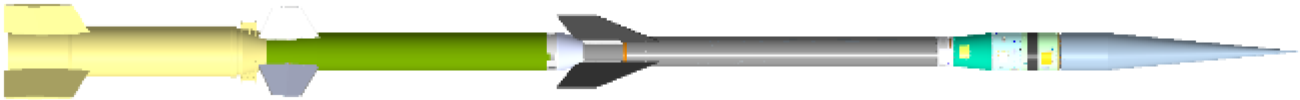
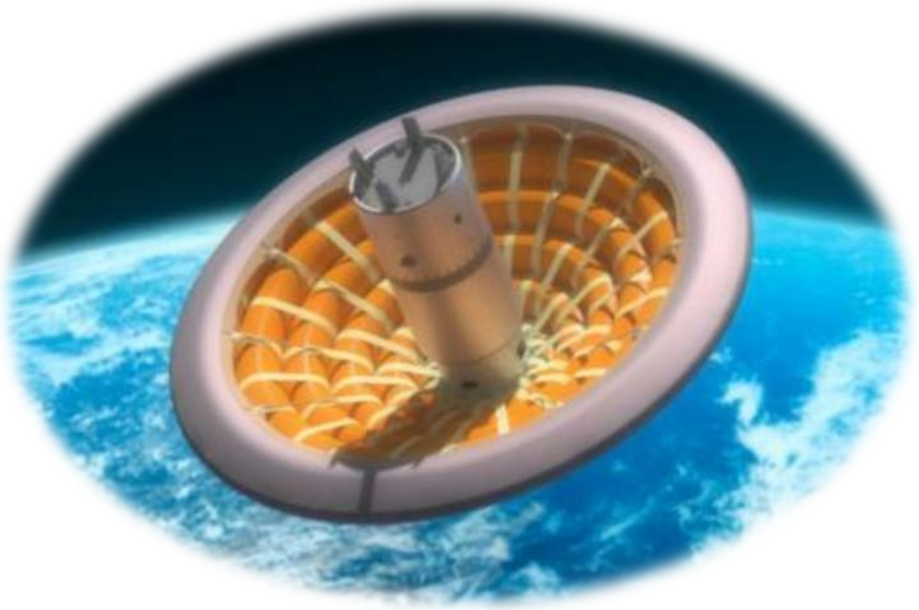


Inflatable Reentry Vehicle Experiment-3 (IRVE-3) Project Overview & Instrumentation

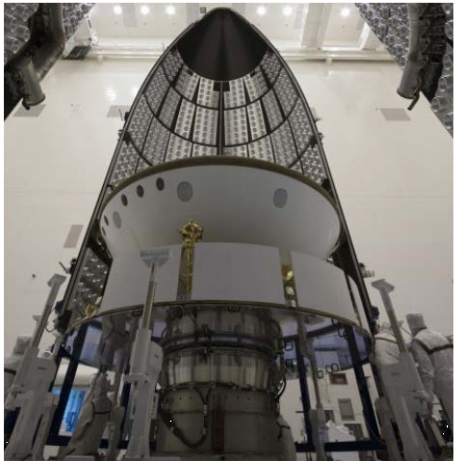


Robert Dillman, NASA LaRC
August 18, 2015

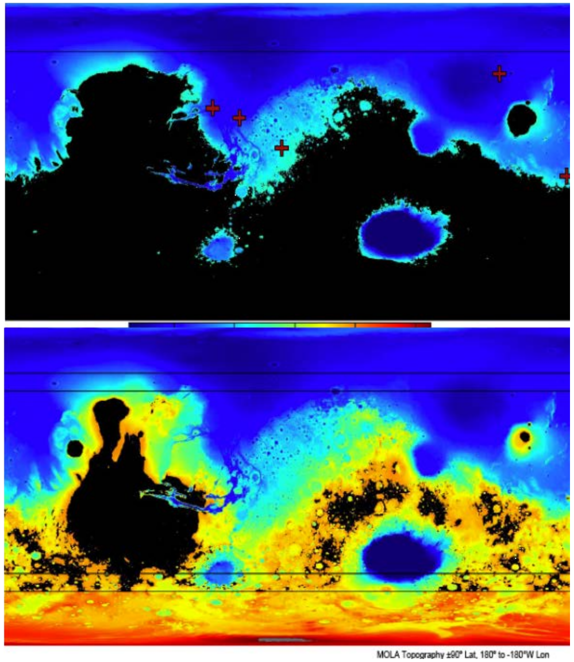
Background: Why Inflatables?

