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

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Background: Why Inflatable?

- 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).
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)
    \[ V = 6 \text{ km/s} \]
    \[ m = 2200 \text{ kg (Entry)} \]
  - 10m Inflatable would see \(~30\text{-W/cm}^2\) peak flux

- 15m Inflatable
- 4.57m Rigid
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/cm^2
  – 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”)

Inflatable Structure
Flexible TPS
Aeroheating and Dynamic Pressure

Deployed (3m [118”] diam)

Kapton / Kevlar film
Pyrogel felt insulation
TPS Layup (~¼”)

Cameras
ACS
TM & Power
CG Offset System
Inflation System
IRVE-3 Mission Sequence

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

- **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

- **3rd Stage Ignition, 23.0s**

- **2nd Stage Burnout, 18.5s**

- **2nd Stage Ignition, 15.0s**

- **1st Stage Burnout, 6.4s**

- **1st Stage Ignition, 0s**

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

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

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

- **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**

- **Apogee**
  - 364s, 469km

- **Coast…**

- **Vent NIACS and Inflation System Gas**
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
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