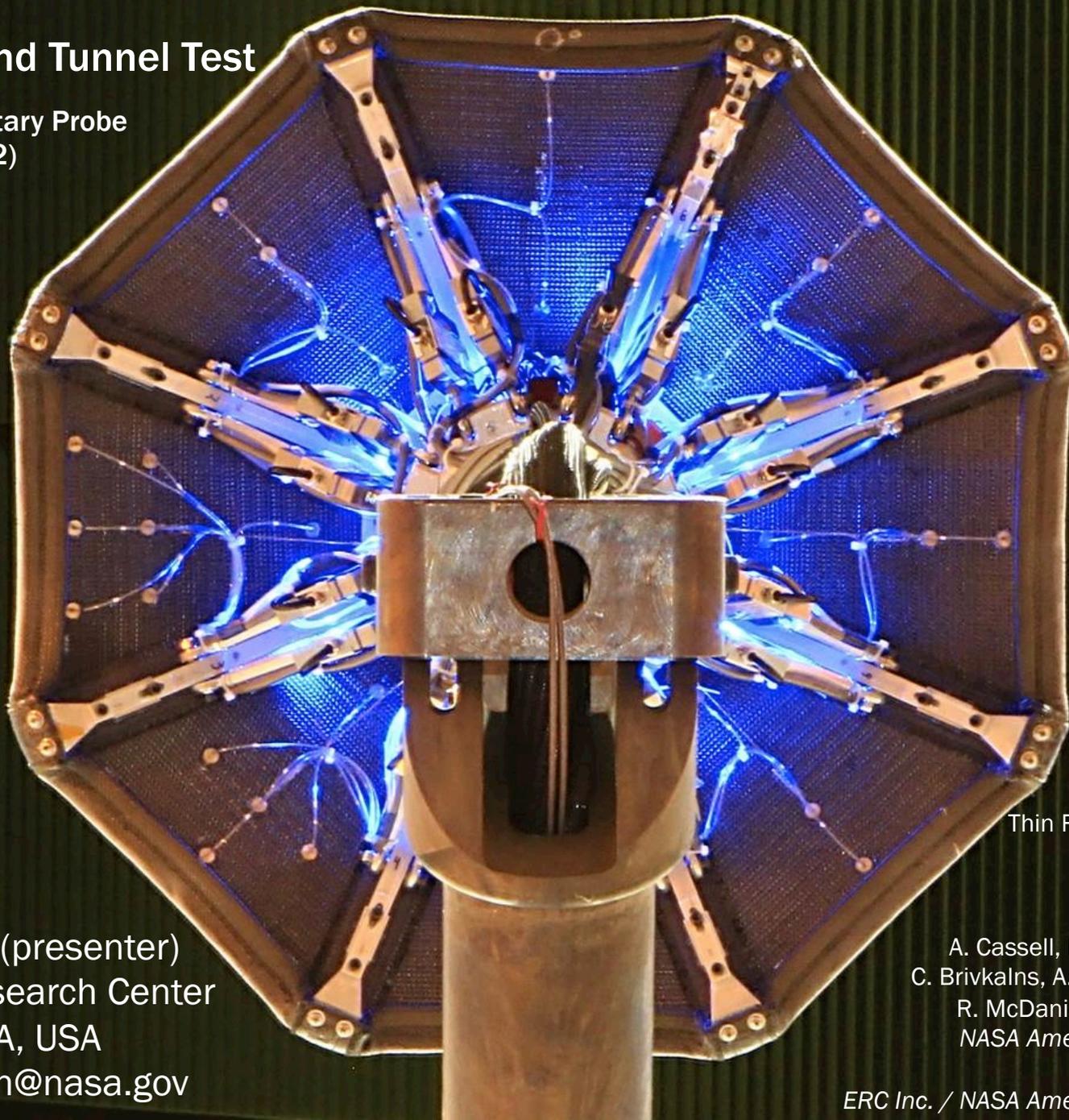


Nano-ADEPT Aeroloads Wind Tunnel Test

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Brandon Smith (presenter)
NASA Ames Research Center
Moffett Field, CA, USA
brandon.p.smith@nasa.gov

