ADEPT Sounding Rocket One
Flight Test Overview

Alan Cassell
Entry Systems & Vehicle Development Branch
NASA Silicon Valley Ames Research Center
AIAA Aviation Conference 2019
Aerodynamic Decelerator Systems Technology
Dallas, TX USA
June 17, 2019
Outline

• Background & Motivation
• Test Description
• Results
• Mission Success Criteria & Future Work
• Acknowledgements
Adaptive Deployable Entry and Placement Technology

Ribs

3D Woven Carbon Fabric

Main Body

Struts

3D Woven Carbon Fabric

Fabric Joint Design

High density structural stitching

Fabric tested to 250 W/cm² (2100 °C).

Electrically driven actuators achieve high fabric pre-tension

Three stage spring-based deployment actuation.

### ADEPT Mission Applicability

**Launch Vehicle Packaging**

Deployable Entry Vehicles efficiently stow within launch vehicle primary or secondary volume. Once deployed, high drag area reduces entry loads over conventional rigid aeroshells.

**Relevant Mission Concepts**

ADEPT is being considered for Aerocapture missions to Mars & Venus for Small Satellite class payloads.

### ADEPT Designs

<table>
<thead>
<tr>
<th>ADEPT Designs</th>
<th>SmallSat Class (Tech Demo or Secondary Payload)</th>
<th>Robotic Class (Discovery)</th>
<th>Flagship or New Frontiers Class</th>
<th>Exploration Class (Human Mars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballistic Concepts</td>
<td><img src="image1.png" alt="SR-1" /></td>
<td>Design Trades Underway</td>
<td>ADEPT VITaL</td>
<td>![image2.png]</td>
</tr>
<tr>
<td>Lifting Concepts</td>
<td>Aft Drag Skirt</td>
<td>Design Trades Underway</td>
<td>Design Trades Underway</td>
<td>![image3.png]</td>
</tr>
<tr>
<td>Lifting NanoADEPT</td>
<td>![image4.png]</td>
<td>![image5.png]</td>
<td>![image6.png]</td>
<td>![image7.png]</td>
</tr>
<tr>
<td>Diameter Range</td>
<td>&lt; 3 m</td>
<td>2-6 m</td>
<td>6-10 m</td>
<td>&gt;16 m</td>
</tr>
</tbody>
</table>
ADEPT SR-1 Operations Concept

Stowed ADEPT Separates from Rocket

Yo-Yo De-spin Lowers spin rate

Ascent High spin rate

Launch UP Aero SR T = 0.0min

Spaceport America Truth or Consequences, NM

ADEPT Deployment Altitude ~ 100 km T = 1.6 min

Peak Mach Number Mach 3 (~70 km)

Subsonic Mach 0.8 T = 6 min

White Sands Missile Range, NM

Ground Impact Impact speed: 25 m/s No parachute T = 15 min Data stored on board

Albuquerque, NM
## Key Performance Parameters

<table>
<thead>
<tr>
<th>Performance Parameter</th>
<th>Threshold Value</th>
<th>Project Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1- Exo-atmospheric deployment to an entry configuration of the 1m-class ADEPT.</td>
<td>Less than fully locked condition resulting in shape with less than 70-degree forebody cone angle.</td>
<td>Full, locked deployment before reaching 80 km altitude on descent, to 70-degree fore body cone angle achieving 6x greater drag area.</td>
</tr>
<tr>
<td>#2- Aerodynamic stability without active control of the 1m-class ADEPT in a flight configuration.</td>
<td>Does not tumble prior to M=0.8 while decelerating from peak Mach # (when Mach number is decreasing after passing through peak Mach number).</td>
<td>ADEPT does not tumble* before ground impact; Sign of pitch damping coefficient (Cmq) is determined; FF-CFD simulation tool is validated</td>
</tr>
</tbody>
</table>

## Mission Success Criteria

| A | ADEPT separates from the sounding rocket prior to apogee. |
| B | ADEPT does not re-contact any part of the launch vehicle after separation. |
| C | ADEPT reaches an apogee greater than 100 km. |
| D | ADEPT achieves fully deployed and locked configuration prior to reaching 80 km altitude. |
| E | Obtain on-board video of deployed ADEPT to observe fabric response and flight dynamics during entry. |
| F | Obtain data necessary to reconstruct ADEPT 6 DOF descent trajectory to **required accuracy below** with 95% confidence from Mach 3.0 while decelerating to ground impact:  
  a. Mach number: 0.1  
  b. Drag coefficient: Larger of 5% or 0.005  
  c. Total angle of attack: 2 deg (if not tumbling)  
  d. Sign of pitch damping sum |
SR-1 Development Campaign Highlights

**AERODYNAMICS DATABASE DEVELOPMENT**

- Static and dynamic aerodatabase predictions were used to perform preflight trajectory analysis of vehicle performance and helped inform risk and safety management.

