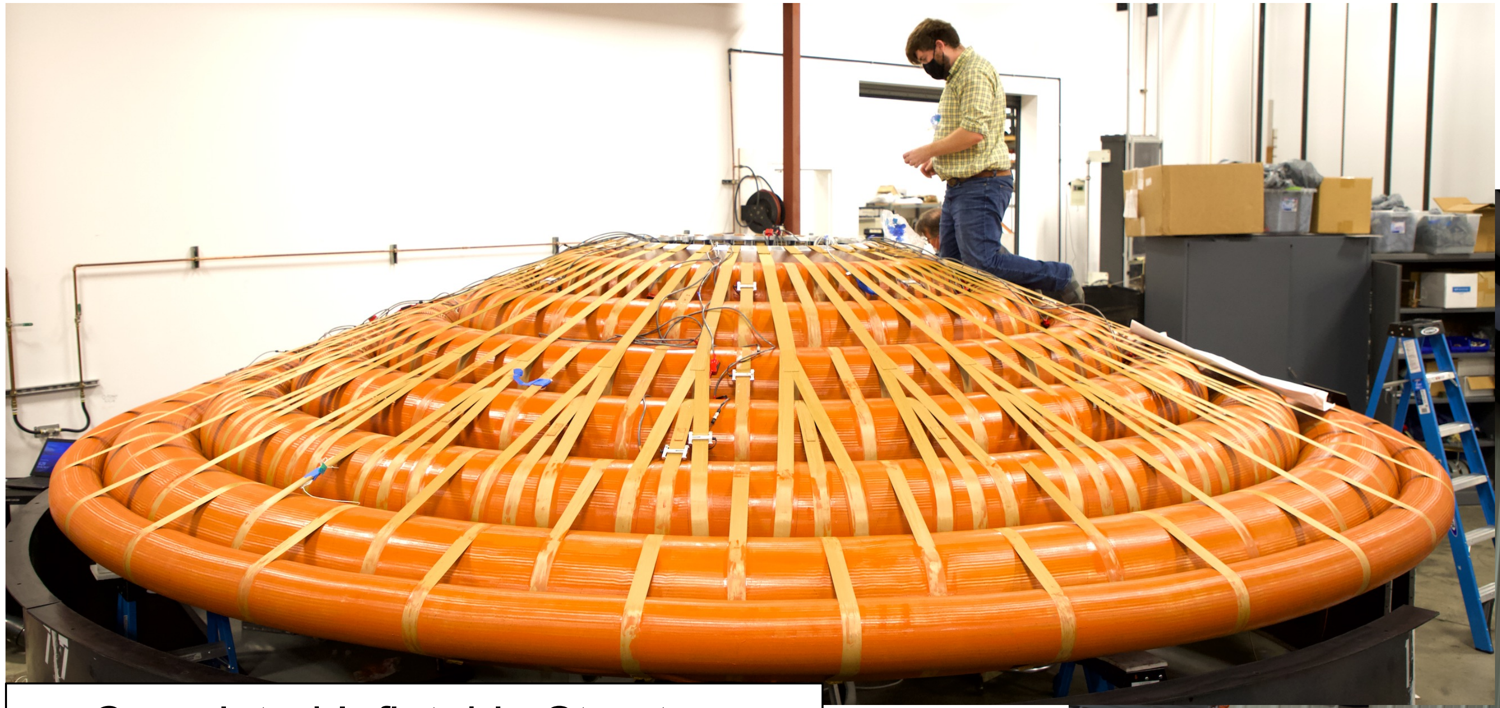


Stacking and Strapping

FTPS Fabrication

Rigid Nose and FTPS

Completed Aeroshell Components



Completed Inflatable Structure

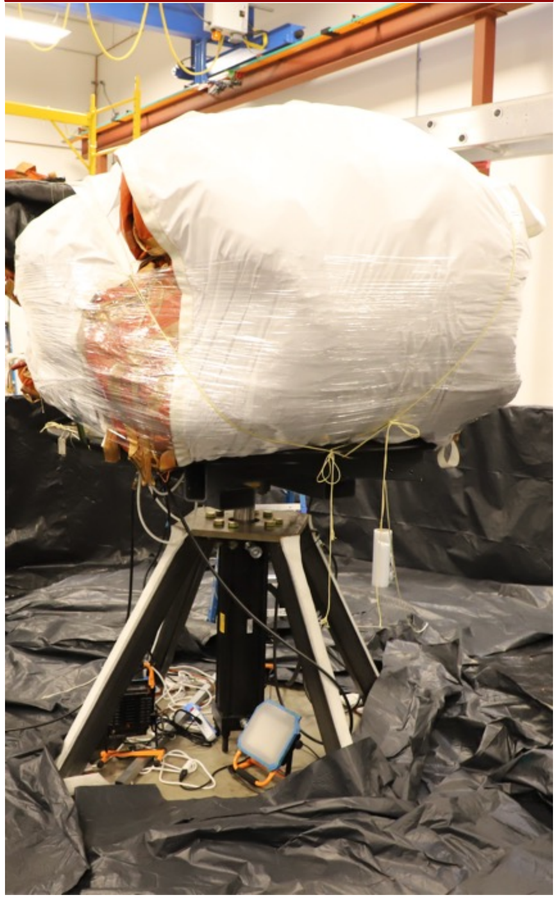
Completed Nose

Completed Flexible TPS

Static Load Test Video

Pack and Deployment Testing

Rough Pack