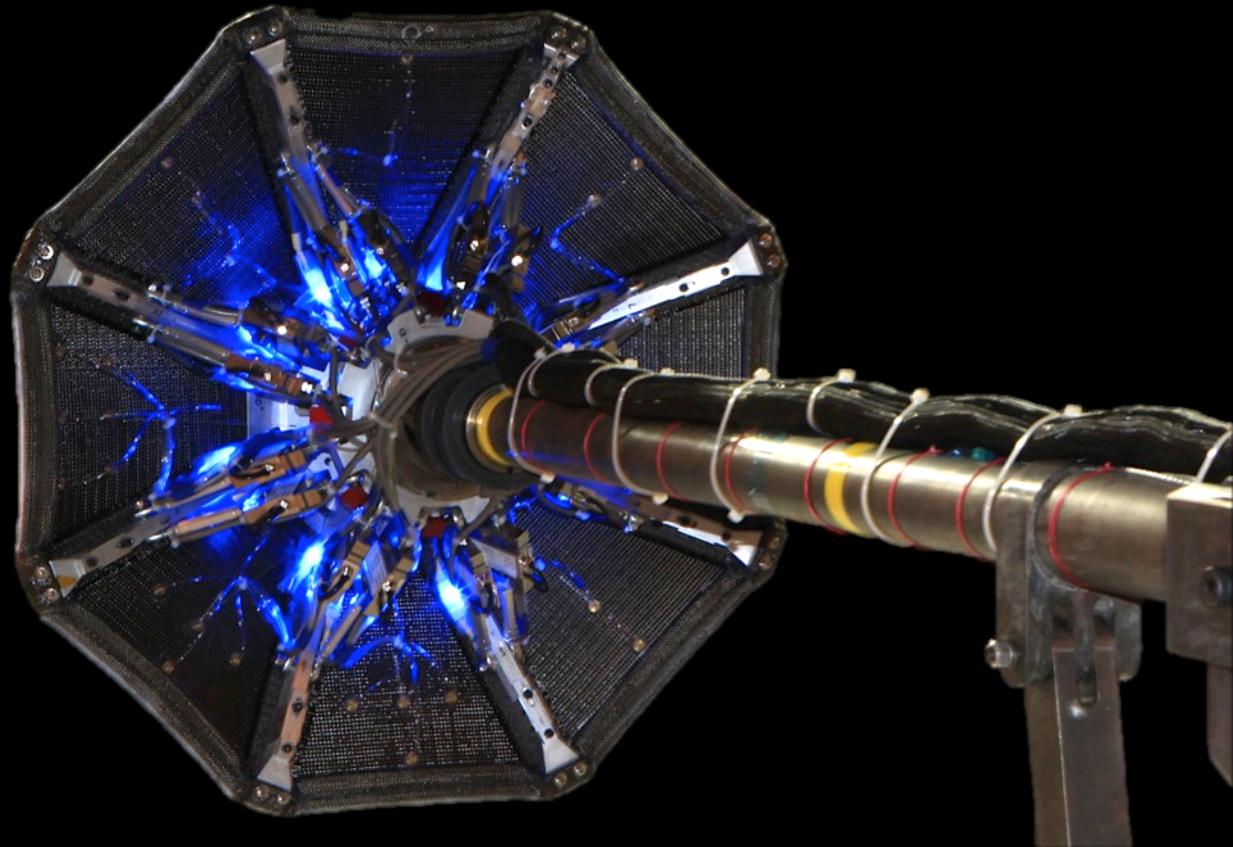
Industry Partners:
Bally Ribbon Mills
Thin Red Line Aerospace
CFDRC

Co-Authors:
A. Cassell, B. Yount, C. Kruger,
C. Brivkaiņs, A. Makino, K. Zarchi,
R. McDaniel, E. Venkatapathy
NASA Ames Research Center
G. Swanson
ERC Inc. / NASA Ames Research Center



