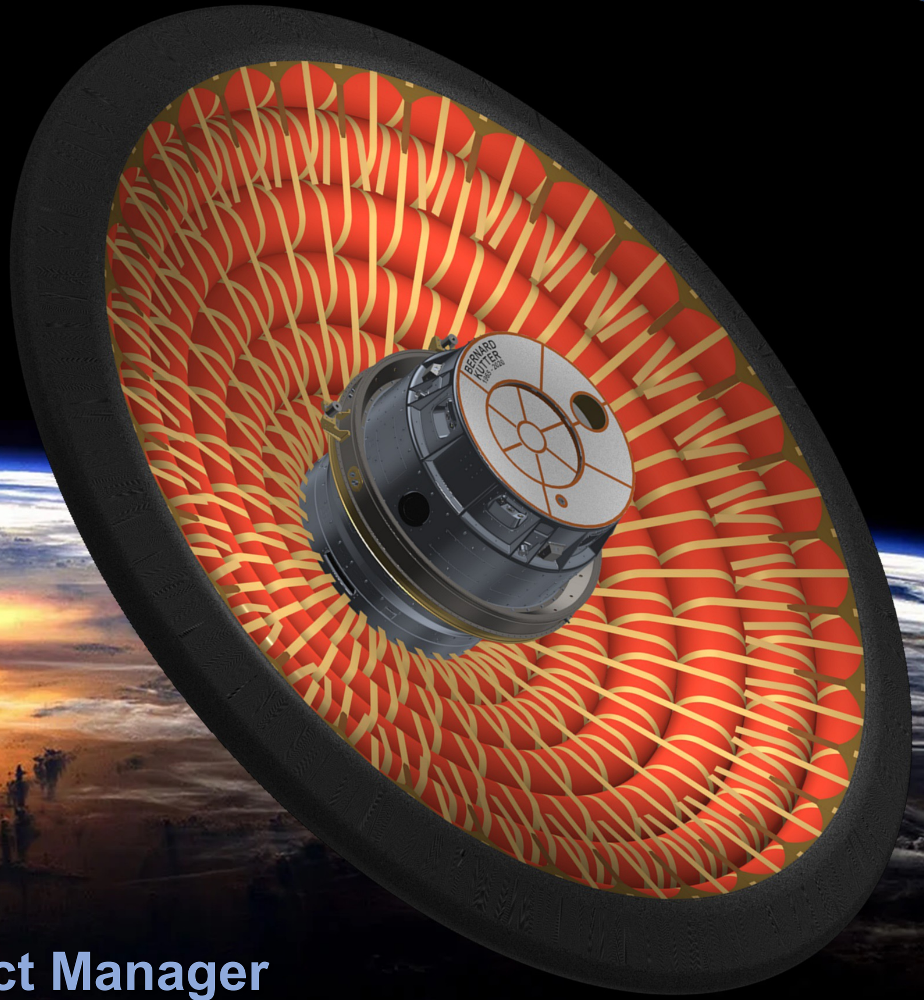
The Bernard Kutter LOFTID Mission

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



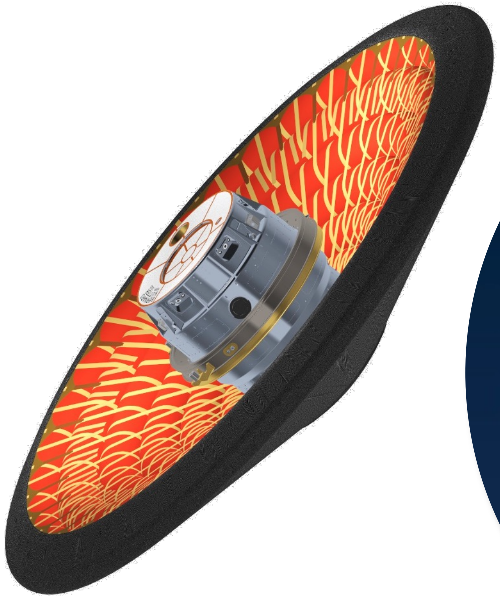
NASA Advisory Council

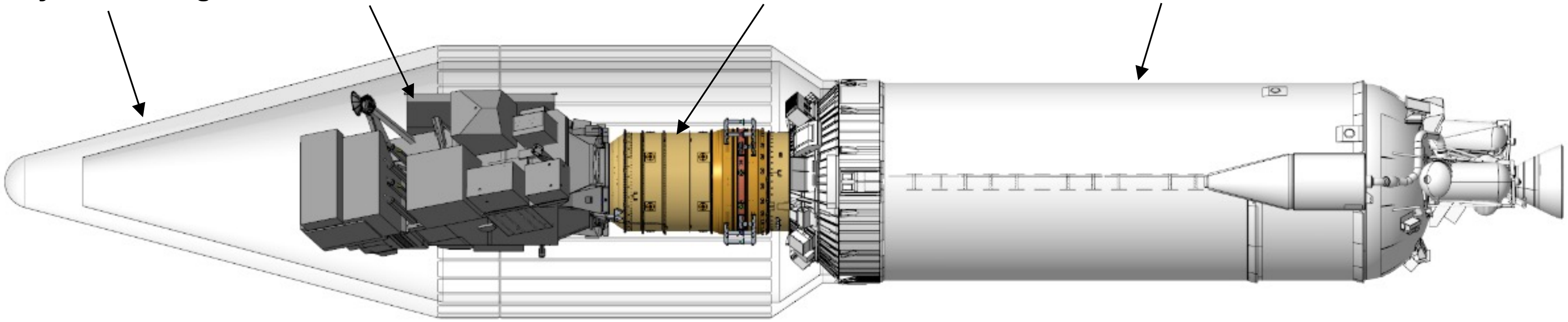
Presenter: Joseph Del Corso, LOFTID Project Manager
Slides Courtesy of: John DiNonno, LOFTID Chief Engineer

