# Nano-ADEPT
# Aeroloads Wind Tunnel Test

International Planetary Probe Workshop (IPPW-12)
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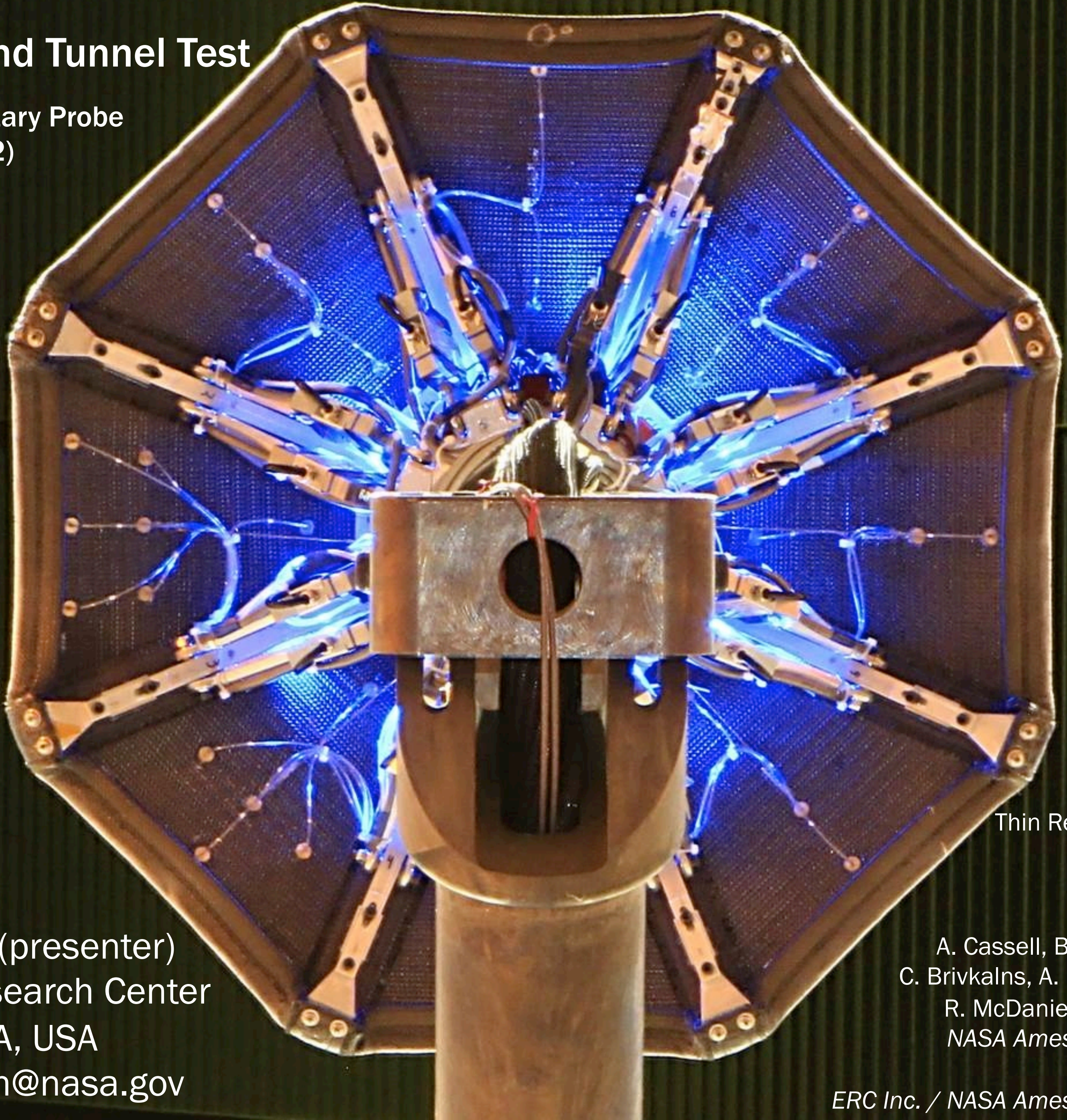
Cologne, Germany



