National Aeronautics and
Space Administration

Inflatable Reentry Vehicles and Instrumentation Needs

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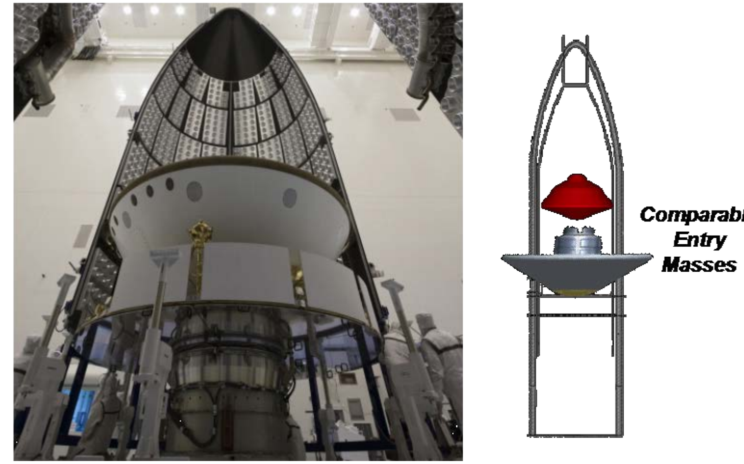
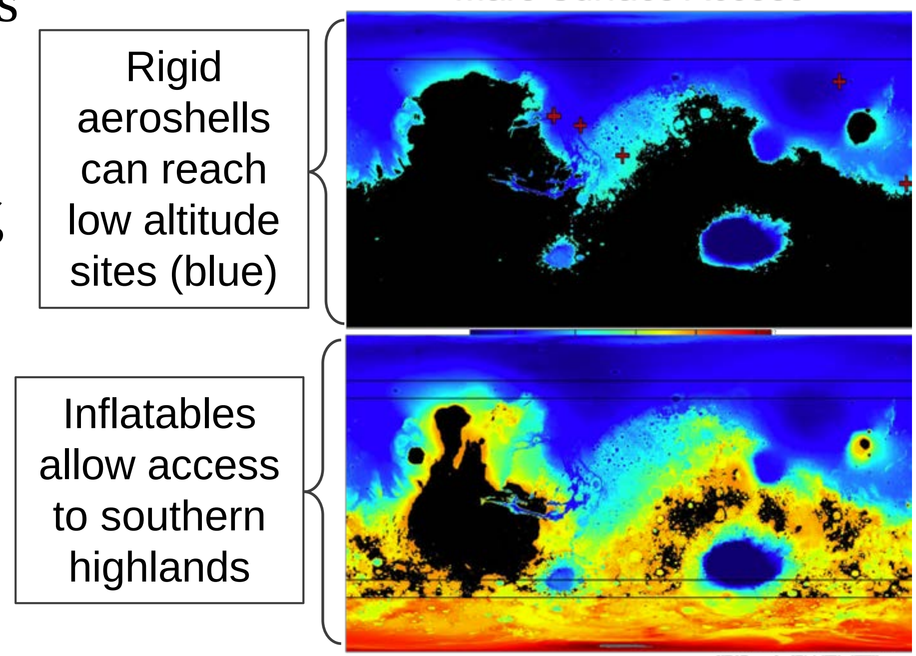
Background: Why Inflatables?

- Payload mass to Mars surface is limited by what fits in a rigid capsule that will fit inside the launch vehicle fairing
- Landing altitude at Mars is limited by the ballistic coefficient (mass per area) of the entry vehicle – more massive payloads need longer to slow down
- Inflatable technology allows payloads to use the full diameter of the launch fairing, and deploy a large aeroshell before atmospheric interface, landing more payload mass at higher altitude
- Also enable return of large payloads from Low Earth Orbit (LEO)

