Hypersonic Inflatable Aerodynamic Decelerators Technology Development Overview

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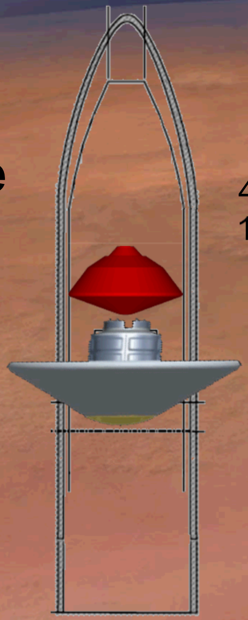
Outline

- [illegible] and Background
- [illegible] Organizational Structure
- Flexible System Development (FSD)
- Advanced Entry Concepts (AEC)
- Flight Projects
- Conclusions and Future Work

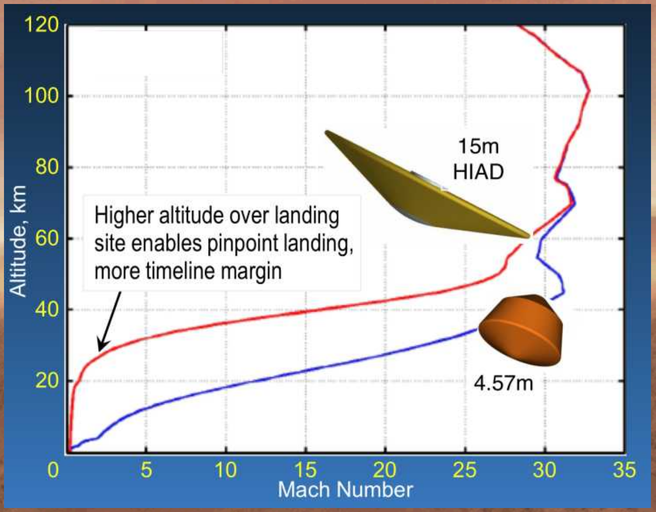
Motivation for HIAD

- [illegible] akes it difficult to [illegible] masses and limits accessible [illegible] titudes. Science payload size and site [illegible] itude are limited by Viking EDL architecture
- Aeroshell size limited by Launch Vehicle fairing
- Improved payload access
- After inflation, HIADs behave like a rigid device
  - Aerodynamics are scalable
  - HIADs are lighter – increasing delivered payload
- Lower ballistic coefficient from increased drag area allows higher altitude deceleration (aerocapture or entry) leading to reduced heat rates, access to higher surface elevations, & increase in landed mass timeline margin
- Crewed EDL at Mars can benefit from reductions in ballistic coefficient

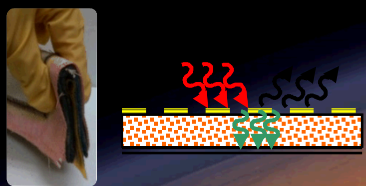


MSL	HEART
3300 kg	3500 kg
4.5 m Dia	8.5 m Dia
125 kg/m^2	40 kg/m^2

Comparable Entry Masses



Vision for HIAD Mission Infusion



Inflatable Structures

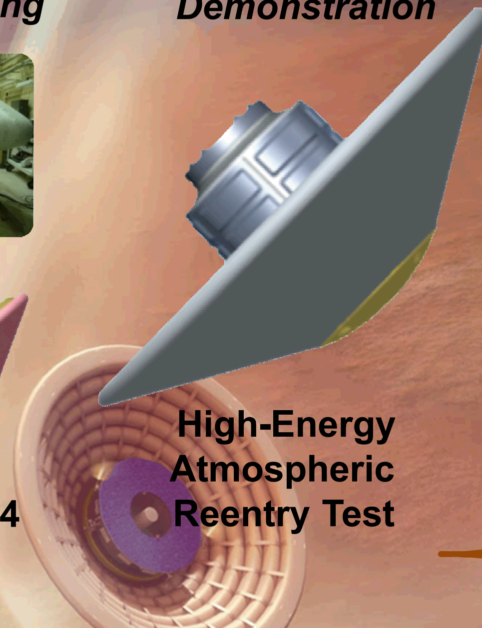
Development and ground testing of HIAD components.

bital
ght Testing

IRVE-3 & 4

Sub-orbital flight tests on a cost-effective test platform (heating, lift, maneuverability).

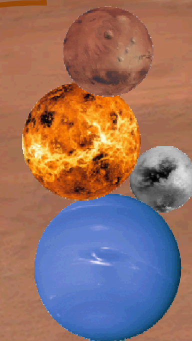
System Demonstration



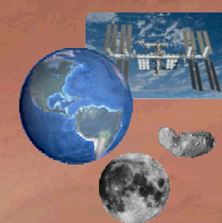
High-Energy Atmospheric Reentry Test

Flight test to demonstrate system performance at relevant scales and environments.

6–25 meter HIAD Class

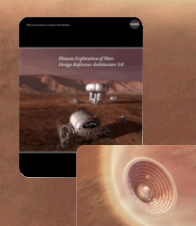


Robotic Missions (entry or aerocapture):
- *Mars*
- *Venus*
- *Titan*
- *Neptune (and other gas giants)*



Robotic or Crewed Earth Return (entry or aerocapture):
- *LEO (including ISS)*
- *GEO, NEO, Lunar*

DoD Applications



Technology Development & Risk Reduction for Human Mars Missions

Proposed initial GCT investment spans these elements

Potential on-ramps for future investments.

HIAD Organization Structure

Steering Group
(ED, ESOD, FPD)

Business Team

HIAD Project

PM: Mary Beth Wusk
PI: Neil Cheatwood
CE: Steve Hughes

Advanced Entry Concepts

Deputy PI: Henry Wright

- Mission Applications
- Next Gen Subsystems
- IRVE-4 Study
  Lead: Daniel Litton
- High-Energy Atmospheric Reentry Test
  Lead: Henry Wright

Flexible Systems Development

Deputy PI: Anthony Calomino
PM: Monica Hughes

- Flexible TPS
  Lead: Joe Del Corso
- Inflatable Structures
  Lead: Keith Johnson