- Details in upcoming talk entitled: “Aerodynamics for the ADEPT SR-1 Experiment” presented by Ashley Korzun.

**FREE-FLIGHT DYNAMICS TESTING**

- Assessed the dynamic behavior of ADEPT SR-1 at sub-sonic speeds, and aided in the selection of center of mass location to maximize likelihood of nose first impact. Testing performed in the Langley Vertical Spin Tunnel.

- “Subsonic Dynamic Testing of a Subscale ADEPT Entry Vehicle” presented by Justin Green.

**IMPACT TESTING**

- Drop testing enabled testing of various impact attenuators, characterization of impact load and demonstrated survivability of the on-board memory cards and battery design robustness.

- Impact testing also enabled battery safety procedures to be rehearsed in the event of severe damage to the rechargeable lithium-ion batteries upon impact.
SR-1 Flight Article Description

- Rib tip to Rib tip diameter: 0.70 m
- Half cone angle (ribs): 70 deg
- Mass: 11.0 kg (24.3 lb)
- $\beta \approx 20 \text{ kg/m}^2$
- $Xc_g/D = 0.15$

### Instrumentation

<table>
<thead>
<tr>
<th>Instrumentation</th>
<th>Data/Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVA</td>
<td>Accelerometers, Rate Gyros, Magnetometer, GPS Tracking</td>
</tr>
<tr>
<td>NGIMU</td>
<td>Accelerometers, Rate Gyros, IMU Board Temp Sensors</td>
</tr>
<tr>
<td>LED Indicator Board</td>
<td>System Health Indicator Status</td>
</tr>
<tr>
<td>GoPro Video</td>
<td>1080p, 60 fps video</td>
</tr>
<tr>
<td>C-Band Transponder</td>
<td>WSMR Radar Tracking</td>
</tr>
<tr>
<td>SPOT Trace</td>
<td>GPS Recovery Tracker</td>
</tr>
<tr>
<td>Separation Sensors</td>
<td>Power-on signal for deployment timer, C-Band &amp; GoPro</td>
</tr>
<tr>
<td>Deployment Switch</td>
<td>Indicates full deployment</td>
</tr>
</tbody>
</table>

---

SR-1 Stowed in LV

Stowed Diameter: 0.24 m

- Four-Layer 3D Woven Carbon Fabric
- Rib Tips
- Ribs
- Ribs
- Second-Stage Springs
- Deployment Latches
- Impact Attenuation Foam
- Retention Cord Loops
- Push-off Springs
- Rails
- Pull-off Springs
- Push-on Springs
- Aft Deck & Late Access Connectors
- Rib Release Deck
- Electrical Power System
- Moving Ring

---

GO PRO

1080p, 60 fps video
Launch Vehicle Description

GoPro Cameras

Booster

AFTU Slam Stick LV Avionics

ADEPT

Nose Section
Operations Timeline

LAUNCH
12 SEPT, 2018, SPACELOFT XL
SPACEPORT AMERICA, NM

AODEPT
DEPLOYMENT, L+135 s

APOGEE, L+156 s
~110 km

ATMOSPHERIC INTERFACE, L+ 229 s
85 km

TRANSONIC, L+290 s
M=1.4

YO-YO DESPIN, L+55 s
NOSE SEPARATION, L+60 s

IMPACT, L+ 857 s
WSMR

RECOVERY
WSMR US ARMY
BLACKHAWK HELICOPTER
Pre-Launch Preparations

9/8/18- Compatibility Check & Vehicle Integration

9/11/18- Mission Dress Rehearsal

9/12/18- Launch Day Power-Up Procedures
Launch & On-board Video
## Results - Ascent & Exoatmospheric Deploy

<table>
<thead>
<tr>
<th>EVENT #</th>
<th>DESCRIPTION</th>
<th>PLANNED TIME (SEC)</th>
<th>ACTUAL TIME (SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LIFTOFF</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>BOOSTER BURN-OUT*</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>DE-SPIN DEPLOY*</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>4</td>
<td>NOSE FAIRING SEPARATION*</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>BOOSTER SEPARATION*</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>ADEPT SEPARATION*</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>7</td>
<td>ADEPT DEPLOY*</td>
<td>100</td>
<td>135</td>
</tr>
</tbody>
</table>
Video Stills - Ascent & Exoatmospheric Deploy

