Nano-ADEPT
Aeroloads Wind Tunnel Test

International Planetary Probe Workshop (IPPW-12)
15-19 June 2015
Cologne, Germany

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Outline

- ADEPT background
- Nano-ADEPT development roadmap
- Test overview and objectives
- Test articles: solid and fabric
- Test matrix & execution
- Notable findings
- Video highlights
- Conclusions & next steps
ADEPT: Adaptable Deployable Entry and Placement Technology

• ADEPT is a mechanically deployed Entry, Descent, and Landing (EDL) system
  • Stows during launch and cruise (like an umbrella)
  • Serves as both heat shield and primary structure during EDL

• Nano-ADEPT is the application of ADEPT for small spacecraft where volume is a limiting constraint
  – NanoSats, CubeSats, other secondary payloads, etc.

• Why Nano-ADEPT?
  • Achieve rapid technology development extensible to large ADEPT applications
  • Give rise to novel applications for small spacecraft by offering an entry system

6 m diameter ADEPT-Venus in cruise (left) and entry (right) configurations

0.7 m diameter Nano-ADEPT shown with notional 2U chassis payload
Nano-ADEPT Development Roadmap to TRL 5

- Strategy addresses technical challenges with four system-level tests
- Common geometric features between design reference missions (DRMs), ground tests, and flight test provide ground-to-flight traceability

### Primary geometric features

#### Design Reference Mission 1
- $\theta_c = 70^\circ$
- $R_n = 0.25$ m
- $R_b = 0.35$ m
- $R_n/R_b = 0.71$

#### Design Reference Mission 2
- $\theta_c = 55^\circ$
- $R_n = 0.13$ m
- $R_b = 0.18$ m
- $R_n/R_b = 0.72$

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**ADEPT**

Nano-ADEPT Development Roadmap to TRL 5

Deployment Prototypes

- Interface with primary payload
- Achievable fabric pre-tension
- Deployment reliability
- Ejection from primary spacecraft
- Tip-off rates
- Aero stability
- Landing loads
- Flight-like design

Subsonic Aeroloads

- Fabric edge buzz/flutter (Dynamic FSI)
- Shape Knowledge
- Thermo-structural loads
- Gore Deflection (Static FSI)
- Peak heat rate
- Shear pressure

Wind Tunnel

- System-Level Arc Jet (SPRITE-C)
- 'FSI'

Tech Maturation for Mission Infusion

- Interface with primary payload
- Achievable fabric pre-tension
- Deployment reliability
- Ejection from primary spacecraft
- Tip-off rates
- Aero stability
- Landing loads
- Flight-like design

Flight Test

- Tech Maturation for Mission Infusion
- Interface with primary payload
- Achievable fabric pre-tension
- Deployment reliability
- Ejection from primary spacecraft
- Tip-off rates
- Aero stability
- Landing loads
- Flight-like design

Primary geometric features of deployment prototypes, subsonic aeroloads wind tunnel test articles, sounding rocket flight test, and some DRMs

**Config. 1**

0.70 m

**Config. 2**

590x540
Aeroloads Test Overview and Objectives

- Testing was completed in seven business days at the US Army’s 7x10 Foot Wind Tunnel located at NASA Ames (27-Apr to 5-May 2015)
- Shared funding was provided through NASA STMD GCDP ADEPT program (FY15) and a NASA Ames Center Innovation Fund Award (FY14)
- Test objectives trace to technical challenges identified by the ADEPT development team
- Rich data set was obtained through instrumentation suite designed to be redundant yet non-invasive

<table>
<thead>
<tr>
<th>Test Objective</th>
<th>Instrumentation</th>
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<tbody>
<tr>
<td>Obtain static deflected shape and pressure distributions while varying pre-tension* at dynamic pressures and angles of attack relevant to Nano-ADEPT entry conditions at Earth, Mars, and Venus.</td>
<td>Photogrammetry; String potentiometers; Outer Mold Line (OML) static pressure taps</td>
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<tr>
<td>Observe dynamic aeroelastic behavior (buzz/flutter) if it occurs as a function of pre-tension, dynamic pressure, and angle of attack.</td>
<td>High speed video; Strut load cells</td>
</tr>
<tr>
<td>Obtain aerodynamic forces and moments as a function of pre-tension, dynamic pressure, and angle of attack.</td>
<td>Internal balance</td>
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</tbody>
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*Tension in the carbon fabric is caused by two sources: "pre-tension" resulting from the mechanical deployment of ADEPT prior to atmospheric entry and additional tension resulting from the aerodynamic load during entry.