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



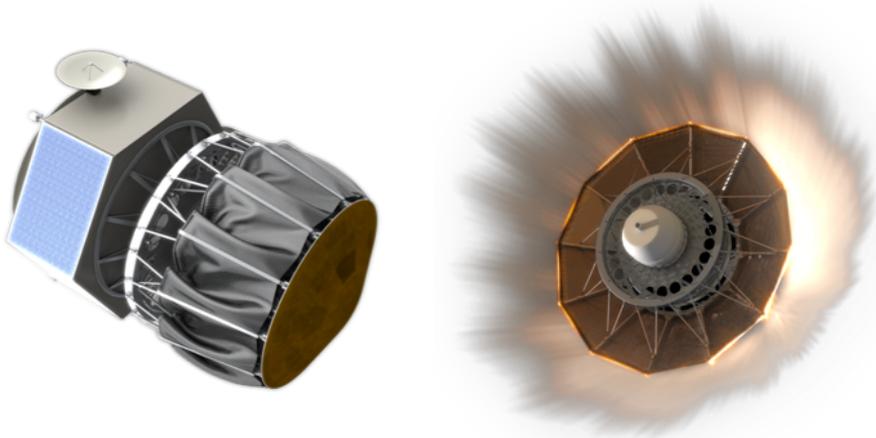
Fabric model rear view mounted on sting in 7x10 Foot Wind Tunnel at NASA Ames Research Center



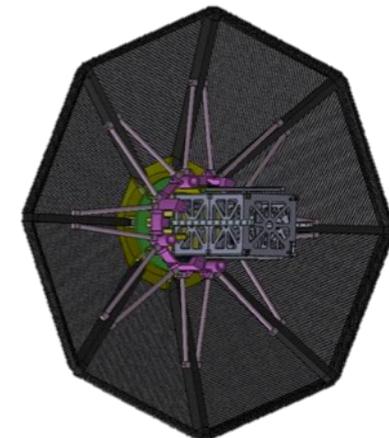
ADEPT:

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



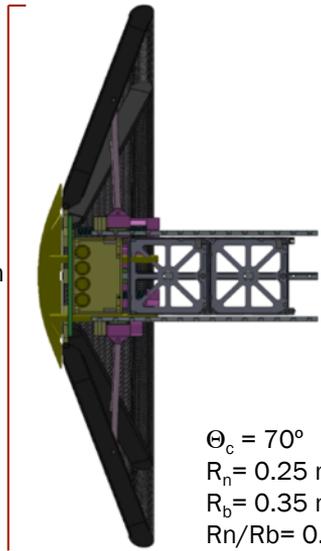
0.7 m diameter Nano-ADEPT
shown with notional 2U chassis payload