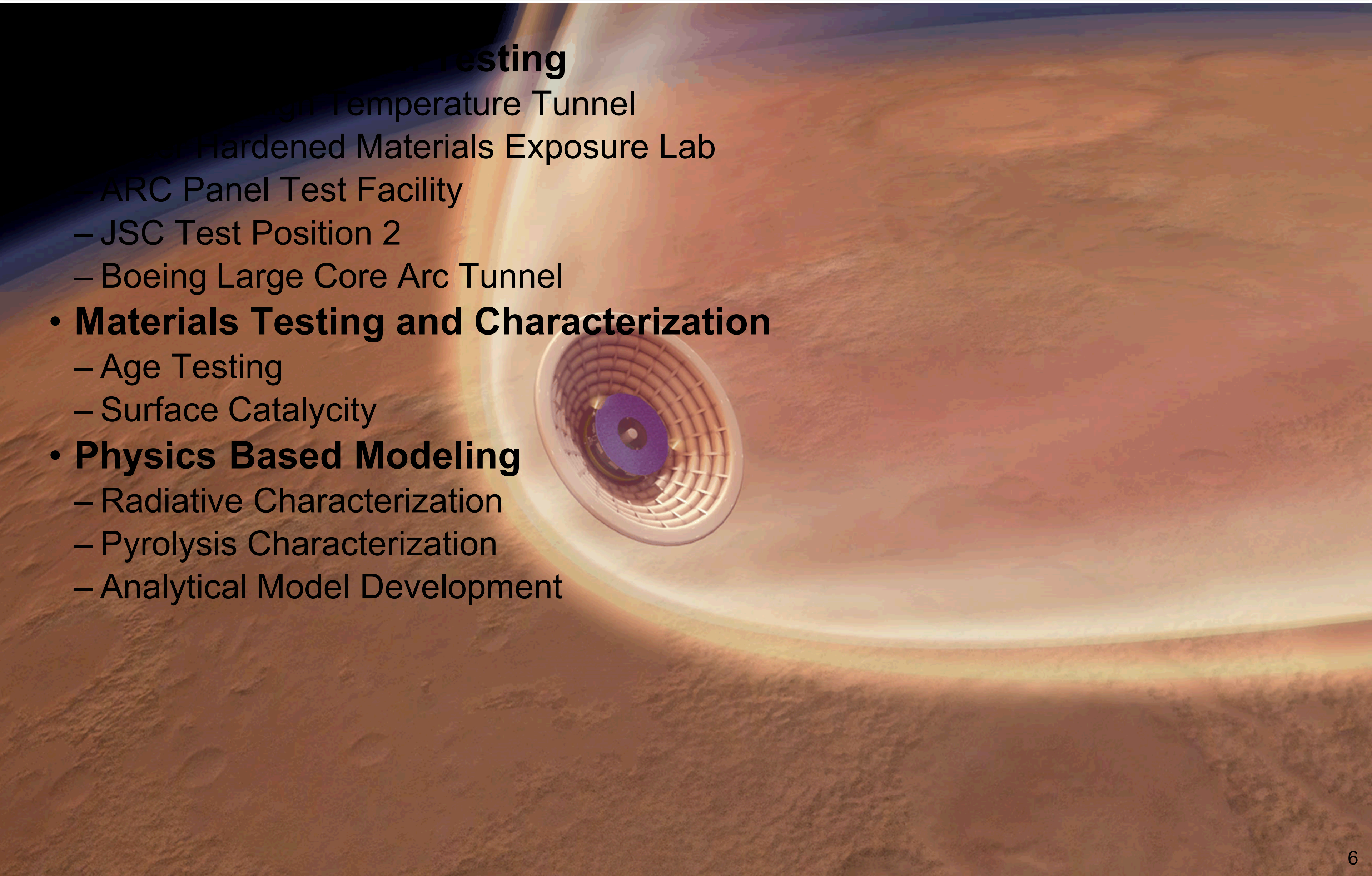
IRVE-3 Flight Project

PM: Jonathan Cruz
DPM: Barmac Taleghani
CE: Robert Dillman

Subject Matter Experts

Jim Arnold (ARC) – TPS
Deepak Bose (ARC) – entry heating
Chris Cerimele (JSC) – G&C
Mike Lindell (LaRC) – structures
Rob Manning (JPL) – entry systems
Mark Schoenenberger (LaRC) – aero

FSD Flexible TPS



- **…esting**
  - …igh Temperature Tunnel
  - …er Hardened Materials Exposure Lab
  - ARC Panel Test Facility
  - JSC Test Position 2
  - Boeing Large Core Arc Tunnel
- **Materials Testing and Characterization**
  - Age Testing
  - Surface Catalycity
- **Physics Based Modeling**
  - Radiative Characterization
  - Pyrolysis Characterization
  - Analytical Model Development

Flexible TPS Development

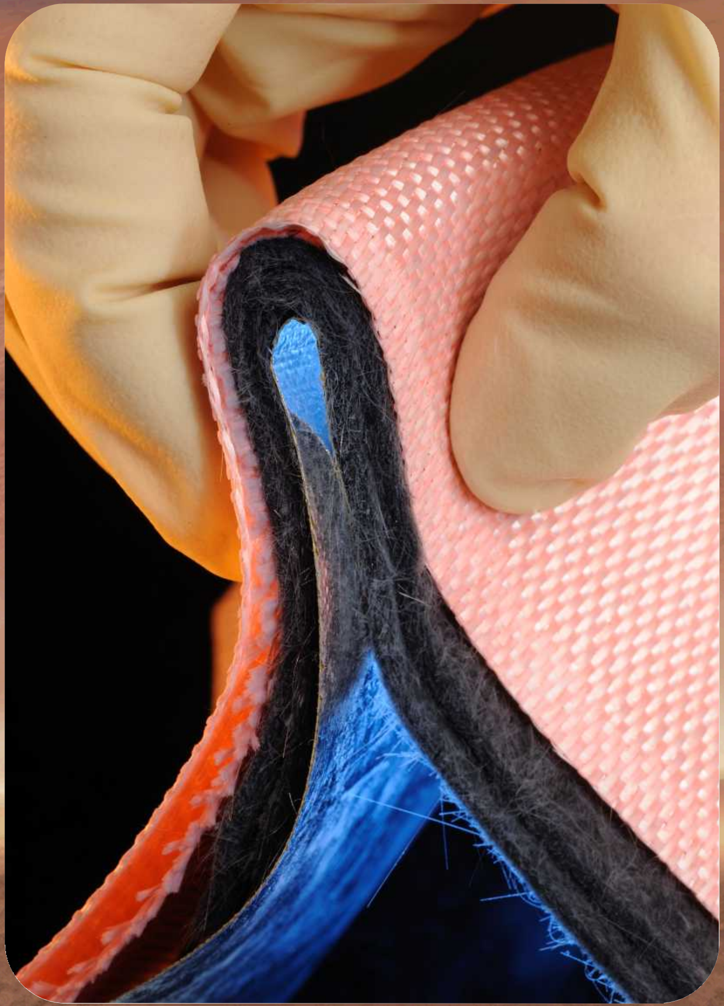
   - Pyrogel
   - Kapton/Kevlar Laminate
- Developmental Materials
   - SiC Fabric
   - Polyimide Aerogel