Suspension Fixture

Organize Soft Goods

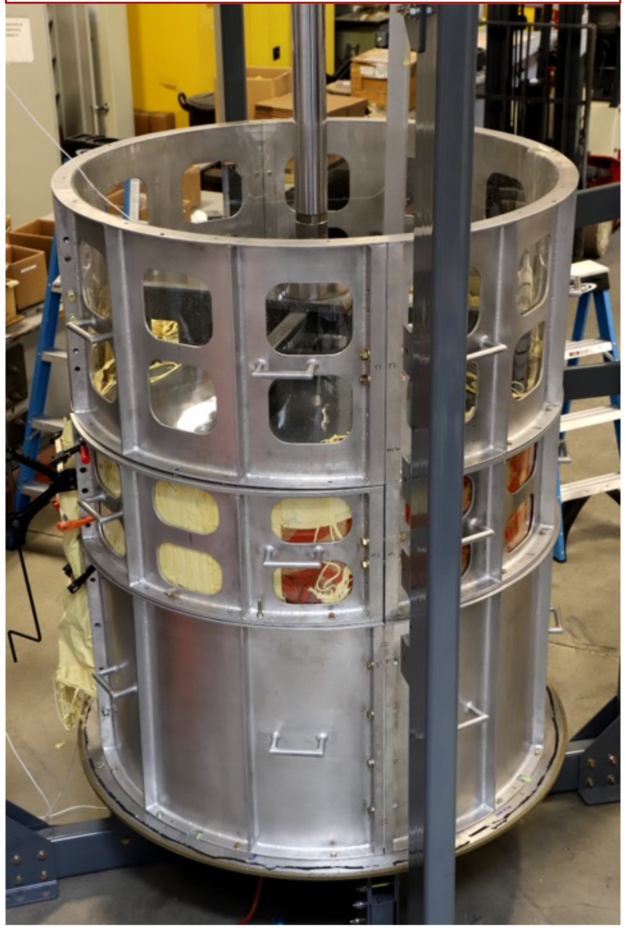
Initial Pack

Pack and Deployment Testing

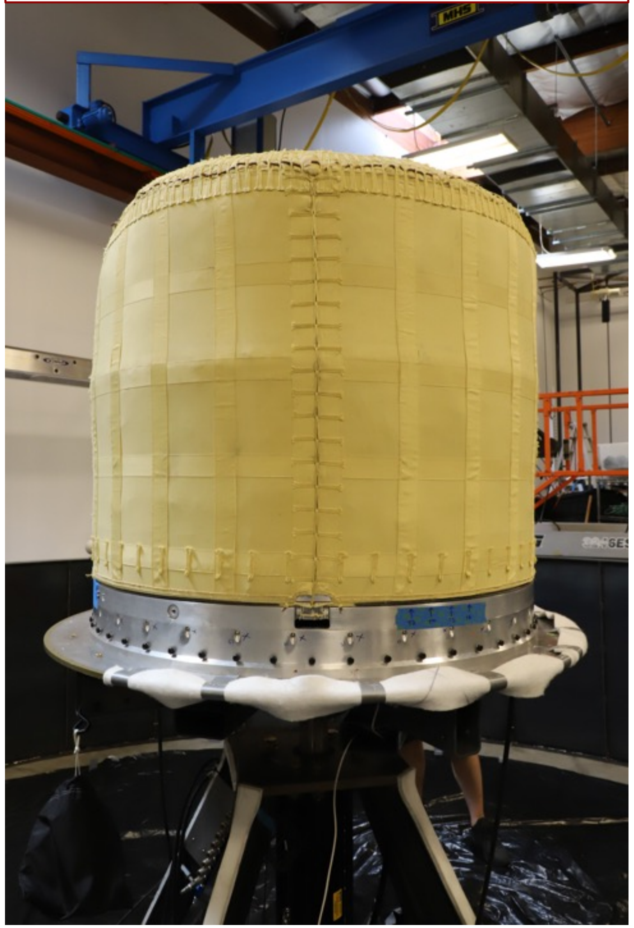
Turn Over

Packing Fixture

Ram Packed

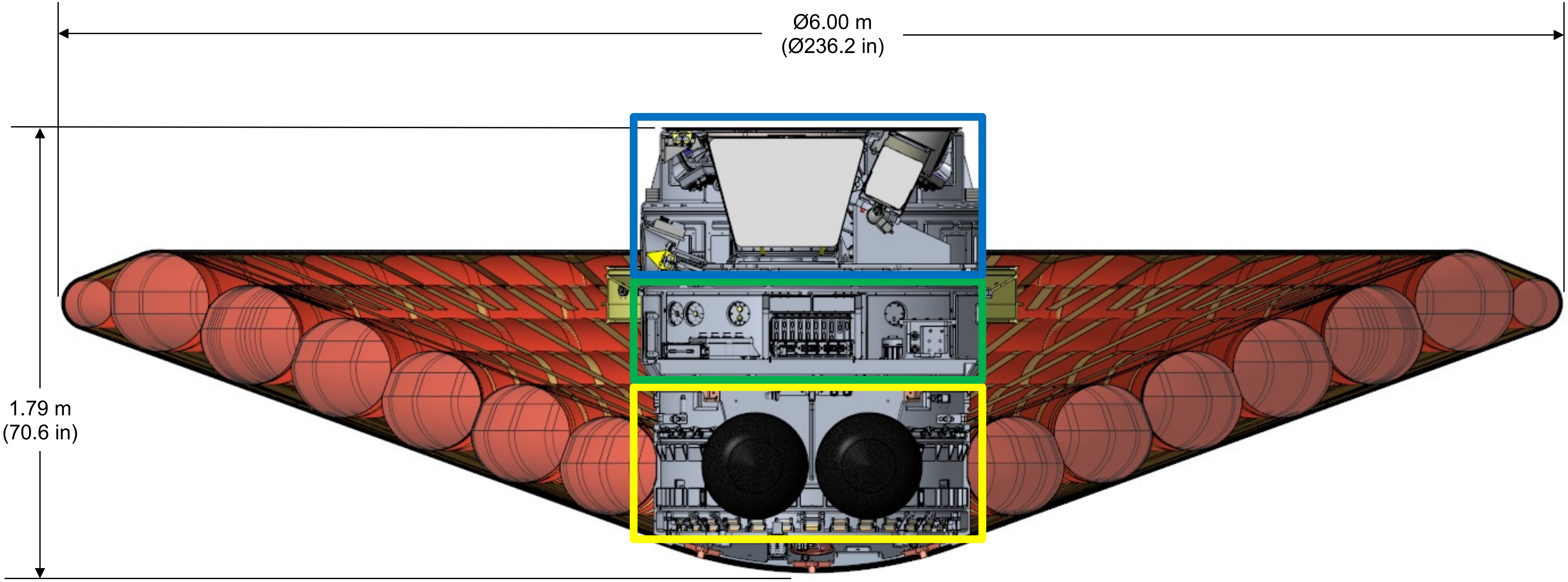


Final Pack



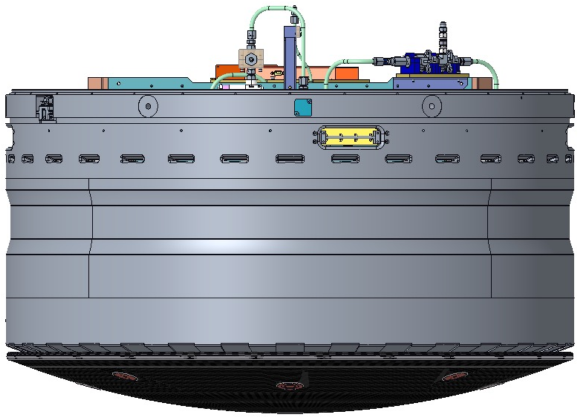
Time Lapse Deployment Video