- Entry mass at Mars is limited by the payload size that can be carried by a rigid capsule that can fit inside the launch vehicle fairing
- Landing altitude at Mars is limited by ballistic coefficient (mass per area) of entry body
- Inflatable technologies allow payload to use full diameter of launch fairing, and deploy larger aeroshell before atmospheric interface, landing more payload at a higher altitude
- Also useful for return of large payloads from Low Earth Orbit (LEO)

Launch Vehicle Fairing Constraints

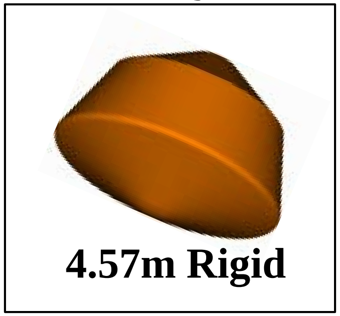


Mars Surface Access

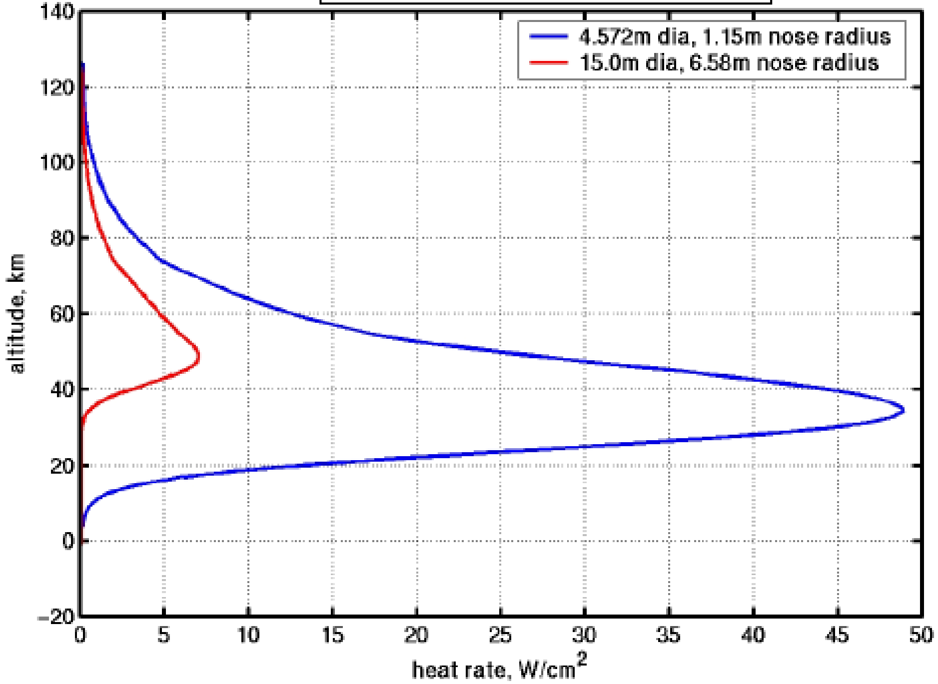


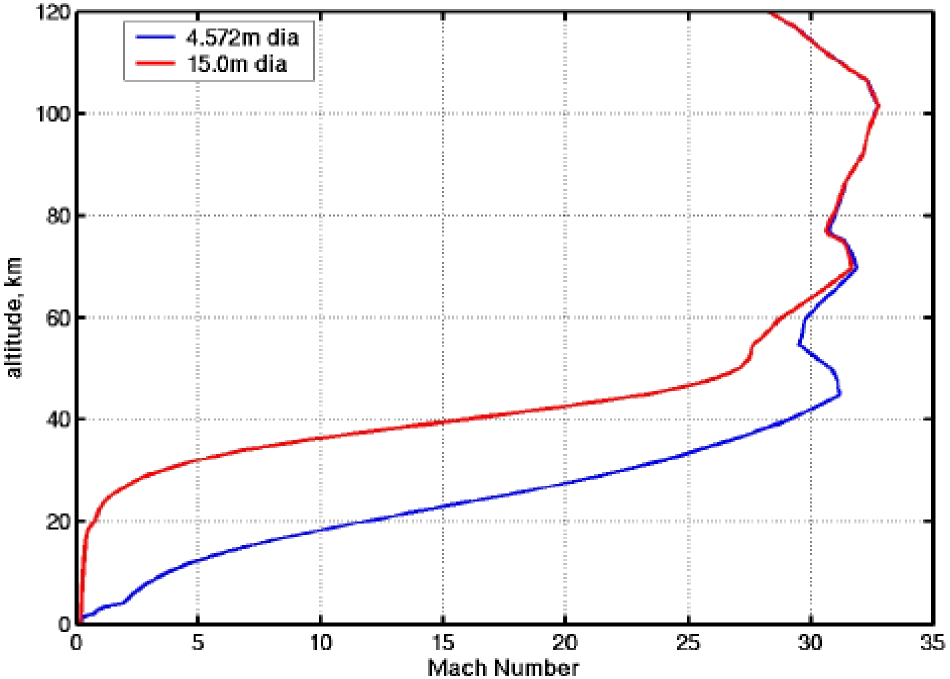
Additional Benefit

- Lower ballistic coefficient, larger nose radius, & larger drag area of inflatable aeroshell also reduce peak heat flux for the same entry conditions & payload mass
- Mars entry of MSL-mass payload:



Ballistic (non-lifting)
V = 6 km/s
m = 2200 kg (Entry)





- 10m Inflatable would see ~30-W/cm2 peak flux

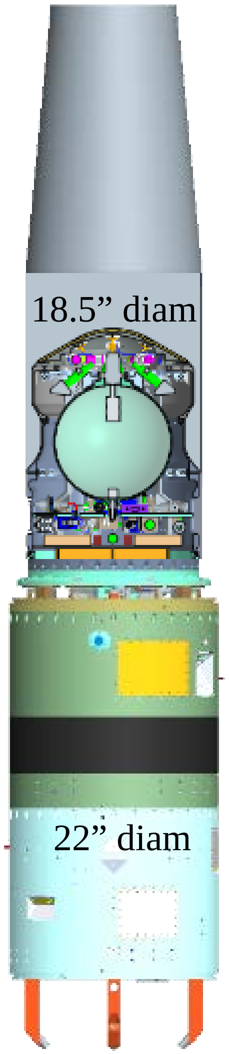
Development History

- NASA Langley has been developing Hypersonic Inflatable Aerodynamic Decelerators (HIADs) for over 10 years
- Systematic technology advancement steps
  - Ground Effort: Project to Advance Inflatable Decelerators for Atmospheric Entry (PAI-DAE): Softgoods technology development
  - Flight Test: Inflatable Reentry Vehicle Experiment (IRVE), 2004-7: 3m diam 60° cone – sounding rocket failed to release payload, no experiment
  - Flight Test: IRVE-II (reflight), 2008-9: Fully successful suborbital flight to 218km validated design & analysis techniques, demonstrated HIAD inflation, reentry survivability, & hyper/super/trans/subsonic stable flight
  - Ground Effort: HIAD Project designed improved inflatable structure, advanced flexible TPS performance (Gen-1 & Gen-2)
  - Flight Test: IRVE-3, 2009-12: 3m diam 60° cone with improved inflatable structure & Gen-1 TPS; 20G launch, 469km apogee, 20G entry, 14.4 W/cm2
  - Ground Effort: HIAD-2 inflatable structure & TPS development continues
- Next: LEO reentry flight test, approximating Mars direct entry flux
  - Proposed twice (HEART, THOR) but not yet funded

IRVE-3 Design Overview

- 3m diam, 60°, 7-toroid inflatable aeroshell with flexible TPS on forward face
- Centerbody houses inflation system, CG offset mechanism, telemetry module, power system (batteries), ACS, cameras
- Inflatable aeroshell packs to 18.5” diam inside nose cone for launch
- Restraint cover holds aeroshell packed for launch; pyrotechnic release
- Inflation system fills aeroshell to 20psi from 3000psi Nitrogen tank
- Attitude control system uses cold Argon thrusters to reorient for entry
- CG Offset mechanism shifts aft half of centerbody laterally for evaluation of inflatable aeroshell L/D
- 281kg entry mass

Stowed (18.5”)