Launch

LV Nose Camera Prior to Booster Separation

LV Nose Camera After Separation

Payload Separation Section Camera at ADEPT Separation
Results - Full Deployment & Health Status

KPP #1- Project goal of full and locked deployment achieved
KPP #2- Project threshold of no tumbling prior to M=0.8 achieved

<table>
<thead>
<tr>
<th>EVENT #</th>
<th>DESCRIPTION</th>
<th>PREDICTED TIME (SEC)</th>
<th>ACTUAL TIME (SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>APOGEE</td>
<td>161</td>
<td>156</td>
</tr>
<tr>
<td>9</td>
<td>ADEPT RE-ENTRY (85 km)</td>
<td>244</td>
<td>229</td>
</tr>
<tr>
<td>10</td>
<td>PEAK MACH # (3.2, PREDICTED)</td>
<td>270</td>
<td>254</td>
</tr>
<tr>
<td>11</td>
<td>PEAK DYNAMIC PRESSURE (~822 Pa,)</td>
<td>294</td>
<td>282</td>
</tr>
<tr>
<td>12</td>
<td>ADEPT MACH 0.8</td>
<td>318</td>
<td>307</td>
</tr>
<tr>
<td>13</td>
<td>MACH 0.4</td>
<td>363</td>
<td>352</td>
</tr>
<tr>
<td>14</td>
<td>IMPACT (~25 m/sec, NOMINAL)</td>
<td>879</td>
<td>856</td>
</tr>
</tbody>
</table>

- Half cone angle (ribs)- 70 deg
- Mass- 11.0 kg (24.3 lb)
- $\beta$~ 20 kg/m$^2$
- $Xcg/D$= 0.15
Vehicle Recovery

Impact Site

Recovery Procedure

Battery Safeing

Blackhawk Returns to Launch Complex

Offloading Recovered Components

Recovered ADEPT
# Data Sources

<table>
<thead>
<tr>
<th>Data Sources</th>
<th>Status/Notes</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVA IMU</td>
<td>Utilized in initial trajectory reconstruction</td>
<td></td>
</tr>
<tr>
<td>AVA GPS</td>
<td>Not utilized in trajectory reconstruction</td>
<td>Minimum number of satellites not met</td>
</tr>
<tr>
<td>AVA Magnetometer</td>
<td>Utilized in initial trajectory reconstruction</td>
<td></td>
</tr>
<tr>
<td>NGIMU</td>
<td>Utilized in initial trajectory reconstruction</td>
<td></td>
</tr>
<tr>
<td>GoPro Video</td>
<td>Video recorded through launch +595 seconds</td>
<td>GoPro stopped recording below M=0.2, Qualitatively confirmed key data observations.</td>
</tr>
<tr>
<td>LV IMU</td>
<td>Utilized in initial trajectory reconstruction</td>
<td></td>
</tr>
<tr>
<td>AFTU GPS</td>
<td>Utilized in initial trajectory reconstruction</td>
<td></td>
</tr>
<tr>
<td>Radar Tracking</td>
<td>Utilized in initial trajectory reconstruction</td>
<td>Data obtained on descent from 99 km altitude</td>
</tr>
</tbody>
</table>

(a) GPS Data.

(b) Tracking Radar Data.
Post-Flight Data Analysis

- Total angle of attack remains below stability threshold of 20 degrees through $M=0.4$.

- The spin rate increase through supersonic deceleration was unexpected. Post flight analysis is ongoing to determine cause.

- For details on the flight mechanics modeling, see: Soumyo Dutta’s paper and presentation “Flight Mechanics Modeling and Post-Flight Analysis of ADEPT SR-1”

- Trajectory reconstruction simulated at 100 Hz using LV IMU, AVA IMU, AVA Magnetometer, radar tracking and atmospheric models. For more details see the following paper by Jake Tynis “Reconstruction of the ADEPT Sounding Rocket One Flight Test”
## Mission Success Criteria