November 30, 2023

LOFTID, a HIAD Technology Demonstration

- **Hypersonic Inflatable Aerodynamic Decelerator (HIAD) is a softgoods aeroshell that can be packed and stowed for launch and cruise, then deployed prior to atmospheric entry to decelerate payloads**
- **LOFTID was an orbital entry demonstration of a HIAD Reentry Vehicle (RV) for heavy down-mass missions and commercial applications**
- **Launched on a United Launch Alliance (ULA) Atlas V rocket as a ride-share payload out of Vandenberg Space Force Base (VSFB), LOFTID demonstrated HIAD technology at scale and entry conditions relevant to Earth and Mars applications**





Largest blunt-body aeroshell ever

Entered at 8 km/s, and reached Mach 30

LOFTID Architecture

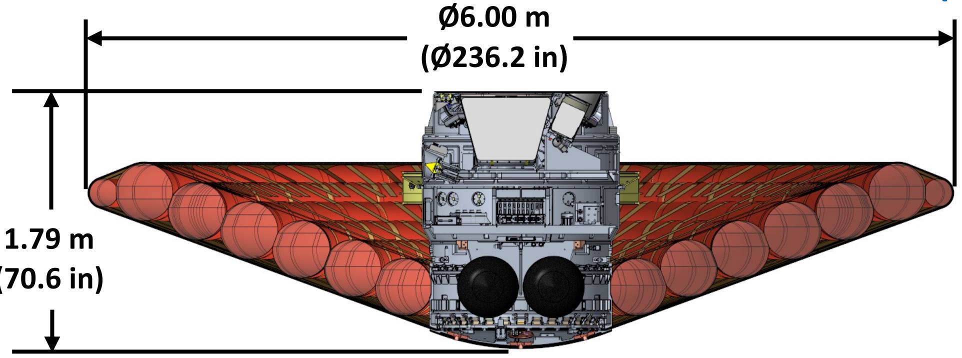
Payload Adapter Separation System (PASS)
Remains with PLA Canister at PLA Canister Jettison

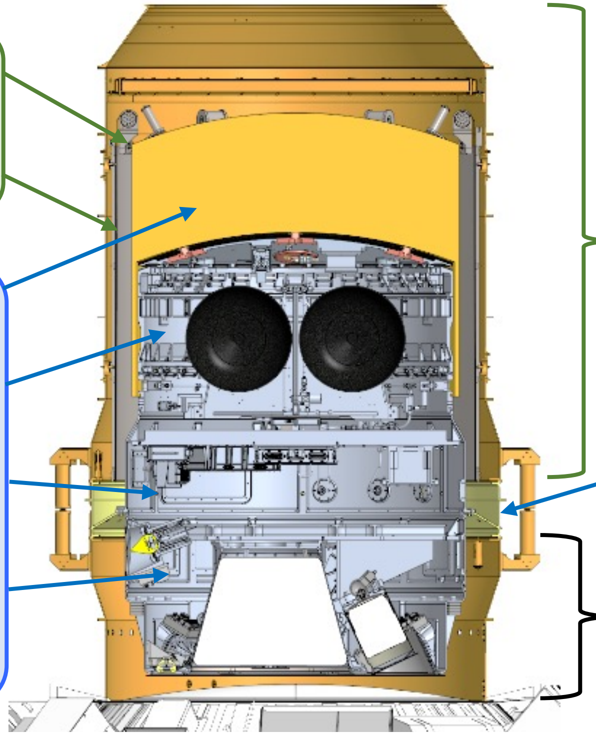
- Halo & Springs
- Inner Shroud

Reentry Vehicle (RV)

- Hard-packed Aeroshell
- Fwd Segment & Inflation System with Tanks
- Mid Segment & Avionics Deck
- Aft Segment & Ejectable Data Recorder, Cameras, Beacons, & Parachute System

Reentry Configuration
Mass: 1100 kg (2426 lbm)