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Test Approach: Two Test Articles

**Solid test article**
- Simulates fabric test article with infinite pre-tension
- First article to be tested in the tunnel

**Fabric test article**
- Common pressure tap pattern
- Common sting/balance interface

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**Fabric Test Article Details**

- Flight-like carbon fabric skirt includes key features such as carbon yarn stitching and seam resin infusion.
- Central nut moves all struts simultaneously to pre-determined positions to induce a known pre-tension in fabric (based on pre-test measurements: 20 lbf/in, 10 lbf/in, 5 lbf/in, 2 lbf/in)
  - Note that fabric test article does not deploy from a fully stowed state.
- Ribs and struts (two per rib) are oversized compared to flight to comply with tunnel safety requirements and maximize use of COTS parts for cost savings.
- String potentiometers are attached at mid-gore to give a live measure of deflection in the control room and provide a global view of gore deflections in lieu of photogrammetry view obstructions.
- Blue lights indicate power to strut load cells.

0° gore left unpainted to isolate effect of photogrammetry paint on fabric stiffness.

White speckle paint is for photogrammetry surface tracking.
Photogrammetry and high speed video data were recorded at most test points.

Solid article was tested first
- Q sweeps from 0-100 psf (bounds peak dynamic pressure for Nano-ADEPT Mars DRMs and some entry from LEO DRMs)
- AoA/Yaw from -20 to +20
- Repeats

Fabric test article covered same range of Q and AoA as the solid test article
- Four pre-tension “nut settings” were planned:
  - 20, 10, 5, 2 lbf/in

Behavior of test article warranted modification of test matrix in real time
- ~40% loss of pre-tension after the first run at 20 lbf/in due to fabric relaxation
- Fabric was completely slack at 5 lbf/in nut setting

Added to test matrix during test execution:
- 20 lbf/in pre-tension based on in-tunnel measurement (post-relaxation)
- Asymmetric shape (bonus experiment)
Static Pressure Data

- Static pressure taps on both test articles provided repeatable data (example shown below: solid test article pressure coefficient @ 100 psf)
- Instrumentation integration approach worked well and could be repeated for flight test
- Data is presently being compared to CFD solutions

Fabric test article pressure coefficient @ 100 psf (20 lbf/in measured pre-tension)
Bonus Finding: Asymmetric Shape

- Two pairs of struts were shortened to give the 3 o’clock gore a cone angle of ~67º (compared with 70º for the rest of the gores)
  - Tension nut was set to 20 lbf/in nut setting so results may be compared with the same symmetric nut setting

- Resulted in offset of zero-moment angle of attack from 0º (symmetric) to +2.4º (asymmetric)
  - See yaw moment coefficient plot below

- At hypersonic speeds, the lift generated by deflecting gores could be used for vehicle control
Conclusions and Next Steps

- Analysis completed since the test suggests that all test objectives were met
  - This claim will be verified in the coming weeks as the data is examined further
  - Final disposition of test objective success will be documented in a final report submitted to NASA stakeholders (early August 2015)
  - Expect conference paper in early 2016

- Data products and observations made during testing will be used to refine computational models of Nano-ADEPT

- Carbon fabric relaxed from its pre-test state during the test
  - System-level tolerance for relaxation will be driven by destination-specific and mission-specific aerothermal and aerodynamic requirements

- Bonus experiment of asymmetric shape demonstrates that an asymmetric deployable blunt body can be used to generate measureable lift
  - With a strut actuation system and a robust GN&C algorithm, this effect could be used to steer a blunt body at hypersonic speeds to aid precision landing