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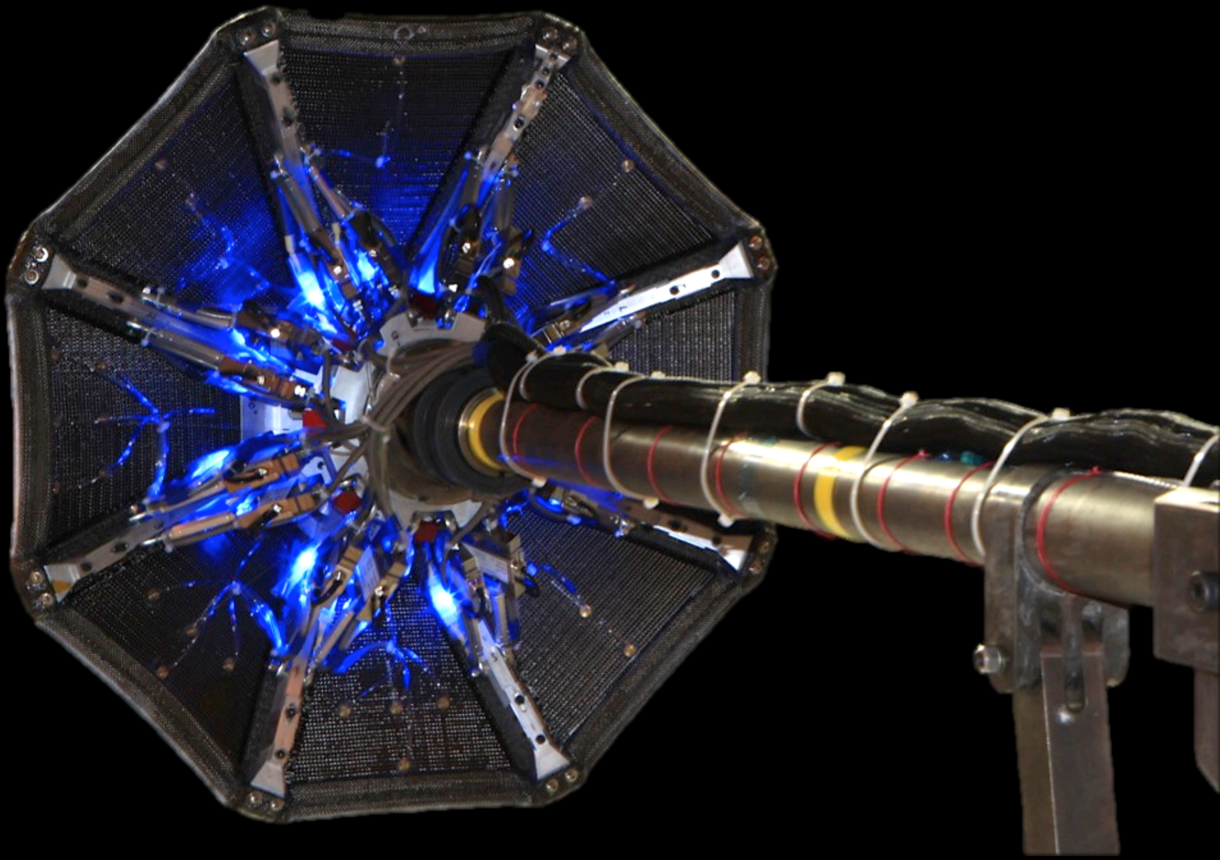
# Outline

- 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



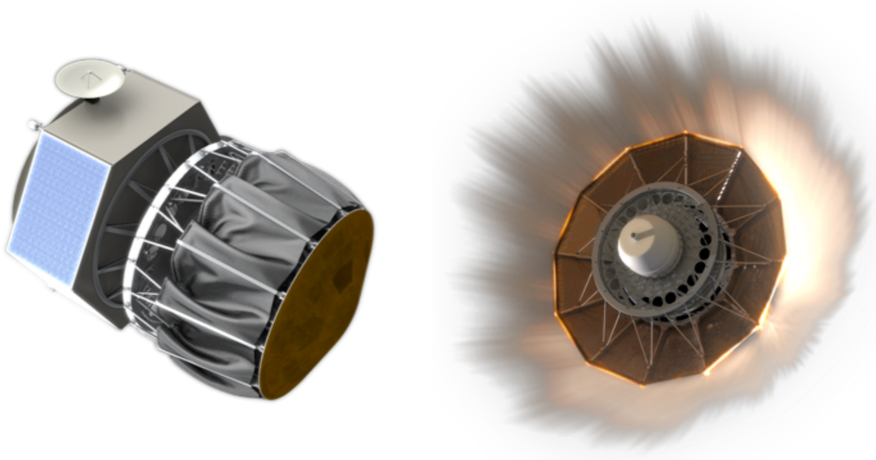
*Fabric model rear view mounted on sting in 7x10 Foot Wind Tunnel at NASA Ames Research Center*