Rigid Structures



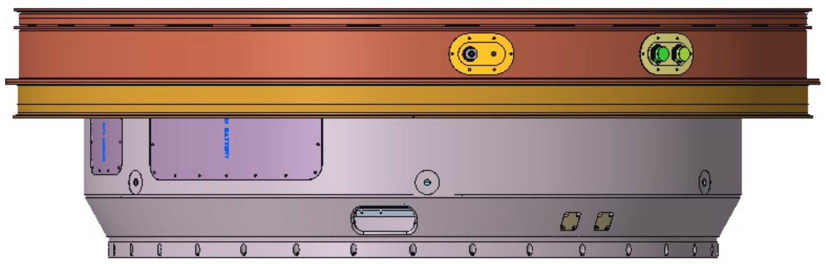
Rigid Structures

Forward Interface
- Forward Segment Radax Joint
- Inflation System and Mid-Segment Pass-Thru
- Aeroshell interface



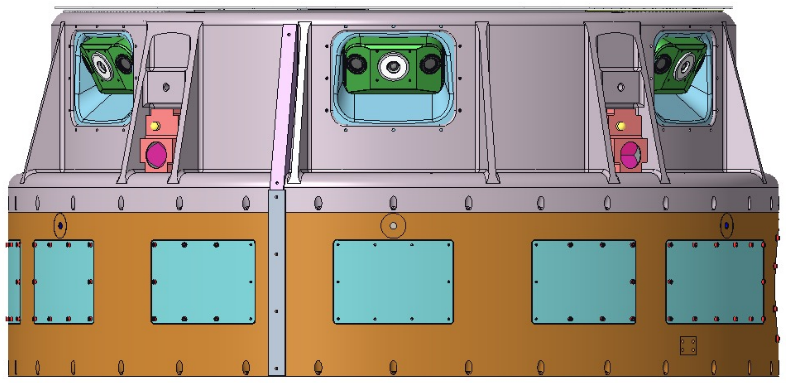
Status
- Primary Structure assembled
- Secondary structures almost finished

