Adaptable Deployable Entry & Placement Technology (ADEPT) for Cubesat delivery to Mars Surface

Briefing for CubeSat to Mars Workshop

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ADEPT is an atmospheric entry architecture for missions to most planetary bodies with atmospheres.

- Current Technology development project funded under STMD Game Changing Development Program (FY12 start)
- Stowed inside the launch vehicle shroud and deployed in space prior to entry.
- Low ballistic coefficient (< 50 kg/m2) provides a benign deceleration and thermal environment to the payload.
- High-temperature ribs support 3D woven carbon fabric to generate drag and withstand high heating.

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ADEPT Accomplishments to Date (FY12-present)

Carbon Fabric Combined Environment Performance (FY12) and SPRITE Test Methodology

Key Capabilities Demonstrated
- Successful demonstration of carbon fabric thermal and mechanical performance under relevant testing in arcjets
- SPRITE (rigid configuration) 35 cm diameter, 45 sphere-cone tested as pathfinder for arc-jet facility configuration study
- Design and analysis of larger (up to 0.5 m diameter) SPRITE-C test methodology to “test as you fly, fly as you test” is underway.

2 m Ground Test Article (FY13)

Key Capabilities Demonstrated
- Developed fabric gore manufacturing & integration process at 2 m scale
- Demonstrated reliable operational functionality of the mechanical design, software control logic, and integration scheme of the ADEPT concept.
- Characterized the system’s response to off-nominal conditions during deployment.
- Focused ADEPT GTA team designed, built and tested in < 8 months

Fabric Seam Development (FY14)

Key Capabilities Demonstrated
- High Strength seams designed and fabricated for the first time with carbon thread, ultimate tensile strength in excess of 3000 lbs/in
- Seam arc jet test methodology developed that simultaneously pulls the seam under load while exposing to aerothermal environments (100 W/cm² for 220 seconds), heat load in excess of 20 kJ/cm².
- Phenolic seam infusion process developed
- Tests provide validation that carbon-stitched seams are viable for the ADEPT design

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## Technology Maturation Activity

<table>
<thead>
<tr>
<th>Distributed Load Wind-tunnel test</th>
<th>FY15</th>
<th>FY16</th>
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</thead>
<tbody>
<tr>
<td>• Demonstrate fabric shape retention under aeroloading in 7 x10 wind tunnel (subsonic)</td>
<td>Q1</td>
<td>Q1</td>
</tr>
<tr>
<td>• 0.7m diameter model</td>
<td>Q2</td>
<td>Q2</td>
</tr>
</tbody>
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<thead>
<tr>
<th>SPRITE-C Arc Jet Test</th>
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<tbody>
<tr>
<td>• Demonstrate aerothermal flight environment performance (TAYF/FAYT)</td>
<td>SPRITE-C Pathfinder</td>
<td>SPRITE-C Interface Test</td>
</tr>
<tr>
<td>• Peak heating rates comparable to Mars, Earth, and potential Venus entry</td>
<td></td>
<td>Response Model Testing</td>
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<thead>
<tr>
<th>Sounding Rocket Test</th>
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<tbody>
<tr>
<td>• Demonstrate Flight-like deployment in exo-atmosphere (zero-g, vacuum)</td>
<td>Deployment Demo</td>
<td>PDR</td>
</tr>
<tr>
<td>• Demonstrate critical supersonic aerodynamic stability</td>
<td></td>
<td>CDR</td>
</tr>
<tr>
<td>• Flight-like configuration of 0.7m ADEPT and ~15kg</td>
<td>SL10 Flight Demo</td>
<td>ADEPT Flight Test (TBD)</td>
</tr>
</tbody>
</table>

1) Development approach leverages system level testing (SPRITE, W/T testing, Sounding Rocket) to demonstrate performance at flight relevant scale (0.7m diameter) and environments (Mars DRM)

2) Common design configuration between 3 major tasks areas essential for streamlined system level performance demonstration

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• **OBJECTIVE:** Characterize response of system level design features under relevant aerothermal environments.
  – Utilize flight-like interface designs (Nose/fabric, Nose/Joint, Joint/Rib, Trailing Edge Close-out)

• **APPROACH:** A relevant scale, 360 degree test article allows for multiple design features and their interactions to be characterized for design tool validation.
  – Heavily instrumented test article allows for multiple flight-like design features to be characterized.

