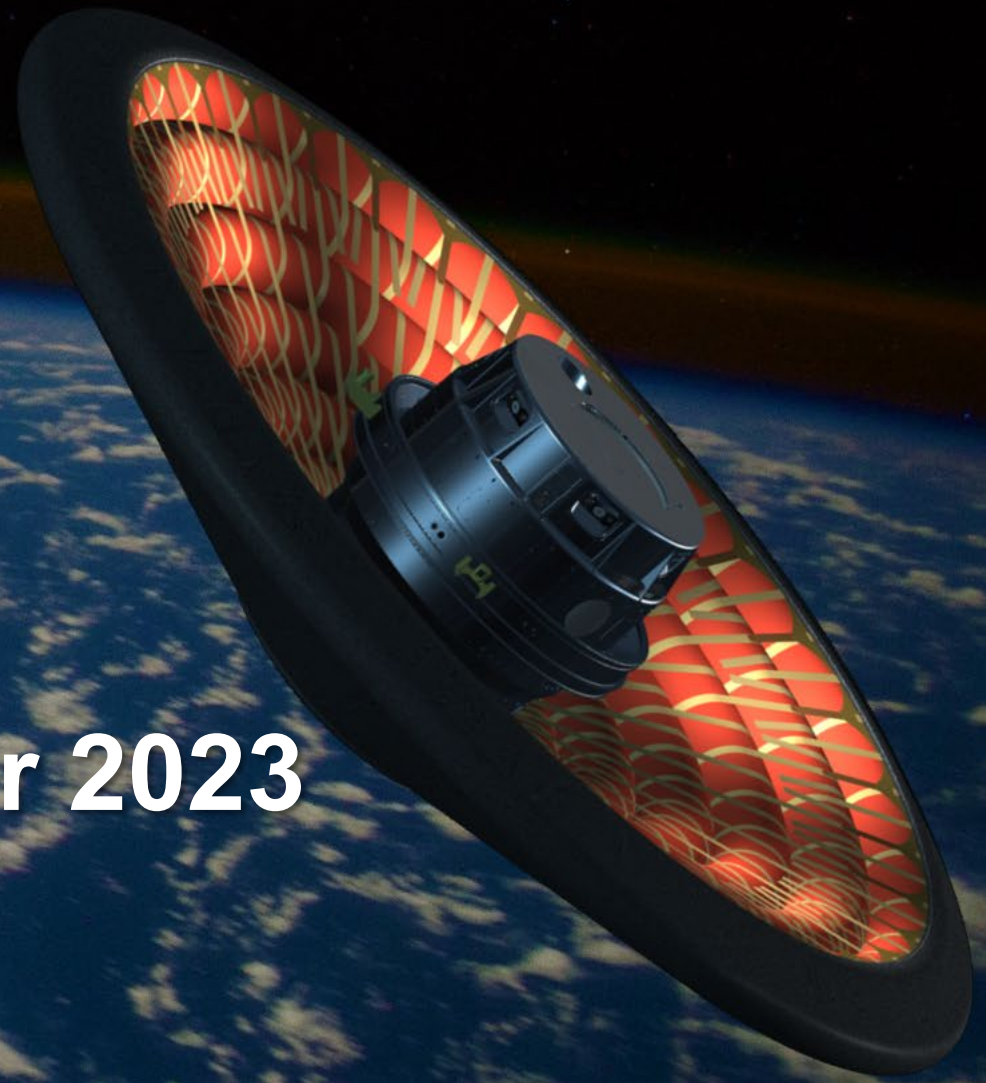


Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID)

EDL Seminar Series Summer 2023

Steve Hughes, Aeroshell Lead

Greg Swanson, Instrumentation Lead / Aeroshell Development

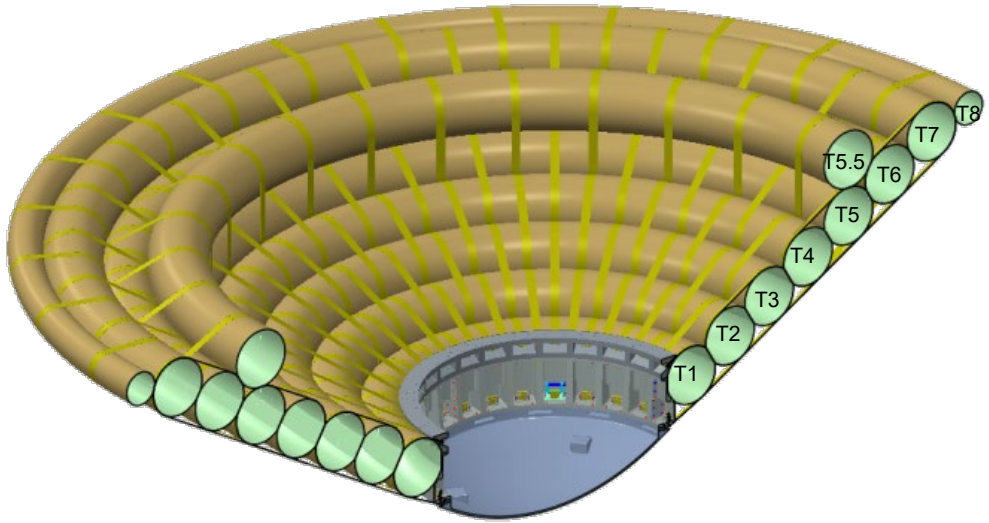
HIAD Technology

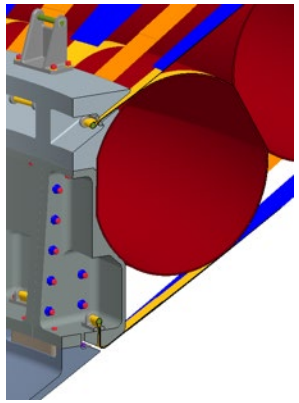
What is a HIAD?

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.

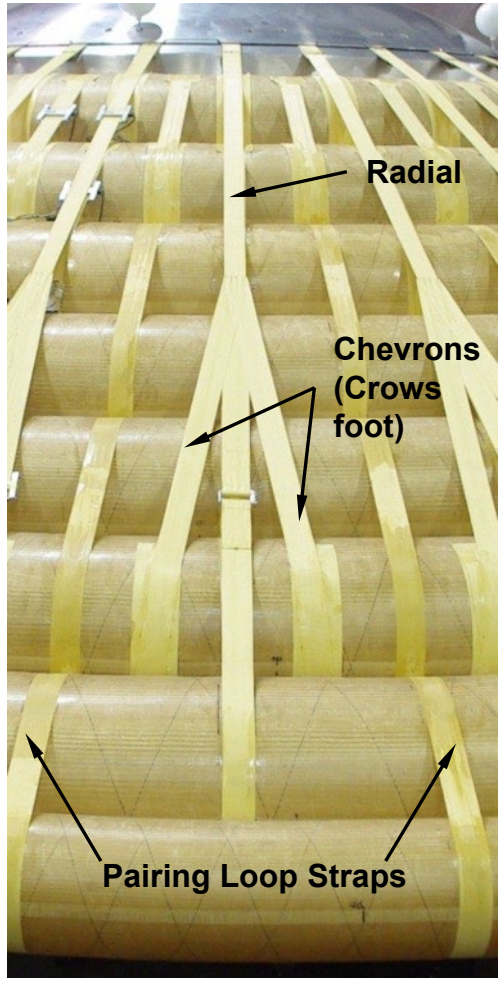
Anatomy of a HIAD

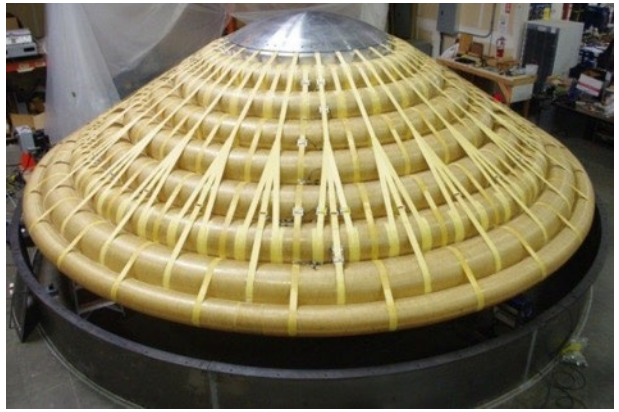
Inflatable Structure (IS): Stacked torus design with straps to establish shape and distribute loads





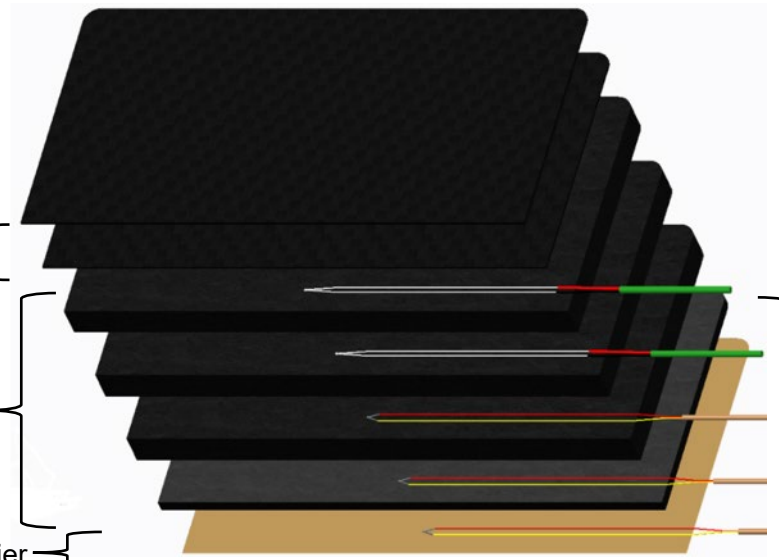
Forward and Aft straps attach IS to centerbody/vehicle



