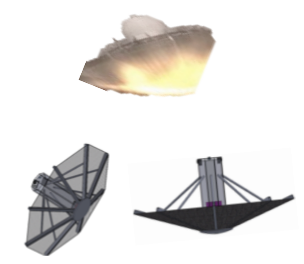
Adaptable, Deployable Entry and Placement Technology (ADEPT) – Overview of FY15 Accomplishments

P. Wercinski[§], C. Brivkalns[§], A. Cassell[§], Y-K Chen[§], T. Boghozian*, R. Chinnapongse[§], M. Gasch[§], S. Gorbunov[#], C. Kruger[§], A. Makino[§], F. Milos[§], O. Nishioka[§], D. Prabhu*, B, Smith[§], T. Squire[§], G. Swanson*, E. Venkatapathy[§], B. Yount[§], and K. Zarchi[§]
[§] NASA ARC; *ERC Inc.-Moffett Field, CA; [#]Jacobs Technology, Inc.-Moffett Field, CA

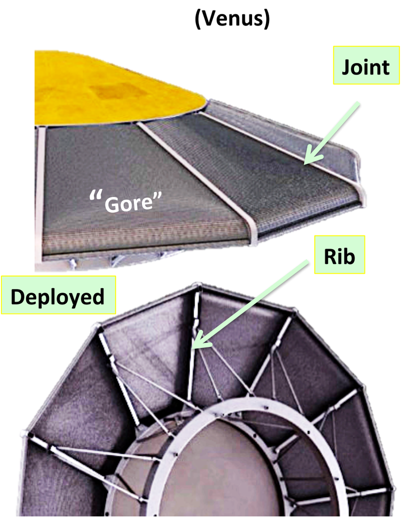
Background – What is ADEPT?

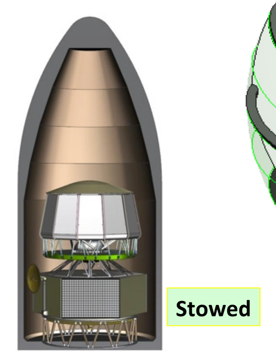
- **ADEPT** is an atmospheric entry *architecture* for missions to most planetary bodies with atmospheres.
  - Current Technology development project funded under STMD Game Changing Development Program (FY12 start)
  - Stowed inside the launch vehicle shroud and deployed in space prior to entry.
  - 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.

1m Nano-ADEPT (Mars)

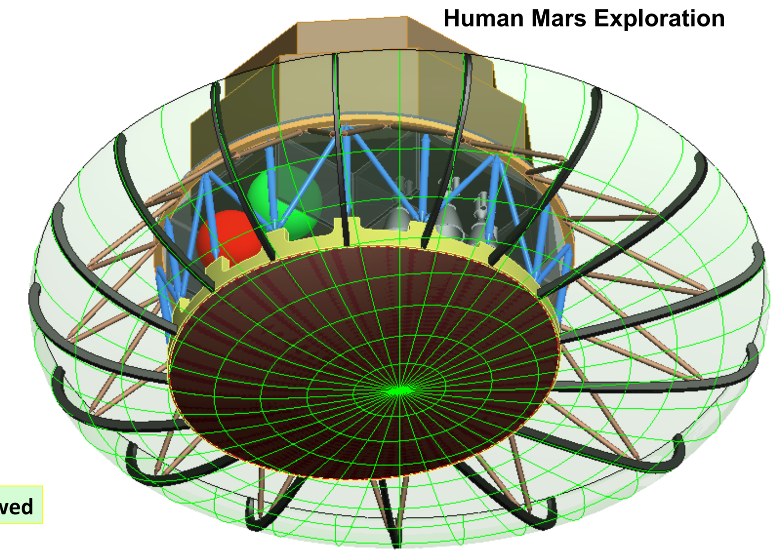


6m ADEPT-VITaL (Venus)