• **IMPACT:**
  Reduces cost and overall development schedule duration to rapidly mature ADEPT 1 m class

• **FY2014 MAJOR ACCOMPLISHMENTS:**
  ✓ Fabricated full-scale prototype to demonstrate skirt manufacturing and tension adjustment (BRM and TRLA)
  ✓ Initial thermal model developed to predict in-depth thermal response of fabric and structure.

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SPRITE-C Pathfinder Test Article
Key Design Features

- **Test Articles (3)** - 1 spherical CA-250 nose, 1 spherical graphite nose, 1 scalloped CA-250 nose
- **Arc Heater Settings** - IHF, 21.5-in nozzle, $I_{arc} = 2200$ A, $m_{air} = 110$ g/s, $m_{air+} = 160$ g/s, $m_{Ar} = 30$ g/s, $P_{arc} = 193$ kPa
- **Stag Point Heating Prediction** - 63 W/cm$^2$
- **Test Duration** - 80 seconds
- **Stag Point Heat Load** - 5 kJ/cm$^2$ (~ 2.5 x the Mars DRM stag point heat load)

*Test Scheduled for January 2015*

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ADEPT Sounding Rocket Flight Test

- **OBJECTIVE:** Demonstrate LV separation and exo-atmospheric deployment. Characterize aerodynamic performance from low supersonic (~ Mach 3) to subsonic flight regimes.
  - Utilize CNAT Avionics and on-board instrumentation to reconstruct trajectory and obtain structural performance data.
- **APPROACH:** Demonstrate ADEPT 1 m class system flight performance for potential use as a secondary payload delivery system.
  - Low cost approach leveraging multiple programs within STMD portfolio. *(GCD, SBIR, Flight Opportunities, Center Innovation Fund)*
- **IMPACT:** Design capable of delivering ~5 kg of cube sat like payloads for low-cost, high-return science with 2-3 U volume.

**FY2014 MAJOR ACCOMPLISHMENTS:**
- Obtained approval as directed payload from Flight Opportunities Program
- Developed two-stage spring-based passive deployment approach
- Completed DSMC force and moment calculations supporting aero database

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ADEPT 1 m Mars DRM & SPRITE-C Test Aerothermal Environment Predictions

Mars Entry Trajectory & SPRITE-C Test Condition

Mars Entry Peak Heating Pt vs SPRITE-C

Rib cap matches well!

Nominal Mars Ballistic Entry Trajectory

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Mass</td>
<td>20 kg</td>
</tr>
<tr>
<td>Half Cone Angle</td>
<td>70 deg</td>
</tr>
<tr>
<td>Rn</td>
<td>0.25 m</td>
</tr>
<tr>
<td>Rb</td>
<td>0.35 m</td>
</tr>
<tr>
<td>EFPA</td>
<td>-15 deg</td>
</tr>
<tr>
<td>Inertial Velocity</td>
<td>6 km/sec</td>
</tr>
<tr>
<td>Peak Deceleration</td>
<td>15.5 g</td>
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<tr>
<td>Heat Load</td>
<td>2.0 kJ/cm²</td>
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Recent Publications (2014)

• 5 ADEPT publications at the International Planetary Probe Workshop in Pasadena, CA (June 2014), including 2 non-affiliated publications from academia
  – *ADEPT for Secondary Payloads* (Smith et al, NASA)
  – *Deployment Testing of the ADEPT Ground Test Article* (Yount et al, NASA)
  – *A versatile 3D-Woven Carbon Fabric for Broad Mission Application of ADEPT* (Kazemba et al, NASA)
  – *Enabling Venus In Situ Missions Using Mechanically Deployed Aerodynamic Decelerator* (Saikia et al, Purdue University)
  – *Trajectory Optimization with ADEPT Architecture* (Saranathan et al, Purdue University)
Three major test campaigns in Sounding Rocket flight test, Arcjet testing, and Wind Tunnel testing are planned for FY15-16. 

- Maximize common configuration and design features
- Mitigate major challenge areas sufficiently to enable credible infusion potential for Secondary Payload class missions.

ADEPT is proposing a Mach 3 sounding rocket flight test with hardware delivery in FY16. Actual flight depend on SR manifest schedule.

ADEPT 1m class development will see clear tech maturation and end-user confidence with successful sounding rocket flight test

- Exo-atmospheric deploy with flight relevant hardware
- Aerodynamic stability (open-back 70 deg sphere cone) through critical transonic flight regime

Simple deployment design (spring-based) with chute-less delivery to Mars Surface

Viable options exist to take advantage of mass and volume available on Mars 2020 cruise stage to deliver multiple ADEPTs (in stowed configuration)