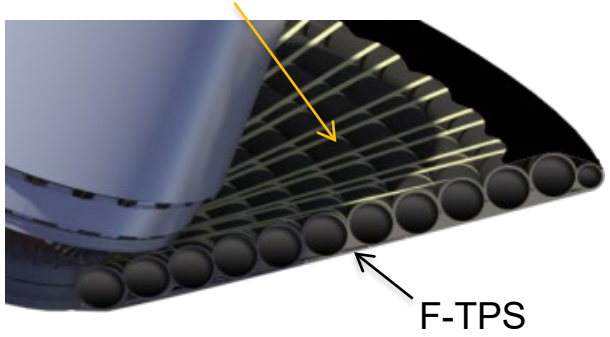


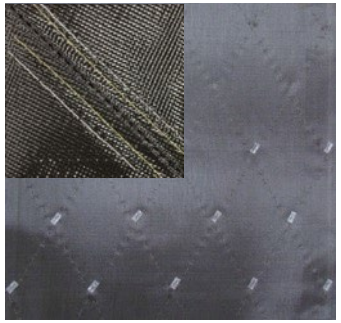
Anatomy of a HIAD

Generic F-TPS

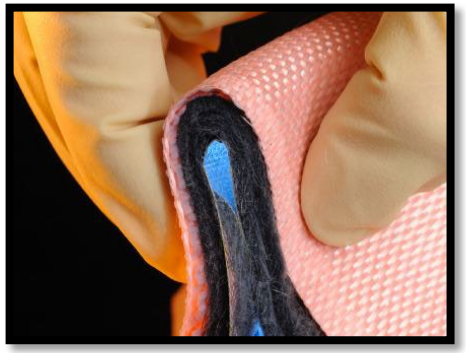


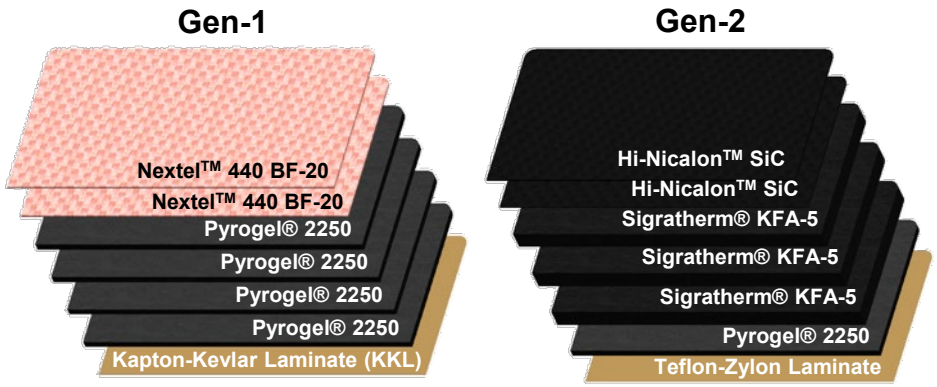
Inflatable Structure





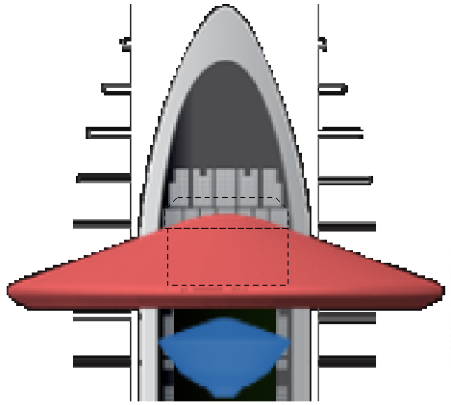
Seams,
Quilting,
Tacking

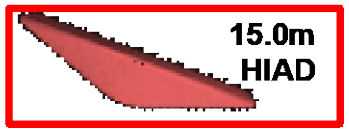




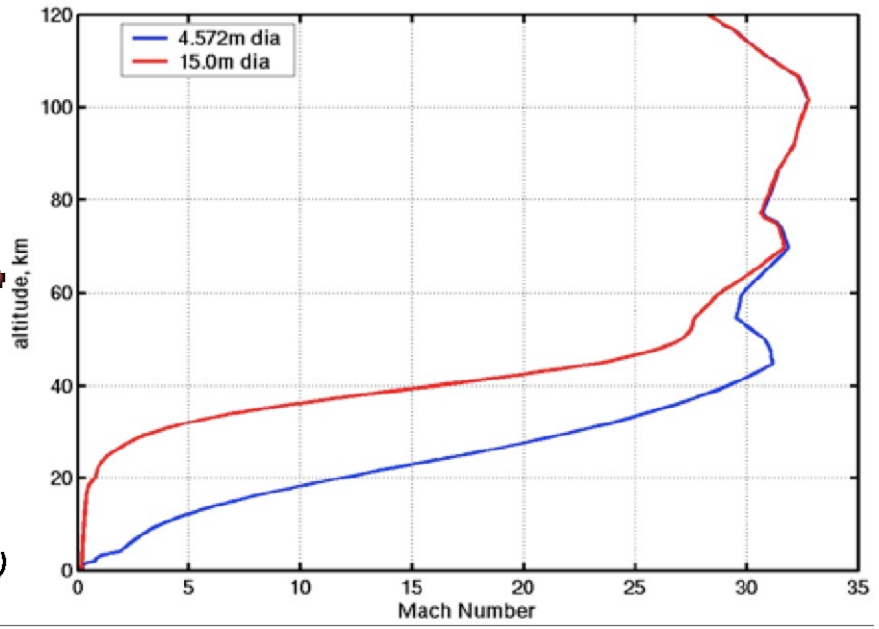
Why Inflatable?

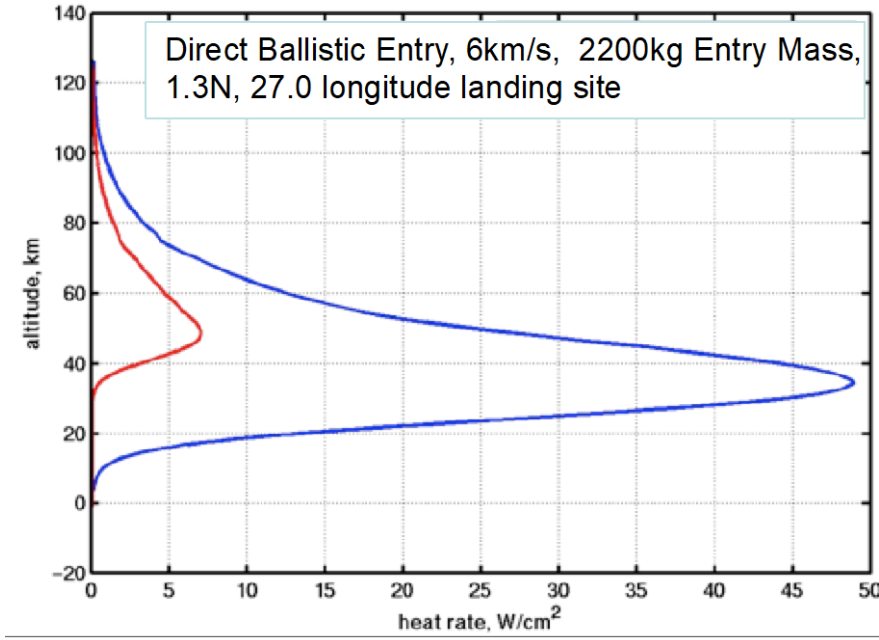
- **Entry mass at Mars, and other destinations with atmospheres, is limited by launch vehicle fairing size**
- **Inflatable technology:**
  - Deploys a large aeroshell before atmospheric interface
  - Enables delivering more payload mass to a larger range of altitudes (including orbit via aerocapture)
  - 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

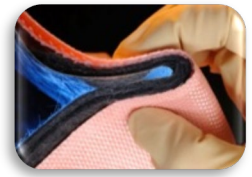
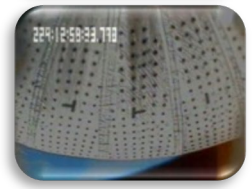
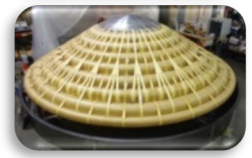
Investments in HIAD Technology

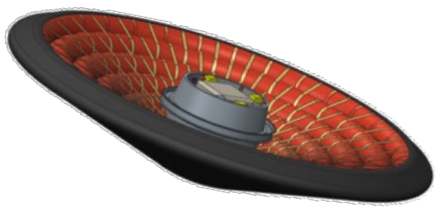
2005

- ✓ **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

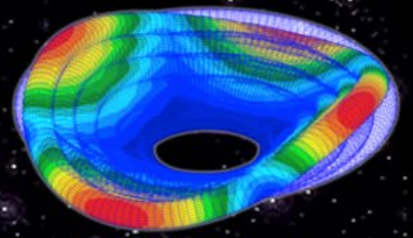
Performance

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

Static Loading

Modeling

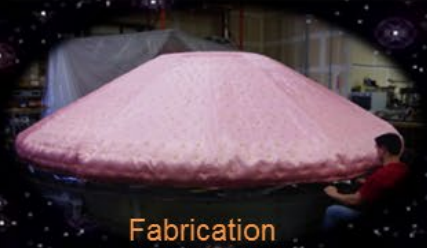
- Validate non-linear structural modeling capability
- Establish structural design procedures and standards
- Define system weight, stiffness, and strength options