Testing Approach

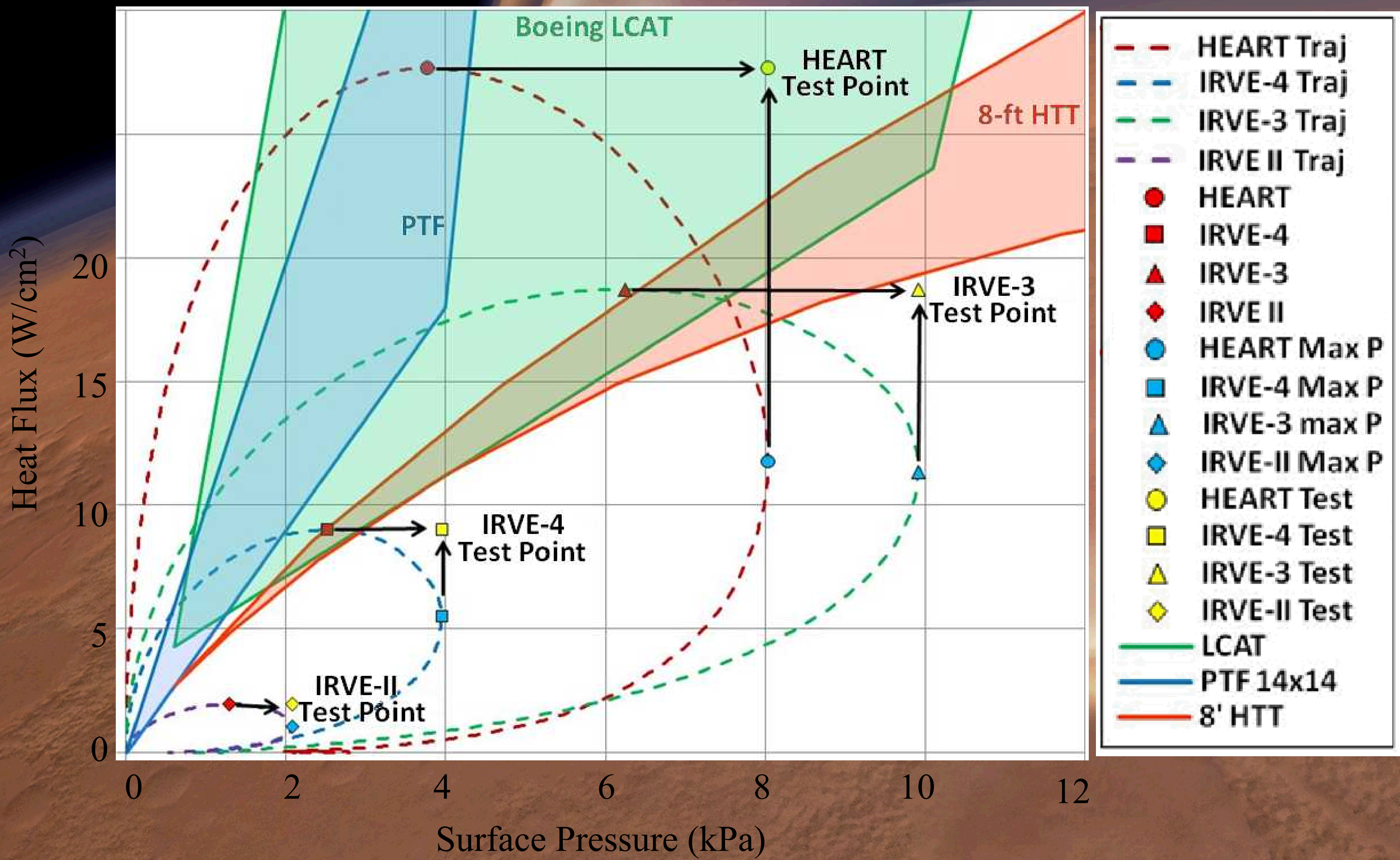
- Develop techniques for testing in candidate facilities
   - Mounting Configuration
   - Coupon Size
   - Aerothermal environments achievable
   - Age tested samples

Testing Products

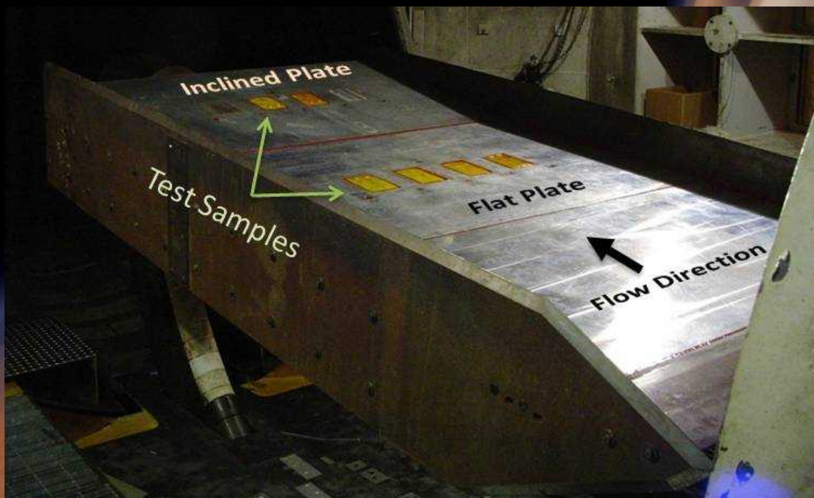
- Performance data to validate modeling efforts
- IRVE-3 TPS & Instrumentation Qualification
- TPS Feature Testing
- Relative performance of materials in different facilities
- Relative performance of developmental materials to baseline materials