Launch Vehicle Fairing Constraints

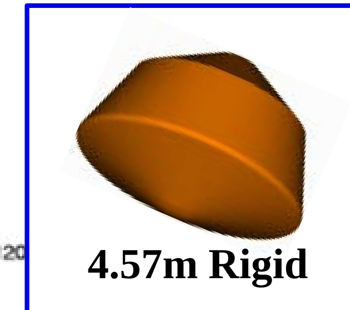


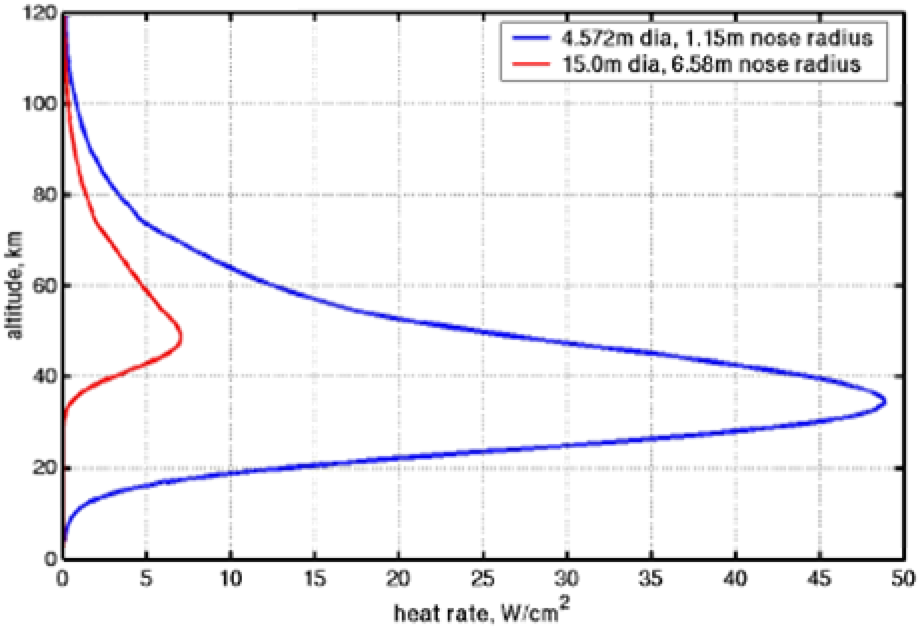
Mars Surface Access

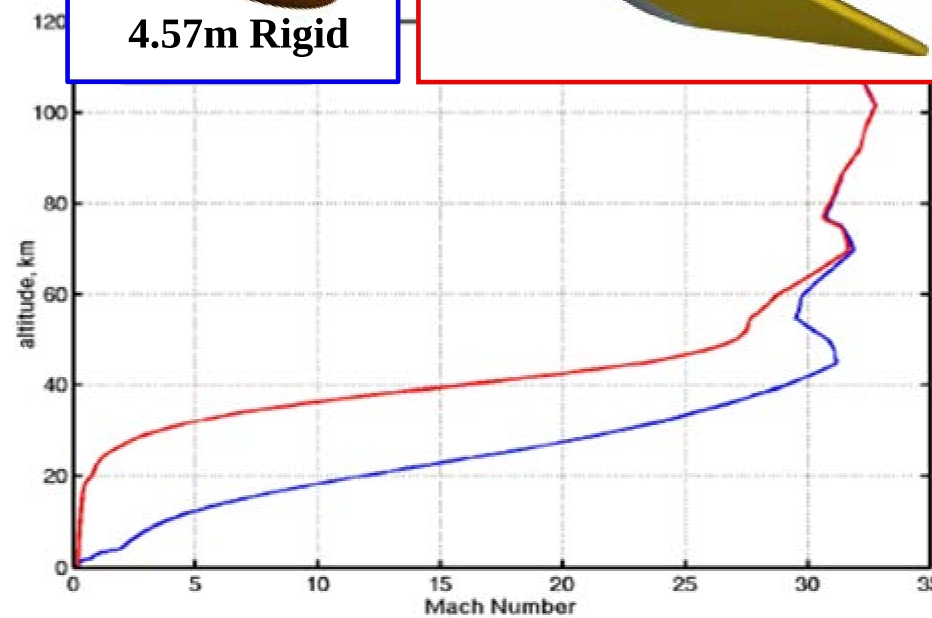


Entry Heating

- The inflatable aeroshell's larger area, blunter nose, and lower ballistic coefficient also reduce the peak heating for the same atmospheric entry conditions and payload mass
- Ballistic entry at Mars:
  - Entry speed: 6km/s
  - Entry mass: 2200kg (MSL-rover class)



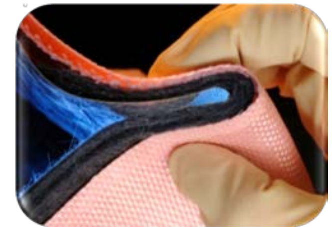
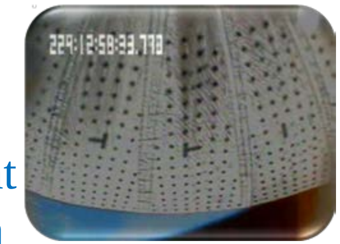
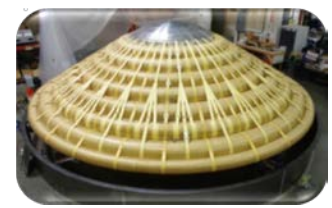
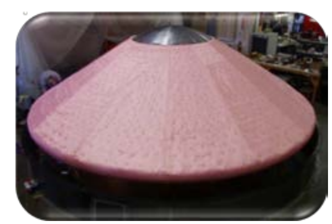




- 10m inflatable aeroshell would see ~30 W/cm2 peak flux
- Flexible fabric heat shield has passed ground tests to 75 W/cm2

