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 Aeroaffecter 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

- **Full-Scale Capability Pathfinder**
  - PDR
  - CDR
  - Launch
  - EDL

- **EDL Architecture Study**
- **IRVE-3**
  - HIAD Gen-1 complete

- **“HIAD-2” (ground-based) Project**
  - Gen-2 & Gen-3 15m-class

- **HIAD ½-Scale Orbital Flight Test**
  - Gen-2 6m-class
  - Cascade Decelerator
  - Gen-2/3 12m-class

- **IRVE-S Sounding Rocket Flight Test**
  - TBD

- **HIAD Full-Scale Orbital Flight Test**
  - TBD

- **ULA Infusion**
  - Launch
HIAD Technology Requirements

- Manufacturability of full aeroshell system at scale
- Demonstrate performance margin at entry aerothermal environments
- Pack aeroshell to high densities (~300 kg/m³ [20lb/ft³] packed, ~40 kg/m³ 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

\[ \rho C_p \frac{\partial T}{\partial t} - \frac{\partial}{\partial x} \left( K \frac{\partial T}{\partial x} \right) = 0 \]
HIAD F-TPS Accomplishments

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>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Fabric</td>
<td>Nextel™ 440 BF-20</td>
<td>Hi-Nicalon™ SiC</td>
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<tr>
<td>Primary Insulator</td>
<td>Pyrogel® 2250</td>
<td>Sigratherm® KFA-5</td>
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<td>Secondary Insulator</td>
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<td>Pyrogrel® 2250</td>
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<tr>
<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

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**1st Generation**

- Nextel™ 440 BF-20
- Pyrogel® 2250
- Pyrogel® 2250
- Kapton-Kevlar Laminate (KKL)

**2nd Generation**

- Hi-Nicalon™ SiC
- Sigratherm® KFA-5
- Pyrogrel® 2250
- Kapton-Zylon Laminate (KZL)
**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
<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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<tbody>
<tr>
<td>Webbing</td>
<td>Kevlar, Technora</td>
<td>Zylon</td>
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<tr>
<td>Torus Braid</td>
<td>Kevlar, Technora</td>
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<tr>
<td>Cords</td>
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<tr>
<td>Liner</td>
<td>Silicone film</td>
<td>PTFE film</td>
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<tr>
<td>Coatings and Adhesives</td>
<td>Silicone</td>
<td>Silicone</td>
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**Webbing**
- Torus Braid
- Cords
- Liner
- Coatings and Adhesives

*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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### Timeline

- **Seaming Construction Complete**
- **Stagnation Test Complete**
- **Shear Test Complete**
- **FTPS Repair Methods Complete**
- **Age Thermal Tests Complete**
- **Space Environment Tests Complete**
- **Dual Pulse Tests Compl.**
- **15m-Class FTPS Design Complete**
- **15m-Class FTPS MDU Complete**
- **Margins Policy Complete**
- **FTPS Repair Complete**
- **15m-Class IS Design Complete**
- **Load Test Complete**
- **Test Report Complete**
- **Integrate IS/TPS Test Complete**
- **Packing GSE Complete**
- **15m-Class Pack & Deploy Complete**
- **Identify Methods & Matl’s Complete**
- **Large Scale Sub Components Complete**
- **Documented Mfg Methods Complete**
- **Optimize 15m Design Complete**
- **Load Test Complete**
- **Test Report Complete**
- **Integrate IS/TPS Test Complete**
- **Packing GSE Complete**
- **15m-Class Pack & Deploy Complete**
- **Sub-scale Packing Complete**
- **Age Thermal Tests Complete**
- **15m-Class IS Design Complete**
- **Load Test Complete**
- **Test Report Complete**
- **Integrate IS/TPS Test Complete**
- **Packing GSE Complete**
- **15m-Class Pack & Deploy Complete**
HIAD-2 Inflation System and Aeroeffectors Development

**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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<th>Ground Effort</th>
<th>FY2015 AMJ</th>
<th>FY2016 AMJ</th>
<th>FY2017 AMJ</th>
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- CGO Requirements Defined
- Lift Capability Demonstrated
- CGO Demonstrated
- Supersonic Testing Completed
- Opportunity Path to Pack & Deploy
- Begin Qual. Testing
- Present Data
- Complete
- Subscale System Tested & Defined
- Concept Trade Complete
- Control Requirements Defined
- EDL Design Study

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**Timeline**

- FY2015
- FY2016
- FY2017
- FY2018
- FY2019
- FY2020

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**Projects & Activities**

- Inflatable L/D Shape Defined
- CGO Requirements Defined
- Lift Capability Demonstrated
- CGO Demonstrated
- Supersonic Testing Completed
- Opportunity Path to Pack & Deploy
- Begin Qual. Testing
- Present Data
- Complete
- Subscale System Tested & Defined
- Concept Trade Complete
- Control Requirements Defined
- EDL Design Study
- Advanced Aero-Affectors
- Non-Axisymmetric Concepts
• 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?