Payload Adapter (PLA) Canister

Interface Ring
Remains with RV at RV Separation

Payload Adapter
Remains with Centaur

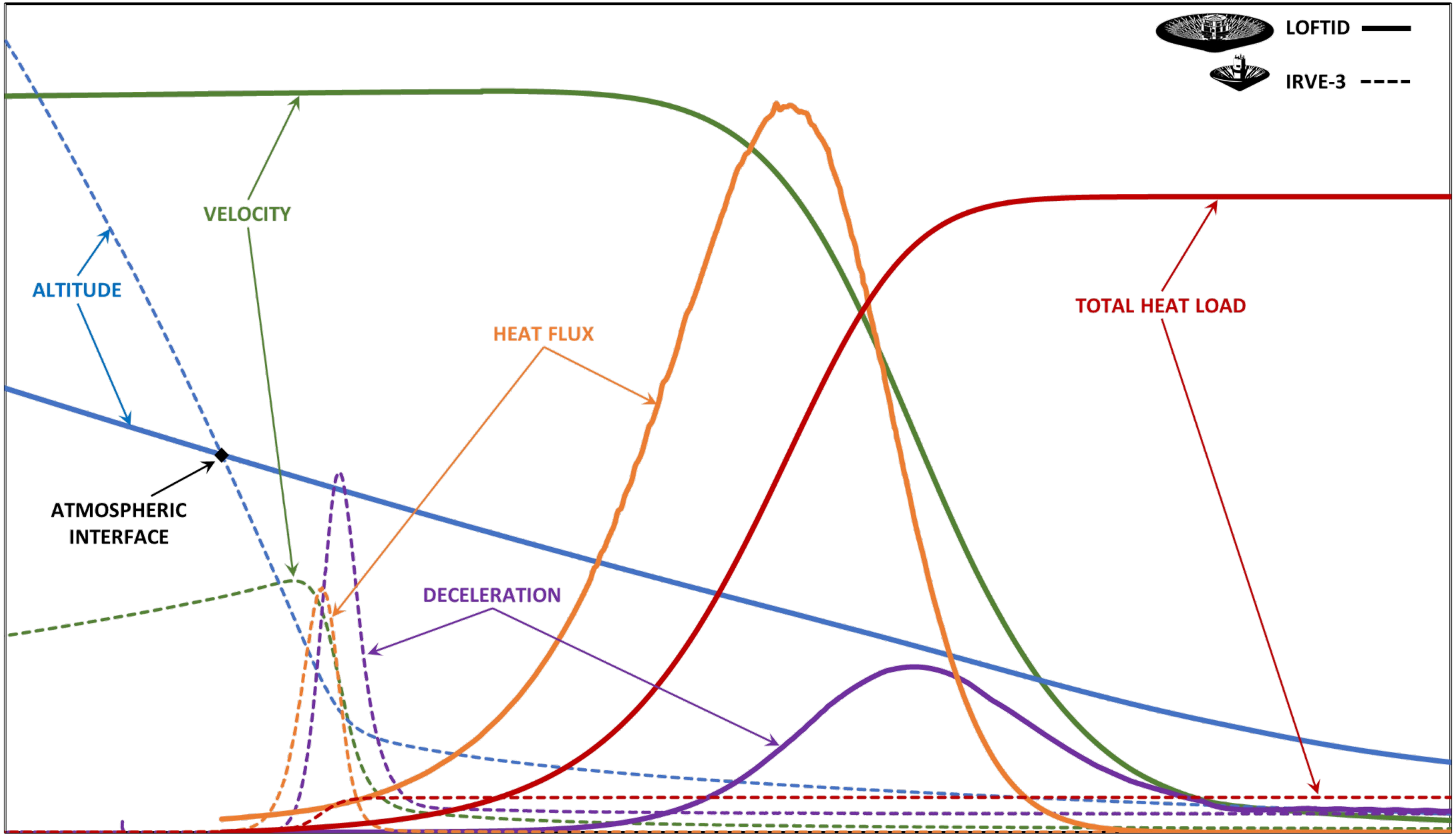
LOFTID vs. IRVE-3 Reentry Pulse

IRVE-3: Inflatable Reentry Vehicle Experiment-3

- HIAD flight demo in 2012
- Suborbital sounding rocket
- 3m diameter aeroshell

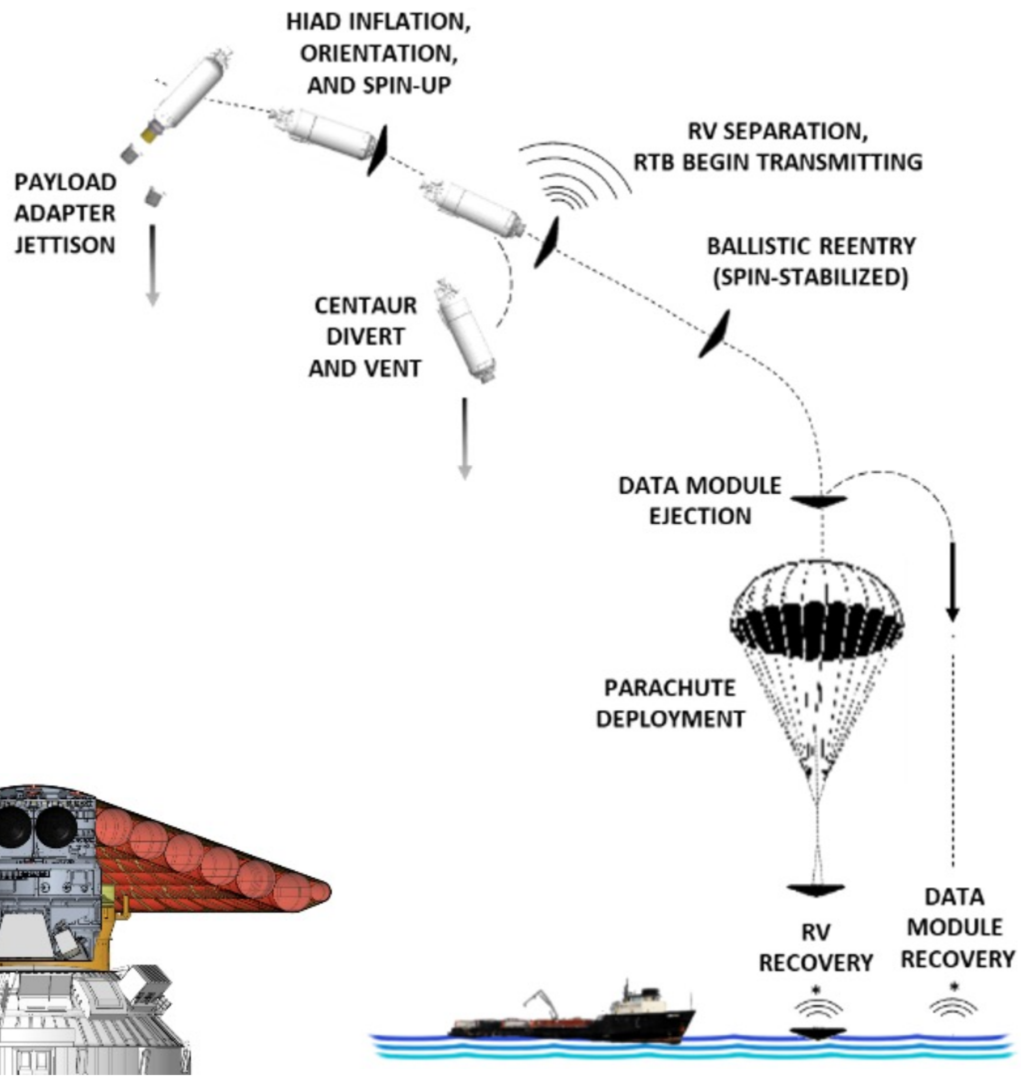
LOFTID saw:

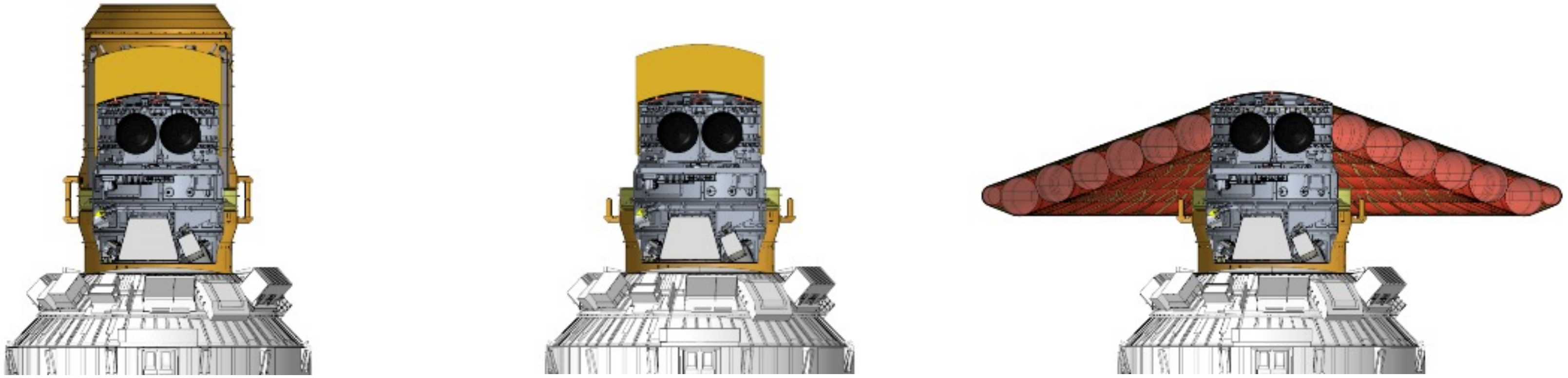
- Nearly 3x the entry velocity
- More than 2x the peak heating
- More than 6x heat pulse duration
- More than 10x the total heat load



Concept of Operations
(after JPSS-2 Delivered and after Deorbit Burn)

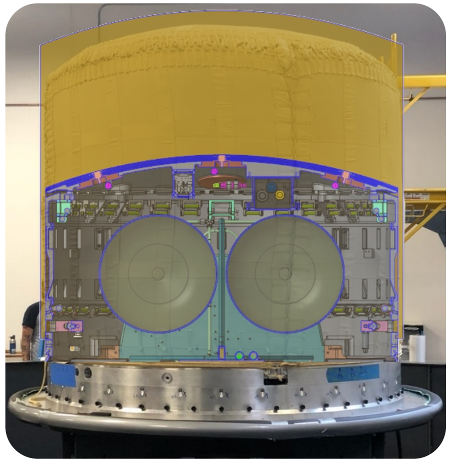
Animation from September 2021. Launched on November 10, 2022.

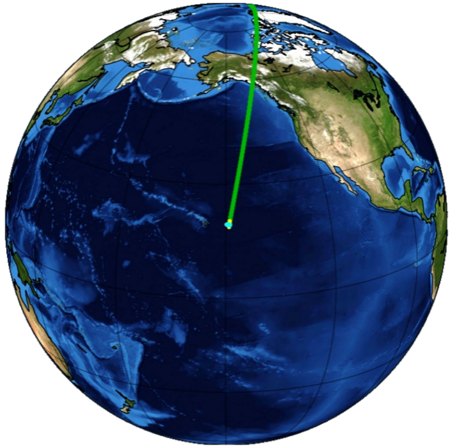


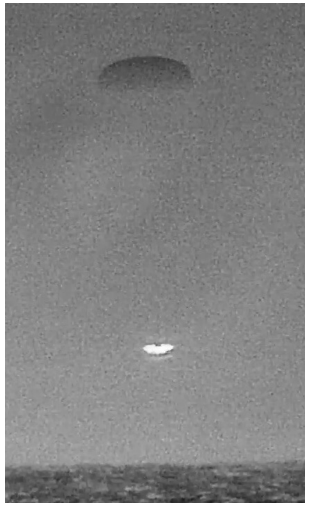


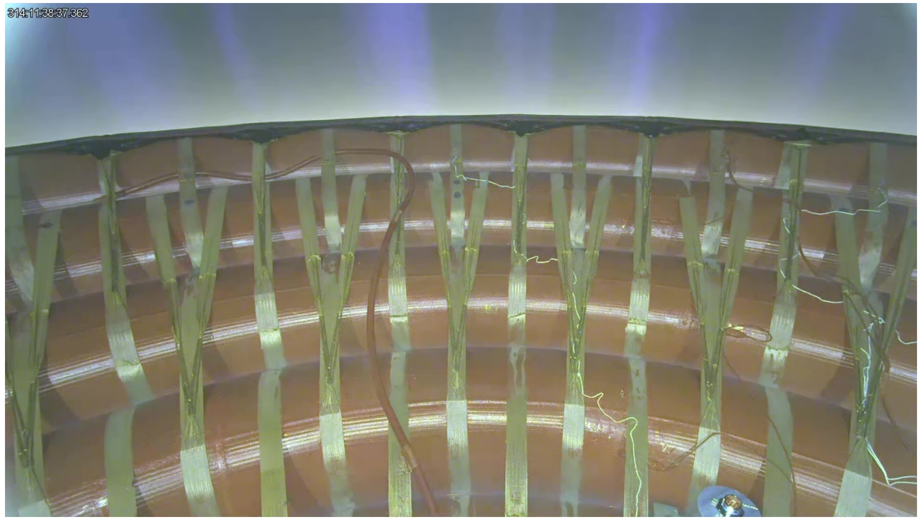
A Triumphant Success

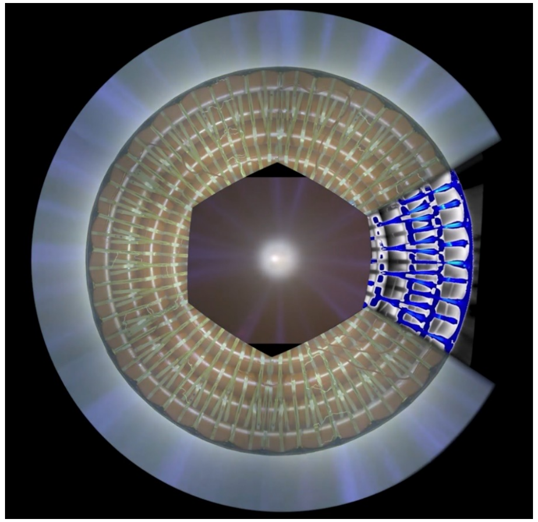
- Packed densely and stowed tightly for launch, deployed and inflated exo-atmospherically prior to entry
- Flexible Thermal Protection System (FTPS) withstood aerodynamic loading while thermally isolating the HIAD structure and payload from the reentry environment
- Inflatable Structure withstood extreme drag loading, elevated temperatures, splashdown, and recovery operations
- Uncontrolled trajectory splashdown under parachute was on target