Dynamic Response

Flexible TPS

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

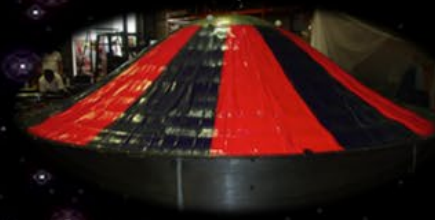


Fabrication

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

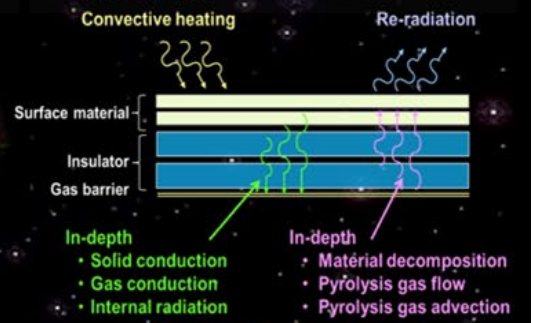
Stagnation

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



Structural Contribution

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

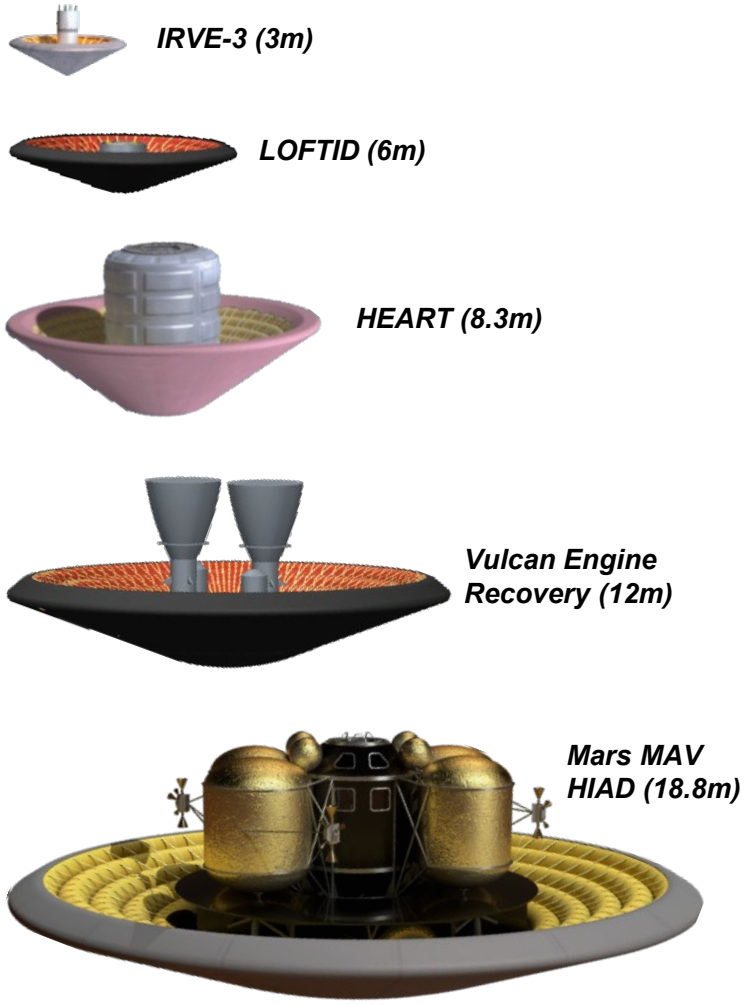


Multi-Physics Model

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

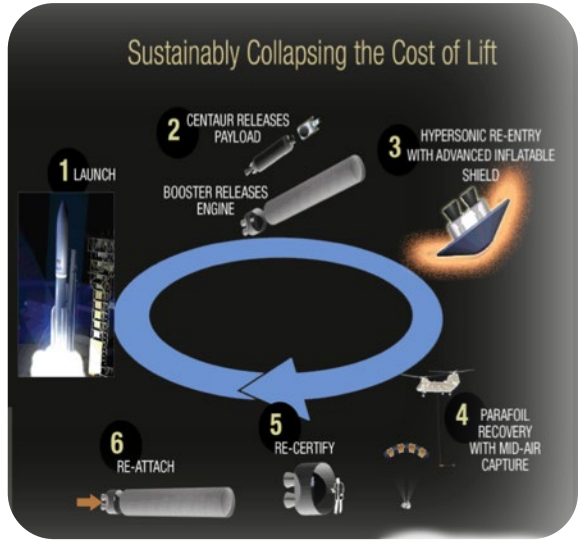


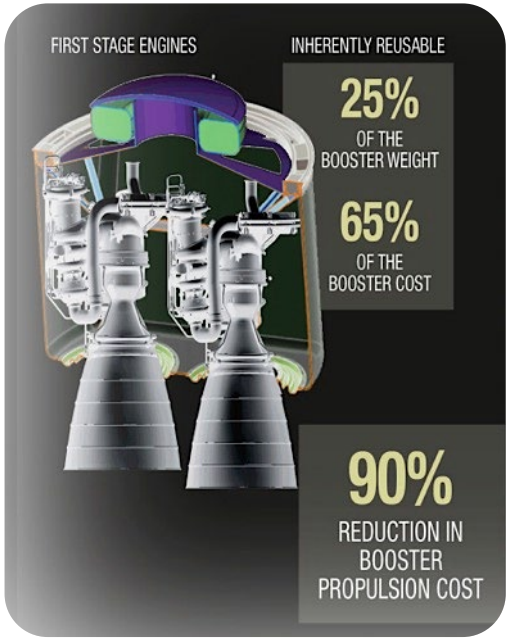

HIAD
Hypersonic Inflatable Aerodynamic Decelerators

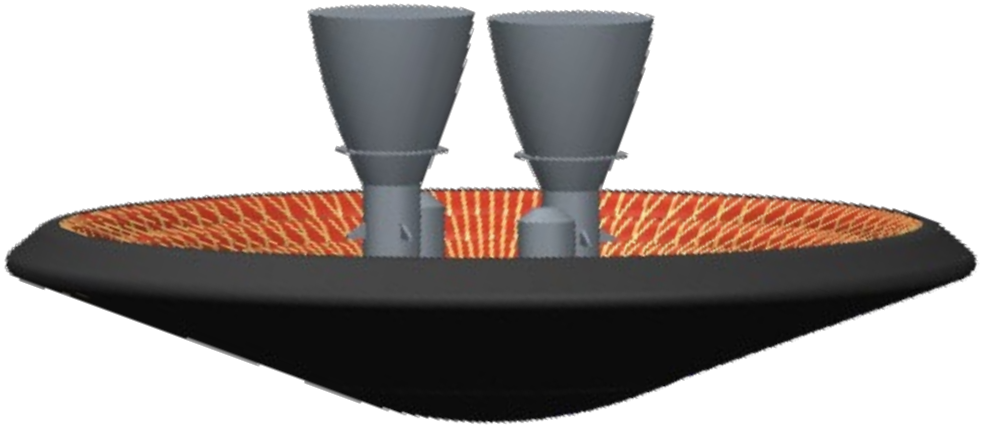
ULA Smart Reuse: Vulcan First-Stage Engine Recovery

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, and explicitly identified HIAD as key enabling technology.
- 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.







IRVE3 YouTube Video

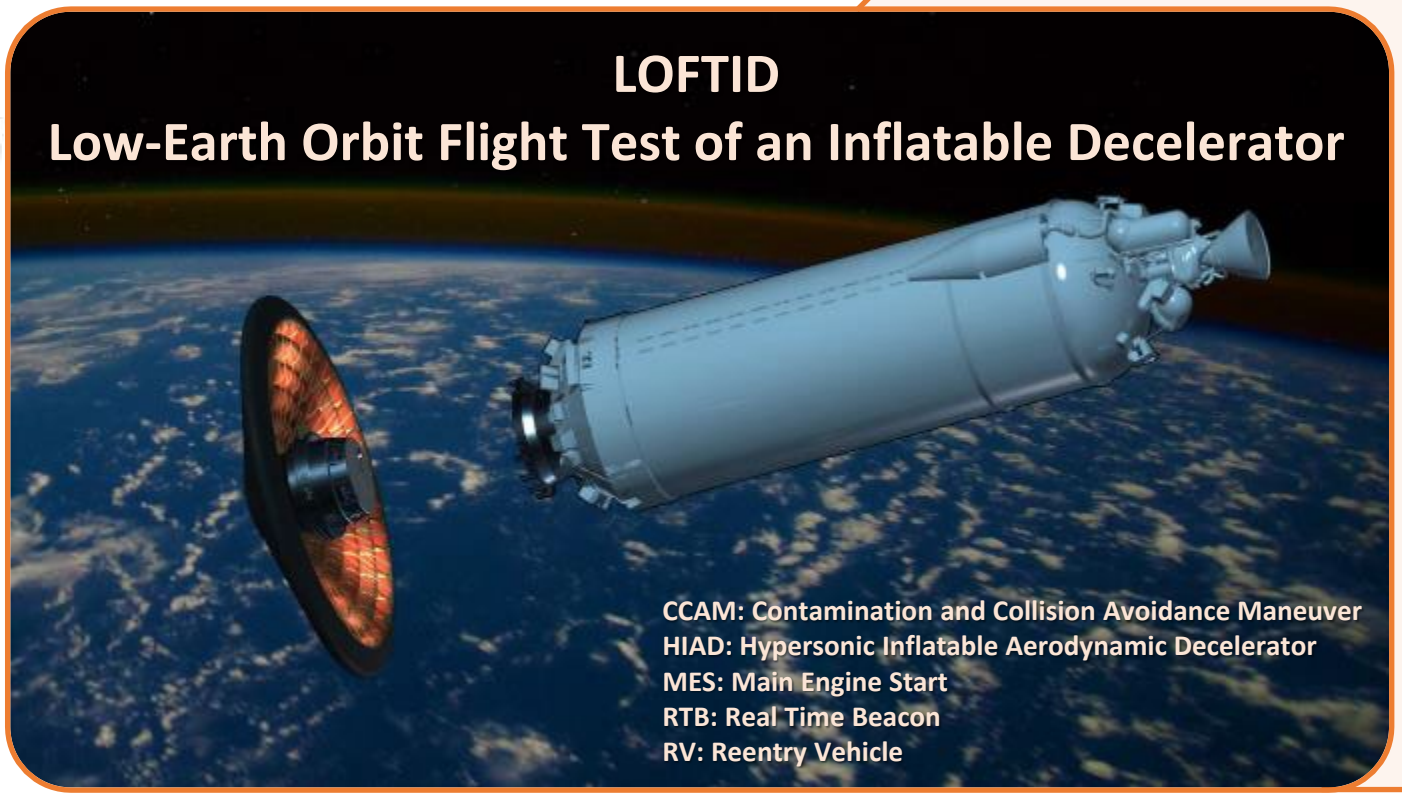
Low-Earth Orbit Flight Test
of an Inflatable Decelerator

National Aeronautics and
Space Administration

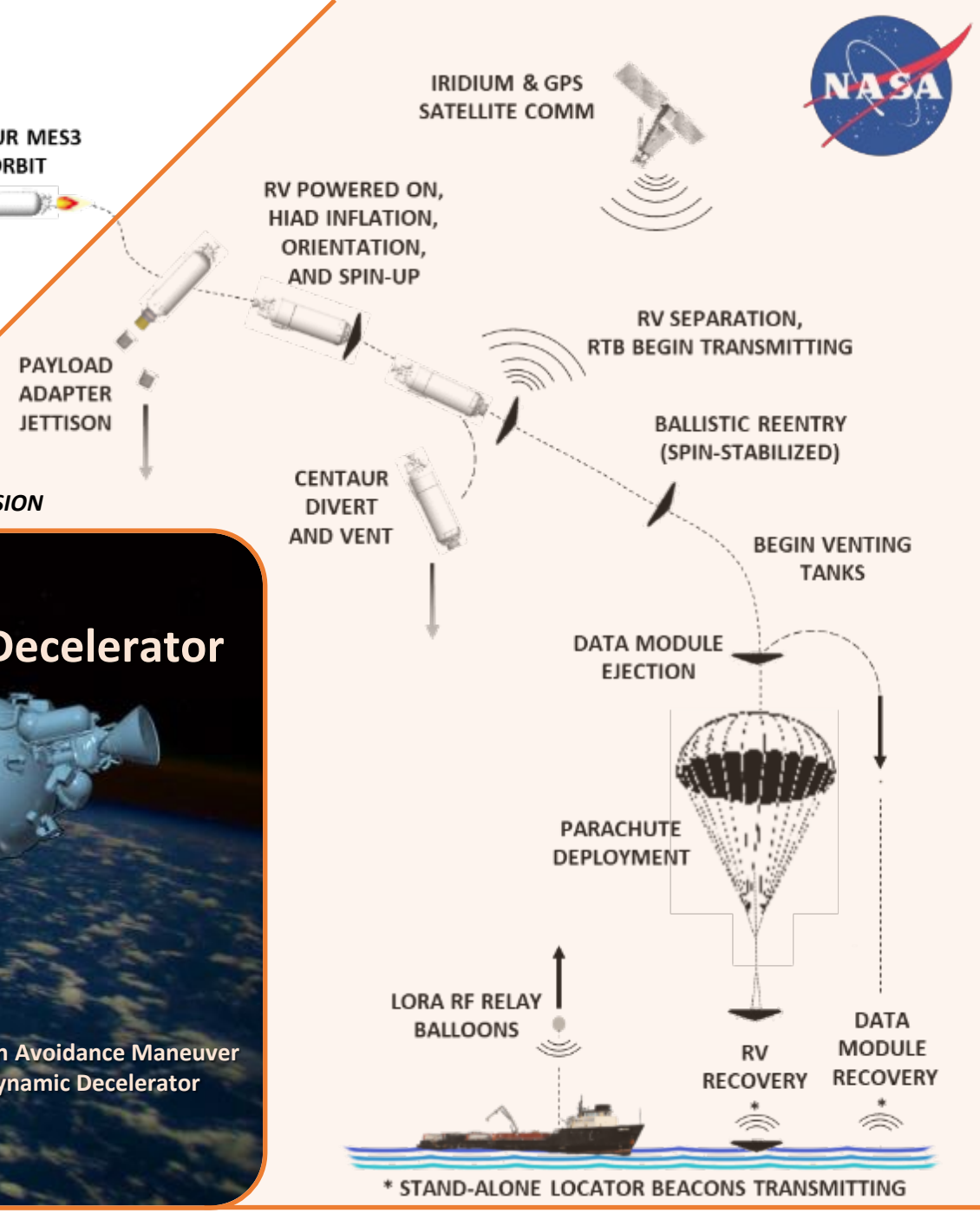
NASA

LOFTID Overview

LOFTID
Low-Earth Orbit Flight Test of an Inflatable Decelerator



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

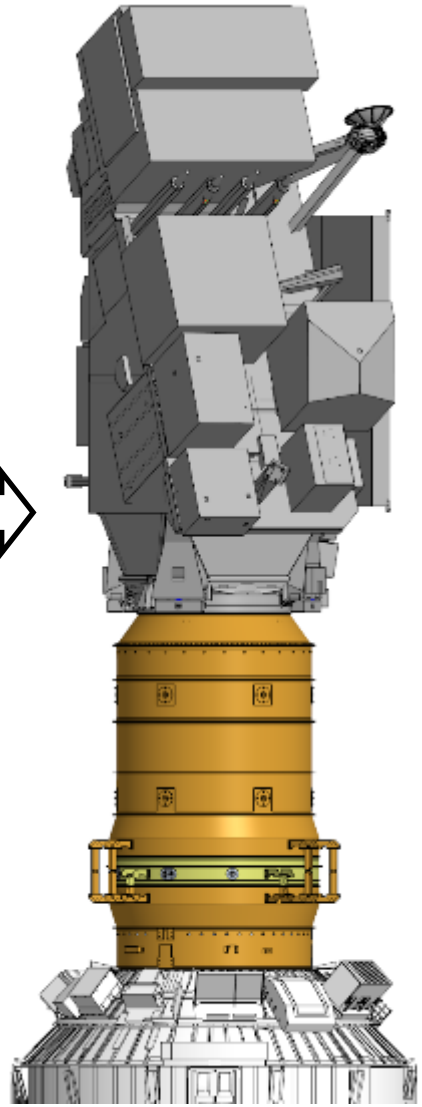
Name	Requirement
Exo-Atmospheric Deployment	LOFTID shall demonstrate the exo-atmospheric deployment of a 6 meter (nominal diameter) Hypersonic Inflatable Aerodynamic Decelerator (HIAD).
Reentry Heat Flux	LOFTID shall perform an atmospheric reentry which yields a minimum peak heat flux of 30 W/cm^2.
Experimental 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.