Nano-ADEPT Development Roadmap to TRL 5

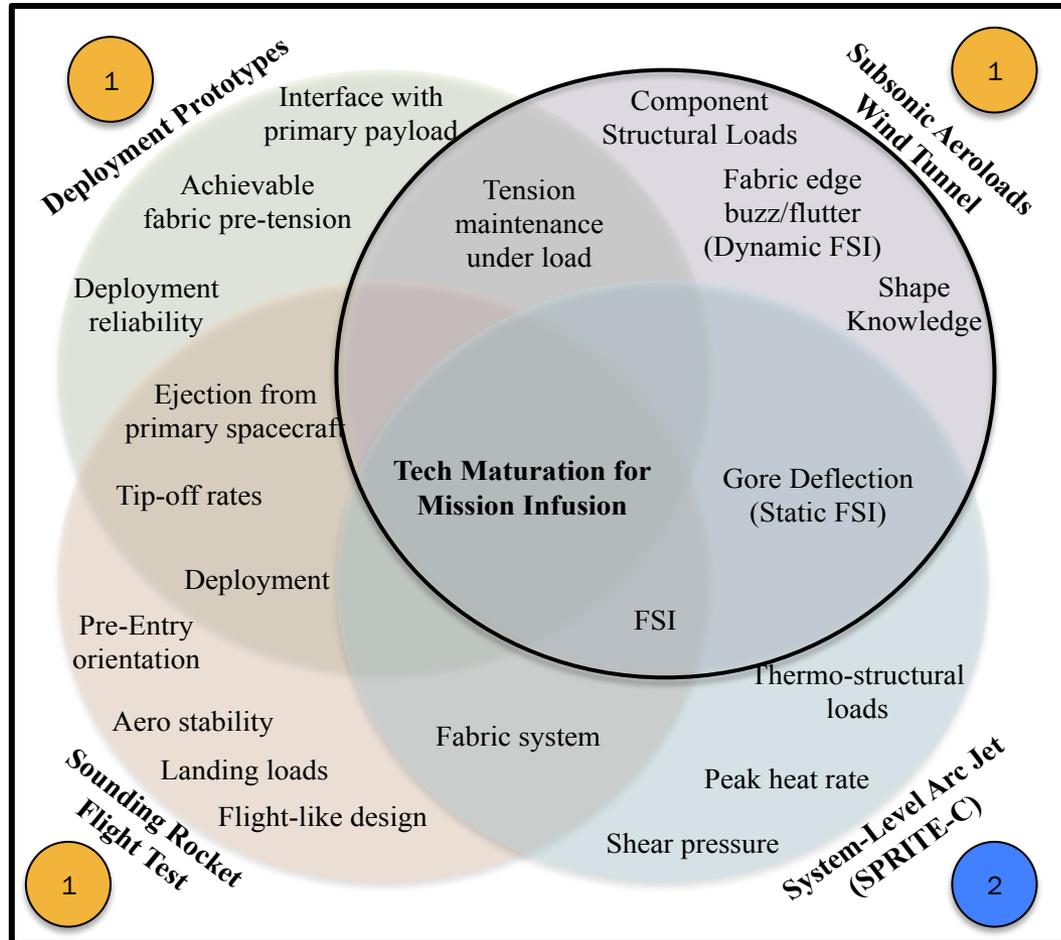
- Strategy addresses technical challenges with four system-level tests
- Common geometric features between design reference missions (DRMs), ground tests, and flight test provide ground-to-flight traceability

Config. 1

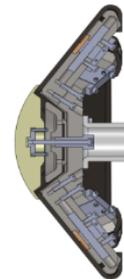


$\Theta_c = 70^\circ$
 $R_n = 0.25 \text{ m}$
 $R_b = 0.35 \text{ m}$
 $R_n/R_b = 0.71$

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



Config. 2



$\Theta_c = 55^\circ$
 $R_n = 0.13 \text{ m}$
 $R_b = 0.18 \text{ m}$
 $R_n/R_b = 0.72$

Primary geometric features of system-level arc jet tests (SPRITE-C)



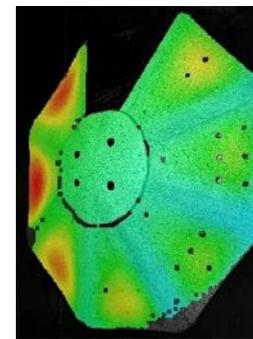
Aeroloads Test Overview and Objectives

- 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

Test Objective	Instrumentation
<p>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.</p> <p>*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</p>	<p>Photogrammetry; String potentiometers; Outer Mold Line (OML) static pressure taps</p>
<p>Observe dynamic aeroelastic behavior (buzz/flutter) if it occurs as a function of pre-tension, dynamic pressure, and angle of attack.</p>	<p>High speed video; Strut load cells</p>
<p>Obtain aerodynamic forces and moments as a function of pre-tension, dynamic pressure, and angle of attack.</p>	<p>Internal balance</p>