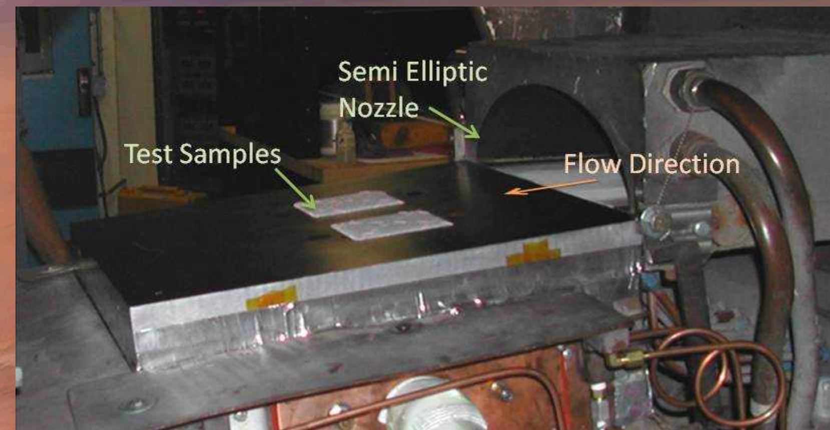
Mission Profiles/Facility Envelopes



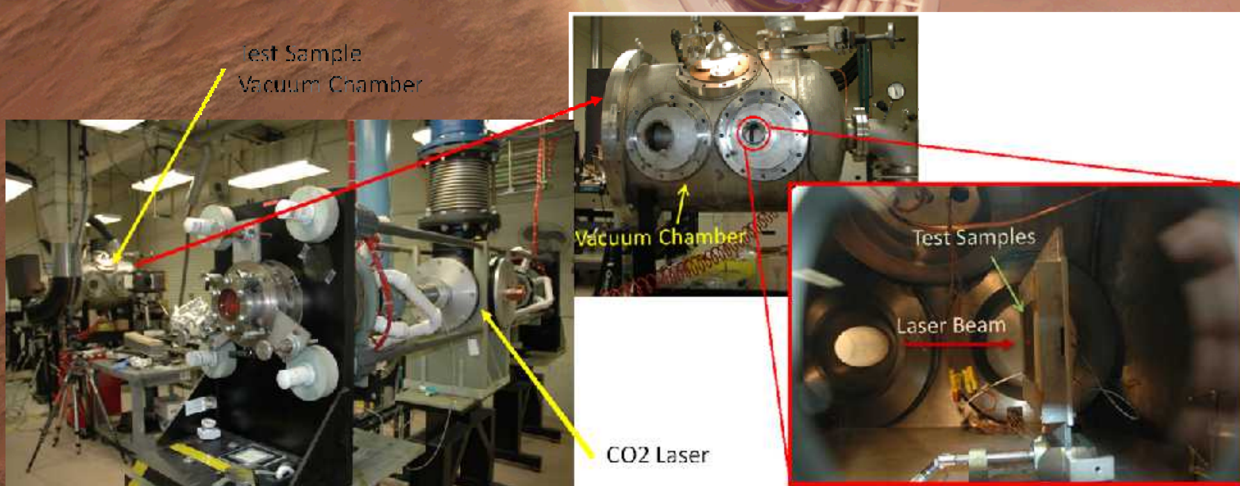
FTPS Test Facilities



8ft High Temperature Tunnel

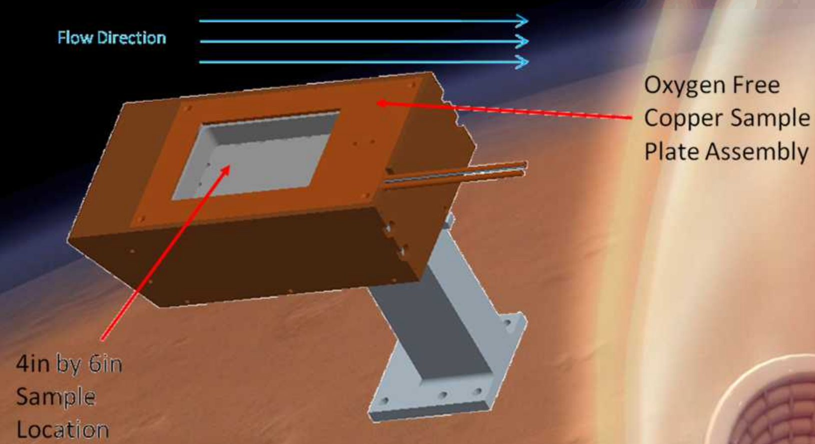


Panel Test Facility

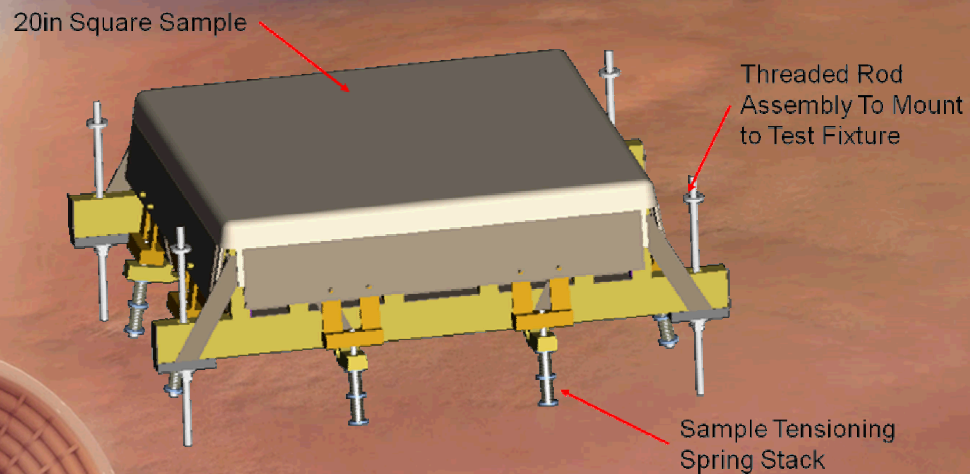


Laser Hardened Materials Exposure Lab

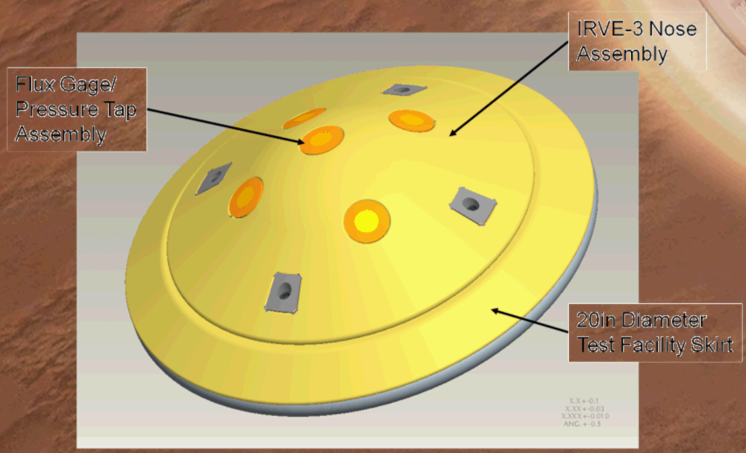
FTPS Test Facilities (Cont)



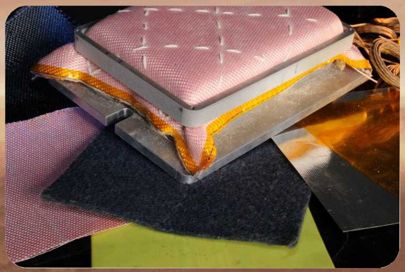
Boeing Large Core Arc Tunnel



8ft HTT Large 2ft Sample Holder



JSC Test Position 2



8ft HTT Large 4in by 6in Sample Holder

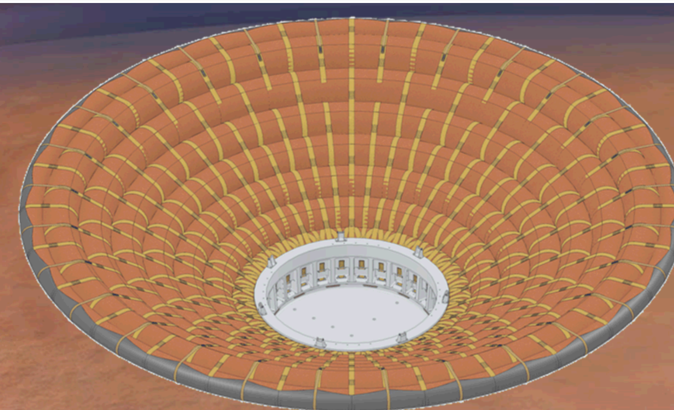
FSD Inflatable Structure

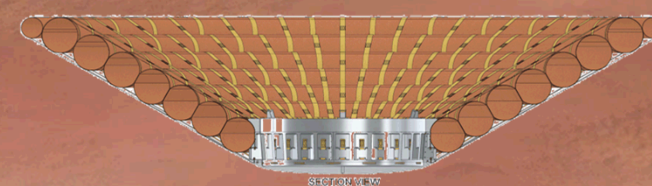
- [illegible] Testing (Acceptance)
- [illegible]nal Full Scale Aerodynamics Complex
    - 6m, 3m IRVE-3 EDU, 8m
- Modal Testing

- **Materials Strength Testing**
  - Strap Load Testing
    - Room Temperature
    - Elevated Temperature
  - Fabric Biaxial Load Testing
  - Tension Torsion Testing Inflated Tubes
  - Higher temperature capable candidate materials

LSA Testing

- …body derived from HEART concept
    - …limeter
    - …ose Pressure taps
  - Inflatable Structure derived from IRVE-3
  - Aerodynamic Skin
    - Photogrammetry
    - Pressure Taps
- 3m IRVE-3 EDU
  - IRVE-3 EDU Centerbody interface
  - Aerodynamic Skin
    - Photogrammetry
    - No Pressure Taps



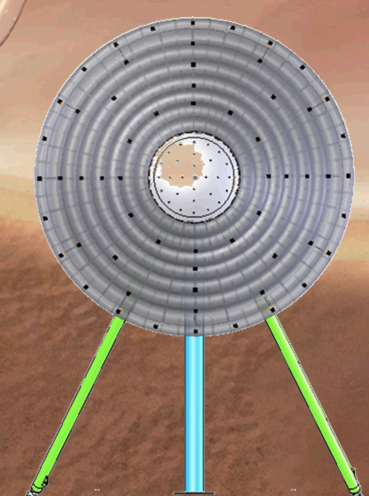


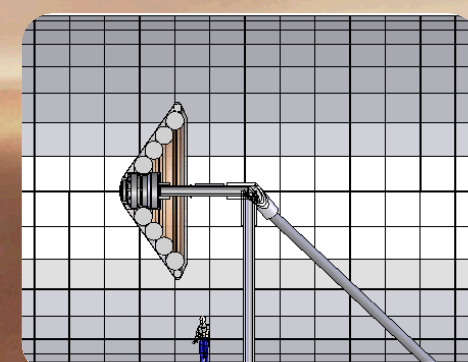
Testing Approach

- Matrix of Dynamic Pressure, Internal Pressure, and Angle of attack

Testing Products

- Large scale construction Demonstration
- LS-DYNA Model validated with photogrammetry
- CFD validated with photogrammetry and pressure data
- Centerbody to Inflatable Structure interface stiffness
- Instrumentation Pathfinder