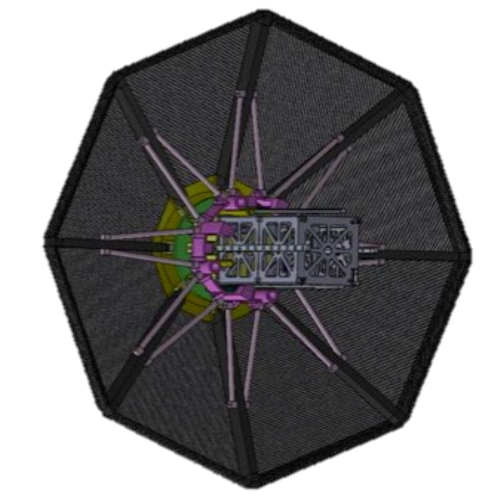
16m Lifting ADEPT Human Mars Exploration



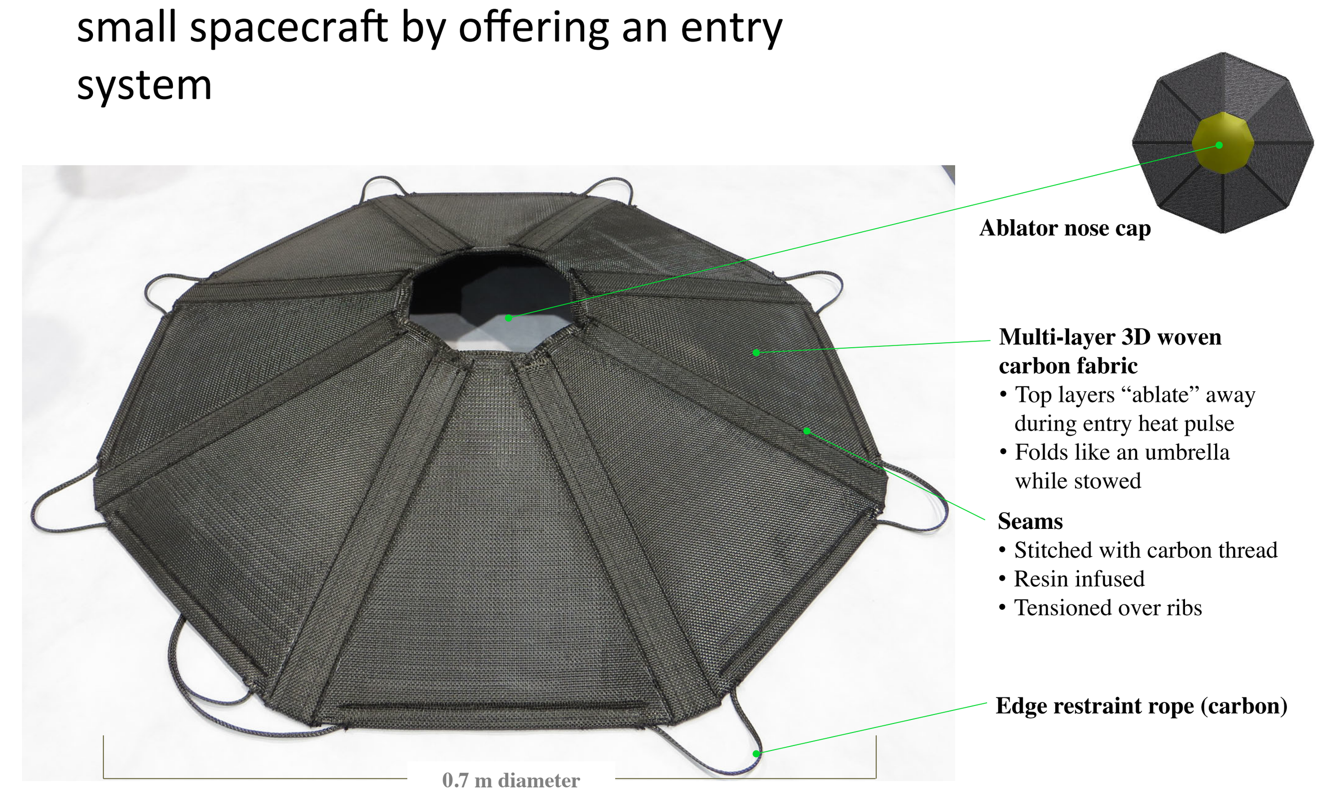
1m-Class (Nano) ADEPT

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



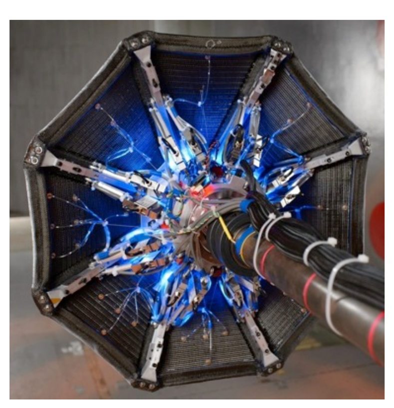
0.7 m diameter Nano-ADEPT shown with notional 2U chassis payload



0.7m AeroLoads Wind-Tunnel Testing (May 2015)

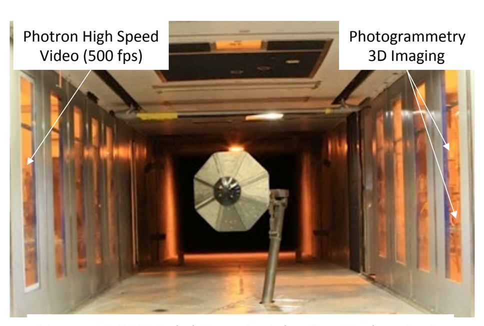
- Testing was completed in seven business days at the US Army's 7x10 Foot Wind Tunnel located at NASA Ames (27-Apr to 5-May 2015)
- Shared funding was provided through NASA STMD GCDP ADEPT program (FY15) and a NASA Ames Center Innovation Fund Award (FY14)

Test 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.	Photogrammetry; String potentiometers; 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; Strut load cells
Obtain aerodynamic forces and moments as a function of pre-tension, dynamic pressure, and angle of attack.	Internal balance



Flight-like carbon fabric skirt includes key features such as carbon yarn stitching and seam resin infusion

- Photogrammetry and high speed video data were recorded at most test points
- Solid article was tested first.
  - Solid model has 'infinite tension' used to directly compare with CFD undeflected shape predictions
  - 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
- 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)