Test Article Patterning



Photogrammetry Solution Overlay



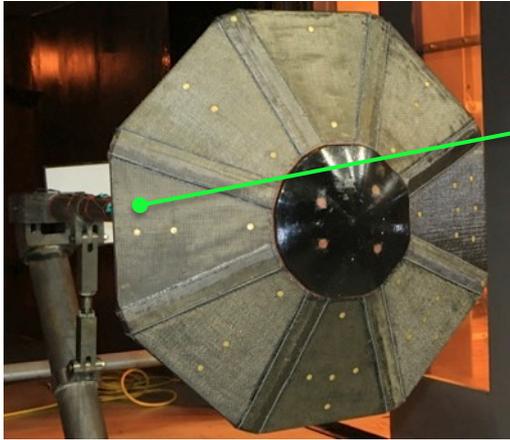
Strut Load Cell Check Outs



Test Approach: Two Test Articles

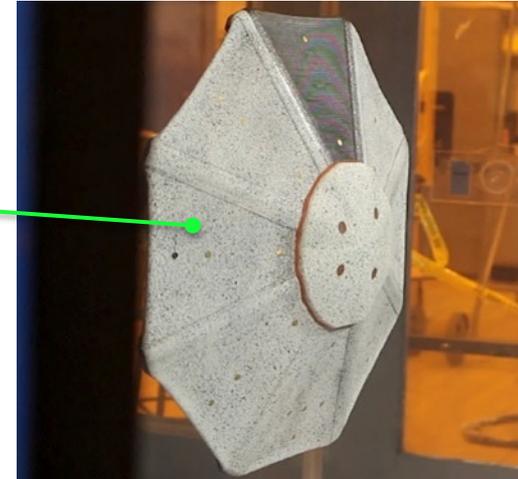
Solid test article

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

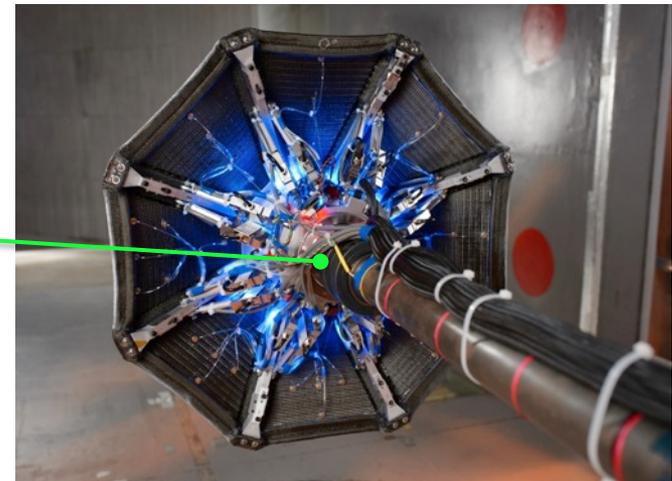
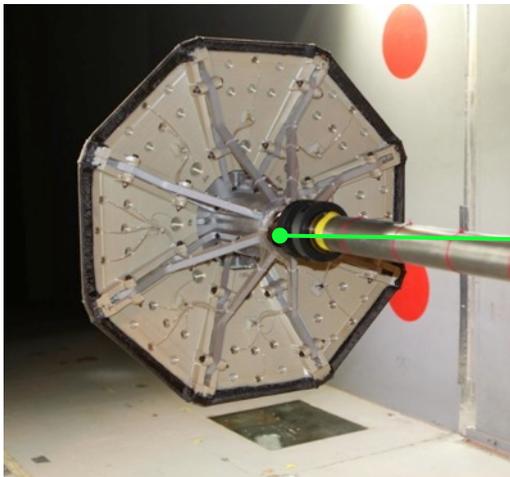