<table>
<thead>
<tr>
<th>Mission Success Criteria</th>
<th>Preliminary Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong> ADEPT separates from the sounding rocket prior to apogee.</td>
<td><em>Pass, confirmed by three independent data sources- Radar, AVA IMU, NGIMU</em></td>
</tr>
<tr>
<td><strong>B</strong> ADEPT does not re-contact any part of the launch vehicle after separation.</td>
<td><em>Pass, no evidence of re-contact from IMUs and on-board GoPro video cameras</em></td>
</tr>
<tr>
<td><strong>C</strong> ADEPT reaches an apogee greater than 100 km.</td>
<td><em>Pass, confirmed by radar tracking, launch conductor verbal call was ~115 km</em></td>
</tr>
<tr>
<td><strong>D</strong> ADEPT achieves fully deployed and locked configuration prior to reaching 80 km altitude.</td>
<td><em>Pass, evidence from on-board GoPro video</em></td>
</tr>
<tr>
<td><strong>E</strong> Obtain on-board video of deployed ADEPT to observe fabric response and flight dynamics during entry</td>
<td><em>Pass, evidence from GoPro video</em></td>
</tr>
<tr>
<td><strong>F</strong> Obtain data necessary to reconstruct ADEPT 6 DOF descent trajectory to <em>required accuracy below</em> with 95% confidence from Mach 3.0 while decelerating to ground impact:</td>
<td><em>Incomplete- trajectory will be reconstructed, but will not meet desired level of accuracy.</em></td>
</tr>
<tr>
<td>a. Mach number: 0.1</td>
<td></td>
</tr>
<tr>
<td>b. Drag coefficient: Larger of 5% or 0.005</td>
<td></td>
</tr>
<tr>
<td>c. Total angle of attack: 2 deg (if not tumbling)</td>
<td></td>
</tr>
<tr>
<td>d. Sign of pitch damping sum</td>
<td></td>
</tr>
</tbody>
</table>
Summary & Future Work

• ADEPT SR-1 satisfied both Key Performance Parameters and met 5 out 6 Mission Success Criteria
• Noteworthy observations:
  • Roll rate increase (from 44 deg/s to 370 deg/s) was observed during supersonic to transonic deceleration
  • ADEPT SR-1 is the bluntest (70 deg half cone angle) open back decelerator to be successfully flown.
  • SR-1 total angle of attack vs Mach performance compares favorably with inflatable IRVE-2 decelerator.

• Aerodatabase Refinements and Free-Flight CFD
  • Updates to SR-1 aerodatabase will be incorporated into future trajectory reconstruction efforts.
  • Entry Systems Modeling project will utilize FF-CFD analysis tool to further understand SR-1 dynamic behavior.

• Development of Guidance & Control Capabilities for ADEPT, Project Pterodactyl
  • See paper and presentation by Sarah D’Souza “Developing an Entry Guidance and Control Design Capability using Flaps for the Lifting Nano-ADEPT”
Acknowledgements

• Soumyo Dutta (LaRC, Flight Mechanics Lead)
• Shakib Ghassemieh (Ames, Lead Avionics Systems Engineer)
• Chris Karlgaard (LaRC-TEAMS2, Traj. Reconstruction)
• Ashley Korzun (LaRC, Aerosciences Lead)
• Carl Kruger (Ames, Mechanical Design)
• Ali Guarneros-Luna (Ames, SS & MA)
• Owen Nishioka (Ames, Mechanical Design)
• Brandon Smith (Ames, SR-1 Principal Investigator)
• Paul Wercinski (Ames, Project Manager)
• Joseph Williams (Ames-AMA, Instrumentation and Test)
• Shang Wu (Ames, Electrical Systems Lead)
• Bryan Yount (Ames, Structures and Mechanics Lead)
• Steve Battazzo (Ames, AVA Integration)
• Chad Brivkalns (Ames, Mechanical Design)
• Juan Cruz (LaRC, Aerodynamic Testing)
• Neil Davies (Ames, Electrical Technician)
• Dzung Hoang (Ames, Test support)
• Nghia Mai (Ames, Electrical Testing Support)
• Alberto Makino (Ames, Structural Testing and Analysis)
• Mark Mallinson (Ames, Risk and CM Manager)
• Ryan McDaniel (Ames, Aero CFD)
• Matt Padilla (Ames, Electrical Technician)
• Justin Green (LaRC, Traj Reconstruction)
• Jake Tynis (LaRC-TEAMS3, Traj Reconstruction)

Space Technology Mission Directorate:
• Game Changing Development Program
• Flight Opportunities Program

Spaceport America
White Sands Missile Range
Bally Ribbon Mills
Thin Red Line Aerospace
Questions?