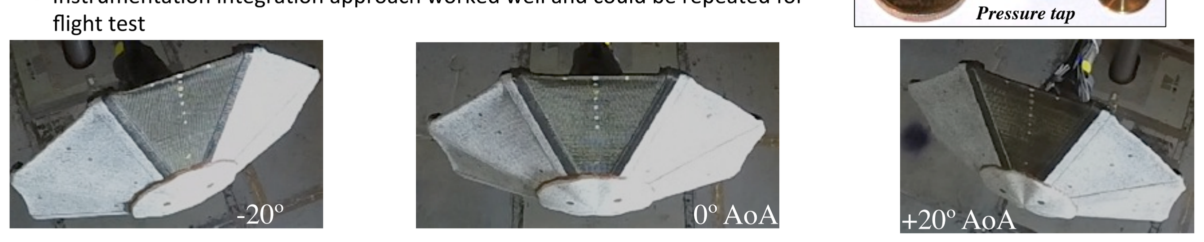


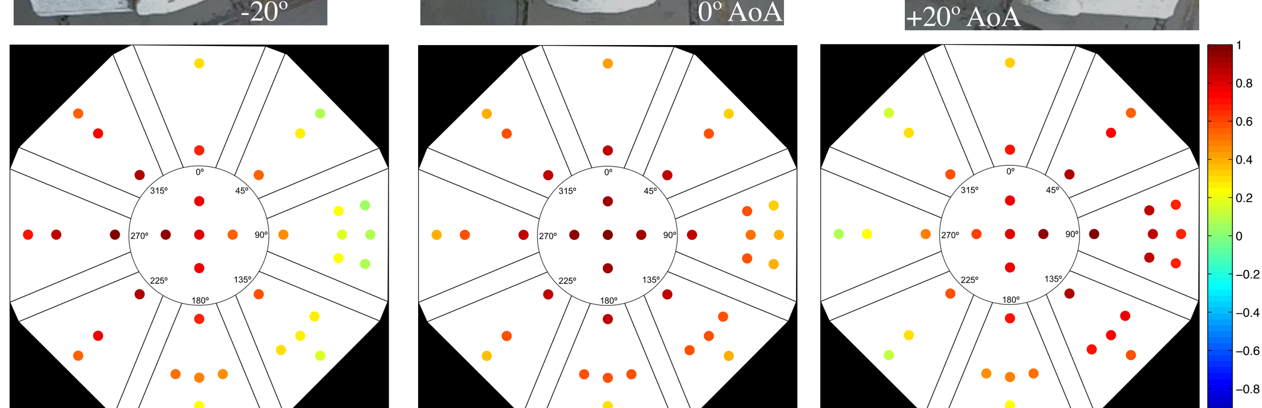
Nano-ADEPT Solid Test Article @ +20 deg AoA

Control Room

- Static pressure 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

Pressure tap



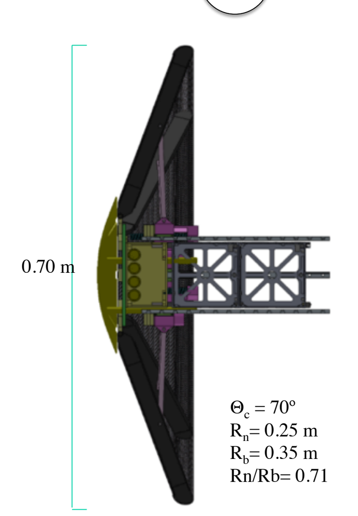


Fabric test article pressure coefficient @ 100 psf (20 lbf/in measured pre-tension)

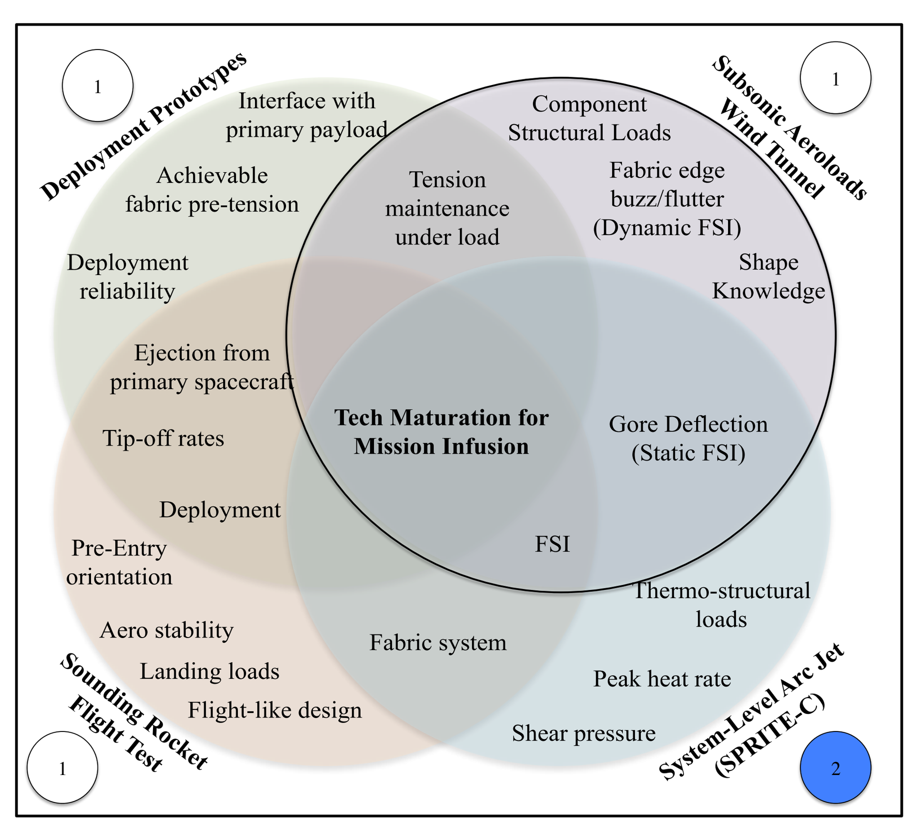
- **All test objectives were met.**
- **Rich data set was obtained using non-invasive instrumentation**
- **Data products and observations made during testing will be used to refine computational models of Nano-ADEPT**
- **Bonus experiment of asymmetric shape demonstrates that an asymmetric deployable blunt body can be used to generate measureable lift**