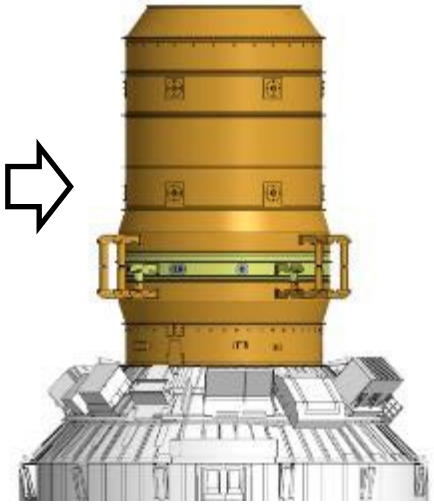
Mission Architecture

JPSS-2 Primary Mission Second Stage

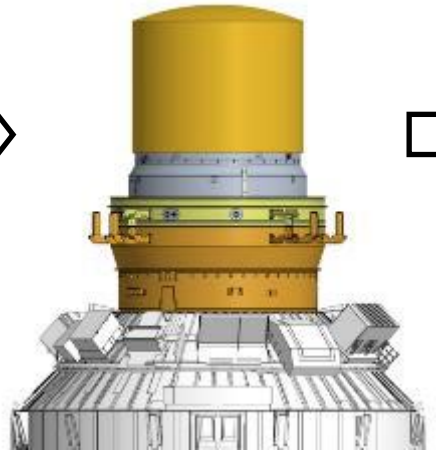
Extended Payload Fairing (EPF) Jettisoned



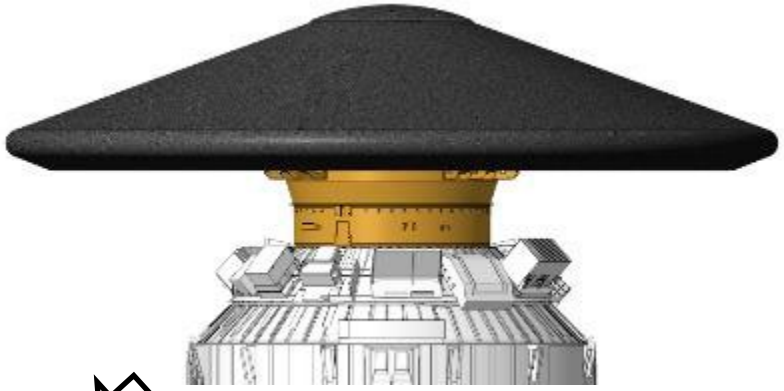
Primary Payload (JPSS-2) Separated



Payload Adapter (PLA) Canister Jettisoned



LOFTID Aeroshell Inflated

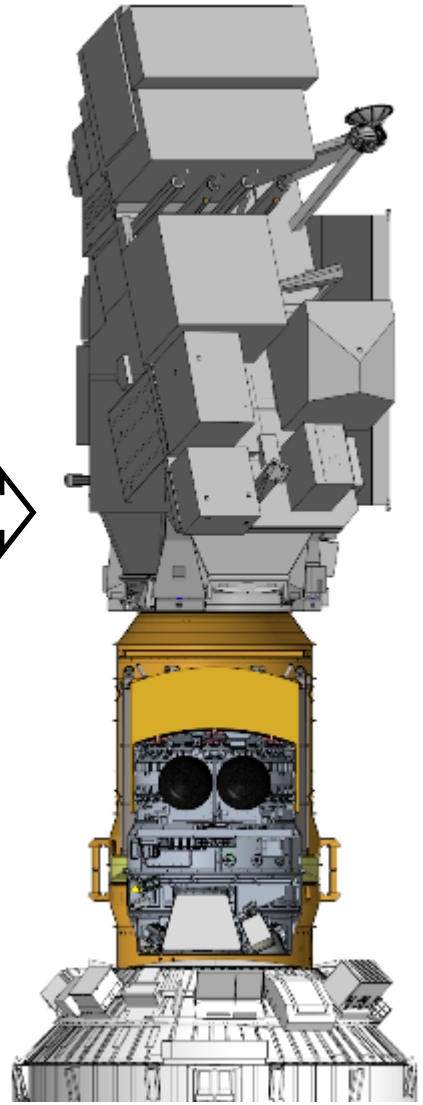


LOFTID Reentry Vehicle

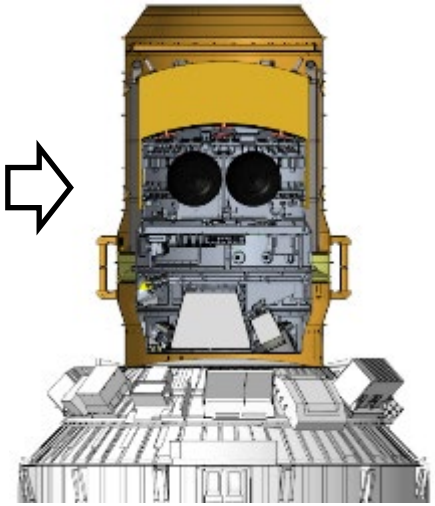
Mission Architecture Cross Section Views

JPSS-2 Primary Mission Second Stage

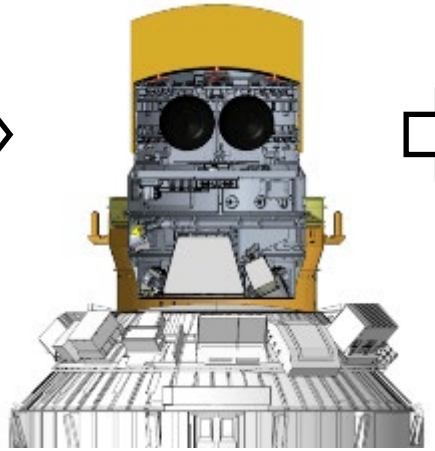
Extended Payload Fairing (EPF) Jettisoned



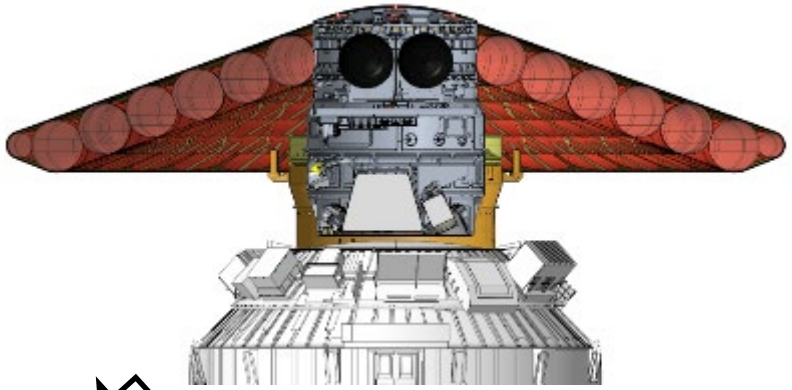
Primary Payload (JPSS-2) Separated



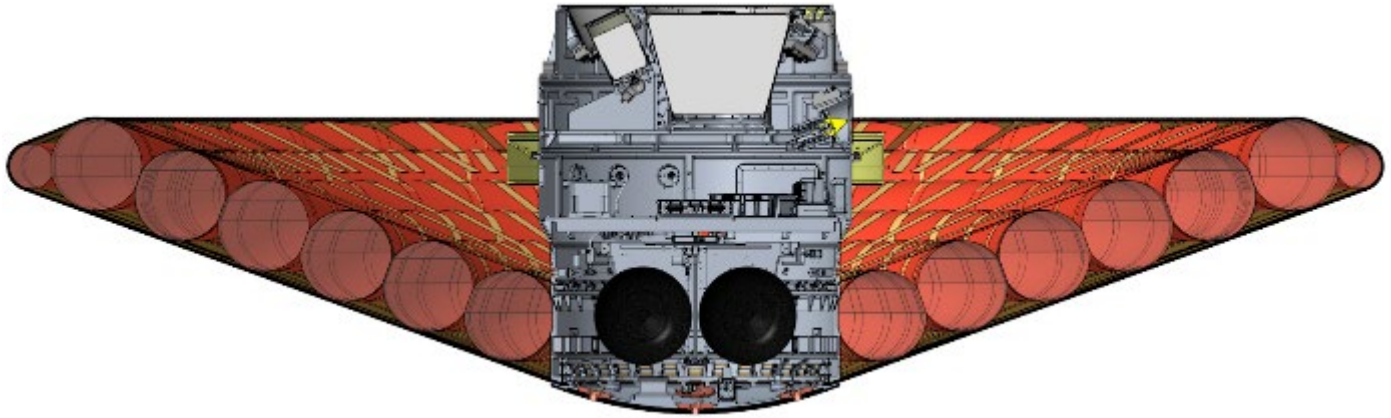
Payload Adapter (PLA) Canister Jettisoned