Common pressure tap pattern

Fabric test article

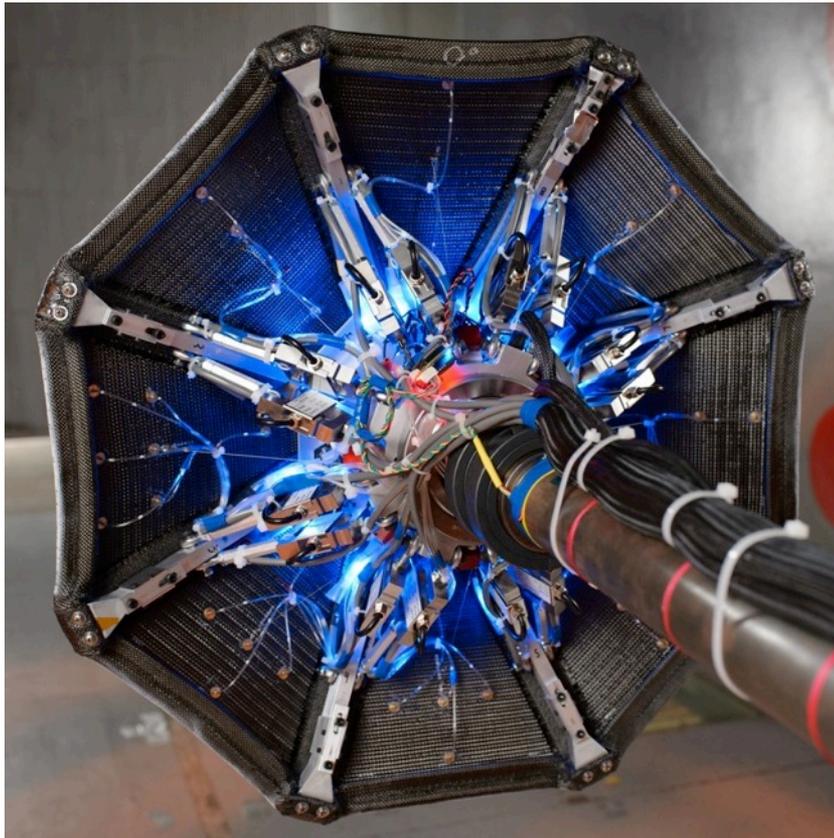


Common sting/
balance interface





Fabric Test Article Details



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

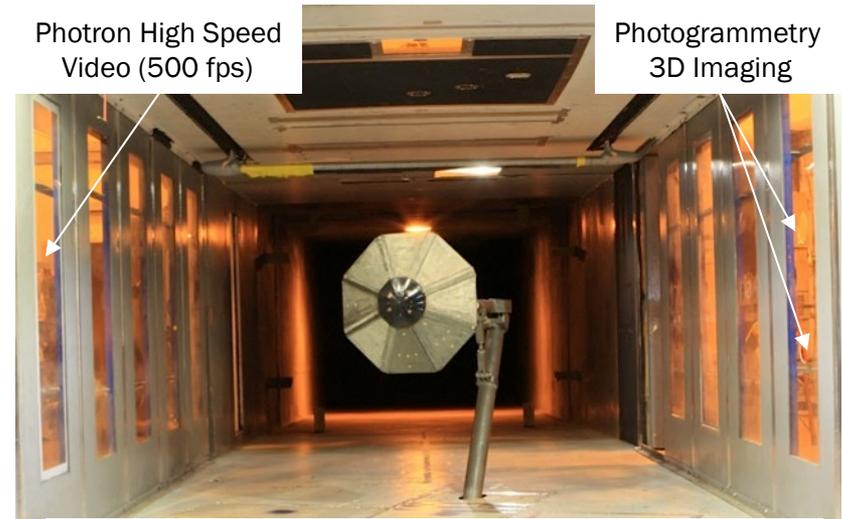
White speckle paint is for photogrammetry surface tracking

- 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



Test Matrix & Test Execution

- 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)



