Hypersonic Inflatable Aerodynamic Decelerator Ground Test Development

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International Planetary Probe Workshop #12
Agenda

• HIAD Context
  - Technology Background (Historical Context)
  - Future Flight and Developments Path
  - Technology Requirements

• HIAD at the end of FY14
  - FTPS Accomplishments and Solutions
  - IS Accomplishments and Solutions

• HIAD-2 “Preparing for Mars”
  - Flexible Systems Development Areas
  - Inflation Systems and Aeroaffect Technology

• Closing Remarks
HIAD Technology History

- Systematic and stepwise technology advancement
  - **Ground Test:** Project to Advance Inflatable Decelerators for Atmospheric Entry (PAI-DAE): Softgoods technology breakthrough
  - **Flight Test:** Inflatable Reentry Vehicle Experiment (IRVE), 2007: LV anomaly--no experiment
  - **Flight Test:** IRVE-II, 2009: IRVE “build-to-print” re-flight: Historic first successful HIAD flight
  - **Ground Test:** HIAD Project improving structural and thermal system performance (Gen 1 & Gen 2): Extensive work on entire aeroshell assembly
  - **Flight Test:** IRVE-3, 2012: Improved 3m IS & FTPS, higher energy reentry; first controlled lift entry

- Next Steps
  - **Ground Effort:** TRL Maturation Project improving Aeroshell capabilities, including scaling to >10m, manufacturing advancements, controllability and demonstrated staging to secondary decelerator option. **Prepares for large scale flight test demo and readiness for Mars mission.**
  - **Flight Test Possibilities:** ULA Asset Recovery Demo at scale and environments relevant to Mars Human Pathfinder.
## Development Timeline for 2024 Mars Demo, Utilizing ULA

<table>
<thead>
<tr>
<th>Year</th>
<th>Flight Test effort</th>
<th>Ground Test effort</th>
<th>Earth flight test</th>
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- **EDL Architecture Study**
- **IRVE-3**
- **HIAD Gen-1 complete**
- **“HIAD-2” (ground-based) Project**
- **HIAD ½-Scale Orbital Flight Test**
- **IRVE-S Sounding Rocket Flight Test**
- **Cascade Decelerator**
- **HIAD Full-Scale Orbital Flight Test**
- **Gen-2 6m-class**
- **Gen-2 & Gen-3 15m-class**
- **Gen-2/3 12m-class**
- **TBD**
- **Launch**

**Note:**
- Flight Test effort
- Ground Test effort
- Earth flight test

**Additional Information:**
- Gen-2/3 12m-class
- ULA Infusion

**Legend:**
- Orange: Flight Test effort
- Blue: Ground Test effort
- Green: Earth flight test

**Timeline Details:**
- Full-Scale Capability Pathfinder
- Launch
- EDL
- PDR
- CDR
- TBD

**Key Projects:**
- HIAD Gen-2/3 12m-class
- Cascade Decelerator
- IRVE-3
- HIAD Gen-1 complete
- “HIAD-2” (ground-based) Project
- HIAD ½-Scale Orbital Flight Test
- IRVE-S Sounding Rocket Flight Test
HIAD Technology Requirements

- Manufacturability of full aeroshell system at scale
- Demonstrate performance margin at entry aerothermal environments
- Pack aeroshell to high densities (~300 kg/m$^3$ [20lb/ft$^3$] packed, ~40 kg/m$^3$ deployed)
- Fold materials to a hard crease (near-zero bend radius) without degrading aeroshell performance
- Withstand long duration exposure to in-situ exo-atmospheric environments, without degrading materials capability.
- Deploy and inflate aeroshell after long duration storage at high packing densities without significantly changing thermophysical characteristics of TPS, leak rate of IS, or inflation capability
- Model and reliably calculate material and system performance in order to size TPS for desired trajectory
F-TPS Development (FY12-14)

- Fabricated 6-m hybrid 1st Gen/2nd Gen F-TPS and a 3.7-m 2nd Gen F-TPS, and successfully load tested integrated 6-m F-TPS and inflatable structure
- Developed new test methodology used to create aerothermal performance data sets of 1st and 2nd Generation layups and conducted 302 stagnation and 33 shear tests during 3 years
- Developed F-TPS multi-physics thermal model which incorporated measured material properties and physical phenomena; and performed initial validation of model to ground and flight test data
- Developed analysis framework which incorporates the F-TPS multi-physics thermal model and uses probabilistic tools which is being used to reduce margined mass while preventing bondline over-temperature
HIAD F-TPS Framework

<table>
<thead>
<tr>
<th>F-TPS Components</th>
<th>1st Gen (30 Watts/cm²)</th>
<th>2nd Gen (50 Watts/cm²)</th>
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<td>Outer Fabric</td>
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<td>Hi-Nicalon™ SiC</td>
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<td>Gas Barrier</td>
<td>Kapton-Kevlar Laminate (KKL)</td>
<td>Kapton-Zylon Laminate (KZL)</td>
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</table>

Inflatable Structure
Temperature Limit

- 1st Generation: 250°C
- 2nd Generation: 400°C
HIAD IS Accomplishments

IS Development (FY12-14)

- **Material and Component Characterization Tests**: Verify material strengths and properties for design margin analysis and structural modeling
- **Modeling and Analysis**: Models correlated to test data to evaluate component loads, response to aerodynamic loading, and performance for mission application
- **Fabrication Demonstrations**: 3m and 6m (Gen 1 - 250°C) and 3.7m (Gen 2 - 400°C)
- **Performance Demonstrations**: Static Load Tests, Aero Load Tests (NFAC), Modal Tests
- **Packing**: Folding and Packing to meet stowage volume constraints and packing densities
## HIAD IS Framework

<table>
<thead>
<tr>
<th>IS Components</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Gen (250°C)</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; Gen (400°C)</th>
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<td>Kevlar, Technora</td>
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<tr>
<td>Torus Braid</td>
<td>Kevlar, Technora</td>
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<td>Cords</td>
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**Diagram:**
- **Webbing**
- **Torus Braid**
- **Cords**
- **Liner**
- **Braid coating**
- **Cord within Torus Braid**
HIAD-2 Flexible System Development

**Developments for FTPS**
- Improve TRL of 3rd Gen F-TPS (75W/cm² @ 400°C)
- 15-m class manufacturability of 3rd Gen TPS

**Developments for IS**
- Investigate alternate inflatable structure concepts
- 15-m class manufacturability
- Develop cascading decelerator option

**Developments for Aeroshell**
- Complete 2nd Gen FTPS
- Develop packing techniques
- Investigate scaling ramifications for 15-m class aeroshell

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**Ground Effort**

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### Developments for Inflation System

- Define logical limitations of compressed gas systems
- Comprehensive study to identify candidate gas generation systems (solids & liquids)

### Developments for Aeroeffectors

- Design approaches for lift generation via trim tabs and morphing structures
- Analyze performance of non-axisymmetric shapes
- Evaluate each with respect to controllability

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• HIAD Technology has been actively developed for nearly a decade.
• Significant work has gone into developing test techniques, manufacturing advancements, understanding and characterizing material systems.
• Successful IRVE flights have verified the technology at subscale.
• Future development to focus on scaling to 15-m class systems, targeting the proposed EDL Pathfinder demonstration, and ultimate use for human exploration of Mars.
Questions?