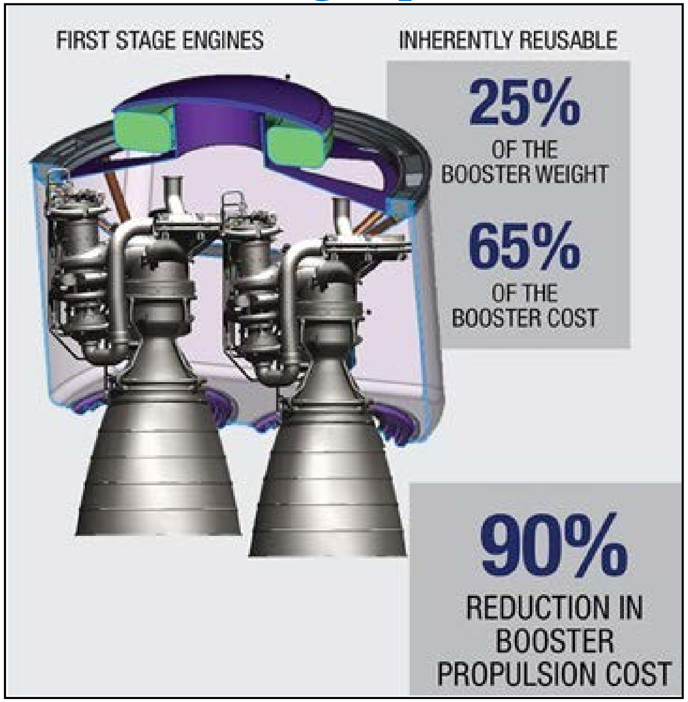
Development History

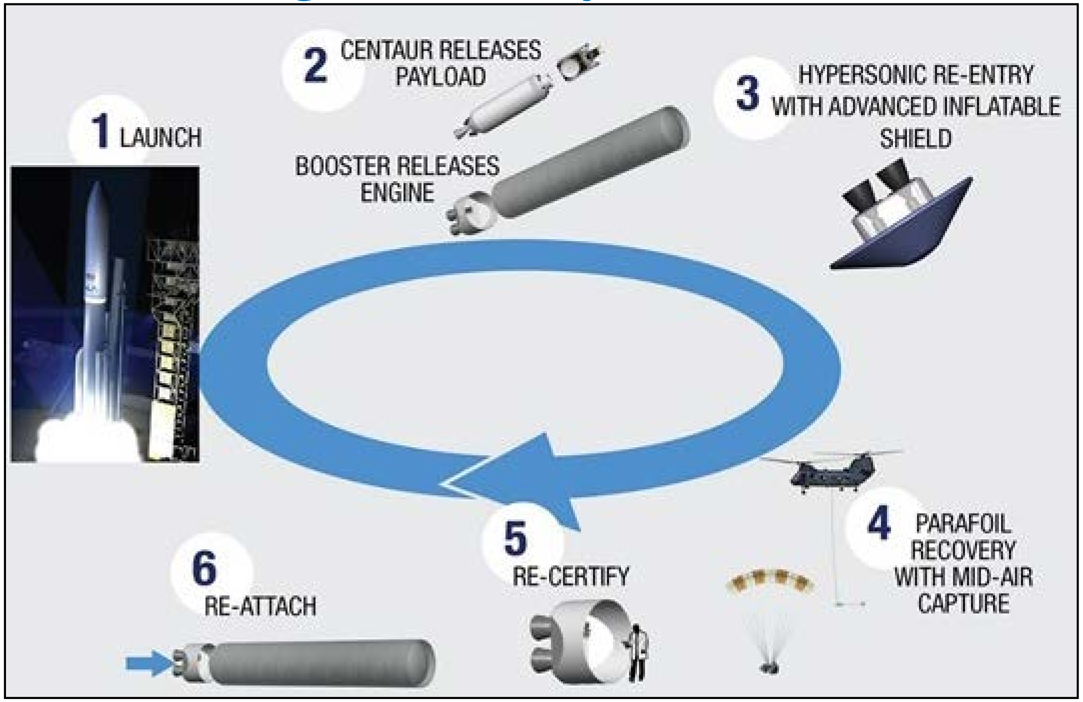
- NASA Langley has been developing Hypersonic Inflatable Aerodynamic Decelerators (HIADs) for over 10 years
- Systematic technology advancement steps
  - Ground Effort: Project to Advance Inflatable Decelerators for Atmospheric Entry (PAI-DAE): Softgoods technology development
  - Flight Test: Inflatable 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 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, tested 6m cone, 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, akin to Mars direct entry flux
  - Proposed twice (HEART, THOR) but not yet funded


Pending Commercial Use

- United Launch Alliance, maker of Atlas and Delta rockets, announced in April 2015 their plans to use a HIAD on their next generation launch vehicle to recover the 1st stage engines for re-use
  - First flight planned for 2019; first engine recovery for 2024





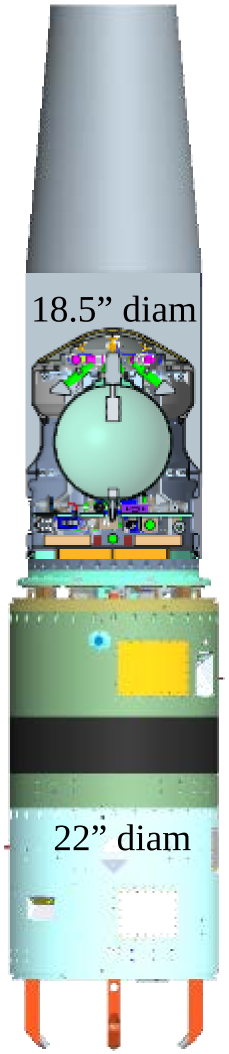
Images courtesy ULA

- Proposing 2019 flight test of 6m HIAD – reentry from LEO
- Estimating 10-12m HIAD for ULA engine recovery, same size as potential 2024 Mars demo flight

IRVE-3 Reentry Vehicle

- 3m diam, 60°, 7-toroid inflatable aeroshell with flexible TPS on forward face
- Centerbody houses the electronics, inflation system, CG offset mechanism, telemetry module, power system (batteries), attitude control system, & 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
- 20G launch, 20G entry
- 281kg entry mass

Stowed (18.5”)