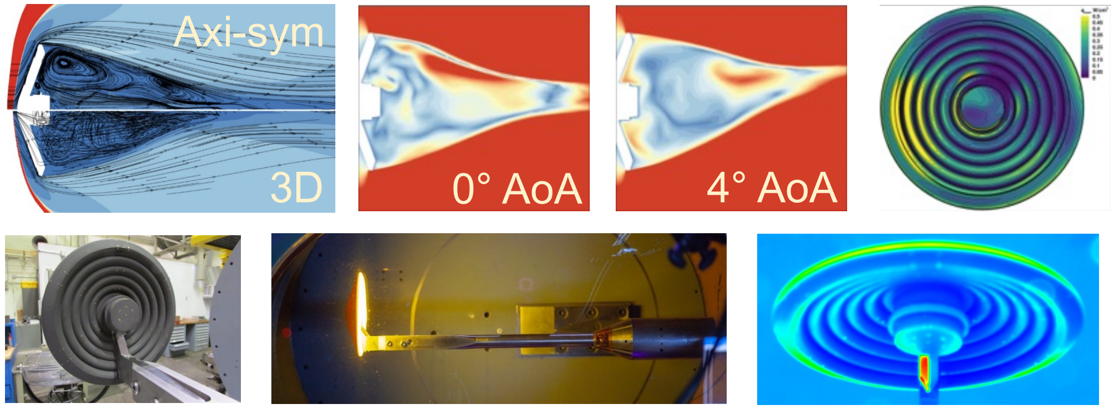


Developed Analytical Tools

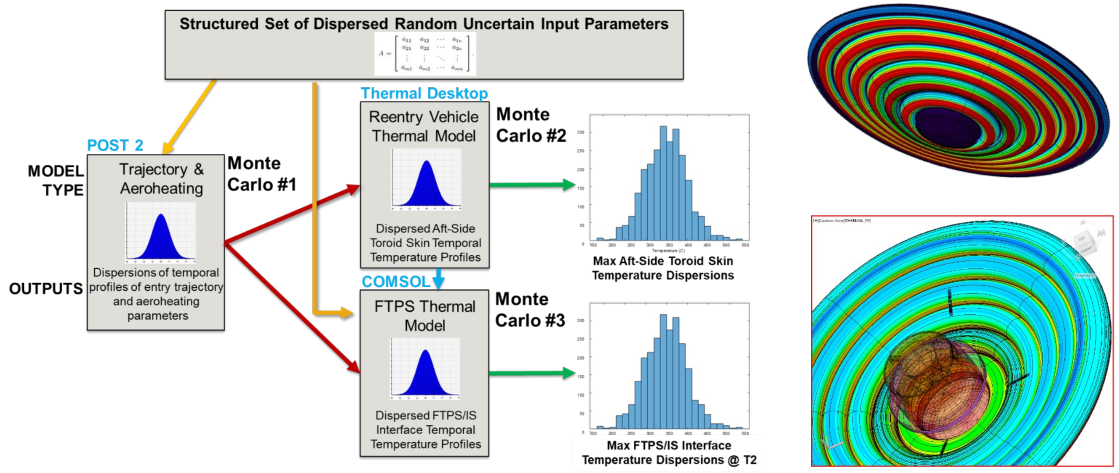
- **LOFTID developed innovative analytical tools that improve future capabilities, even beyond HIAD**
  - Aero/Aerothermal Computational Fluid Dynamics (CFD), particularly for wake flow environment
  - End-to-End Monte Carlo for in-depth heatshield and structure thermal performance assessment
- **These physics-based tools are anchored in ground testing**
- **Beyond LOFTID, the demonstration provides a treasure trove of flight data for use by others for tool development (wake flow simulations, etc.)**