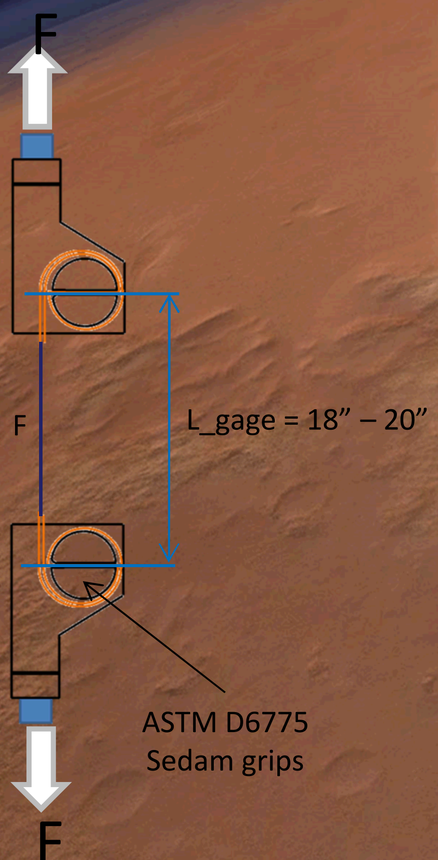




MST - Strap Testing Configurations

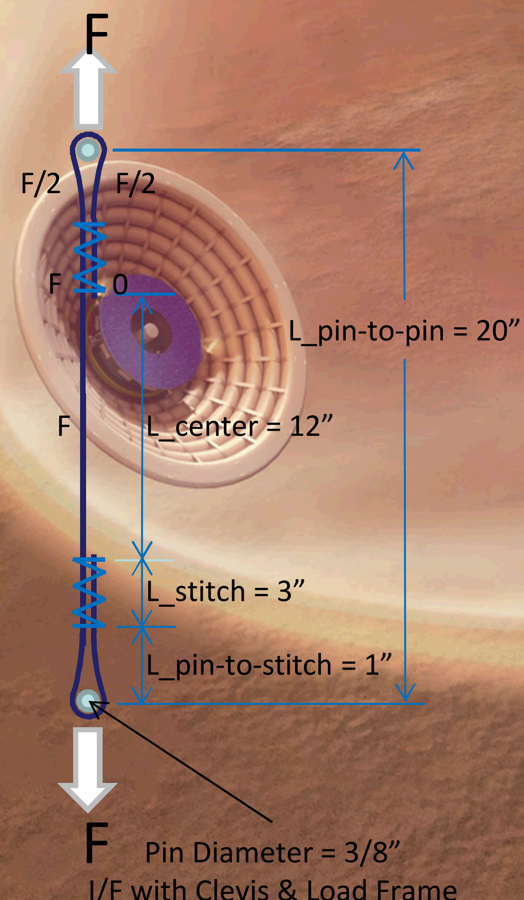
& 2” (2K UTS)

gth (per test): 68”



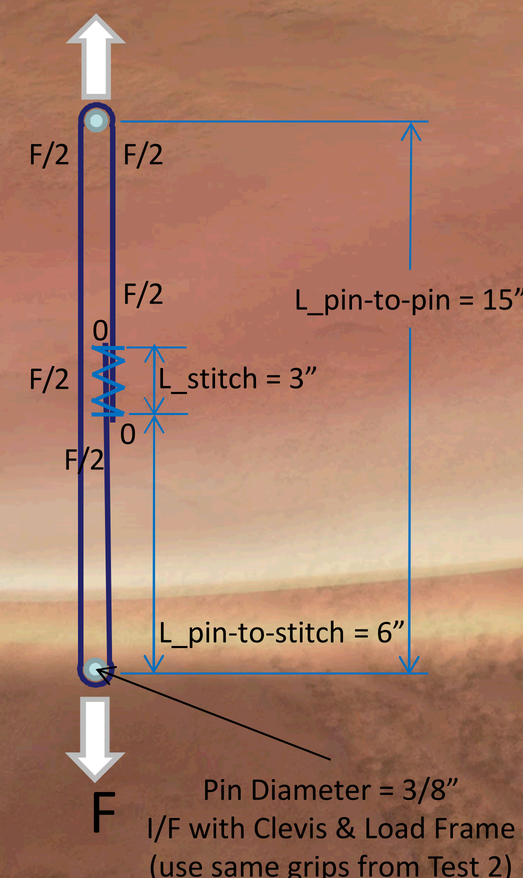
TEST 2:
Frame Stitch Strength Testing

RT, 150C, 300C
Strap Width: 1.75” (4K UTS)
Total Strap Length (per test): 31”



TEST 3:
Lap Stitch Strength Testing

RT, 150C, 300C
Strap Widths: 1.75” (4K UTS) & 2” (2K UTS)
Total Strap Length (per test): 35”



NextGen Subsystems: Plans Forward

- deployable mass
- Articulating mass boom
- Alternate shapes
  - ✓ Sharper shoulders, ellipsoidal noses, hyperboloids
  - ✓ Asymmetric shapes
  - ✓ Gnoffo ideas
  - ✓ Pre-stressed shapes (flex under load to desired shape)

Alternate test methods for large articles

- Balloon drop of >8m at subsonic
- Balloon drop rocket-assist of >8m
- Advanced lab testing

G&C

- Two lift knobs (direction & magnitude)

NextGen structures

- Rib and stringer
- Rigidizable
- Radial boom behind stacked torroids

Inflation systems

Staged aeroshells

- Dual use bladders with two single-use TPS
- Drop TPS after q-pulse for supersonic
- Deploy additional area after q-pulse
- Drop outer torroids (bladder and TPS) after aerocapture before 2nd entry

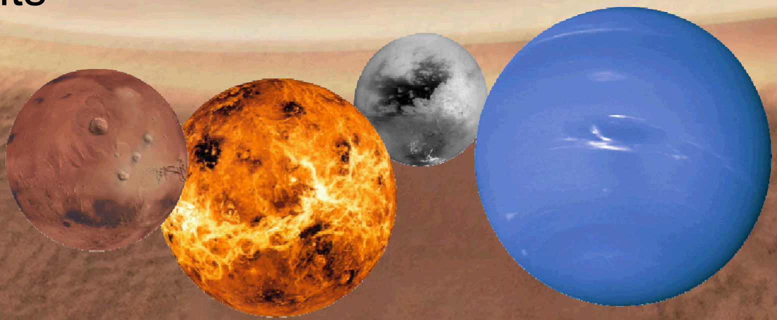
Mission Applications: Plans Forward

gies provide most advances?

flowfield uncertainties really drive the design?