Nano-ADEPT Solid Test Article @ +20 deg AoA



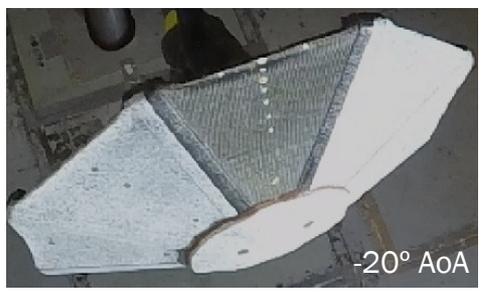
Control Room



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

Pressure tap



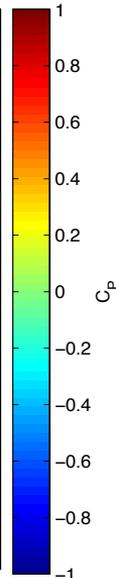
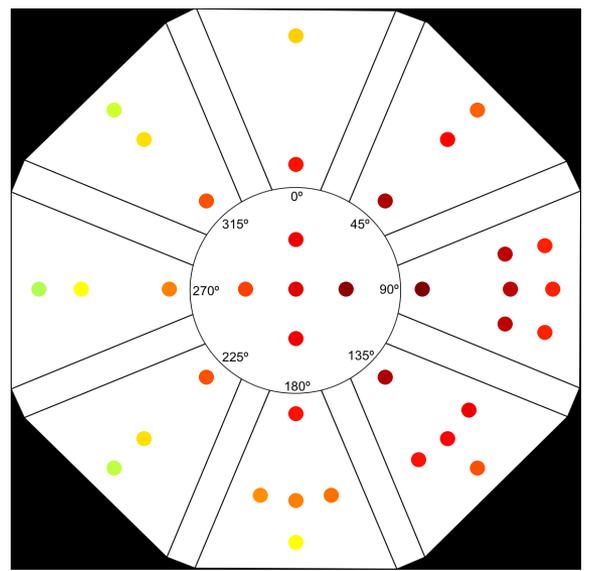
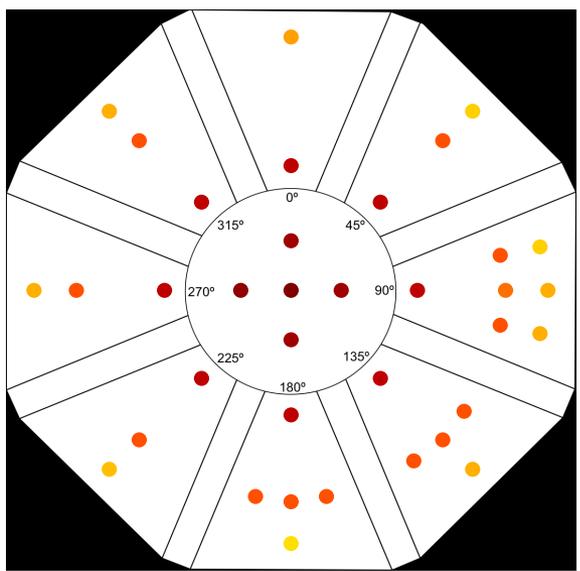
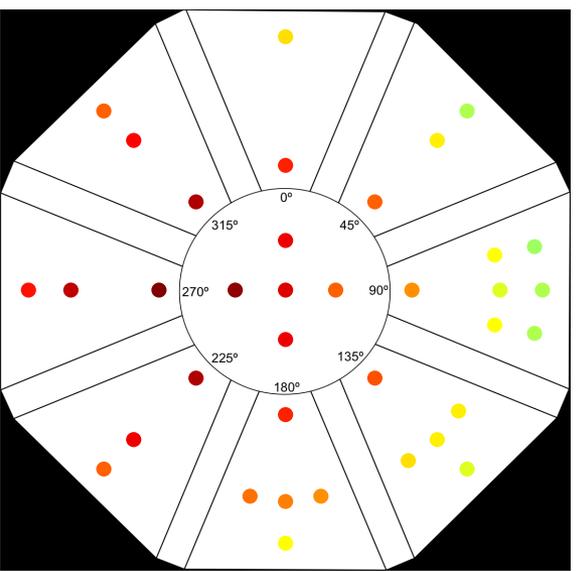
-20° AoA