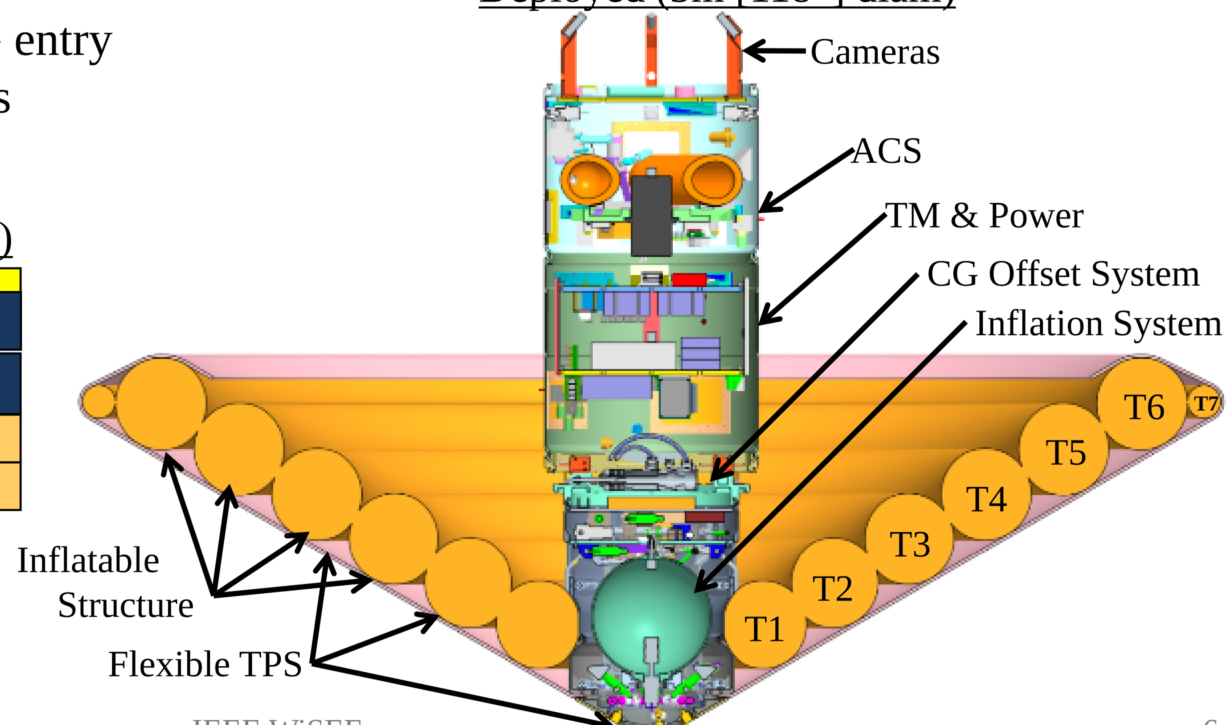


TPS Layup (~¼”)

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

Apogee
364s, 469km

Coast…

Eject Nose Cone
102s, 176km

ACS damps rates
91s (10s duration)