# ADEPT: Adaptable Deployable Entry and Placement Technology

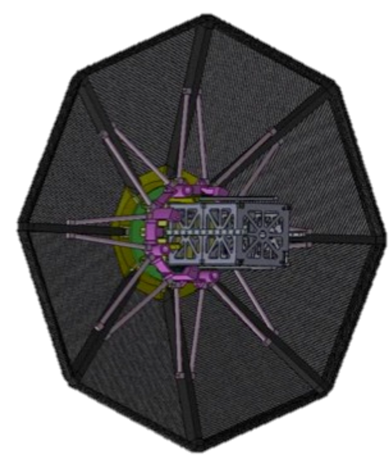
- ADEPT is a mechanically deployed Entry, Descent, and Landing (EDL) system
  - Stows during launch and cruise (like an umbrella)
  - Serves as both heat shield and primary structure during EDL

- 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

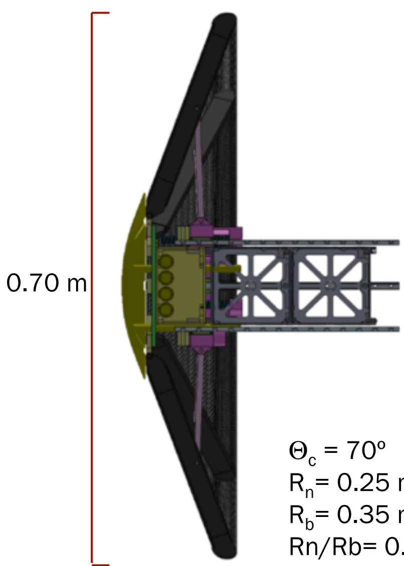


0.7 m diameter Nano-ADEPT
shown with notional 2U chassis payload

# Nano-ADEPT Development Roadmap to TRL 5

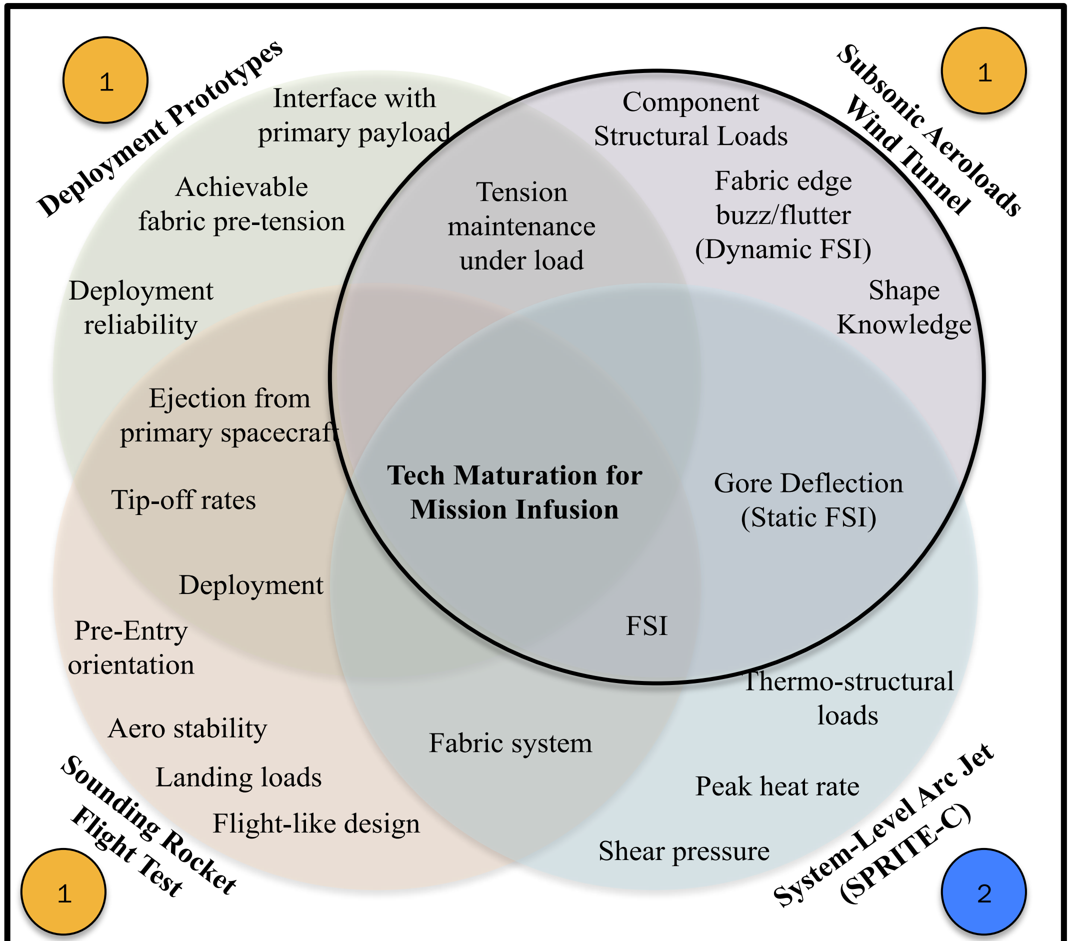
- Strategy addresses technical challenges with four system-level tests
- Common geometric features between design reference missions (DRMs), ground tests, and flight test provide ground-to-flight traceability