Mid Interface
- Forward Segment Radax Joint
- Aft Segment Radax
- Electrical pass throughs
- RV/LV interface



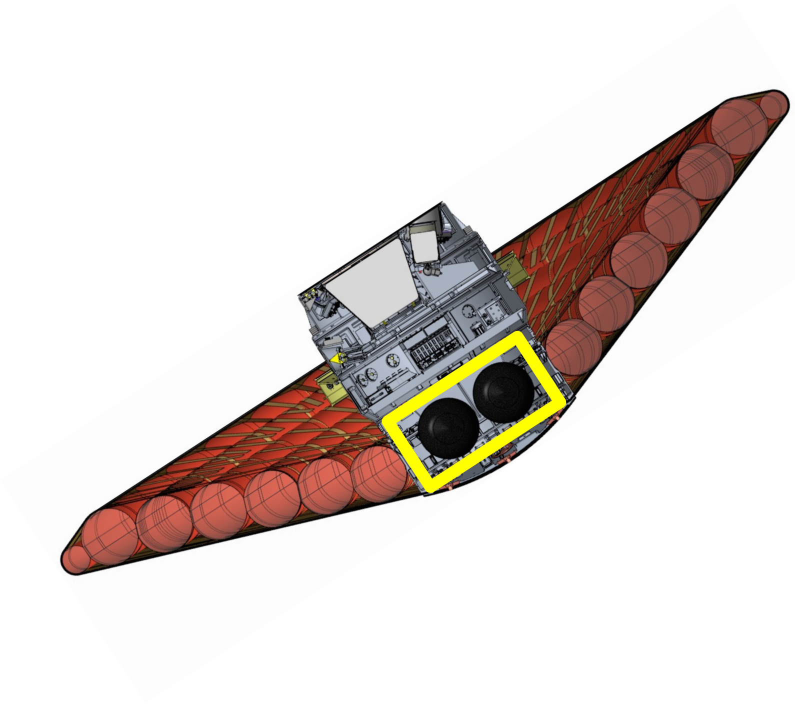
Status
- Primary Structure fabricated
- Majority of Secondary structures fabricated with a few components starting final review

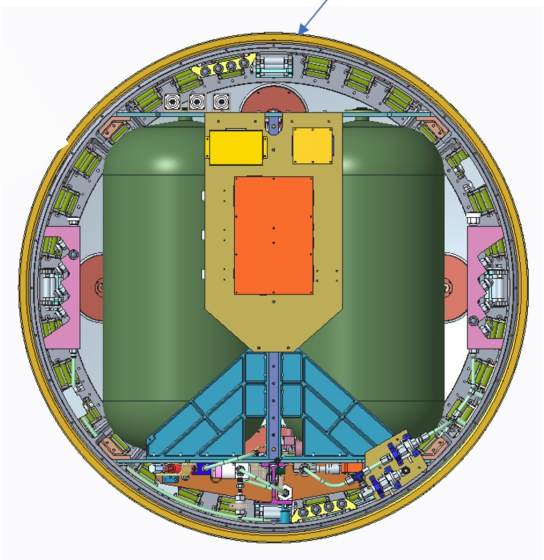
Aft Interface
- Aft Segment Radax Joint
- Parachute System



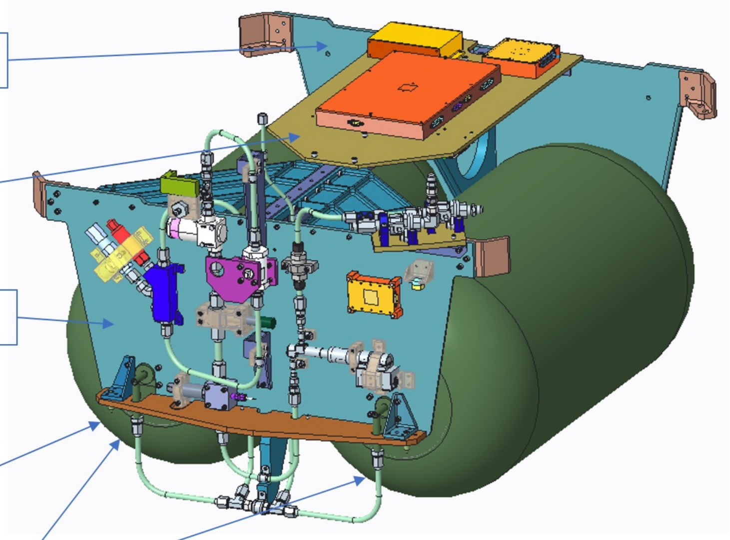
Status
- Primary Structure in fabrication
- Some secondary structures fabricated
- Finishing secondary structure designs