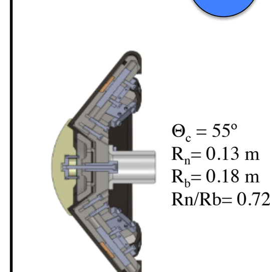
1m (Nano) ADEPT System-level Technology Development Approach

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





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

Summary

- ADEPT brings **High Value** return on technical development progress under limited budgets.
- System level testing in Arcjets and with Sounding Rocket using common configuration – Huge Challenge for EDL!
  - SPRITE arcjet testing of scaled ADEPT configuration (ablating nose, ribs, gores with joints, and trailing edge)
  - SR Flight will address exo-atmospheric deploy with flight relevant hardware and aero stability through critical supersonic-transonic flight regime
- Near Term Development Success will Enable:
  - **ADEPT 1m class infusion ready for Discovery 2017 AO**
  - Highly visible, flight test experience advances confidence and reduces implementation risk for ADEPT entry architecture
  - Characterization and experience using 'real hardware' performance applied to larger scale ADEPT applications
  - FY16-17 Flight test is key step to subsequent ADEPT demonstration of **guided lifting flight**

Acknowledgements

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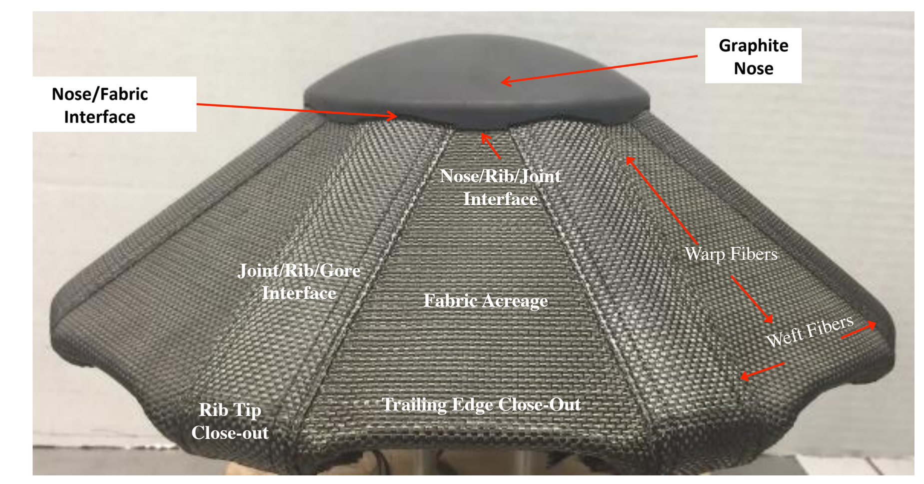
- Authors also acknowledge testing assistance from US Army 7x10 Wind Tunnel Facility and NASA Ames Arcjet Facility

0.35m SPRITE-C Pathfinder Arcjet Testing Results (Sept 2015)