Config. 1

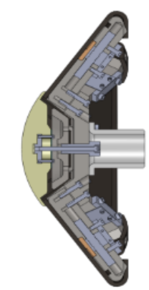



$\Theta_c$ = 70°
$R_n$= 0.25 m
$R_b$= 0.35 m
Rn/Rb= 0.71

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




Config. 2



$\Theta_c$ = 55°
$R_n$= 0.13 m
$R_b$= 0.18 m
Rn/Rb= 0.72

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

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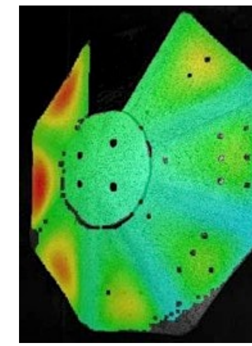
# Aeroloads Test Overview and Objectives

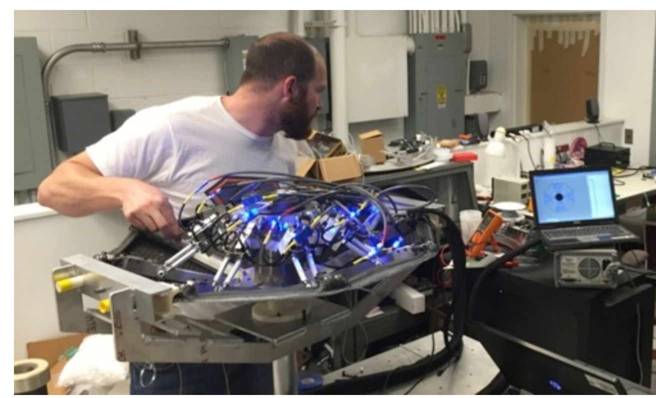
- Testing was completed in seven business days at the US Army's 7x10 Foot Wind Tunnel located at NASA Ames (27-Apr to 5-May 2015)
- Shared funding was provided through NASA STMD GCDP ADEPT program (FY15) and a NASA Ames Center Innovation Fund Award (FY14)
- Test objectives trace to technical challenges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