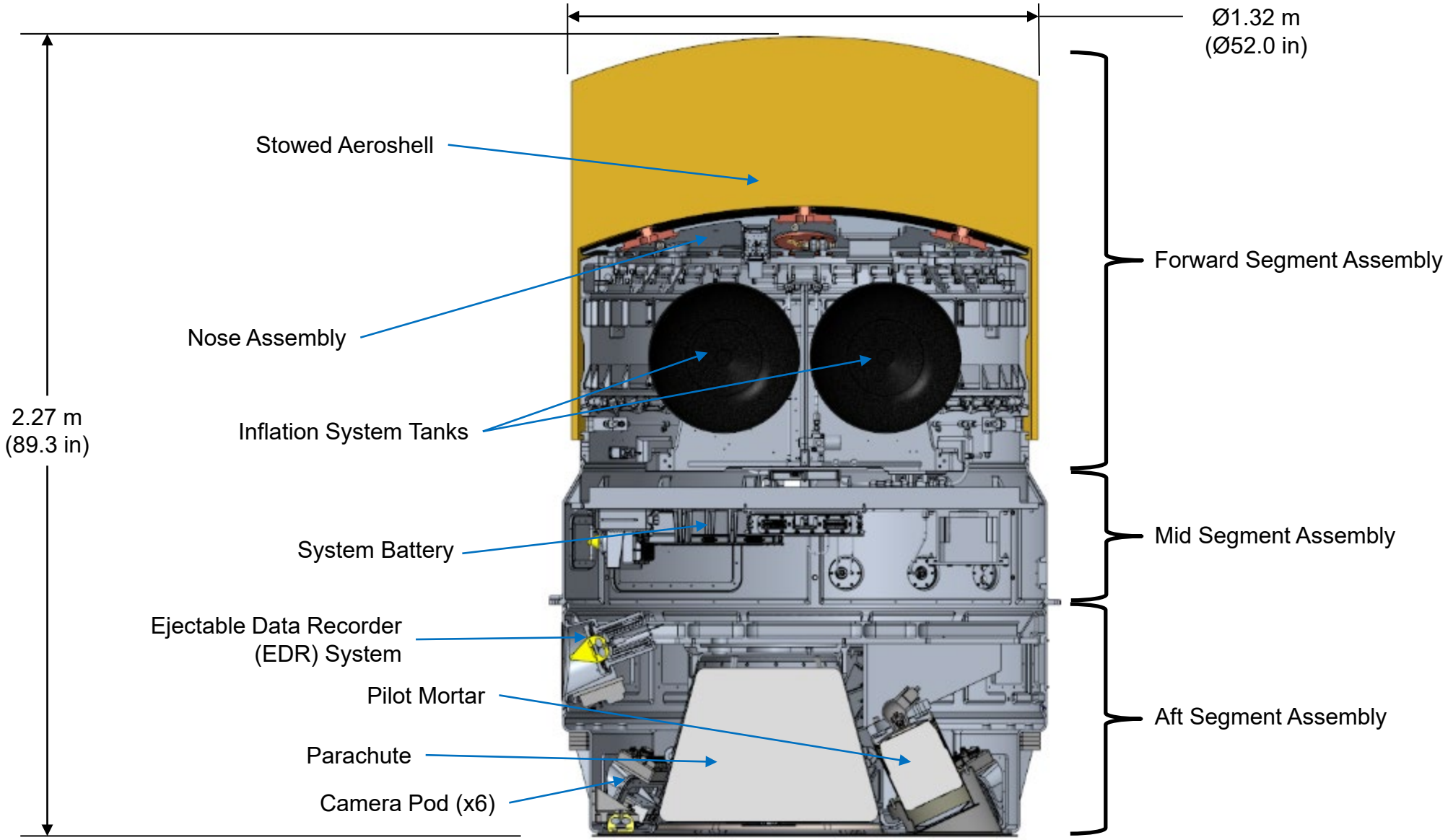
LOFTID Aeroshell Inflated



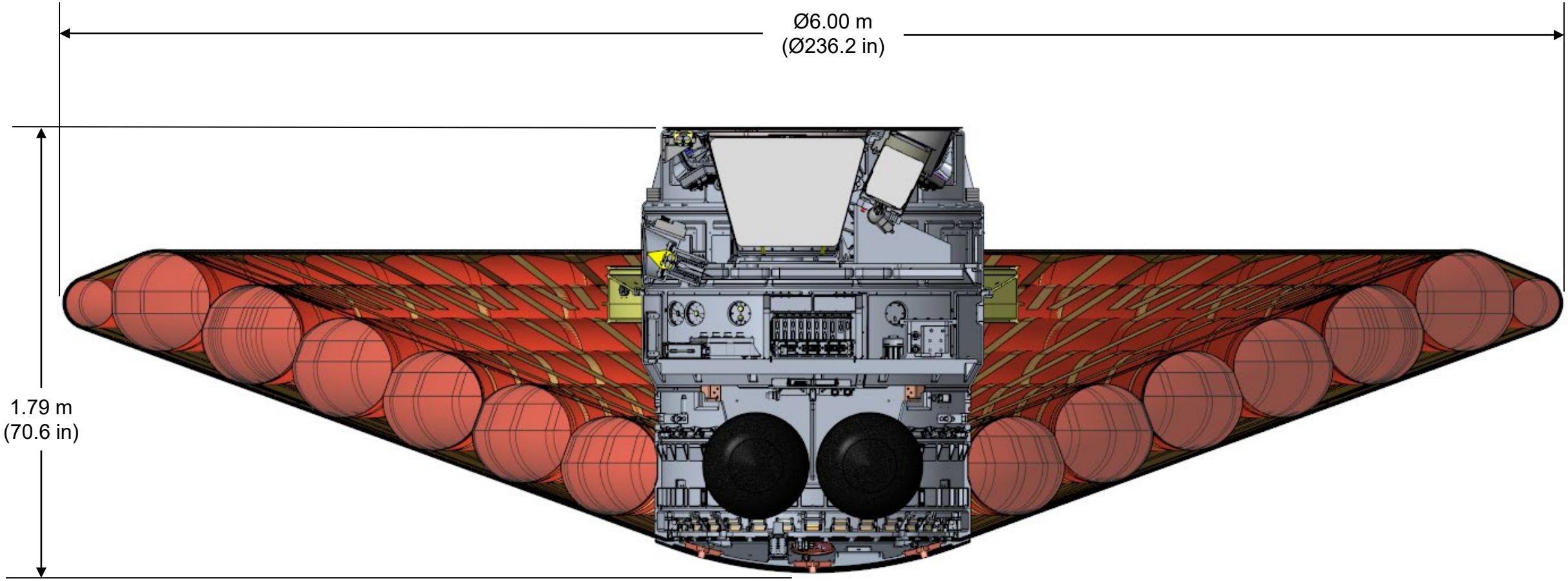
LOFTID Reentry Vehicle



RV at LV Integration

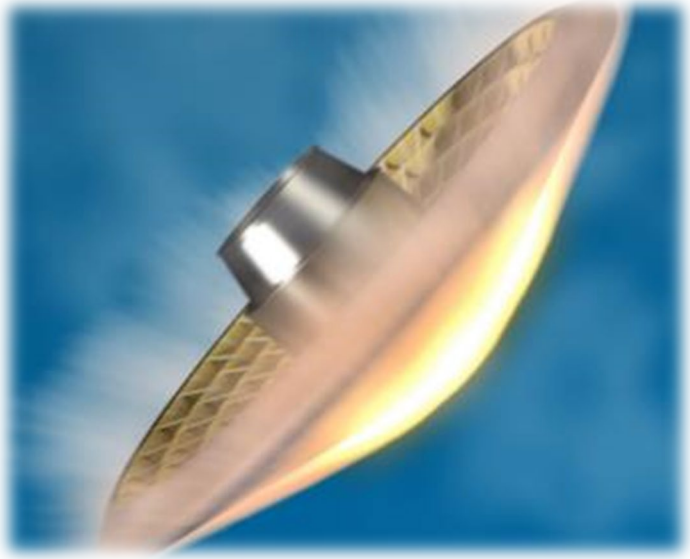


RV at Reentry

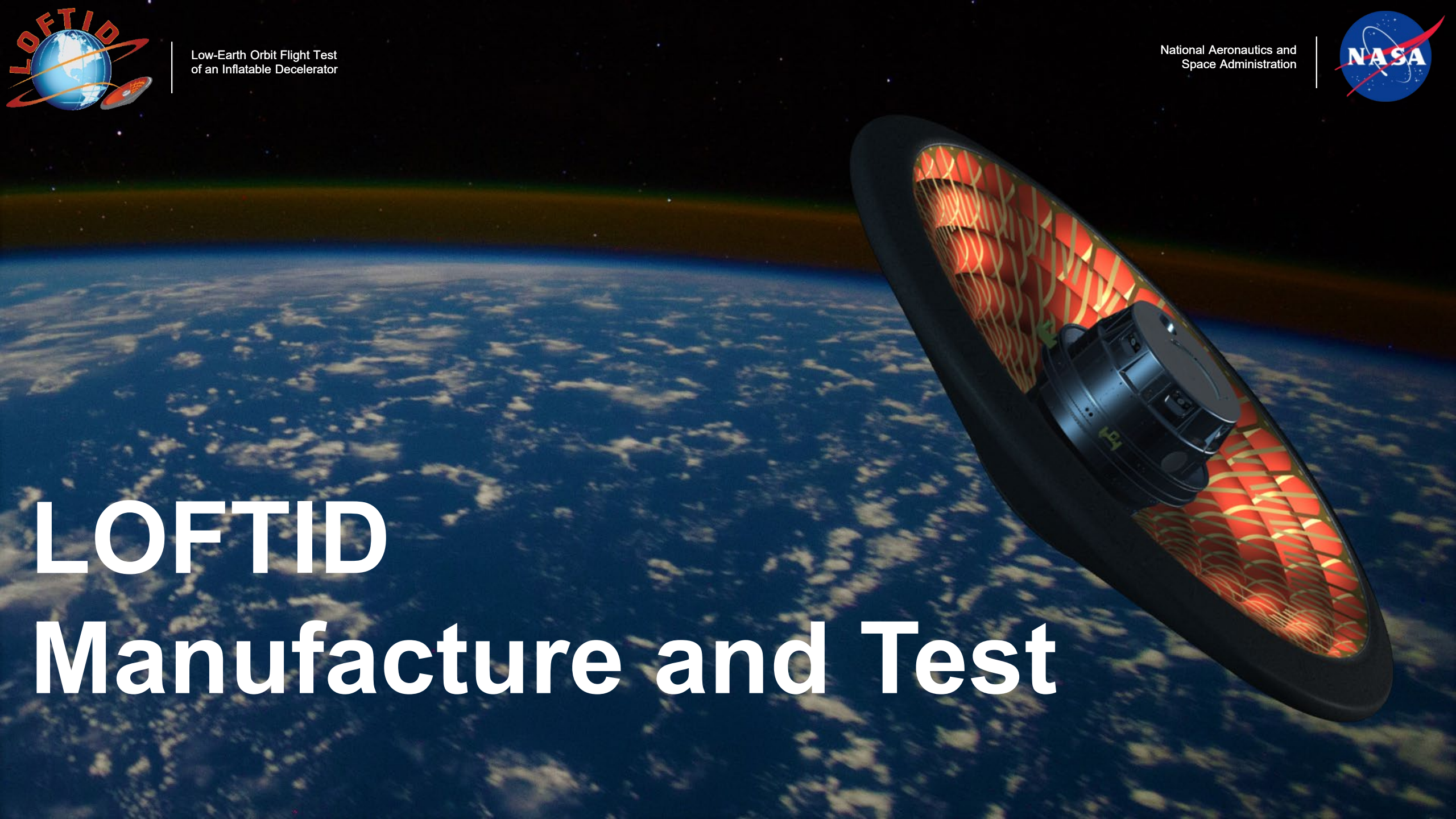


HIAD Flight Test Data Suite

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)



Low-Earth Orbit Flight Test
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National Aeronautics and
Space Administration