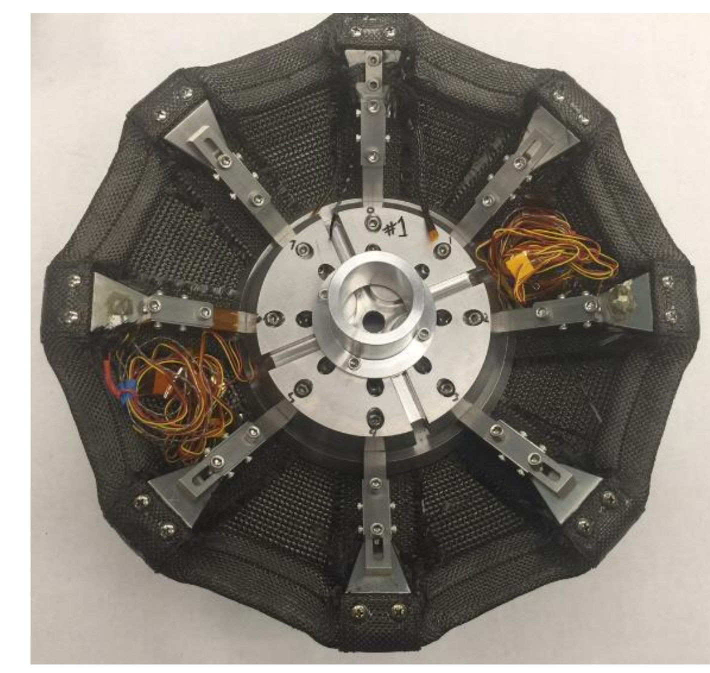
- **OBJECTIVE: Characterize response of system level design features under relevant aerothermal environments.**
  - Utilize flight-like interface designs (*Nose/fabric, Nose/Joint, Joint/Rib, Trailing Edge Close-out*)
- **APPROACH: A relevant scale, 360 degree test article allows for testing of multiple design features**
  - Heavily instrumented 4 test articles
  - Mars entry relevant environments
    - Heating rates on fabric (40-80 W/cm²)
- **IMPACT:**