Inflation System





Forward Segment Top View



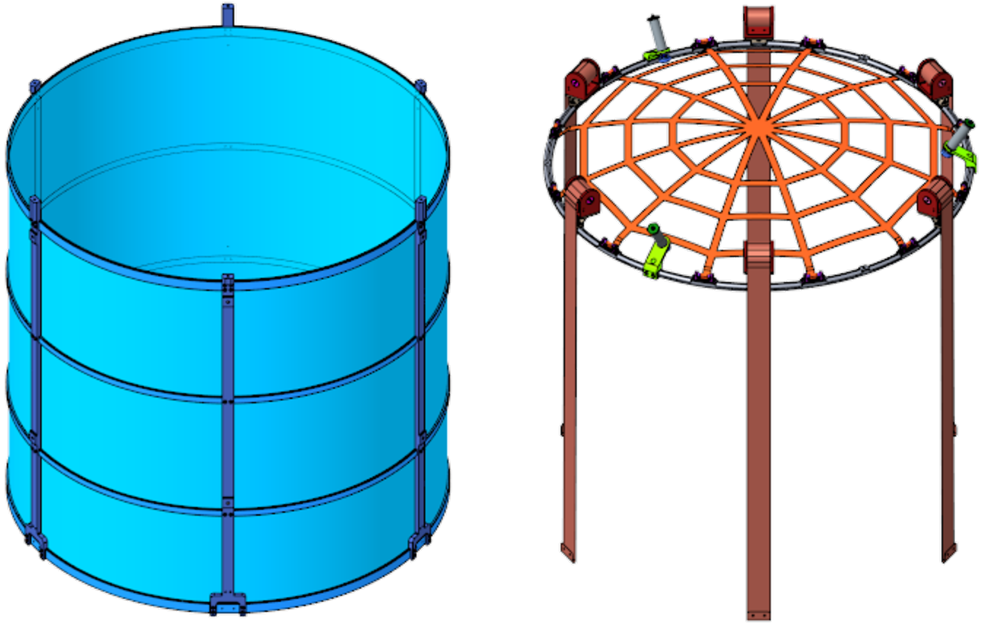
Inflation System

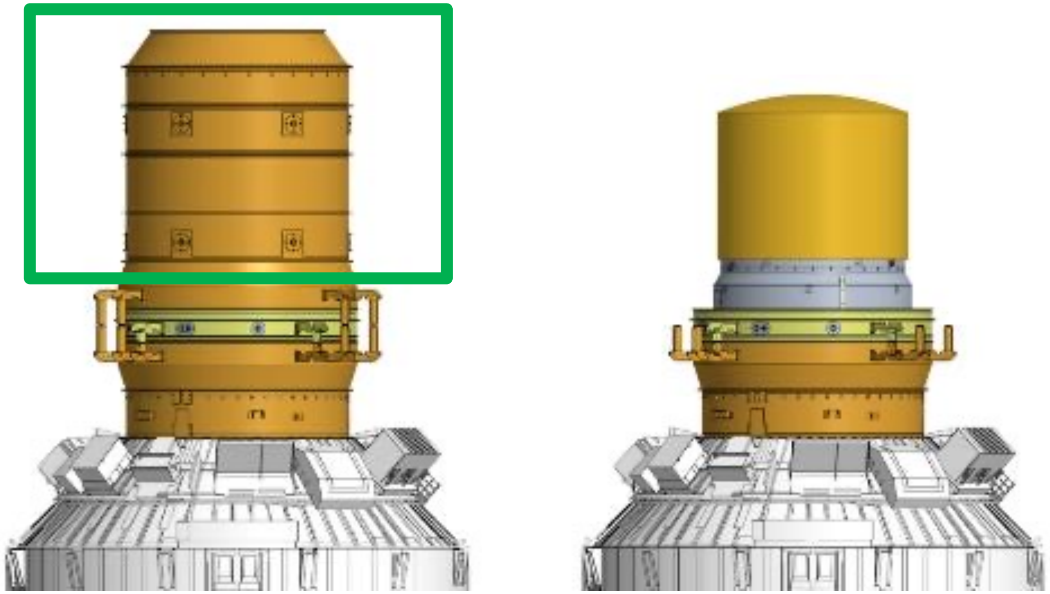
Status:

- The Inflation System pneumatic components were assembled and leak tested at Langley Research Center.
- The system underwent flow characterization testing, during which GN2 flowed through the system into both vacuum and sea-level-static environments to characterize flow over the full spectrum of the flight mission.
- Up next, the Inflation System will complete its assembly of instrumentation, electronics, and wiring harness to prepare it for inflation testing with a mock-HIAD and vibration testing at Goddard Space Flight Center.