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

Test Article Patterning



Photogrammetry Solution Overlay



Strut Load Cell Check Outs

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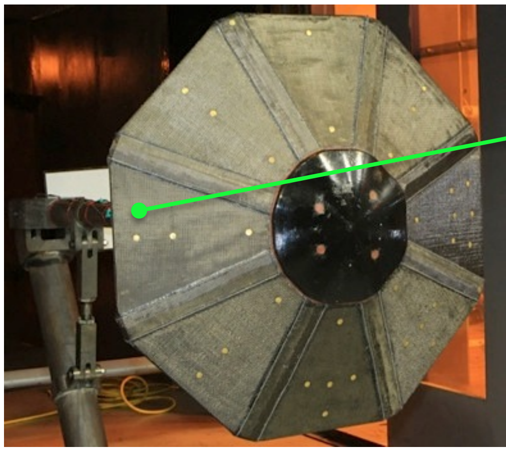
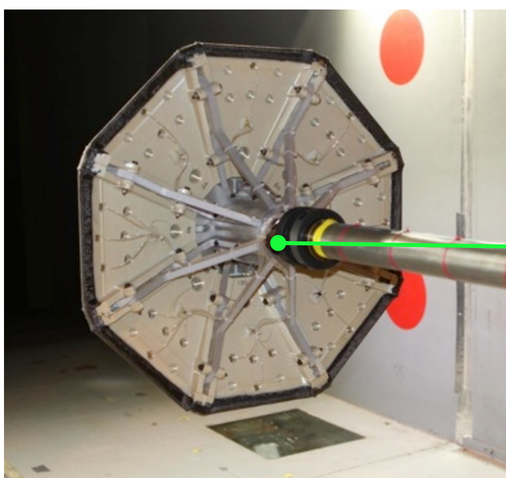
# Test Approach: Two Test Articles

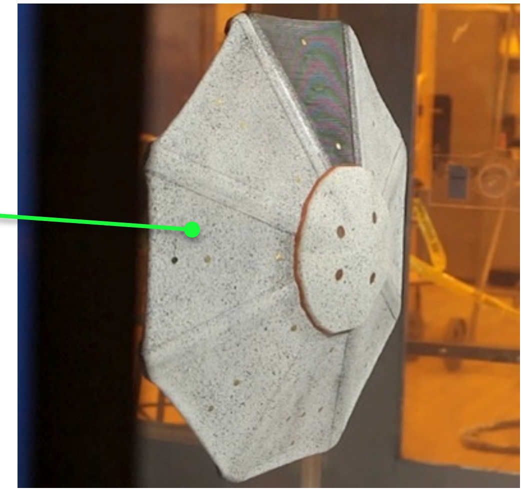
## Solid test article

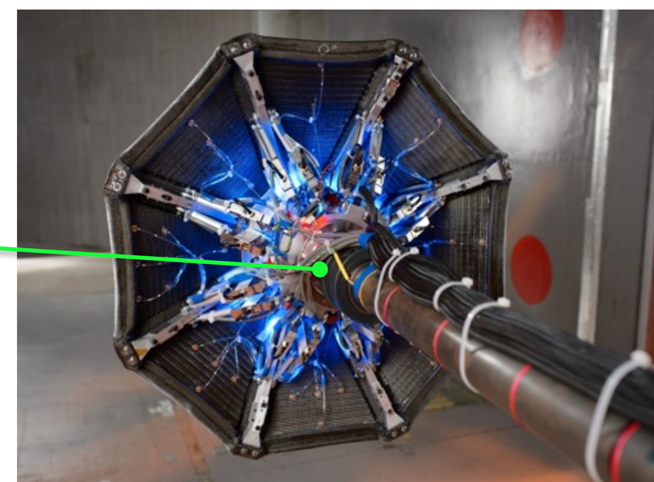
- Simulates fabric test article with infinite pre-tension
- First article to be tested in the tunnel