NASA

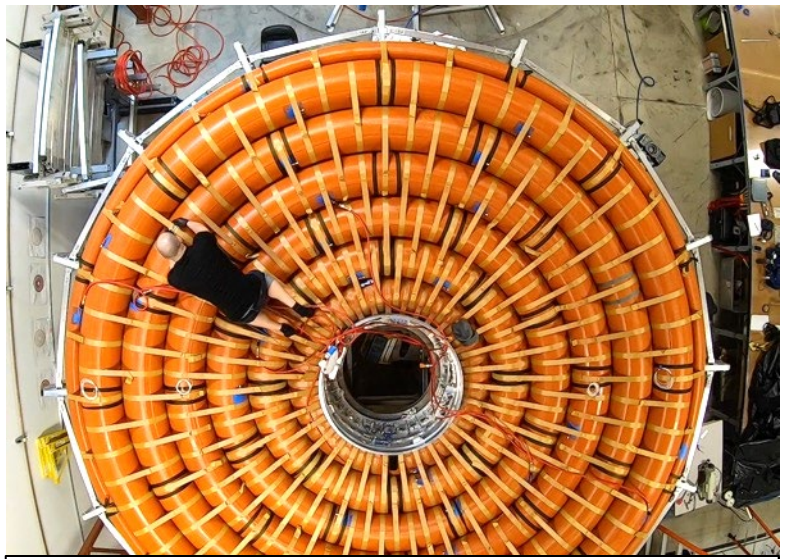
LOFTID Manufacture and Test

Aeroshell Fabrication

Liner Fabrication

Braid Layout

Torus Coating

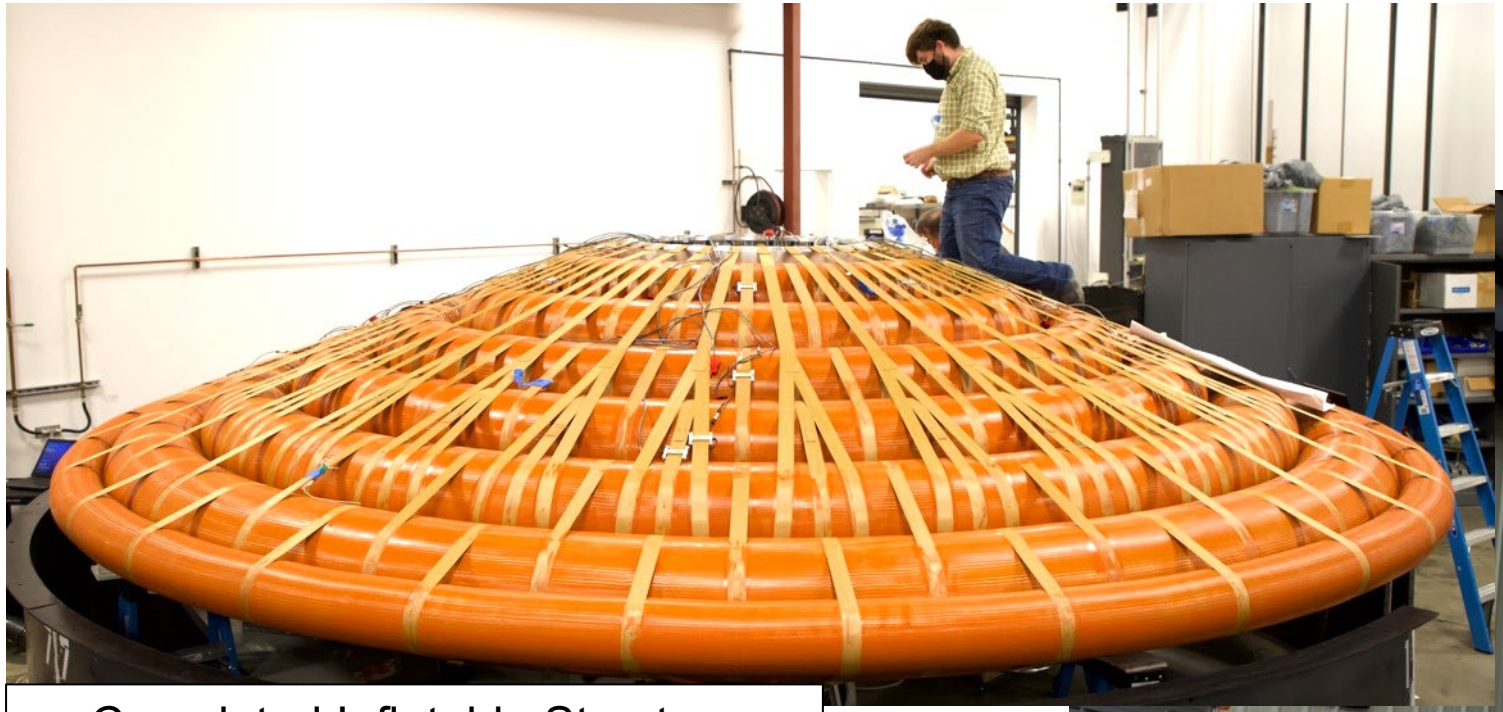


Stacking and Strapping

FTPS Fabrication

Rigid Nose and FTPS

Completed Aeroshell Components



Completed Inflatable Structure

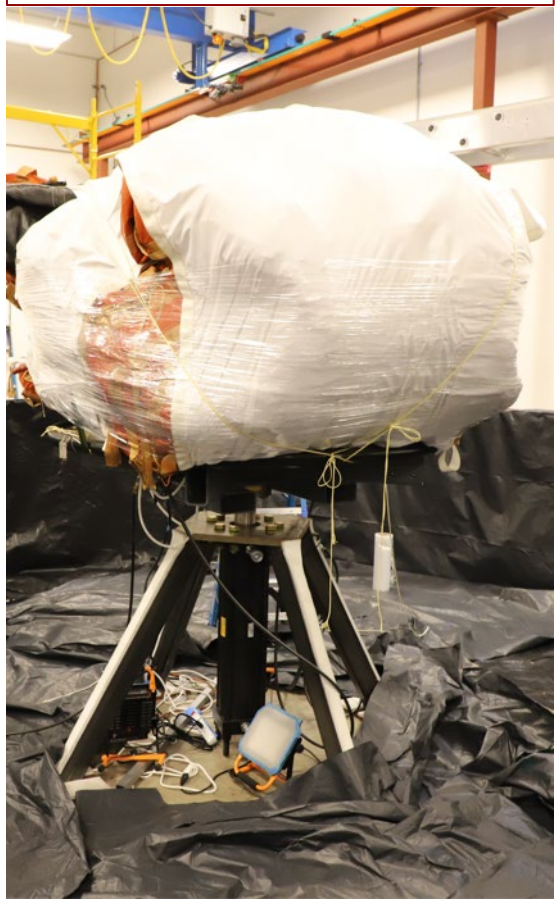
Completed Flexible TPS

Completed Nose

Static Load Test Video

Pack and Deployment Testing

Rough Pack



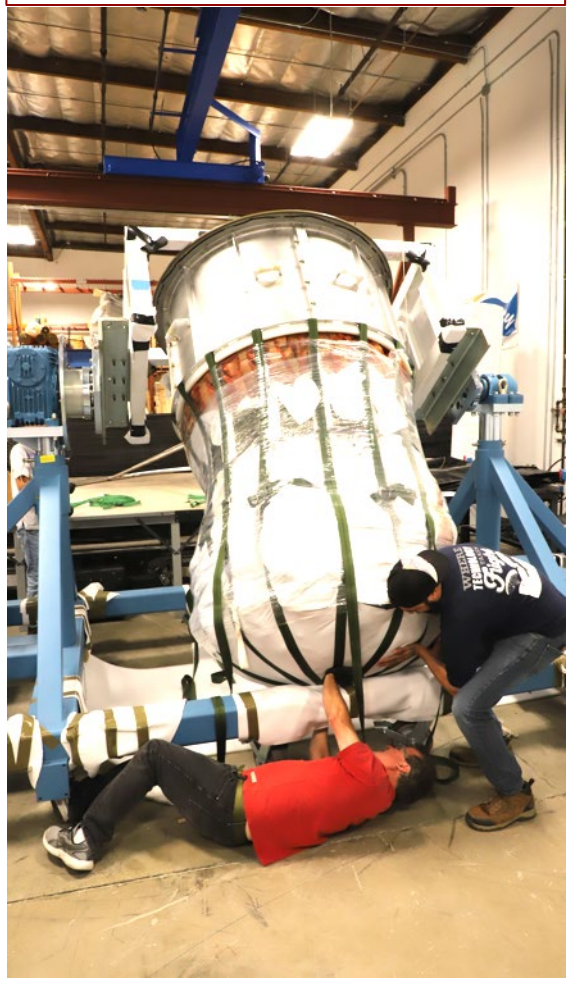
Suspension Fixture

Organize Soft Goods

Initial Pack

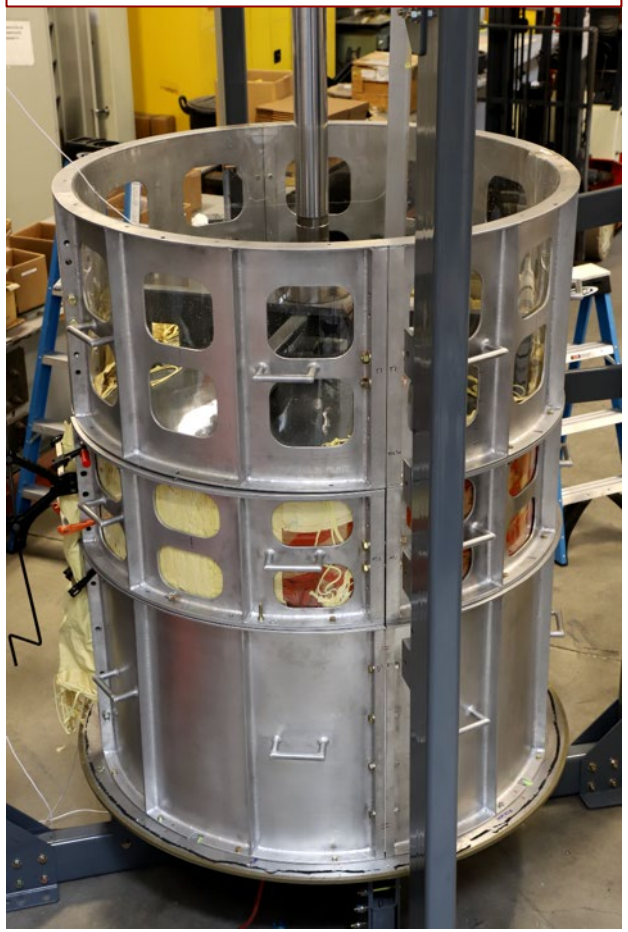
Pack and Deployment Testing

Turn Over

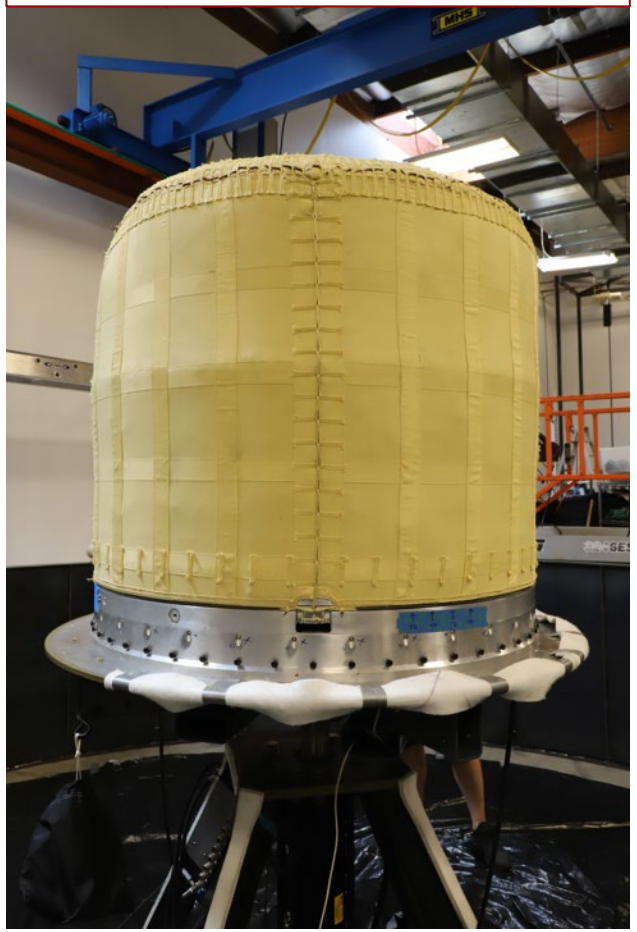


Packing Fixture

Ram Packed