Payload Adapter Separation System

- **Long Stroke Separation System**
  - Provided by LaRC
  - Inner Shroud
    - Mounts inside of PLA
    - Provides smooth surface for separation
  - Halo
    - Hosts 6 long-stroke constant force springs
    - Reacts separation springs against RV

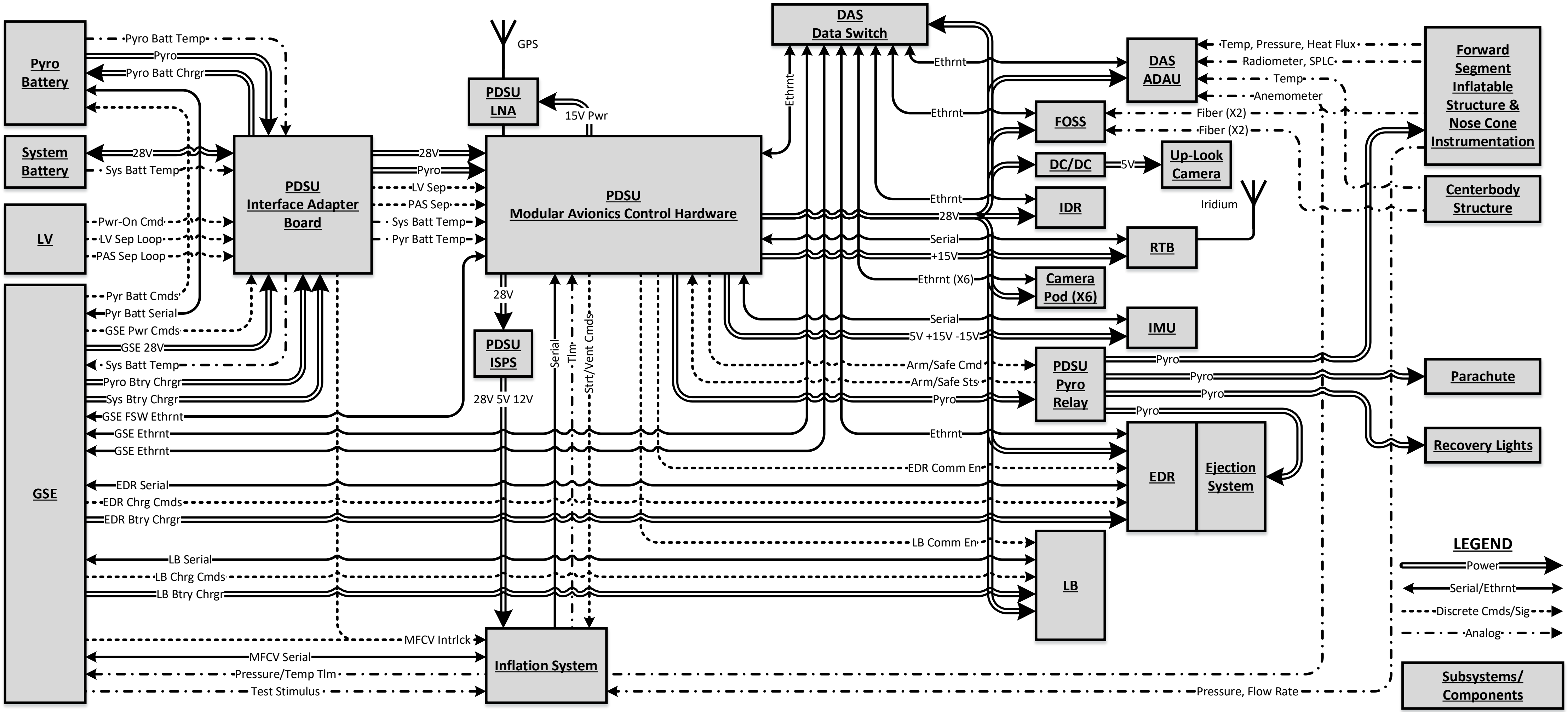




Status:

- LSSS EDU fabrication complete
- Halo load testing complete
- PASS CF Spring characterization in process
- Assembly planned for week of 7/19/21
- EDU qualification testing planned to begin week of 7/26/21

Avionics Introduction
Interaction Diagram

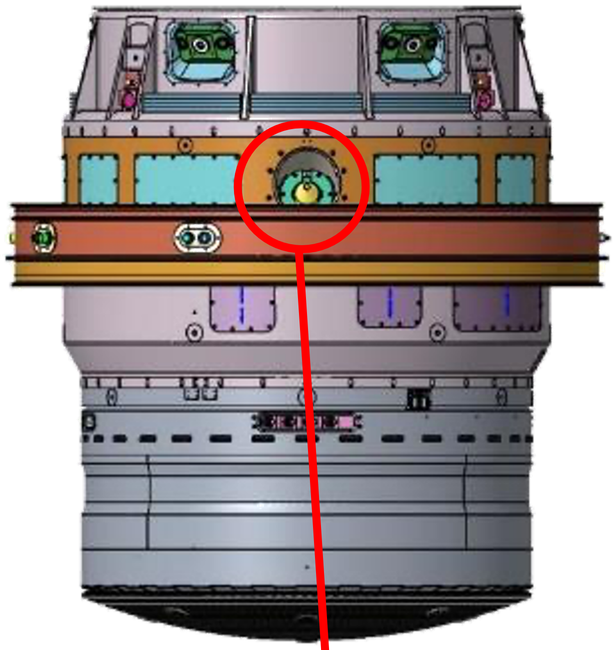


STATUS:

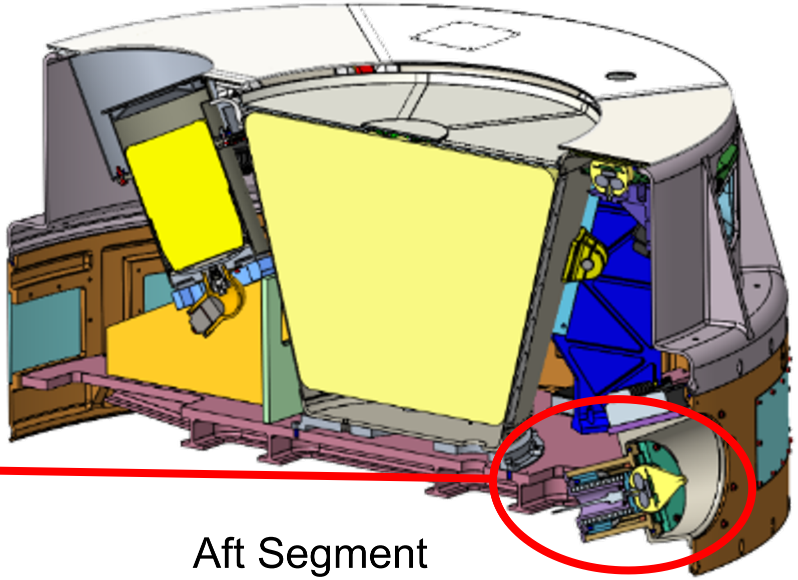
- A ton going on right now: thermal testing, cable design and fab, spread system testing, software testing, EGSE test rack builds, and on and on..
- Uncontrolled Entry System – and still a huge avionics suite!

Ejectable Data Recorder (EDR)

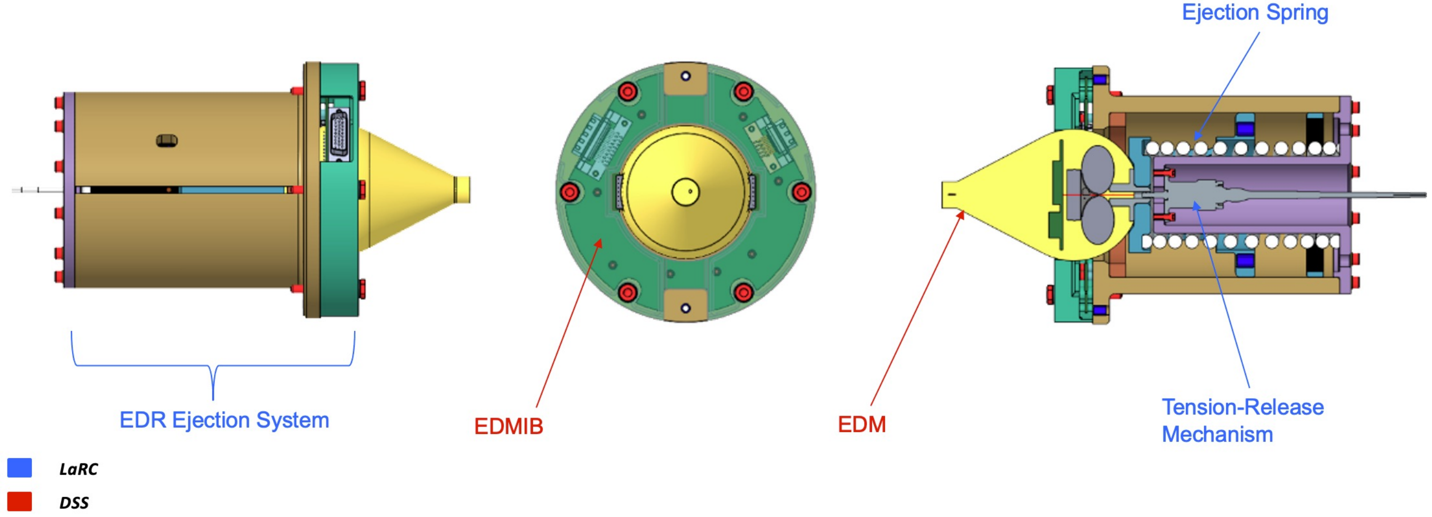
LOFTID Re-entry Vehicle
Aeroshell Removed