## Fabric test article

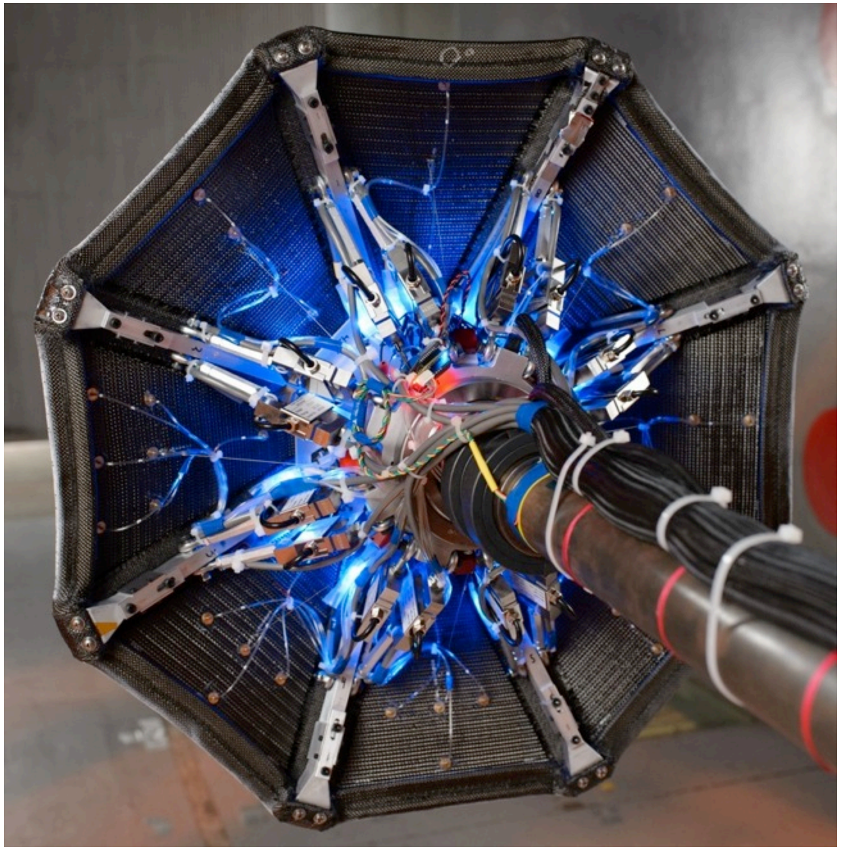




Common pressure tap pattern

Common sting/ balance interface

# Fabric Test Article Details



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

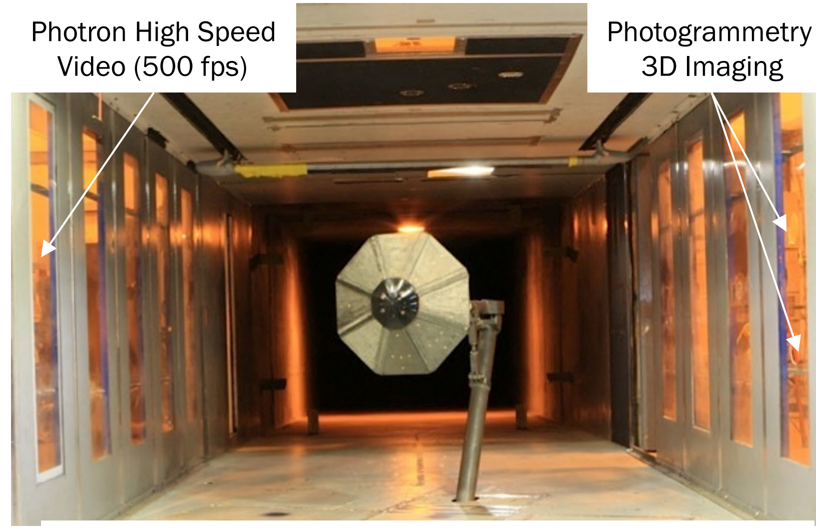
White speckle paint is for photogrammetry surface tracking

- 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

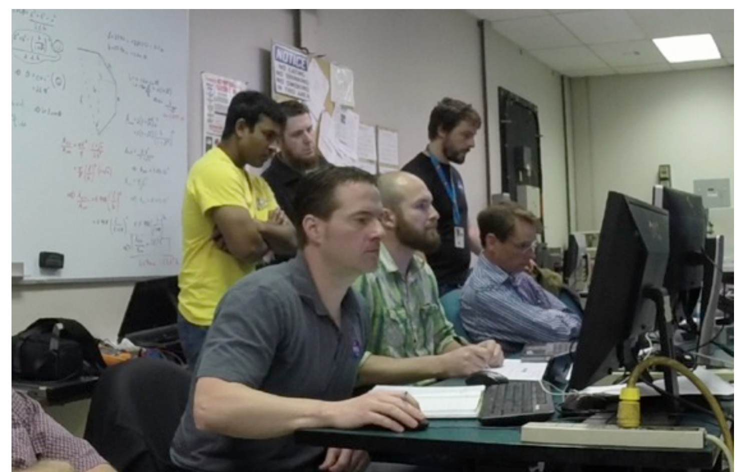
- Ribs and struts (two per rib) are oversized compared to flight to comply with tunnel safety requirements and maximize use of COTS parts for cost savings
- String potentiometers are attached at mid-gore to give a live measure of deflection in the control room and provide a global view of gore deflections 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*