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

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

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

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

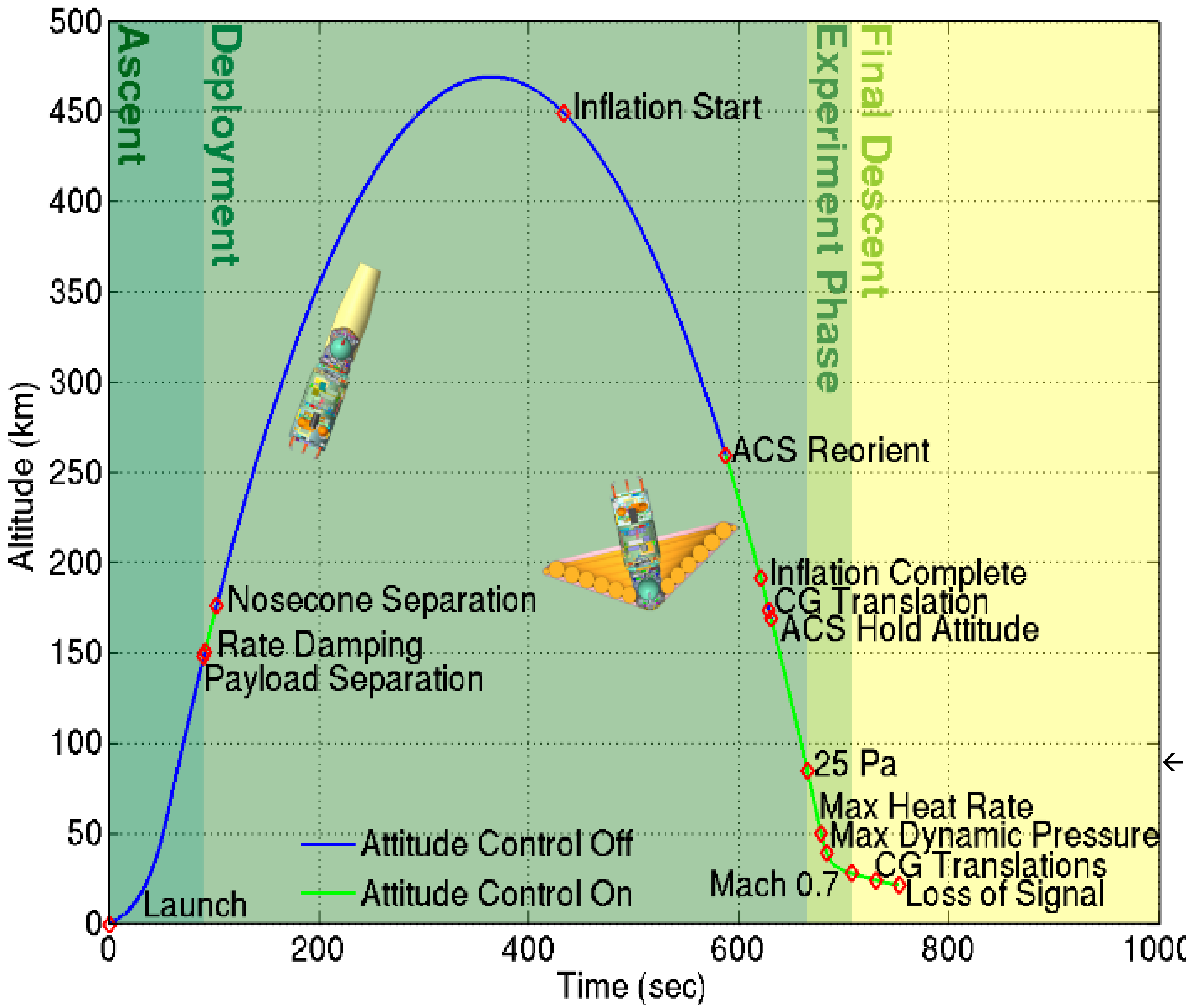
LOS by land radar & TM
910s, 10.5km

Vent NIACS and Inflation System Gas

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

Recovery Attempt - Unsuccessful

IRVE-3 Trajectory at Scale

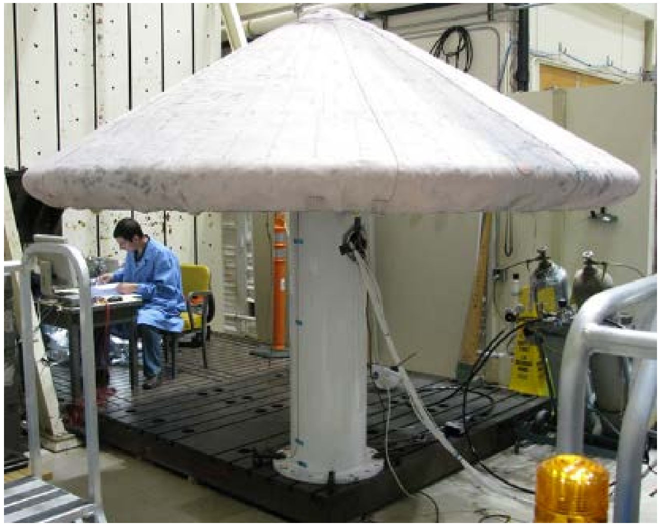


← Top of Atmosphere

Note: Experiment phase only 43sec long

IRVE-3 Instrumentation

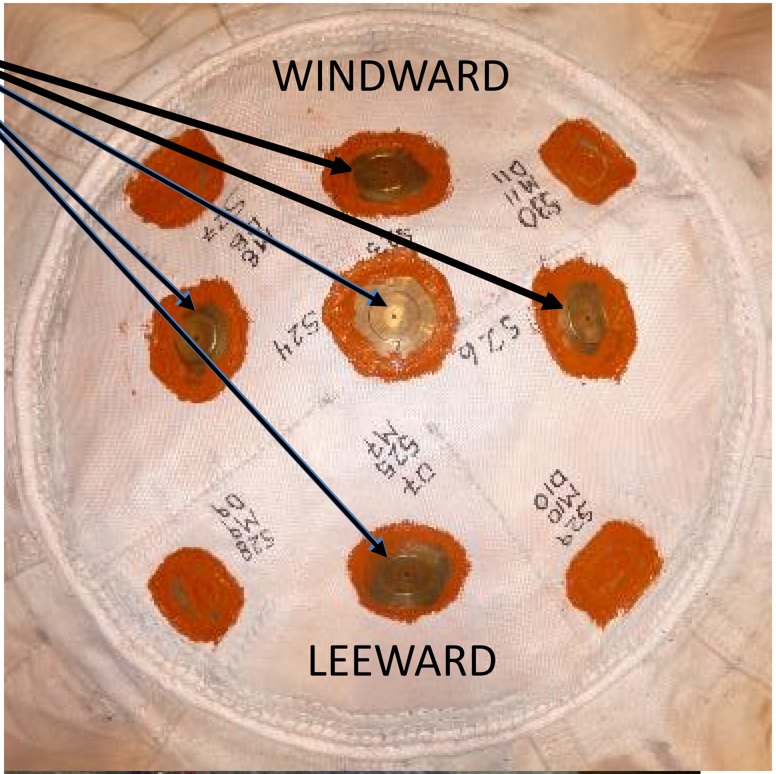
- 5 heat flux gauges on nose
- 64 thermocouples
  - Type K, 30 AWG leads, glass braid
  - Electronics mostly set for 0-1000°C
- 19 pressure gauges
- 4 video cameras
- Inflation gas flow meter
- IMU & GPS in attitude control system
- Accelerometers & attitude sensors
- 8 thermistors (electronics temps)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