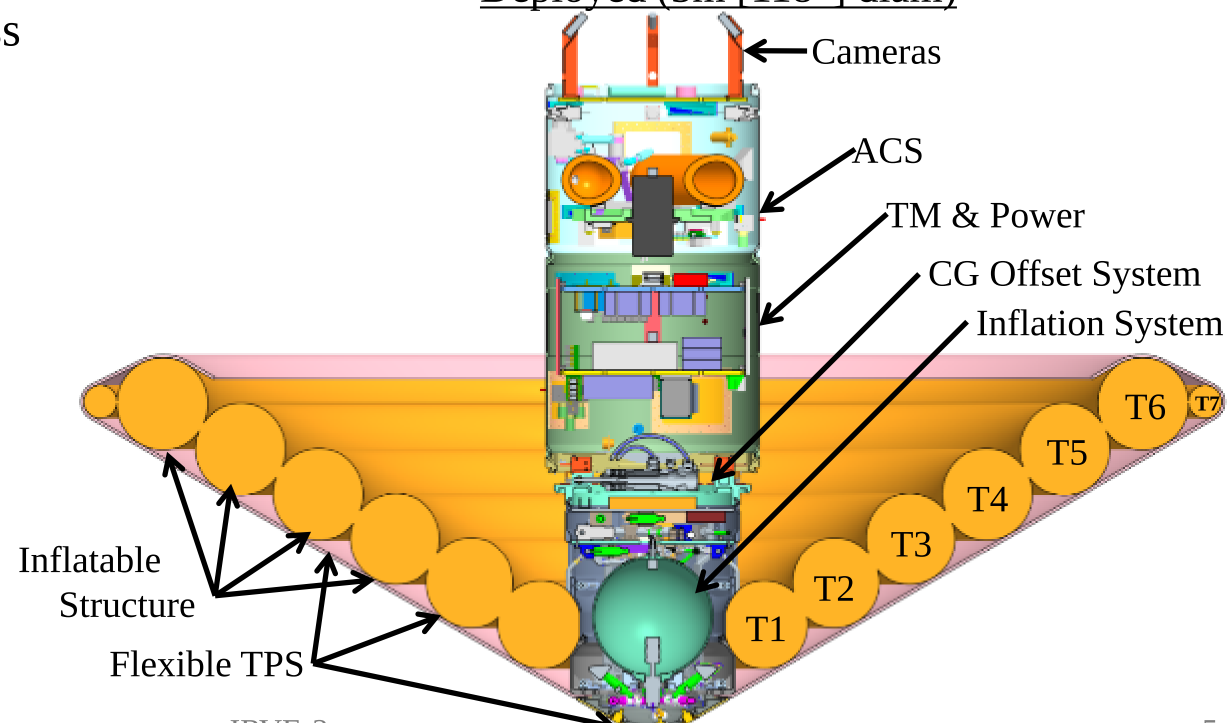


TPS Layup (~¼”)

- Kapton / Kevlar film
- **Pyrogel felt insulation**
- **Pyrogel felt insulation**
- Nextel fabric
- Nextel fabric

Aeroheating and Dynamic Pressure

Deployed (3m [118”] diam)



IRVE-3 Mission Sequence

Launch on Black Brant-XI from WFF
940lb payload, El 84deg, Az 155deg

1st Stage Ignition, 0s
1st Stage Burnout, 6.4s
2nd Stage Ignition, 15.0s
2nd Stage Burnout, 18.5s
3rd Stage Ignition, 23.0s
3rd Stage Burnout, 56.9s
Yo-Yo De-Spin, 80s

Separate RV & Nose Cone
From 3rd Stage Transition
90s, 148km

ACS damps rates
91s (10s duration)

Eject Nose Cone
102s, 176km

Coast…

Apogee
364s, 469km

Start Aeroshell Inflation
436s, 448km (0 to 20psi in 186s)

Reorient for Entry
587s, 260km (40s duration)

Lateral CG Shift
628s, 127km (1s duration)

Atmospheric Interface, 25Pa (664s, 85km)

Peak Heating 14.4W/cm2
678s, 50km, Mach 7 (peak Mach 9.8)

Peak Dynamic Pressure 6.0KPa
683s, 40km, 20.2g's

Reentry Experiment Complete at Mach < 0.7
(707s, 28km)