0° AoA



+20° AoA

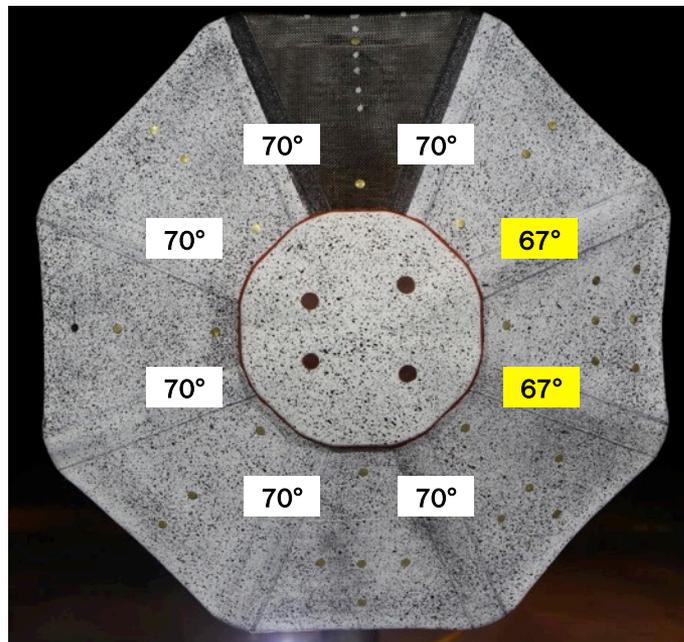


Fabric test article pressure coefficient @ 100 psf (20 lbf/in measured pre-tension)

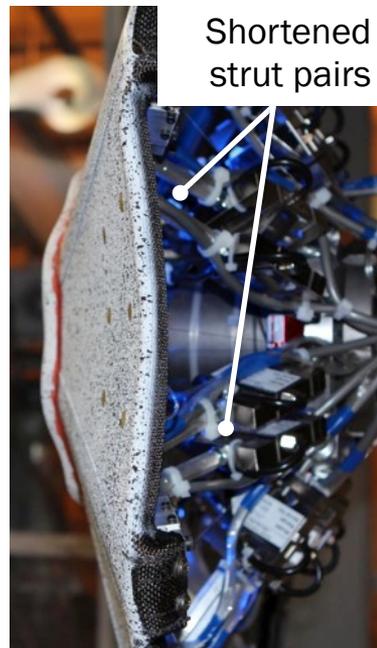


Bonus Finding: Asymmetric Shape

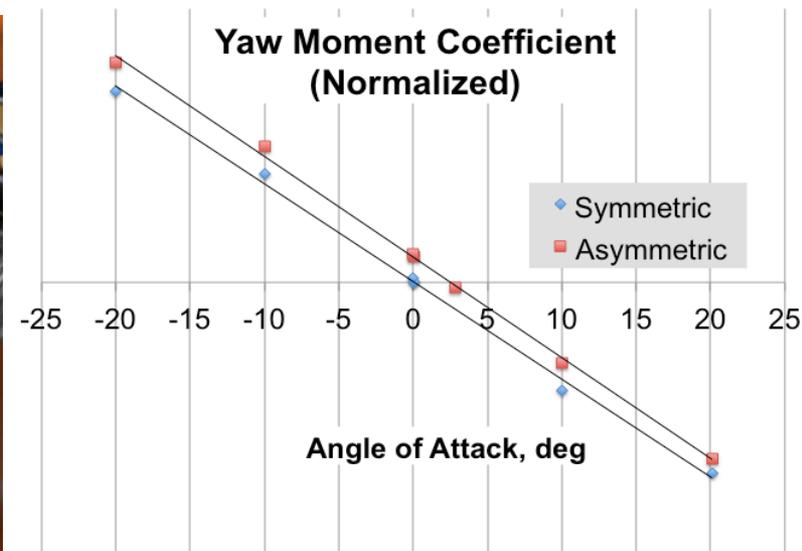
- Two pairs of struts were shortened to give the 3 o'clock gore a cone angle of $\sim 67^\circ$ (compared with 70° for the rest of the gores)
 - Tension nut was set to 20 lbf/in nut setting so results may be compared with the same symmetric nut setting
- Resulted in offset of zero-moment angle of attack from 0° (symmetric) to $+2.4^\circ$ (asymmetric)
 - See yaw moment coefficient plot below
- At hypersonic speeds, the lift generated by deflecting gores could be used for vehicle control



Front View



Side View



20 lbf/in nut setting; $Q = 100$ psf



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



Aeroloads Wind Tunnel Test Team Photo



Not pictured:
Kerry Zarchi
Ryan McDaniel
Sameera Gunatileka
Ethiraj Venkatapathy