Heat Flux Gauges on IRVE-3 Nose

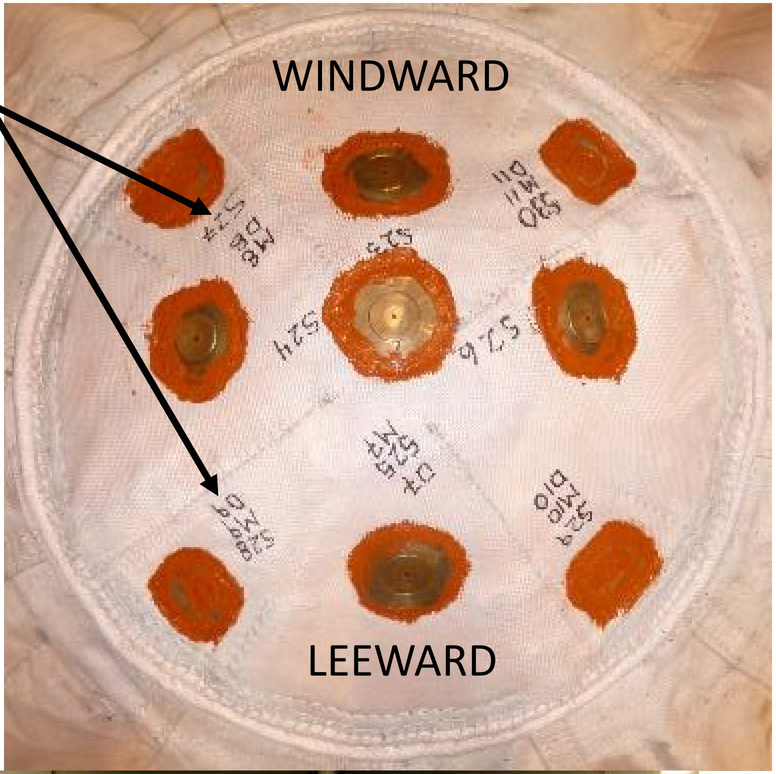
- 5 MedTherm Schmidt-Boelter gauges
- Copper, 1” diameter x 1” long
- Mounted through rigid Al nose
- End is flush with surface of TPS
- Lip of 1.9” diameter copper mounting bracket holds edge of TPS
- Step from edge of bracket to TPS filled with RTV 159

- Assembled, 0.5lb each, plus cabling
- Are too large & heavy for convenient installation on inflatable structure



18 Thermocouples on IRVE-3 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 outer edge of nose, then into centerbody

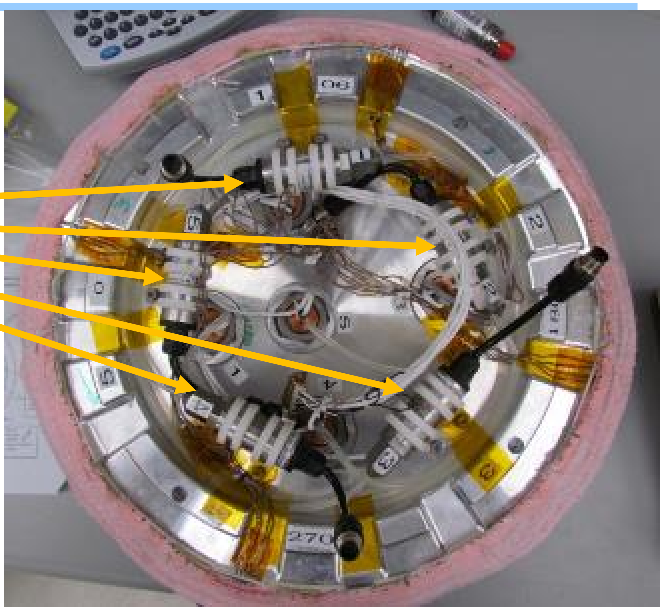


Thermocouples on IRVE-3 Aeroshell

- Most are Surface / Mid / Deep in TPS, as on the nose
- A few on centerbody, & on aft side of the structural straps that connect the inflatable toroids
- To avoid puncturing TPS gas barrier, TC leads run between layers to max diameter, to aft edge of TPS, then (between TPS & inflatable) back to centerbody
  - Long leads affect readings, & can pick up EMI
- Aeroshell must be hard packed for launch:
  - Tight folds, vacuum bagging, & hand-working to smooth out fabric bumps, etc
  - Zig-zag extra lead length to accommodate folds
  - IRVE-3 hard-packed to 39 lb/ft3
- 4 TC leads broke during packing
  - 1st pack for deployment test, 2nd for flight
- 2” diam bundle of TC wires heavy, difficult to pack
- Want more TC’s on 6m flight test article
- What wireless capabilities exist?