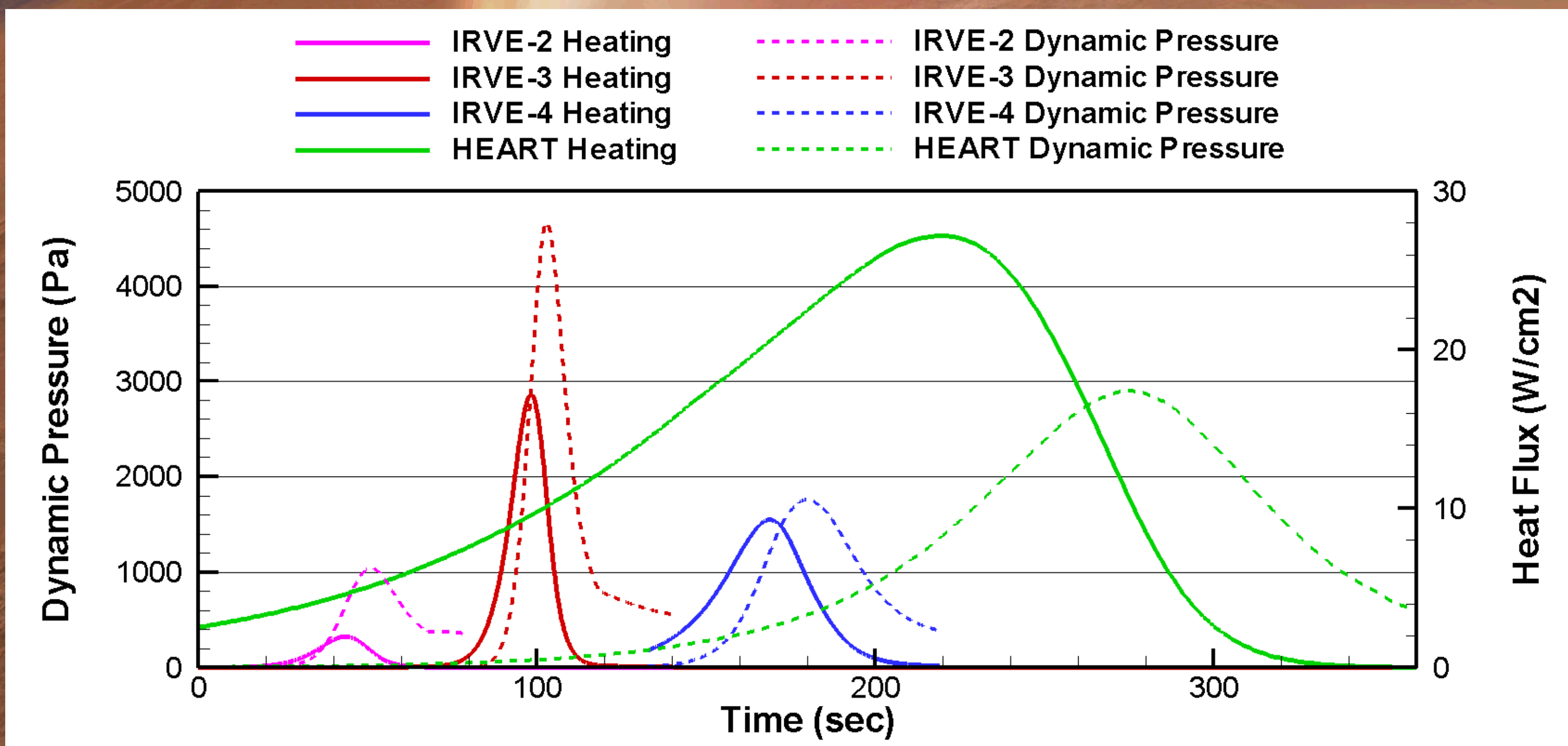
➢ What-if scenarios (impact of 2X decrease in insulation areal weight, 50% increase in bladder operating T, etc.) to guide future investments.

- **Mission Applications**
  - ➢ ISS downmass
  - ➢ LV booster recovery
  - ➢ Earth return of humans from LEO, GEO, lunar, NEO, etc.
  - ➢ Sample return from Mars, comets, etc.
  - ➢ Robotic entry at Mars, Venus, Titan, gas giants
  - ➢ Human-scale entry at Mars



Progression of HIAD Development Flights

	IRVE-II	IRVE-3	IRVE-4	HEART
Peak Heating (W/cm2)	2	16	7	30
Dynamic Pressure (kPa)	1.2	4.7	2	4
Angle of Attack (deg)	0	7	10	0
Diameter (meters)	3	3	3	8.5



First Fully Successful Reentry HIAD Flight Demo

IRVE-II (Inflatable Reentry Vehicle Experiment) Mission

Developing Cutting Edge Technology for Atmospheric Reentry

Mission Objectives Achieved:

- ✓ ***Demonstrated inflation and survival***
- ✓ ***Verified predicted thermal and drag performance***
- ✓ ***Collected data and validated design and performance predictions***

Instrumentation:

- Thermocouples to measure heatshield performance
- Pressure transducers to measure inflation system performance
- Accelerometers, Solar Aspect Sensors, Magnetometer, Rate Sensors for trajectory reconstruction
- Thermistors for system health monitoring

Benefits of Inflatables vs. Rigid Reentry Shells:

- More usable volume in existing shroud space
- Increased payload mass to the planet surface for given set of reentry conditions
- Access to payload in the launch vehicle once configured for launch
- Payload systems available for use during interplanetary cruise phase

Reentry Vehicle Description:
Mass 126kg
Length 1.5m
Stowed Diameter 0.4m
Deployed Diameter 3.0m

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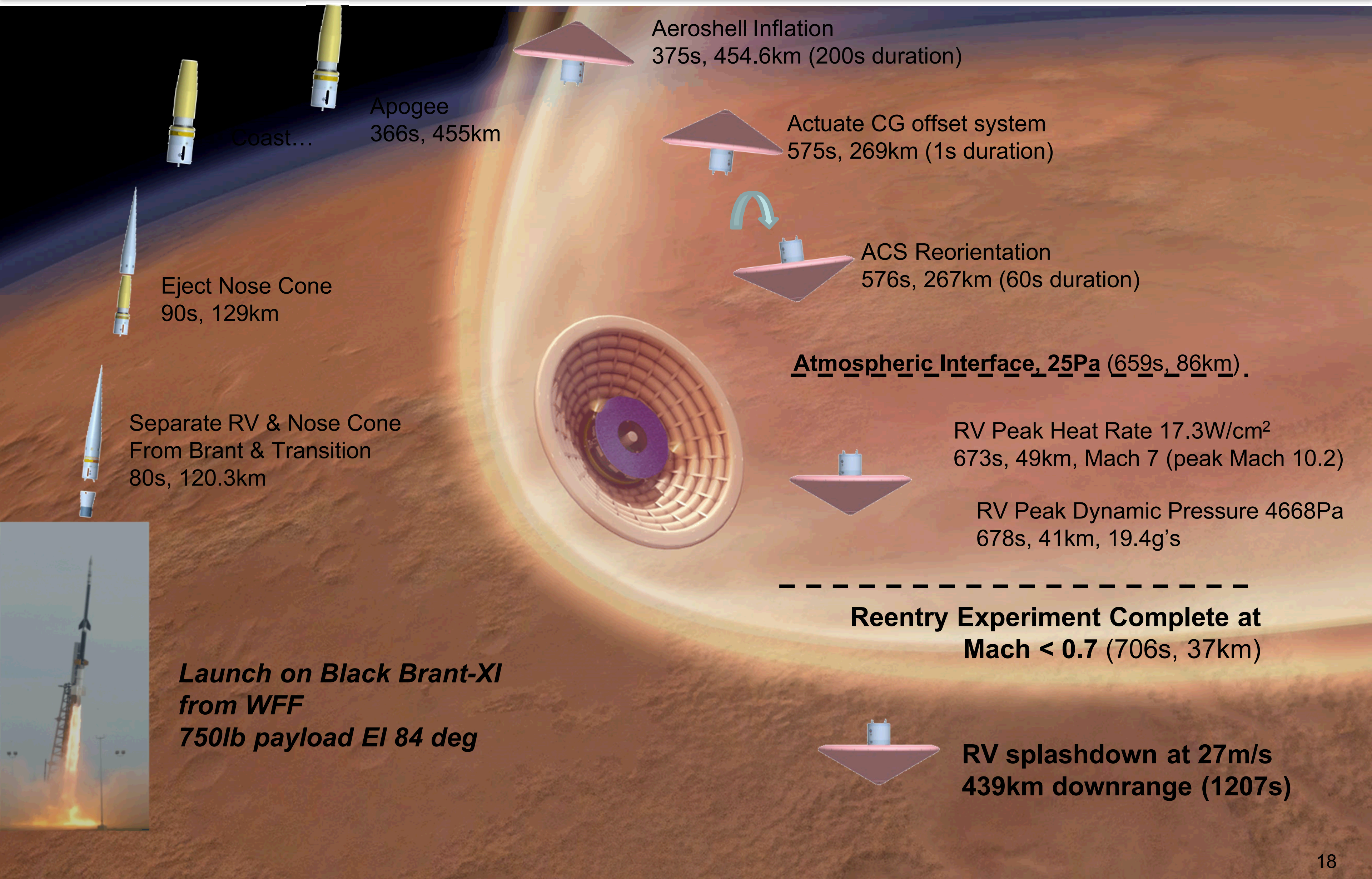
IRVE-3 Mission Concept