LOFTID flight-correlated data validates analytical models

Wake Flow Modeling in 3D

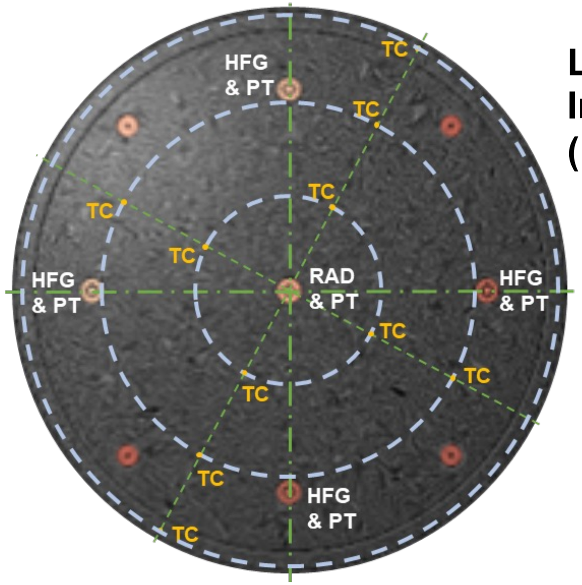


End-to-End Monte Carlo (E2EMC) Thermal Analysis



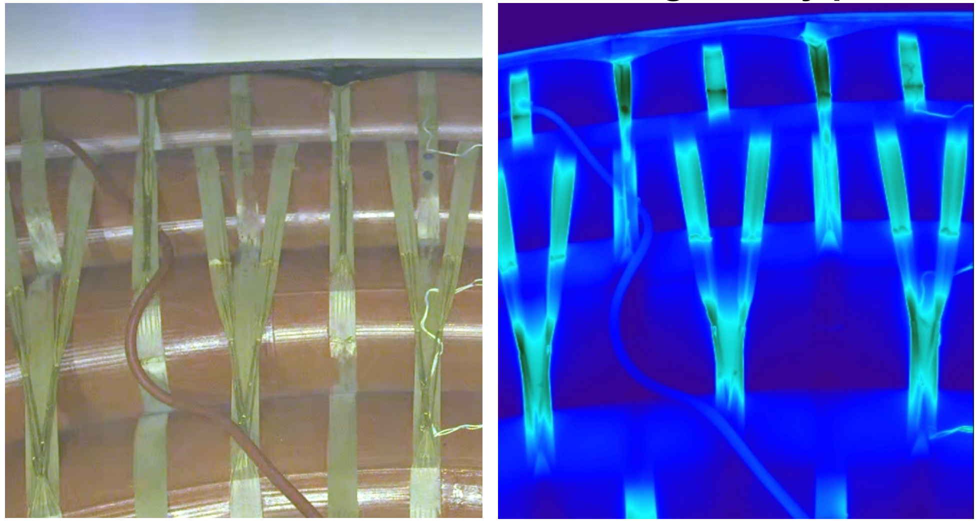
Flight Demonstration Data Suite

- **Nose and aeroshell instrumentation**
  - Surface and in-depth thermocouples (including aftbody)
  - 4x total heat flux gages, and a radiometer
  - Pressure transducers form Flush Air Data System (orientation and atmospheric density)
  - Loadcell clevis pins on IS straps (provide some inertial data)
  - Fiber Optic Sensing System (FOSS) in nose and on centerbody for temperature distribution
- **Internal instrumentation (onboard network error – did not record data)**
  - ~~Inertial Measurement Unit (IMU)~~
  - ~~Global Positioning System (GPS) unit~~
  - ~~Inflation system instrumentation~~
- **Video/Imaging**
  - Visible video (intended 360-deg coverage) for context, structural response, diagnostics (1 of 6 inoperable, known issue prior to launch, yielding 300 deg coverage)
  - 12x Infrared (IR) imaging (360-deg coverage) for aft-side temperature distribution on aeroshell
  - Up-Look HD Camera (captured reentry pulse plasma wake closure)
  - External SCIFLI LOFTID Imaging Mission (SLIM) video of reentry
  - External Infrared video of descent under parachute from recovery ship
- **Data recovery**
  - Comprehensive data set to onboard recorder - recovered with RV
  - Comprehensive set to ejectable recorder - recovered separately
  - Beacon utilizing Iridium network to relay minimal "real-time" data set (orientation/status) – 9 data packets received (8 with GPS lock), after reentry and prior to parachute deployment
  - RV recovery (inspection of HIAD after flight)



LOFTID Nose Instrumentation (FOSS not shown)

