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

Briefing for CubeSat to Mars Workshop

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ADEPT: Mechanically-deployable, Low-Ballistic coefficient hypersonic decelerator

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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ADEPT-1m Technology Maturation Plan (FY15-16)

Note: FY16 Plans are pending STMD approval

Technology Maturation Activity

<table>
<thead>
<tr>
<th>FY15</th>
<th>FY16</th>
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<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
</tr>
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Distributed Load Wind-tunnel test
- Demonstrate fabric shape retention under aeroloading in 7 x10 wind tunnel (subsonic)
- 0.7m diameter model

SPRITE-C Arc Jet Test
- Demonstrate aero thermal flight environment performance (TAYF/FAYT)
- Peak heating rates comparable to Mars, Earth, and potential Venus entry

Sounding Rocket Test
- Demonstrate Flight-like deployment in exo-atmosphere (zero-g, vacuum)
- Demonstrate critical supersonic aerodynamic stability
- Flight-like configuration of 0.7m ADEPT and ~15kg

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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SPRITE-C Pathfinder Arcjet System Level Test

• **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**

- **Nose/Gore Acreage Interface**
- **CA-250 Nose**
- **Nose/Rib/Joint Interface**
- **Rib Tip Close-out**
- **Joint/Rib/Gore Interface**
- **Gore Acreage**
- **Gore Close-Out**

**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/cm²

**Test Duration** - 80 seconds

**Stag Point Heat Load** - 5 kl/cm² (~ 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!

55 deg SPRITE-C Geometry

70 deg Flight Geometry

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>
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<tr>
<td>Inertial Velocity</td>
<td>6 km/sec</td>
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<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)
Summary

• 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)