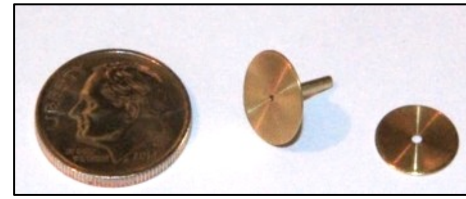


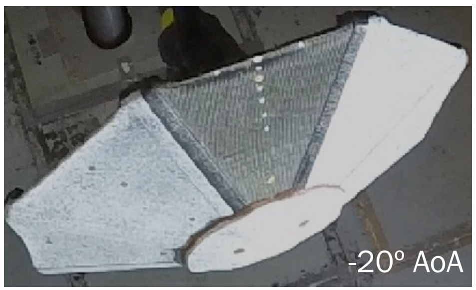
*Control Room*

# Static Pressure Data

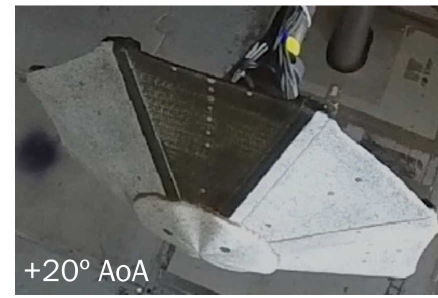
- Static pressure taps on both test articles provided repeatable data (example shown below: solid test article pressure coefficient @ 100 psf)
- Instrumentation integration approach worked well and could be repeated for flight test
- Data is presently being compared to CFD solutions