Bonus: CG Maneuvers

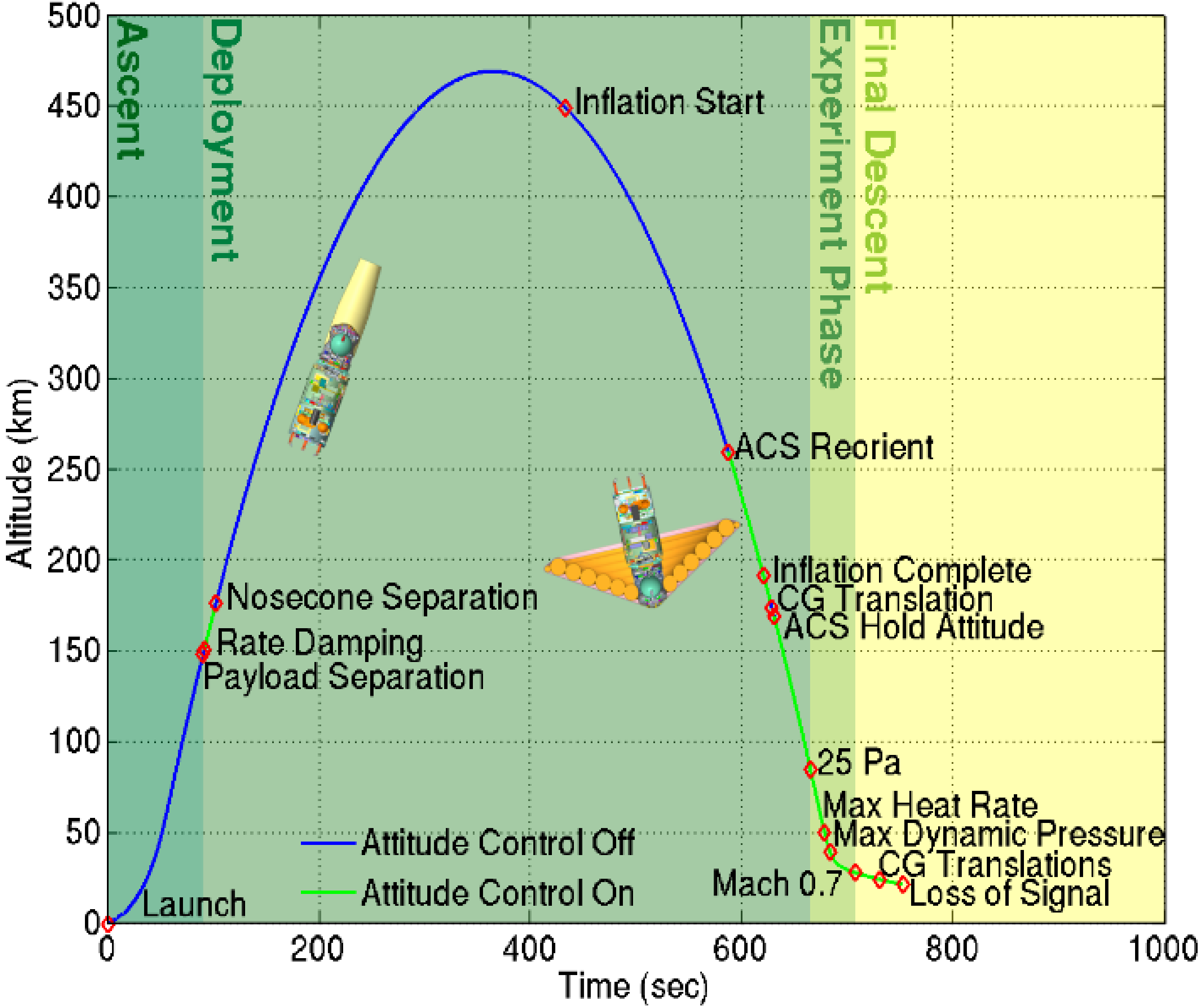
LOS by land radar & TM
910s, 10.5km

Vent NIACS and Inflation System Gas

RV splashdown at 30m/s
1194s (447km downrange)

Recovery Attempt - Unsuccessful

IRVE-3 Trajectory at Scale



Note: Experiment phase only 43sec long

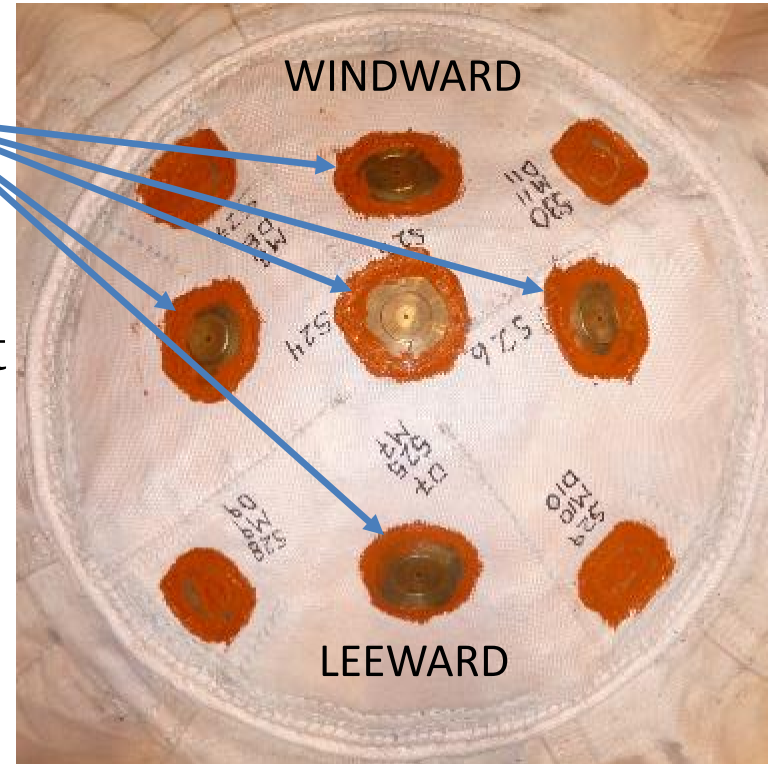
IRVE-3 Instrumentation

- 5 heat flux gauges on nose
- 64 thermocouples
  - Type K, 30 AWG leads with glass braid sheath
  - Electronics mostly set for 0-1000°C
- 19 pressure gauges
- 4 video cameras
- Inflation flow meter
- 6 string pots (CG Offset System)
- IMU & GPS in attitude control system
- Accelerometers & attitude sensors
- 8 thermistors (electronics temps)
- Current & voltage monitors (power system)
- Ground radar tracking / on-board transponder