IRVE-3 Design Overview

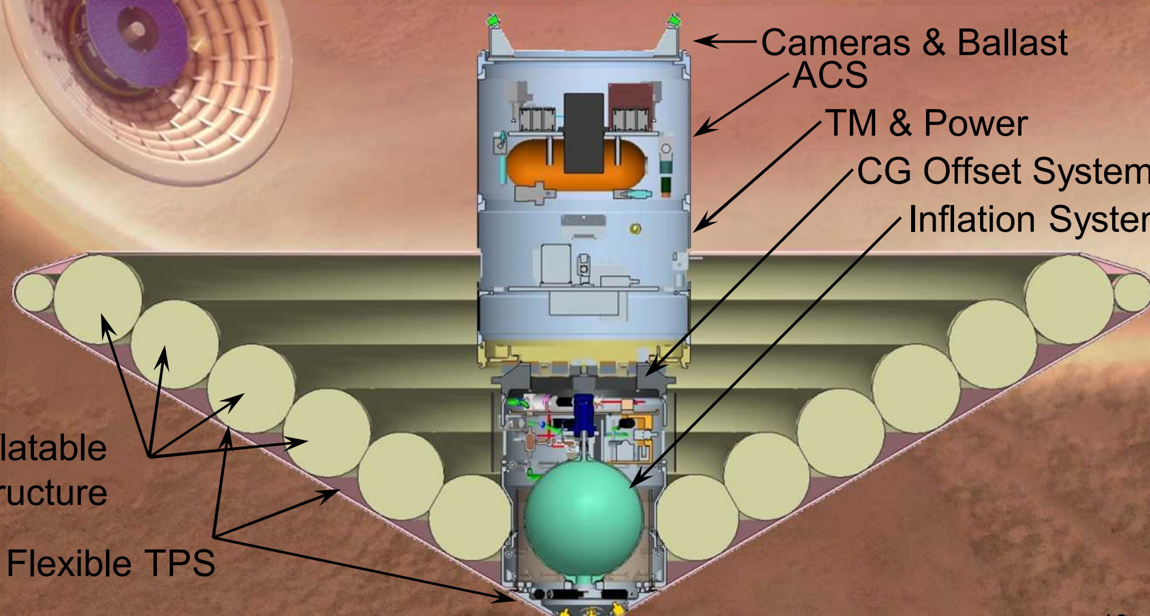
- inflatable aeroshell with flexible TPS on forward surface
- body houses inflation system, CG offset mechanism, telemetry module, power system (batteries), ACS, cameras
- Inflatable aeroshell stows inside 22” diameter nose cone for launch
- Restraint cover holds aeroshell in place; pyrotechnic release in flight
- Inflation system fills aeroshell from 3000 psi Nitrogen tank
- Attitude control system uses cold Argon thrusters to reorient for entry
- CG Offset mechanism allows evaluation of inflatable aeroshell L/D
- Target RV mass 260kg

TPS Layup

1 mil Kapton
5 mil Kevlar
1 mil Kapton
118 mil Pyrogel 3350
118 mil Pyrogel 3350
20 mil Nextel 440 BF-20
20 mil Nextel 440 BF-20

Aeroheating and Dynamic Pressure

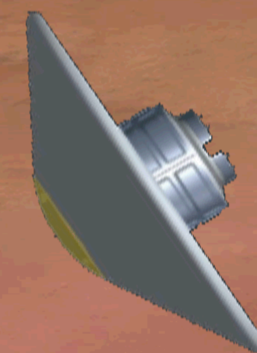
Deployed (3m diam)