EDR



Aft Segment



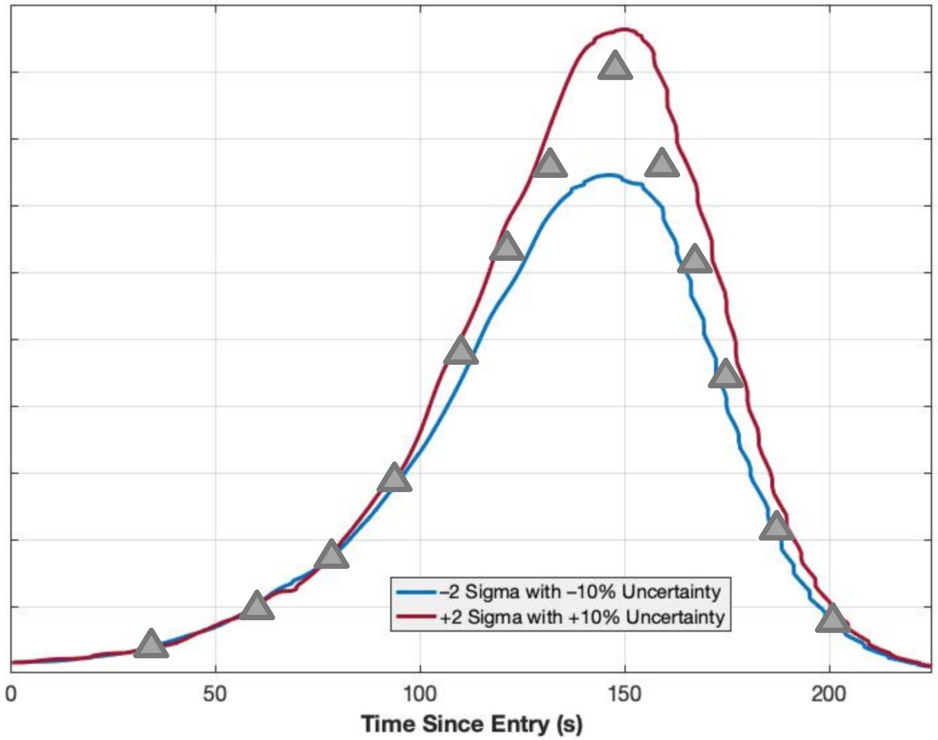
<u>Status</u>

- EDU completed all functional and environmental testing which included:
  - Functional and Performance Testing
  - Random Vibration Testing
  - Thermal Vacuum Testing
  - High Temperature Functional/Performance Test
- Mechanism is now fully qualified for flight
- Flight unit build is currently in fabrication

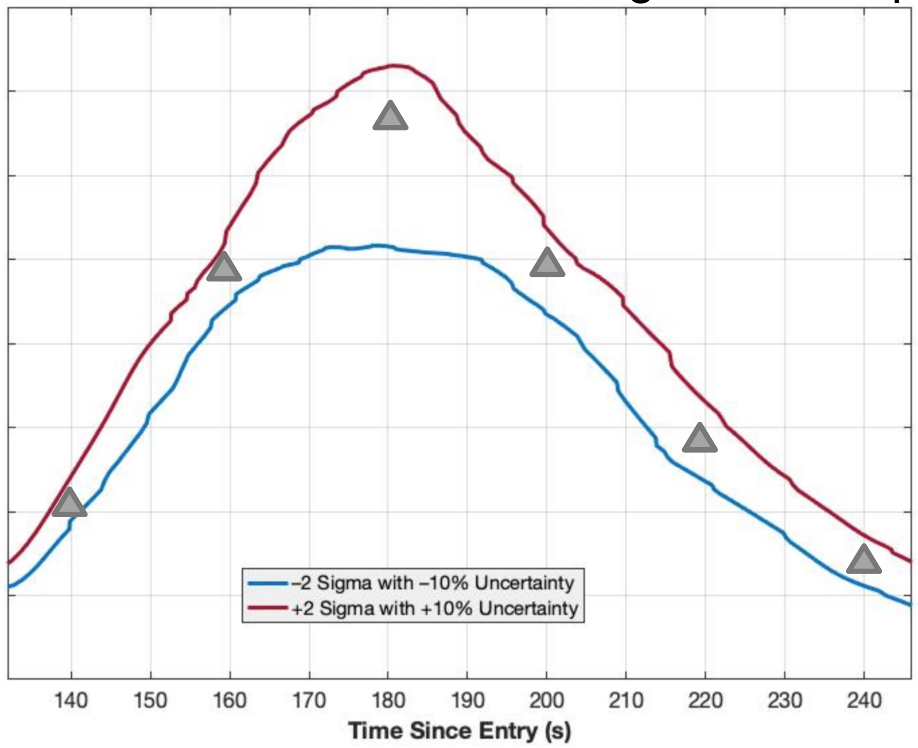
Day of Flight

- Unfortunately, we won't get the real-time data we got for IRVE-3
  - Don’t have the ground station coverage, FTPS not RF transparent, more data overall
- We will have real-time plotting of RTB data
  - Over half of our primary measurements at a much-reduced sample rate
- Recovery of EDR and/or RV to get full dataset and video

Heat Flux Real-Time Plotting Tool Example



Surface Pressure Real-Time Plotting Tool Example



Forward Work

- Component Level Thermal Testing, Now–Aug 2021
- Segment Assembly, Aug-Sept 2021
- Integrated Segment Vibration Testing, Oct-Nov 2021
- Reentry Vehicle Assembly, Nov 2021
- EMI/EMC Testing, Dec 2021
- Complete System Test (CST) in LaRC 60ft Vacuum Sphere, Feb 2022
- Final Aeroshell Pack, April 2022
- Full Reentry Vehicle Acceptance Vibe at GSFC, May 2022
- Delivery to Launch Facility, Jun 2022
- Launch, Sept 2022

LOFTID Video

LOFTID

Questions?