Heat Flux Gauges on Nose

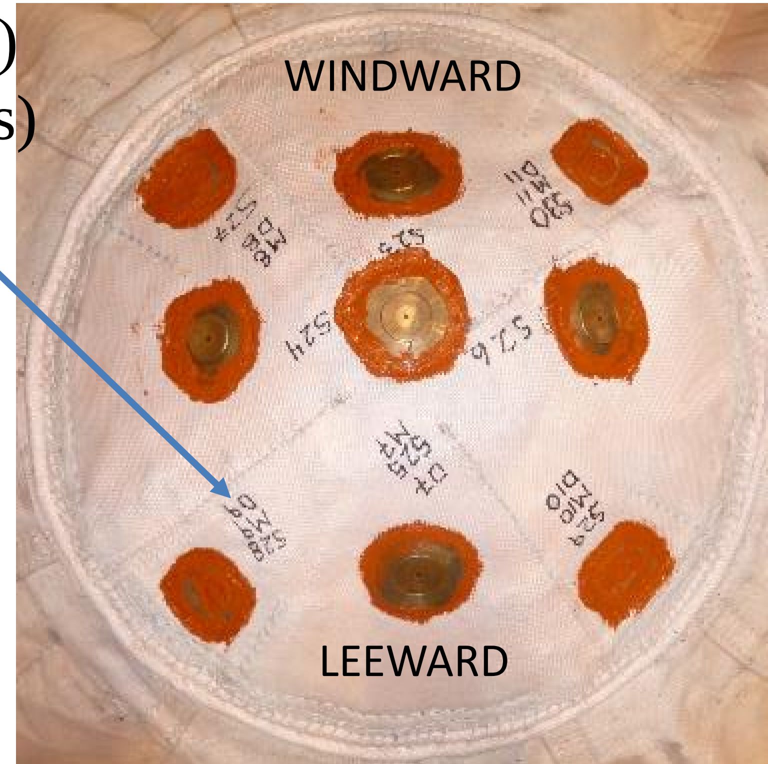
- 5 MedTherm Schmidt-Boelter gauges
- Each 1" diam x 1" long
- Mounted through rigid Al nose
- End is flush with surface of TPS
- Lip of 1.9" diameter mounting bracket holds edge of TPS
- Step from edge of bracket to TPS filled with RTV 159

- Assembled, 0.5lb each

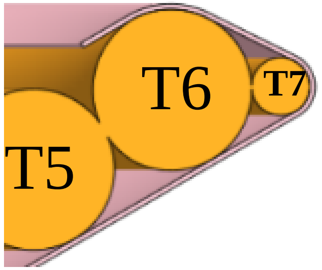


18 Thermocouples on Nose

- S = Surface (between or below Nextel)
- M = Middle (between insulation layers)
- D = Deep (under insulation)
- Some locations have stack of 3 TC's, other locations have solo TC's
- TC's sewn to surrounding material
- To avoid puncturing TPS gas barrier, TC leads run between layers to edge of nose, then into centerbody



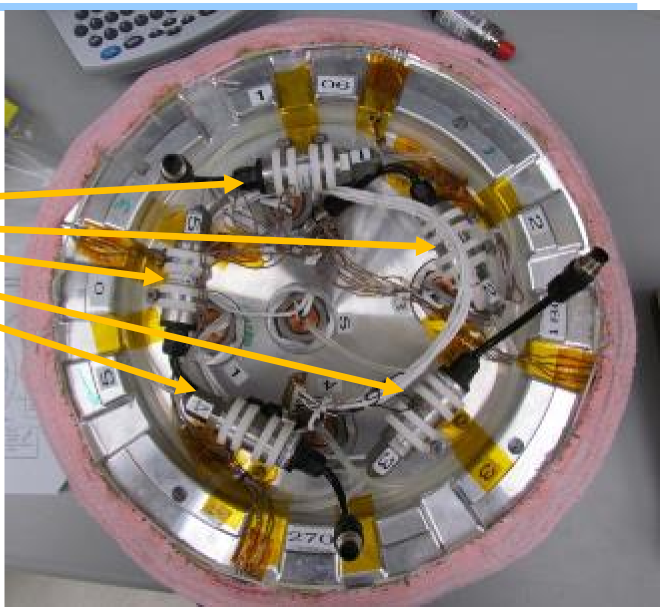
Thermocouples on Aeroshell



- Most are Surface / Mid / Deep in TPS, as on the nose
- A few on centerbody, & on exposed (no TPS) aft structural straps that join the inflatable toroids
- Also on inflation tank, & in downstream gas
- To avoid puncturing TPS gas barrier, TC leads run between layers to max diameter, to aft edge of TPS, then back to centerbody → long leads can affect the reading, & can pick up EMI
- Aeroshell must be hard packed for launch:
  - Almost-zero-radius folds, vacuum bagging, hand-worked to move bumps into valleys, etc
  - Need extra lead length for folds
  - IRVE-3 hard-packed to 39 lb/ft3
- Leads can break during packing
  - 4 TC's died in two hard packs of flight unit (1st pack for deployment test, 2nd for flight)