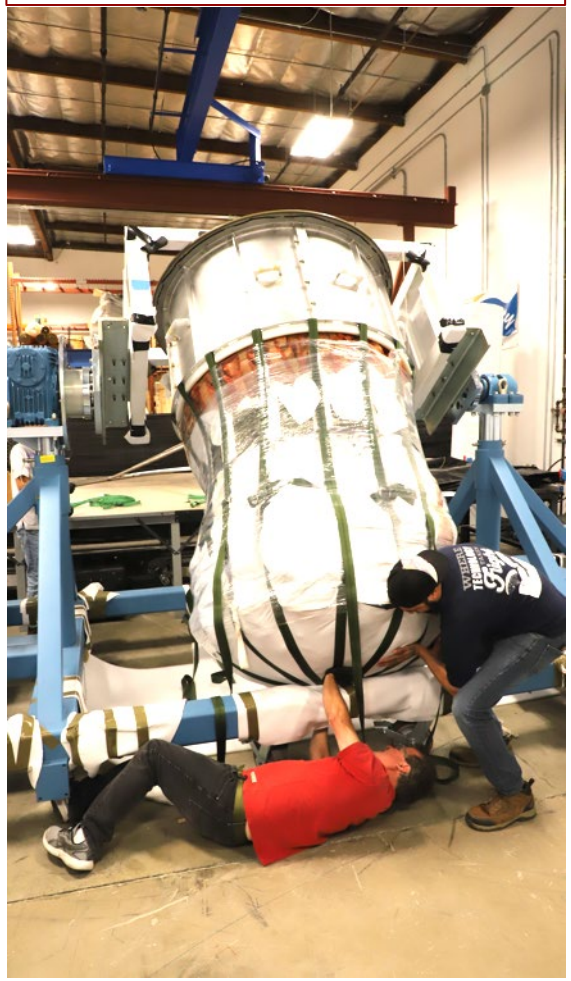


Final Pack



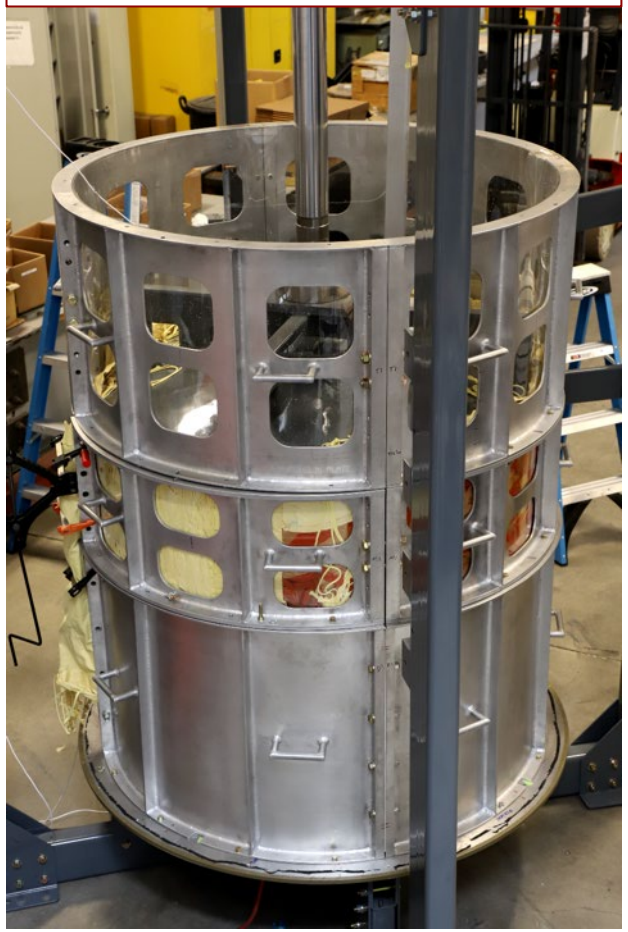
Pack and Deployment Testing

Turn Over

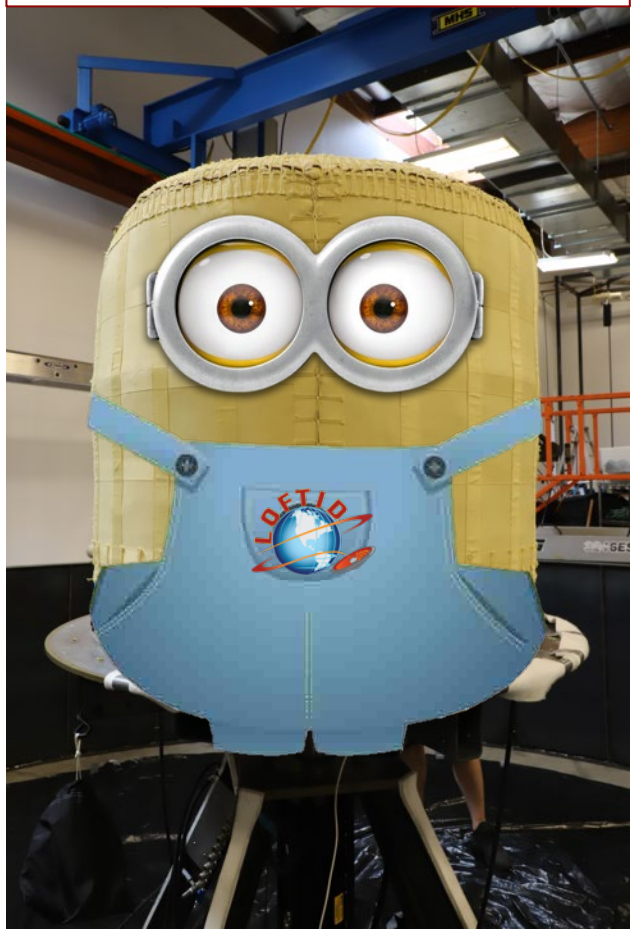


Packing Fixture

Ram Packed



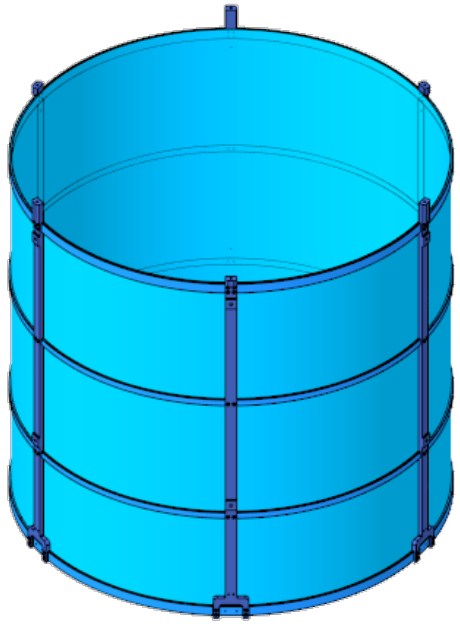
Final Pack

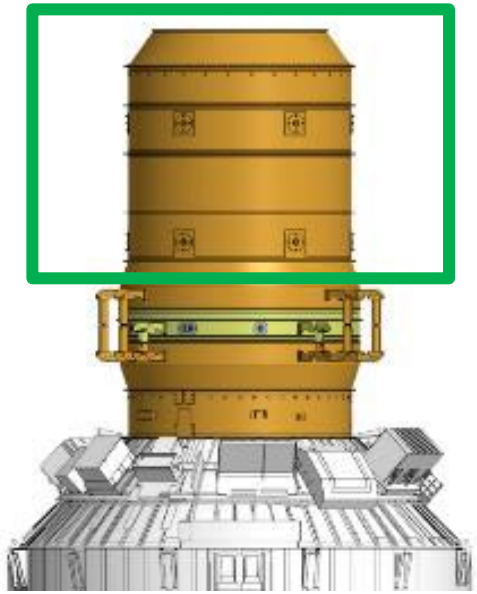


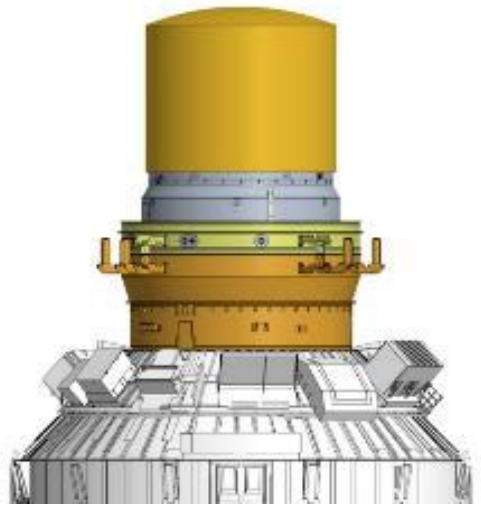
CST Video

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





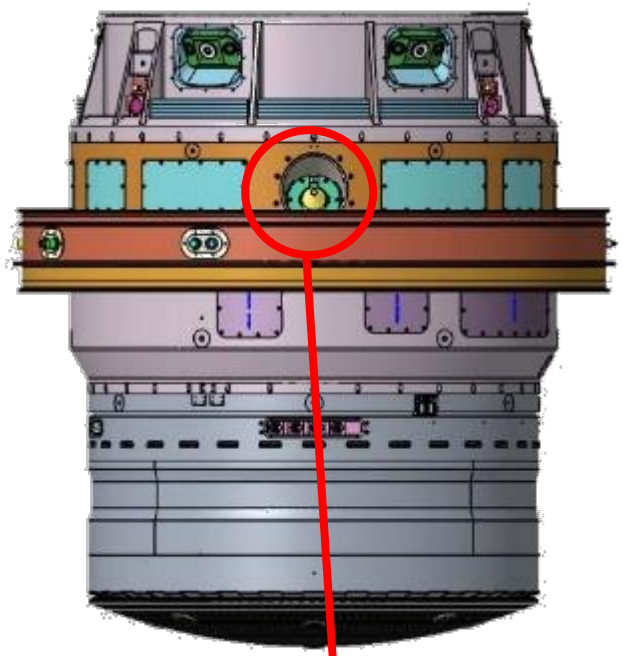


Status:

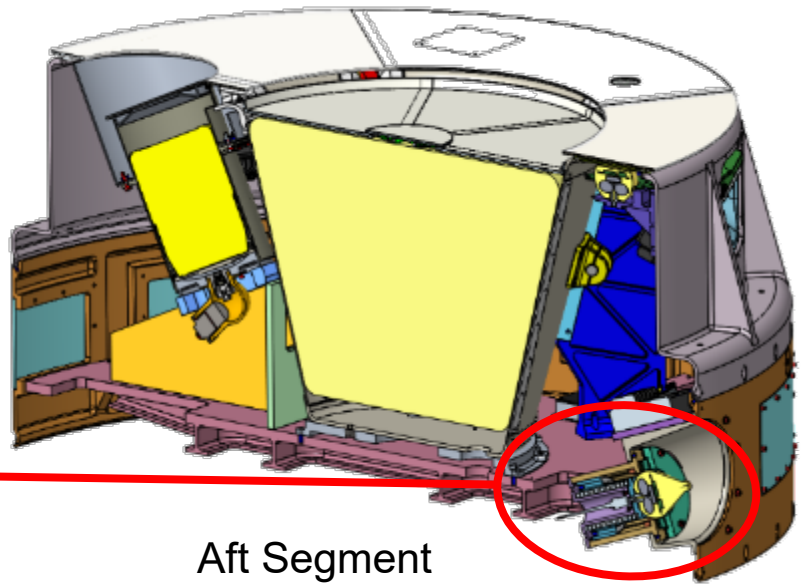
- LSSS EDU fabrication complete
- Halo load testing complete
- PASS CF Spring characterization in process
- Assembly planned for week of 7/19/21
- EDU qualification testing planned to begin week of 7/26/21