Visible & IR at same moment during reentry pulse



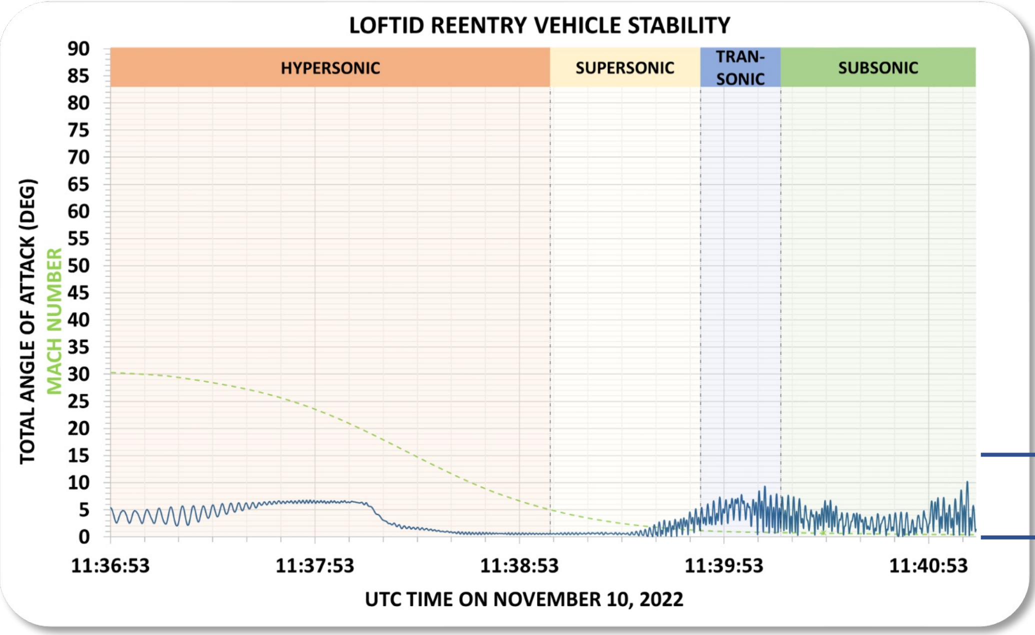
Demonstrated Aerodynamic Stability

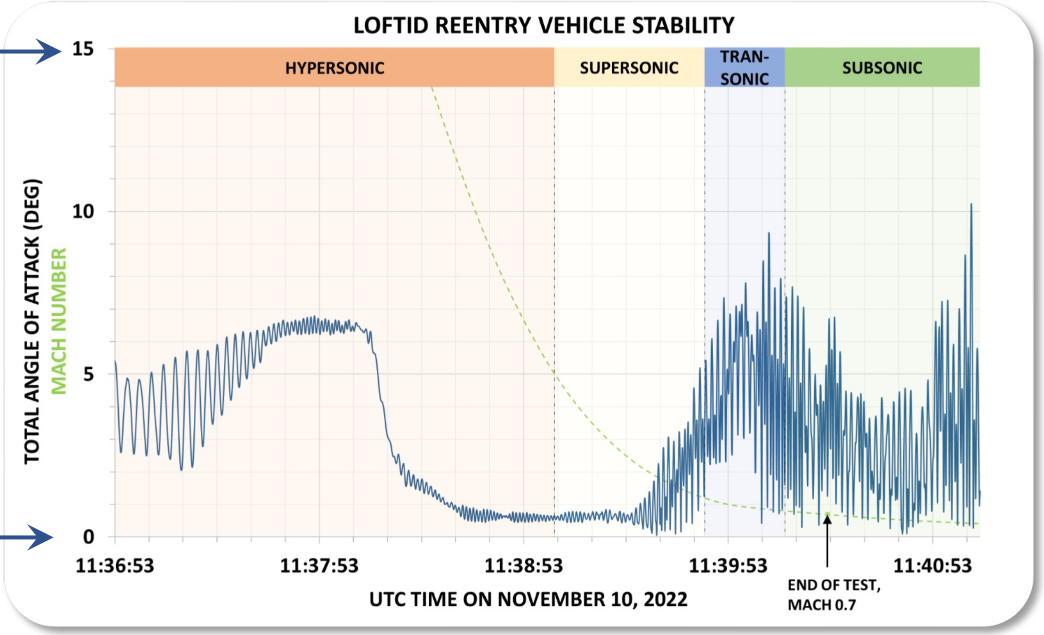
Typical ballistic entries of blunt bodies require stability augmentation for supersonic and below

Conversely, LOFTID demonstrated dynamic stability throughout

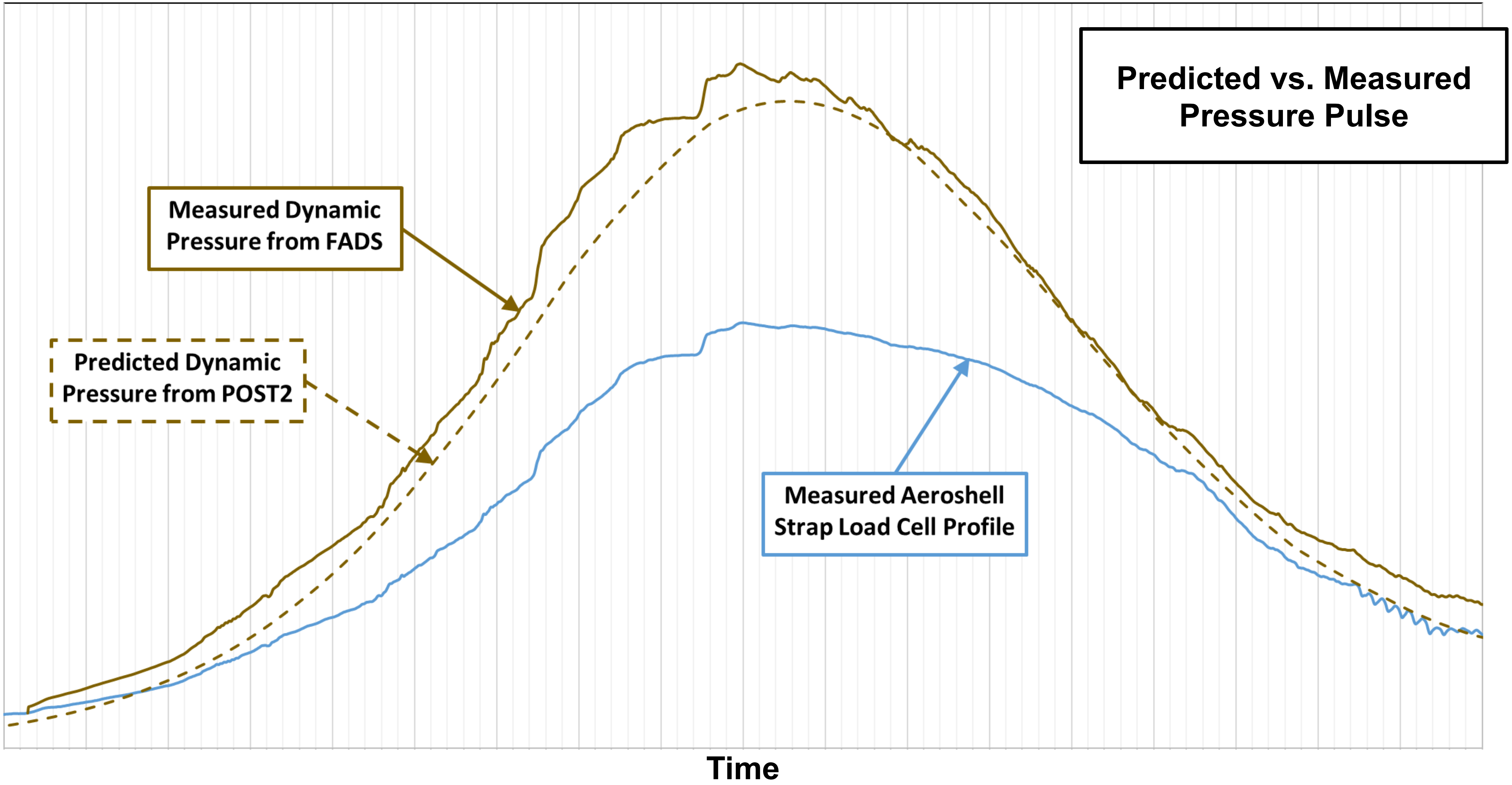
Maintained low Total Angle of Attack within 11 degrees

LOFTID ballistic entry exhibited remarkable aerodynamic stability throughout hypersonic, supersonic, transonic, and subsonic regimes