Pressure Gauges

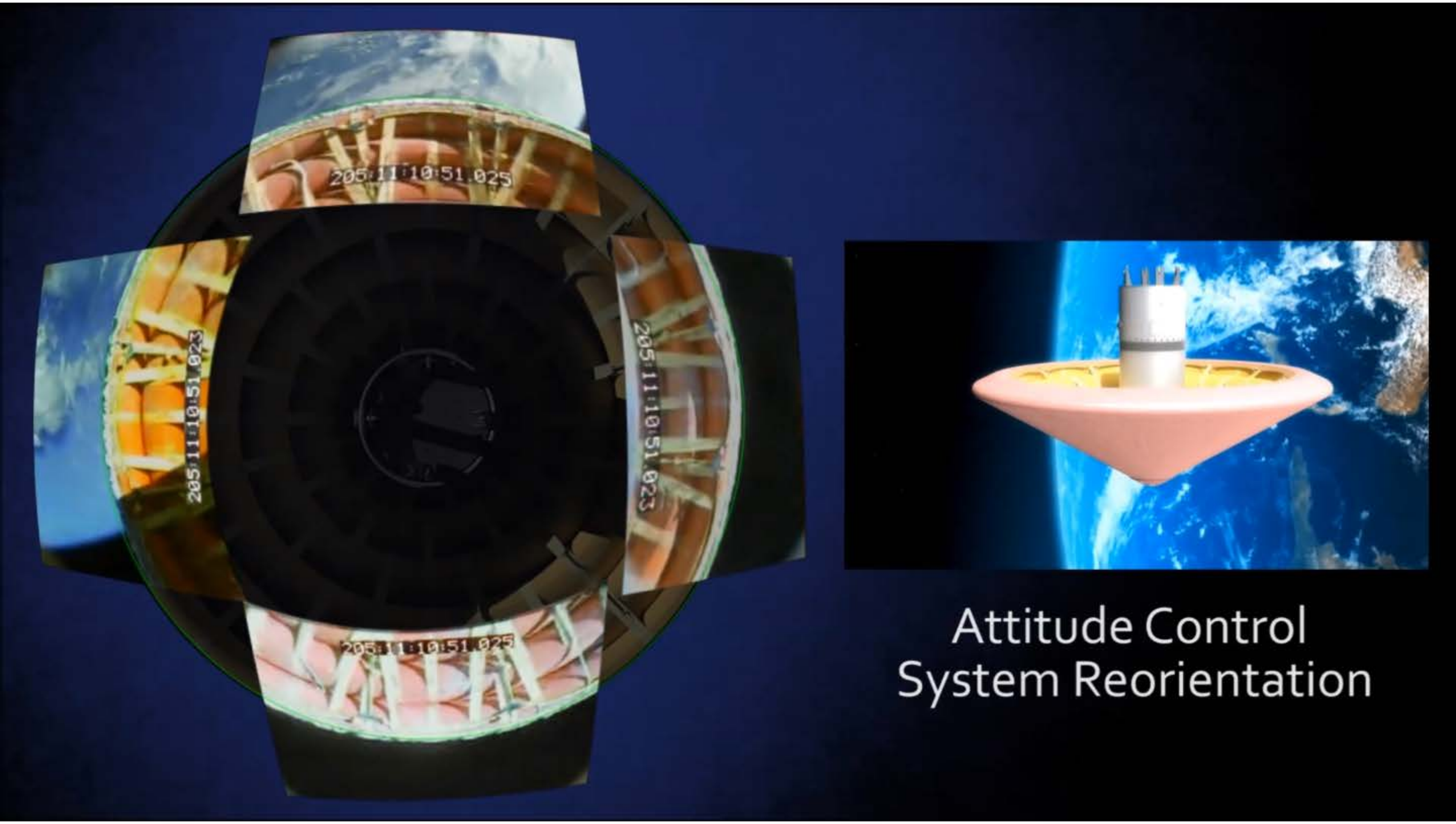
- Taber pressure gauges, each ~1” diam x 3”
- 5 on ports through nose heat flux gauges; attached to underside of nose
- 1 in inflation tank
- 3 in centerbody to measure ambient
- 1 downstream of regulator
- 2 in inflation manifolds
- 7 to monitor toroid pressures