IRVE-3 Pressure Gauges

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



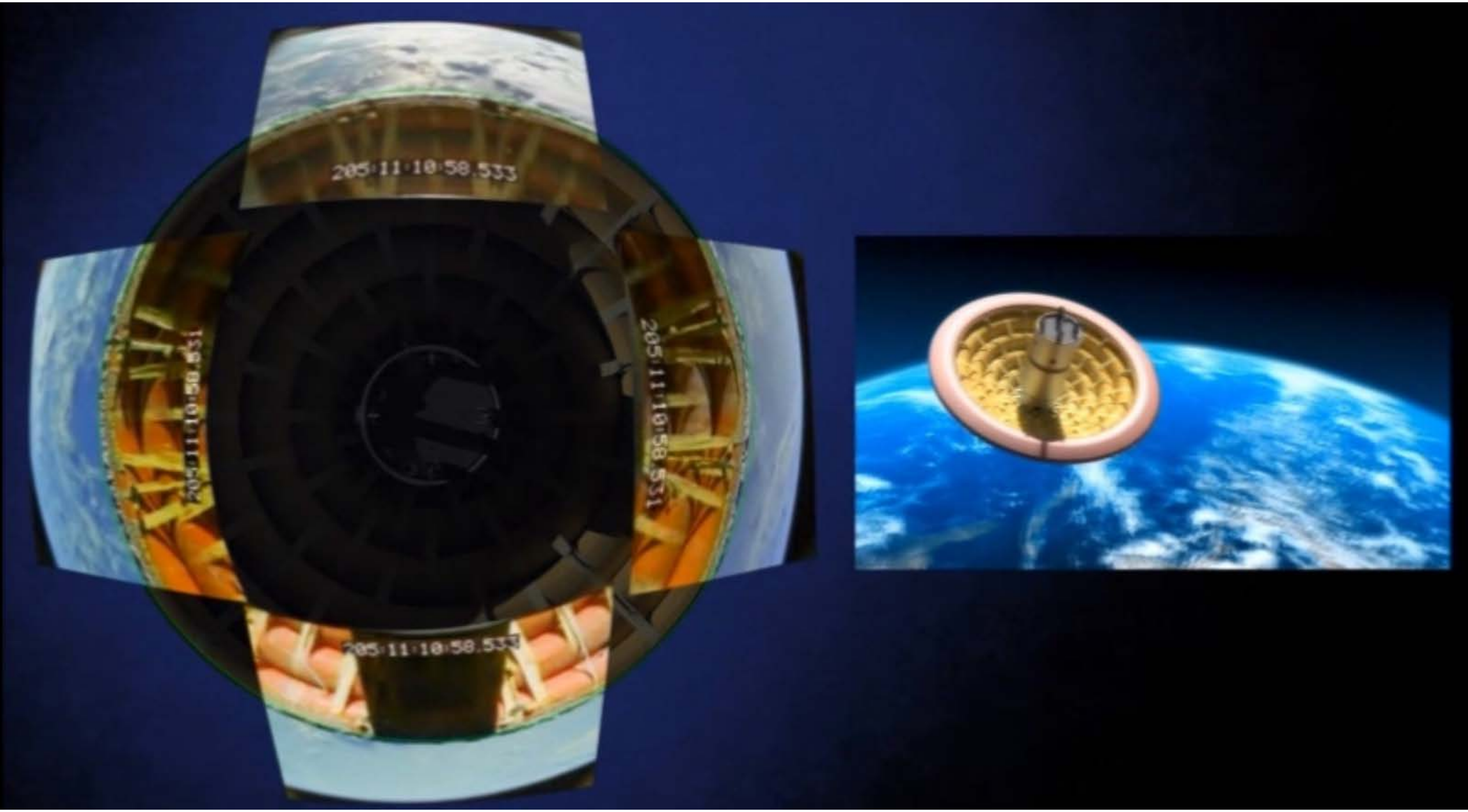
- Like our heat flux gauges, the pressure gauges are too large for convenient installation out on the inflatable structure

IRVE-3 Video Cameras

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

- Planning for HD cameras on future flights, with solid state recorder
- May fly infrared cameras as well (room temp to 200-300C)

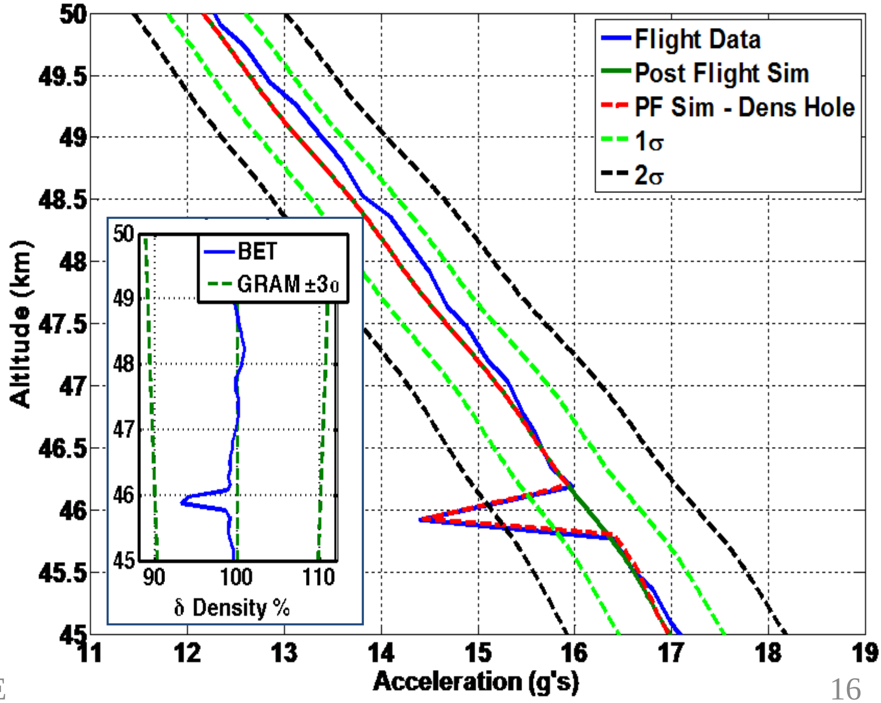
IRVE-3 Flight Video (2 minutes)



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

Some Sensor Redundancy is Good

- Not all TC's survive integration & test – installed symmetric ones
- Saw some unexpected events in flight, where multiple sensors helped
- 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, accelerometers, & 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 reentries