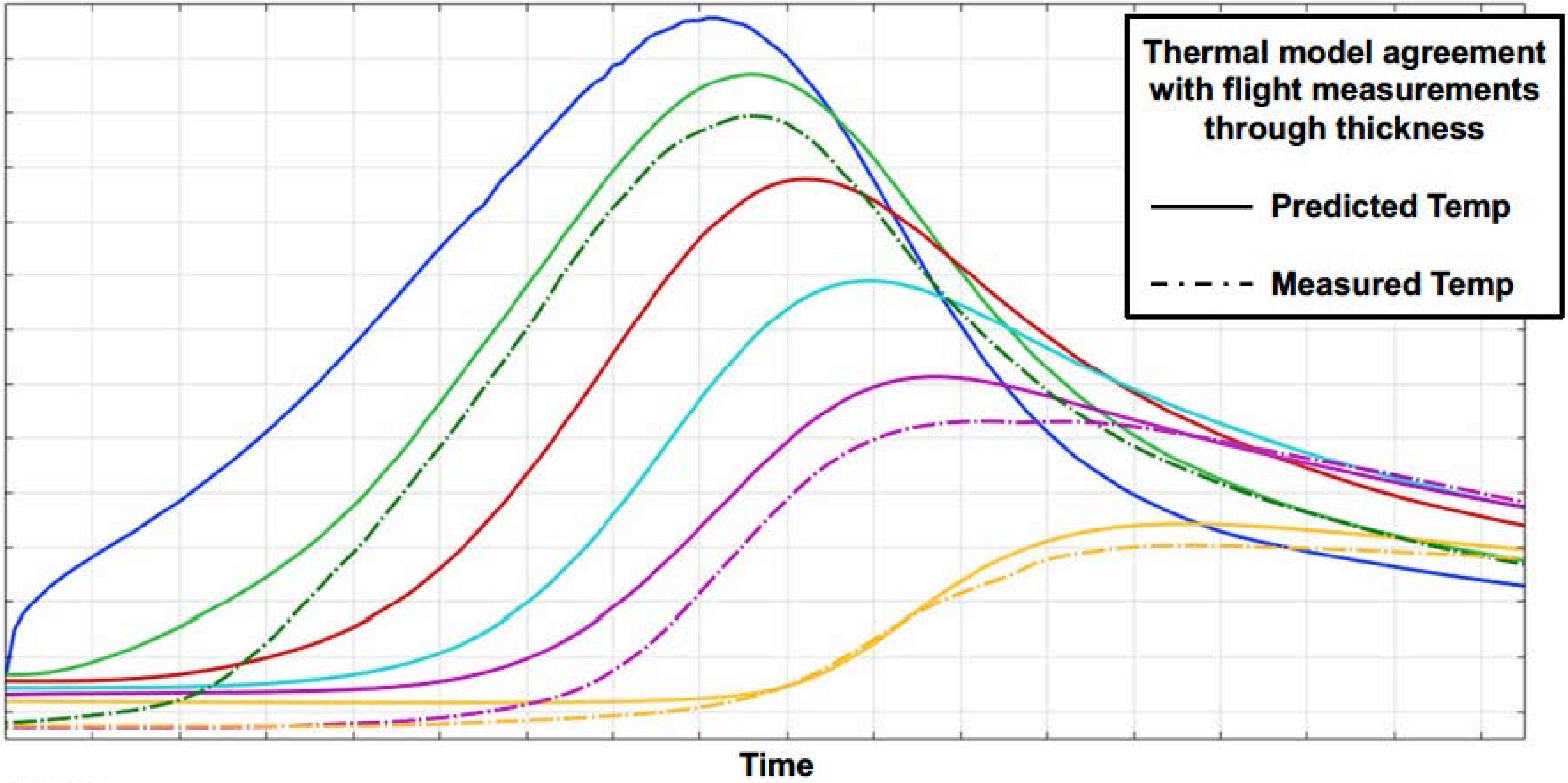




Demonstrated Structural Performance



Demonstrated Thermal Performance



Advantages of HIAD Technology

Application	Diameter (m)	Entry Mass (kg)
Low Earth Orbit return	<6	<1500
Robotic missions to destinations with an atmosphere (including Earth return)	<10	<7800
ISS down mass (without Shuttle, no large-scale down mass capability)	8-10	<6000
Lower cost access to space through launch vehicle asset recovery (for example, ULA's Vulcan booster module)	10-20	10000-25000
High mass delivery to high altitudes at Mars (including humans to Mars)	16-20	60000

HIAD decelerates in the higher, less dense, atmosphere, which greatly reduces heating environments

Aerocapture enables delivering much more mass to orbit than propulsive insertion, without the months-long delay of aerobraking

Future Area of HIAD Technology Development

- Improve Inflatable Structure Materials and Components:
  - Improved/alternate Zylon cord designs and joints,
  - Develop larger inflation hoses and ports
  - Webbing/buffer development - wider, higher load capacity
  - Low -outgassing materials (primarily adhesives)
  - Carbon webbing and cord and testing
  - Zylon Degradation NDE Testing
- Improve Flexible Thermal Protection System Materials and Components
  - Improved Gas Barrier Materials: reduced weight, fabric using lower denier Zylon
  - Gen 3 Insulators
  - Gen 3 outer layer
- Alternate Concepts and Enhanced Capabilities
  - Lift Generation—Trim tab, morphing HIAD, movable CG, MHD, etc.
  - Direct Force Control (DFC) design and analysis
  - Cascade decelerator assessment and analysis
- Manufacturability
  - Studies for manufacturing efficiencies and cost savings
  - Alternate suppliers for soft goods (webbing, thread, cord, fabric)
- Improve Modeling and Flight Performance Predictions
  - Aft body wind tunnel testing and analysis including IR development
  - Advanced vehicle architecture simulation tool development and validation
  - Aerosciences V&V
  - Dynamic stability assessment for bulbous payloads (supersonic, transonic, subsonic)
- Develop Alternate Inflation Capabilities
  - Develop and test low mass high efficiency gas generators to meet HIAD gas temperature and by-product requirements
  - Integrate and demonstration gas generator performance and pressure control with inflatable structures

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Other Partners

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HIAD Technology Validated & Moving Forward

LOFTID Flight Demonstration

- Successful launch, deployment, reentry, splashdown, and recovery
- FTPS and Inflatable Structure performed effectively in extreme environments
- Gathered flight data to correlate physics-based analytical models

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!