Video

- Flew 4 video cameras
- Positioned atop centerbody, to monitor inflated aeroshell geometry
- Used most of the available 10Mbps
- Extremely useful for diagnostics, outreach, and conveying flight events

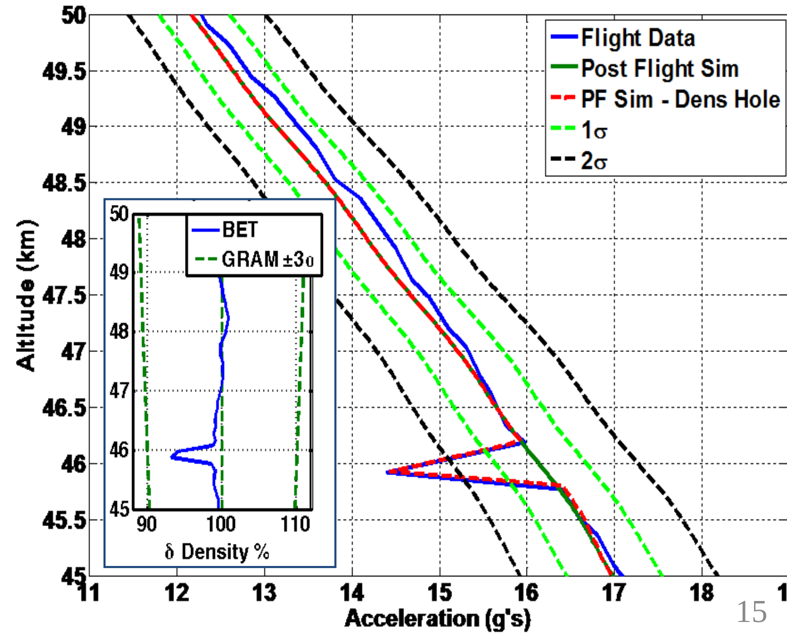
IRVE-3 Flight Video



Several videos are available on YouTube: Search for IRVE-3.

Some Sensor Redundancy is Good

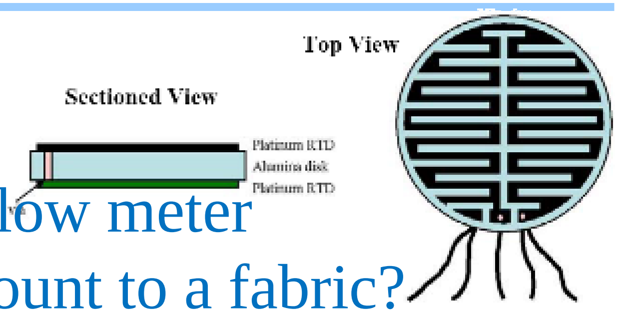
- Not all TC's survive integration & test
  - Installed several in symmetric locations
- Saw some unexpected events in flight:
- Free fall hindered the inflation tank heater more than expected
  - No convection in free fall, then impressive amount at 20G's
  - Electrical current sensor confirmed flight heat generation matched ground test, not a glitch in TC reading
- Post-flight reconstruction showed 1.5G deceleration dip for 100msec
  - Seen by IMU, accelerometer, & pressure gauges; not just a glitch
  - Video showed no aeroshell change
  - Required an 11% density drop, for ~100m ("hole in the sky")
  - Similar pockets were seen during Shuttle reentry



HIAD Progress

- Need sensors for future flights, not 2012 IRVE-3 conditions
- IRVE-3 TPS (Nextel/Pyrogel) saw peak of 14.4W/cm2
- Gen-2 TPS (SiC/Carbon) has survived 103W/cm2 at LCAT
  - Square pulse (no ramp up/down), 220sec duration
  - LCAT cold wall test conditions equate to ~74W/cm2 in flight
  - Peak TPS capability vs flight-like heating profile (ramp up to peak flux, ramp down) is unclear
- Research underway on potential Gen-3 TPS materials
- Working toward 400°C-capable inflatable structure

Desired Sensor Improvements



- Smaller / lighter
  - Data system electronics
  - Heat flux gauges, pressure sensors, gas flow meter
  - How would the Ames heat flux gauge mount to a fabric?
- Easier to pack / more durable
  - Wireless TC's (with small battery-powered transmitter)?
- Added Capabilities
  - Would like to measure physical displacement in flight
    - During load tests we position a laser scanner above the aeroshell – but there are no handy ceiling joists in flight
    - Fiber optic displacement sensors?
  - Higher bandwidth data system
  - Infrared cameras with quantified temperatures
- Sensors for the aeroshell would need to tolerate packing & folding, with no sharp edges to damage fabric & films
- Need to be pyro-safe, & tolerate flight conditions / ground handling

Questions?