Ejectable Data Recorder (EDR)

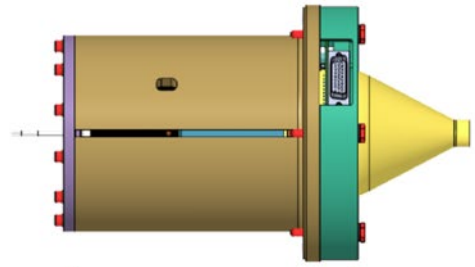
LOFTID Re-entry Vehicle
Aeroshell Removed



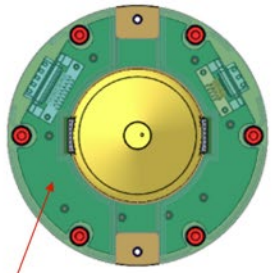
EDR



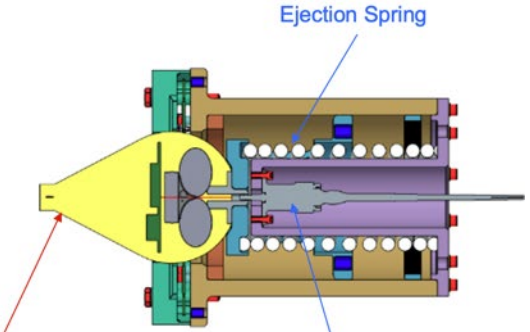
Aft Segment



EDR Ejection System



EDMIB



LaRC
DSS

Status

- 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

LOFTID Overview Pre-Flight Video


LOFTID
Low-Earth Orbit Flight Test
of an Inflatable Decelerator
National Aeronautics and
Space Administration
NASA
LOFTID
Flight Test

LANUCH VIDEO

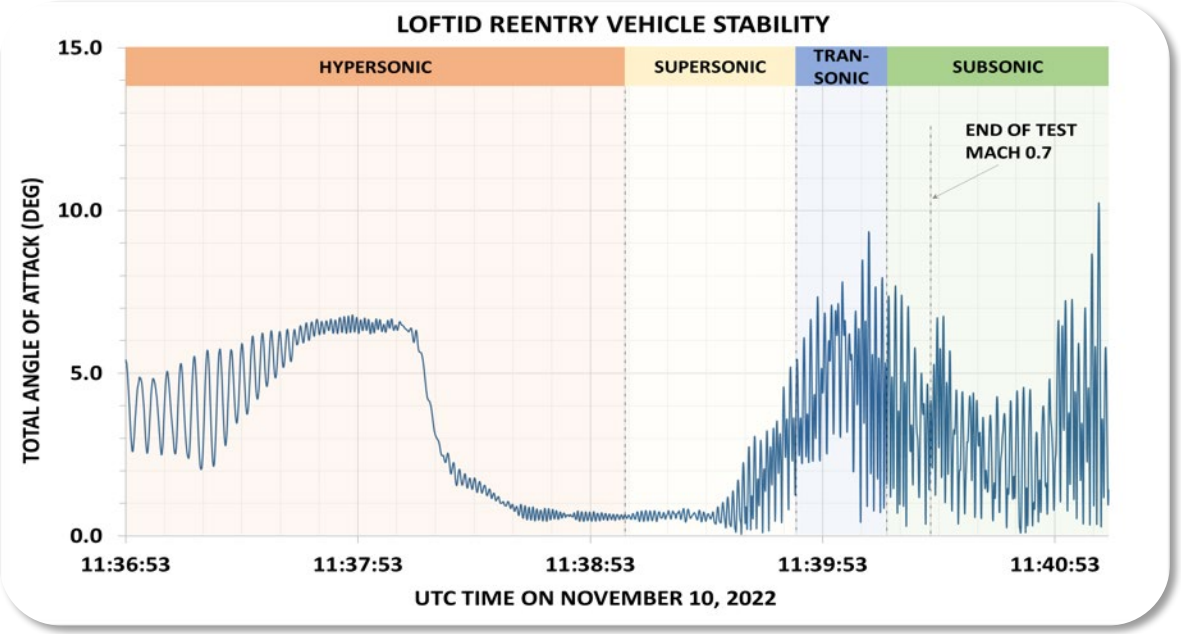
Successful Setup for the Flight Test!

Payload Adapter Jettison	Aeroshell Deployment	RV Inflation and Separation
		
		
Novel long-stroke Payload Adapter Separation System (PASS)	Restraint cover release	Inflation system control

Demonstrated Safety Benefits!

Conversely,
dynamic

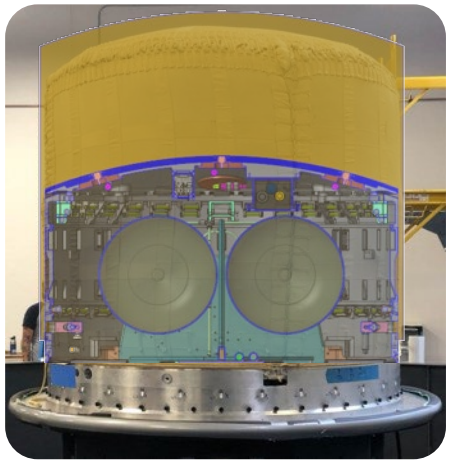
Maintained
wit

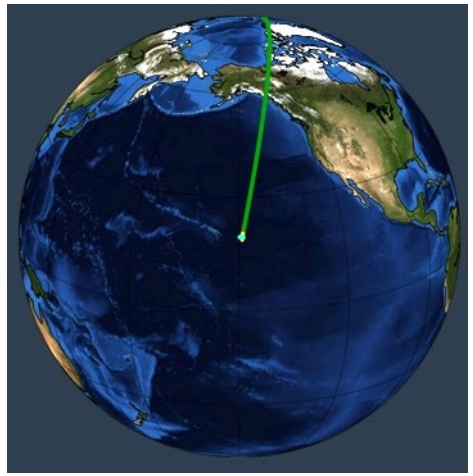


- LOFTID ballistic entry exhibited remarkable aerodynamic stability throughout hypersonic, supersonic, transonic, and subsonic regimes
- Payload well-protected from reentry environments, pristine when recovered
- Achieves descent and landing velocities at very high altitudes, enabling time for typically complex landing operations

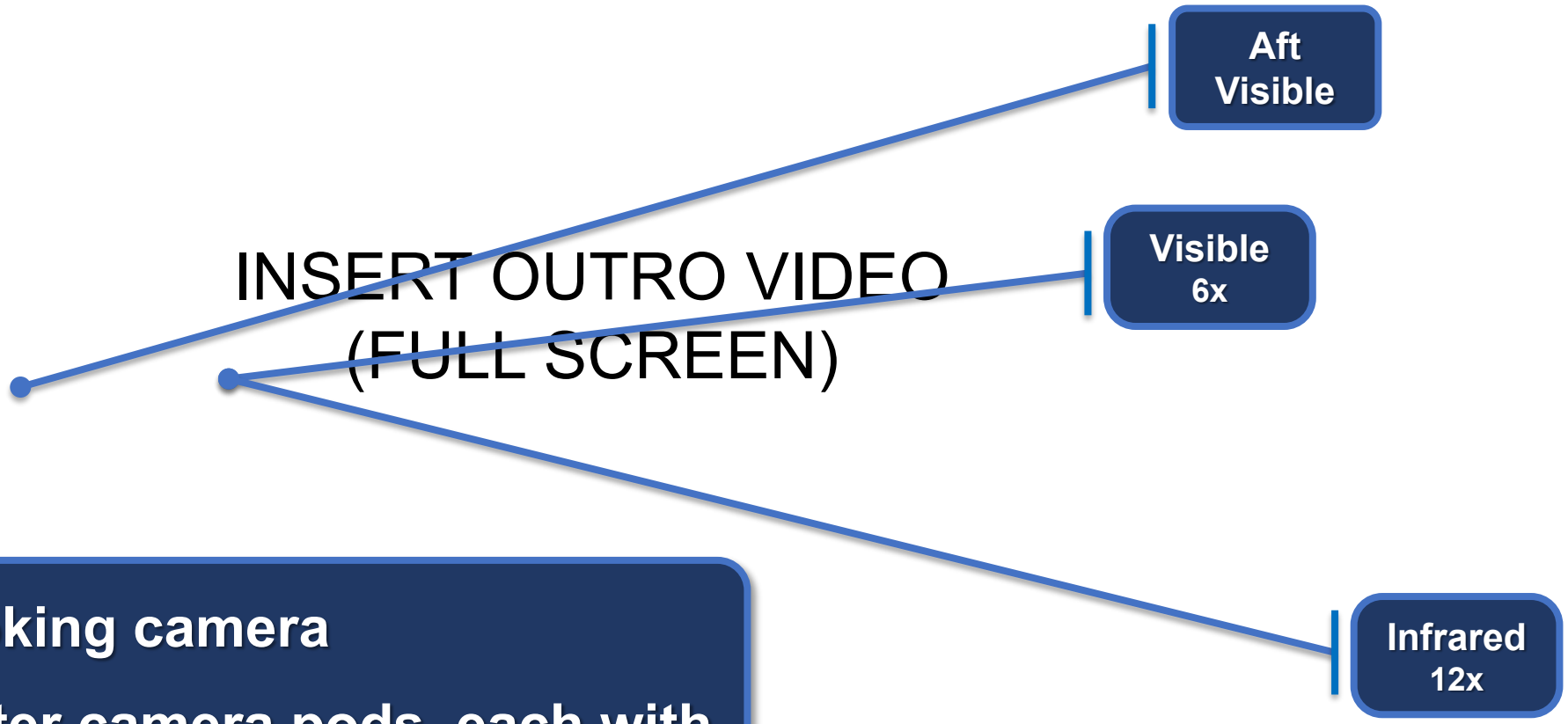
Outstanding Performance!

- Packed densely and stowed tightly for launch, deployed and inflated exo-atmospherically prior to entry
- Flexible Thermal Protection System (FTPS) withstood aerodynamic loading while providing highly effective thermal protection and correlating predictions
- Inflatable Structure withstood extreme drag loading, elevated temperatures, splashdown, and recovery operations
- Ballistic trajectory splashdown under parachute was on target





Entry Video



- **One aft-looking camera**
- **Six perimeter camera pods, each with one visible and two infrared cameras**

HIAD Technology Validated!

LOFTID Flight Demonstration Results

- Successful launch, deployment, reentry, splashdown, and recovery
- FTPS and Inflatable Structure performed effectively in extreme environments
- Validating HIAD technology represents the single largest advancement in Entry, Descent, and Landing (EDL) capability in the last 50 years!

LOFTID Reentry Vehicle in flight

LOFTID Reentry Vehicle back home at NASA Langley Research Center

HIAD technology enables larger, bolder space missions and human exploration of Mars!


HIAD
Hypersonic Inflatable Aerodynamic Decelerators
LOFTID
Questions?