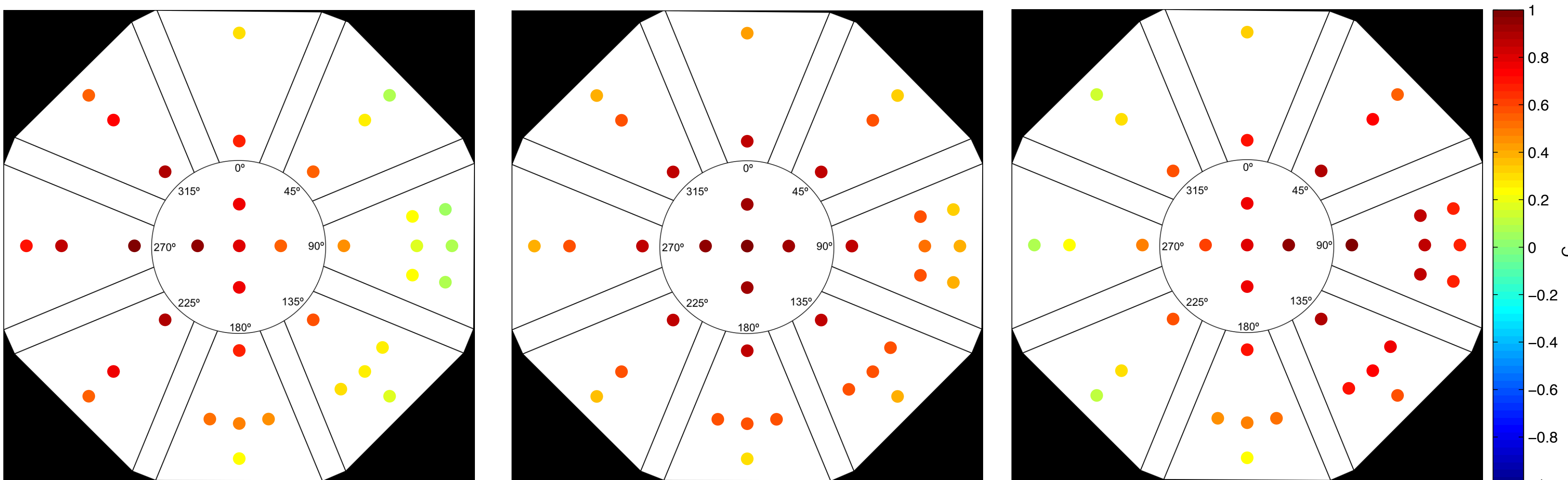
*Pressure tap*










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

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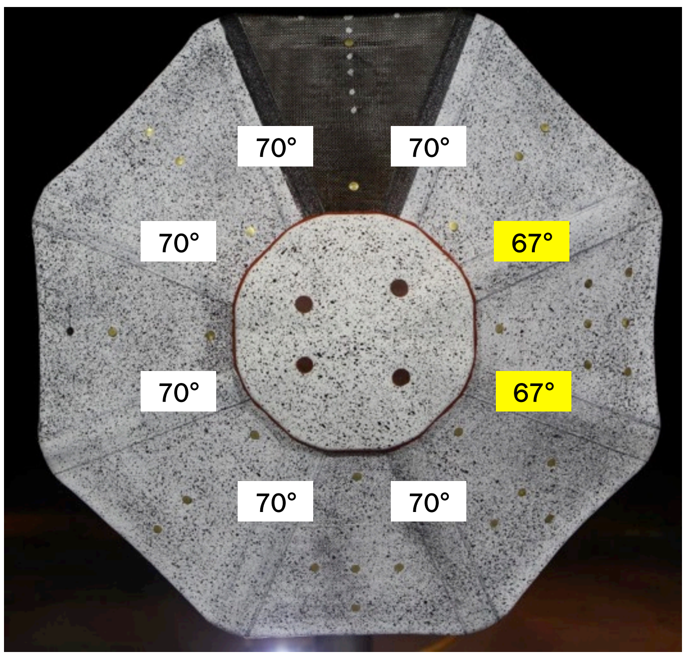
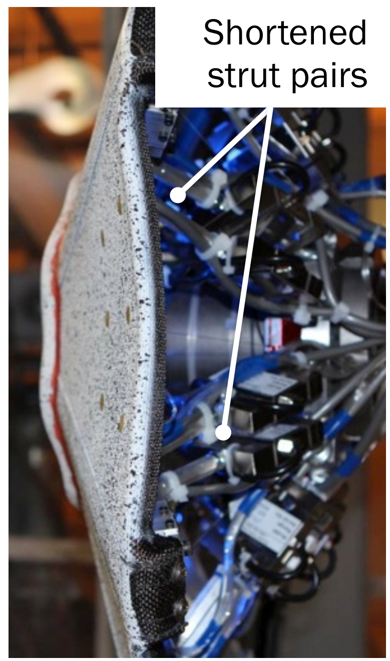
# Bonus Finding: Asymmetric Shape

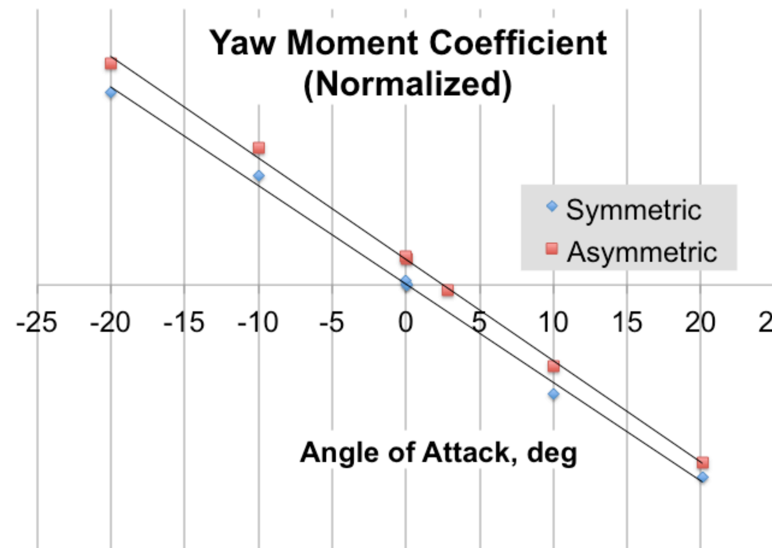
- Two pairs of struts were shortened to give the 3 o'clock gore a cone angle of ~67° (compared with 70° for the rest of the gores)
  - Tension nut was set to 20 lbf/in nut setting so results may be compared with the same symmetric nut setting
- Resulted in offset of zero-moment angle of attack from 0° (symmetric) to +2.4° (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

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# Aeroloads Wind Tunnel Test Team Photo


Not pictured:
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Ryan McDaniel
Sameera Gunatileka
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