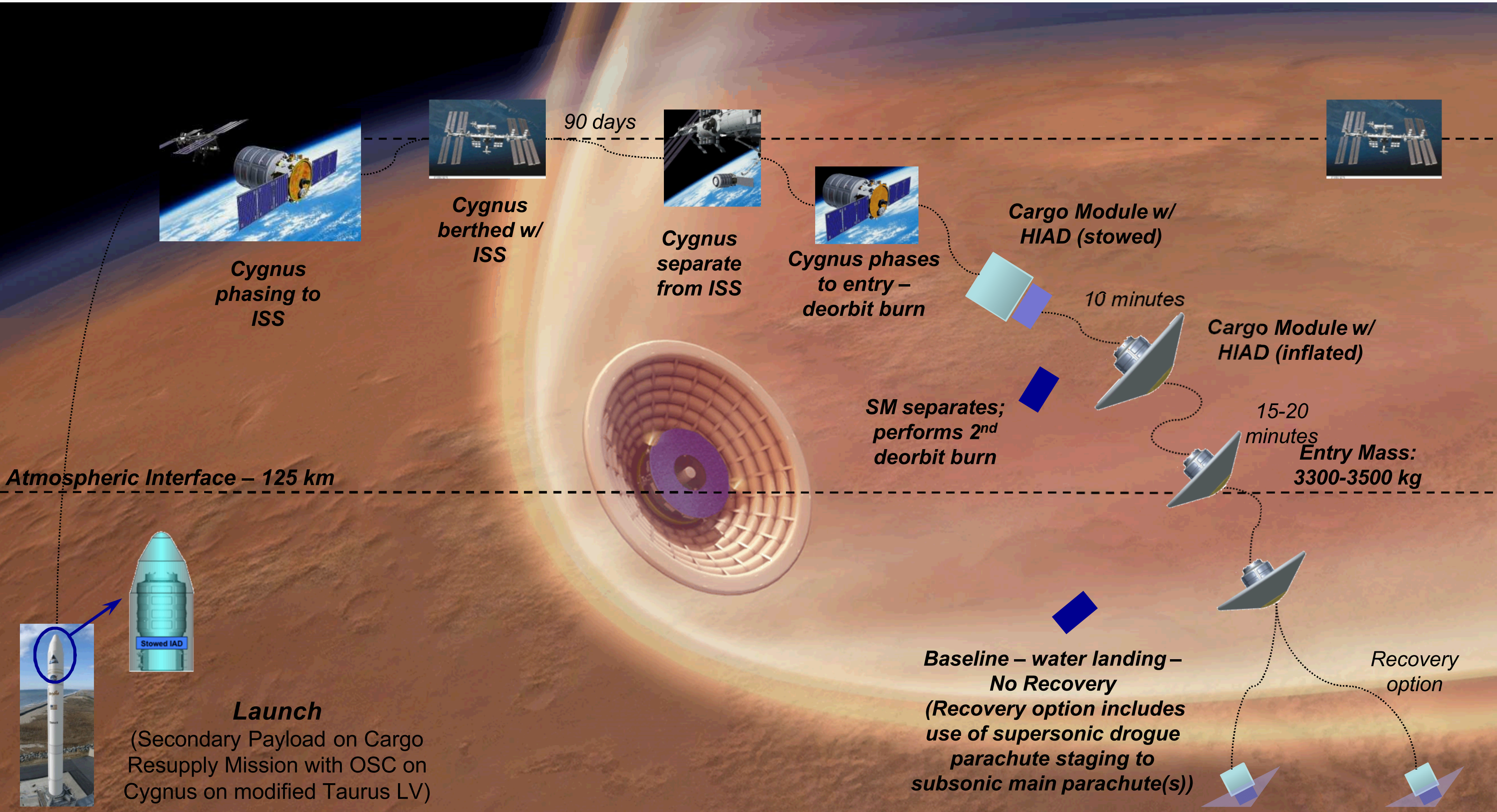
HEART Reference Concept Description

…cts of the HIAD Development Project to …ormance and survivability of an integrated low ballistic …ntry vehicle in a relevant environment

- **…Vehicle**
  - Single 7 - 9 m diameter HIAD (8.5 m nominal)
  - 55 to 65 degree sphere cone – stacked torus (55 degree nominal)
  - Entry –mass ~3300 – 3500 kg; Ballistic Coefficient ~45 kg/m^2
  - Ballistic entry – 0 degree AoA
- **Entry Environments – Initial Limits**
  - Peak heat rate – 25 to 35 W/cm^2
  - Peak dynamic pressure – 4800 Pa
- **Launch, Orbit, De-orbit**
  - Integrated with the Orbital Sciences Corp Cygnus module as part of the ISS Cargo Resupply Service
  - NASA – OSC Data Exchange SAA in Signature Loop
  - Launch on Enhanced Taurus II
  - Cygnus berths with ISS – up to 90 days
  - Cygnus performs all maneuvering
  - Entry from LEO – 7.6 km/s
  - HIAD returns Pressurized Cargo Module



HEART Concept of Operations



Launch
(Secondary Payload on Cargo Resupply Mission with OSC on Cygnus on modified Taurus LV)

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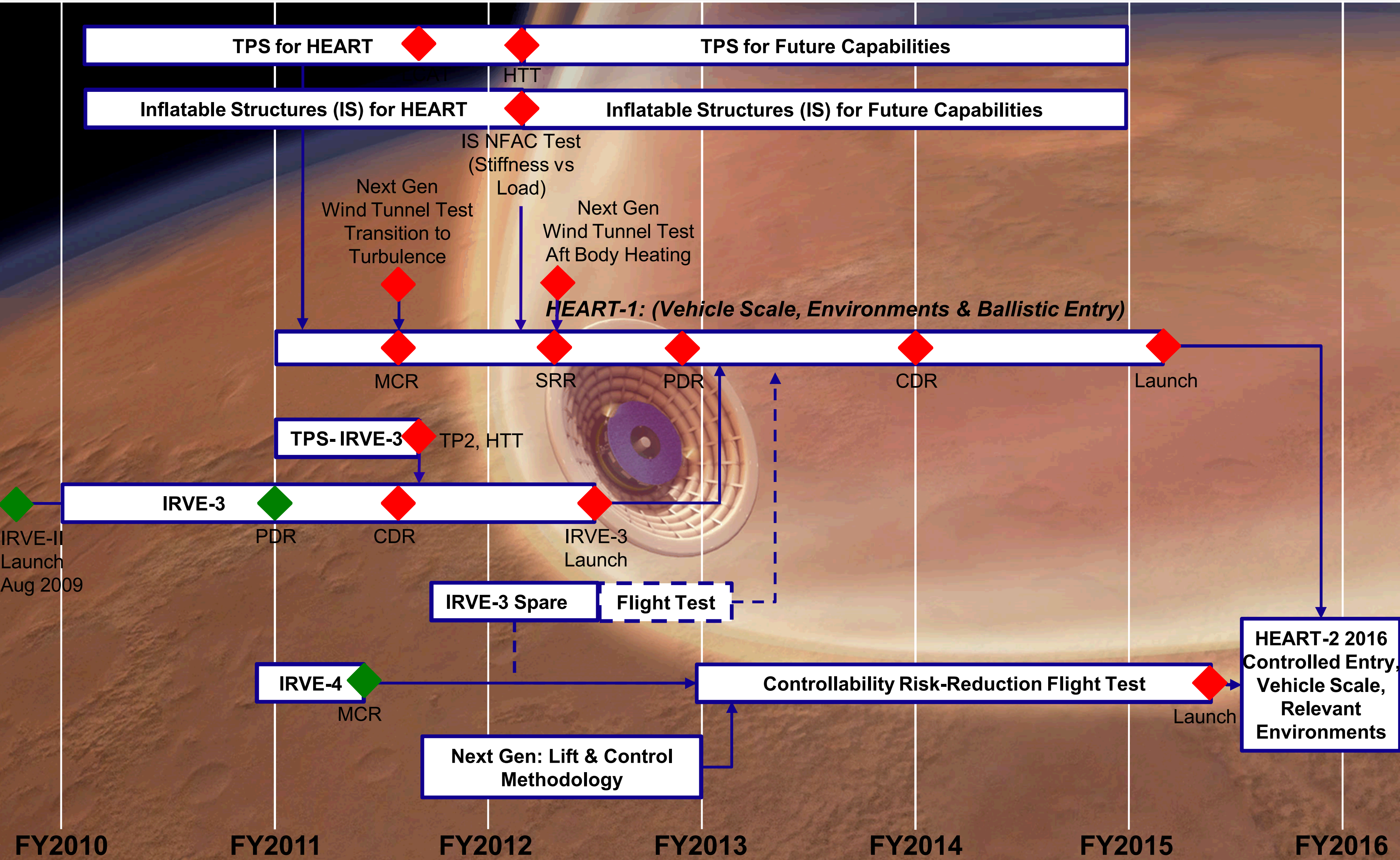
HIAD Project Infusion Strategy



Summary/Next Steps

- [illegible]ures development demonstrating robotic scale [illegible] capabilities with development path to larger scales
- [illegible] flight test to demonstrate IAD Technology in a relevant environment
- **HEART flight test to demonstrate IAD Technology at a relevant environment AND scale**
- **Team focused on achieving FY11/FY12 milestones**
  - IRVE-3: CDR (Jun), TP2 Testing (Jun), Complete System Test (Nov)
  - HEART: Peer Review (May), MCR (Jun), SRR (Nov), PDR (Aug/Sept 2012)
  - Transition to Turbulence Wind Tunnel Test (Jun)
  - Flexible TPS Testing: 8’ HTT (May-Aug), LCAT (Jun)
  - IDIQ release (Aug)
  - Large-scale Inflatable Articles: 6-m (Sep 2011), 8.3-m (Nov 2011), NFAC Test (Jan/Feb 2012)