HIAD Sensor Environment

- Future flights won't duplicate 2012 IRVE-3 test conditions
- IRVE-3 TPS (Nextel/Pyrogel) saw peak heat flux of 14.4W/cm2
- Gen-2 TPS (SiC/Carbon Felt) has survived ground testing to levels analogous to 75W/cm2 flight
  - Ground test facility used 220sec square pulse (no ramp up/down)
  - 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
- TPS insulator thickness sized so back surface of TPS peaks at 300-400°C
- Working toward 400°C-capable inflatable structure, though structure will only reach that where in contact with TPS
- Lower launch acceleration; large rockets to orbit accelerate more slowly than small solid rockets
- Lower reentry deceleration; IRVE-3 reentered almost straight down to maximize heating on the TPS, but LEO reentry will be at a shallow angle

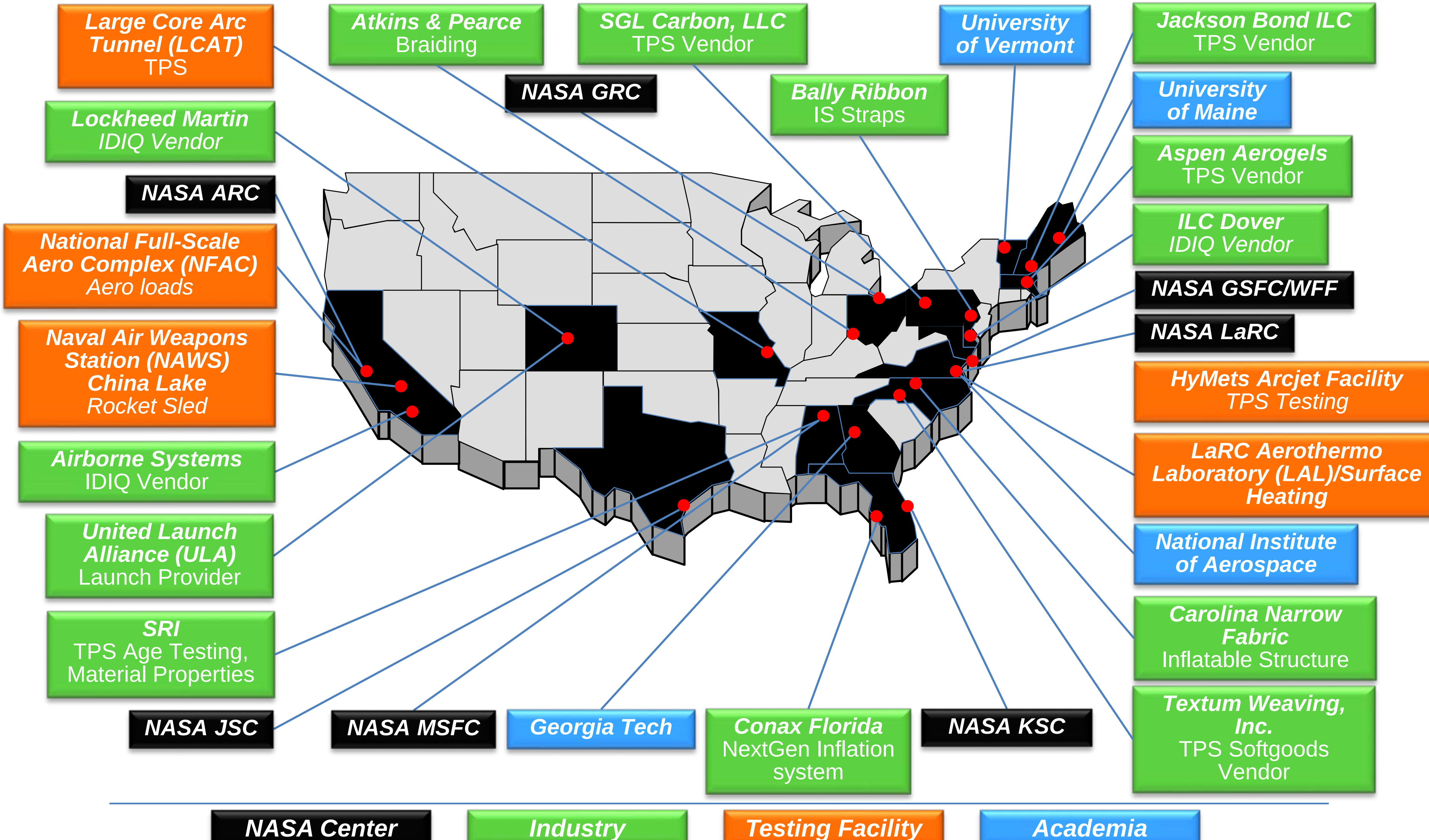
- Note: Gen-2 HIAD TPS is conductive & RF opaque

Desired Sensor Improvements

- Want everything smaller & lighter
  - Data system electronics
  - Heat flux gauges, pressure sensors, gas flow meter, etc
- Interested in wireless measurement of temperature in/behind the TPS
  - How small could the sensor package be?
  - Need a small sensor to accurately measure rapid thermal changes; perhaps use a TC a short distance from the associated electronics?
  - How to power it?
- Interested in additional measurement capabilities
  - For ground tests, used a laser scanner to measure displacement
  - During flight, use embedded fiber optics?
- Sensors for the aeroshell would need to tolerate packing & folding, with no sharp edges to damage fabric & films

- Need to be pyro-safe, or at least powered off until pyro events are done
- Need to tolerate flight conditions / ground handling

Many Thanks to the HIAD-2 Team



Questions?