Achieves system-level aerothermal performance in relevant environments

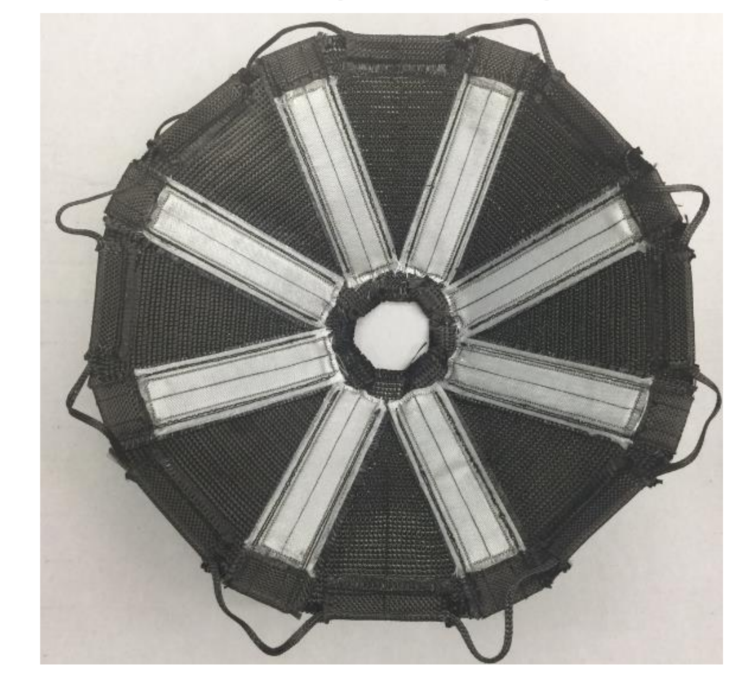
Conformal PICA Nose Cap



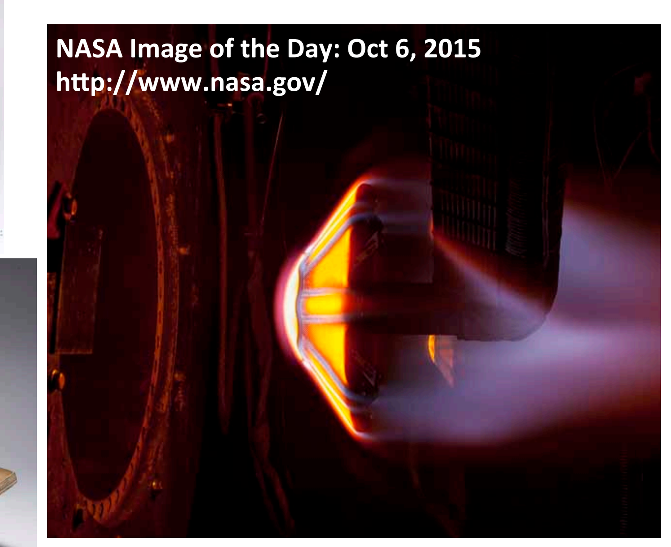
Embedded Instrumentation



Insulating Fabric Skirt Design

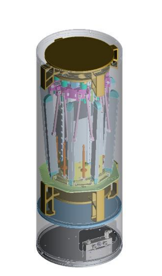


SPRITE-C Pathfinder Test Article #2
Conformal-PICA Nose, 6 Layer Carbon Fabric, Phenolic Resin joint

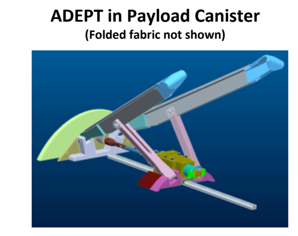


Dual heat pulse (2 separate 40s and 60s exposures – 7.5 kJ/cm² total stagnation point heat load

0.7m Deployment Prototype (Sept 2015)

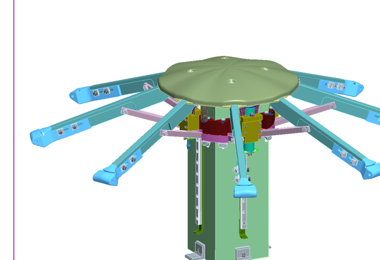


ADEPT in Payload Canister
(Folded fabric not shown)

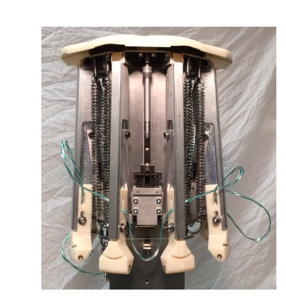


1/4 Model Proof of Concept

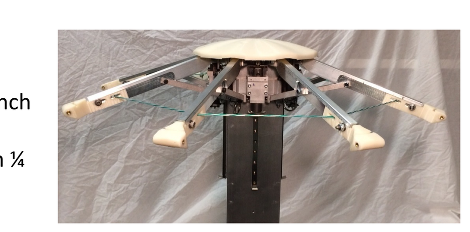
- **Spring actuated deployment proposed for sounding rocket configuration**
  - Fast operation for SR mission timeline
  - Simple (No motors, batteries or control system)
- **Challenges include:**
  - Tight packaging between ADEPT "cubesat payload" and available diameter within sounding rocket
  - Long stroke with high force required at end of stroke to tension fabric (contrary to typical spring behavior)
  - Nose cap movement needed to prevent wrinkling of fabric at nose cap interface
  - Accommodating fabric interfaces and folding into tightly packaged stowed state
- **Approach:**
  - ¼ model designed and built for proof of concept, design debug, bench testing & identifying improvements
  - Full deployment prototype designed & built based on findings from ¼ model debug & test
  - Deployment prototype successfully tested for function
    - Plan to use prototype for testing with modified carbon fabric skirt and for separation from SR canister
  - Lessons learned will be applied to SR flight unit design
- **Deployment Prototype Features**
  - Full-scale for sounding rocket configuration
  - Target fabric pre-tension of 10 lb/in (per flight requirements)
  - Designed for 4-layer carbon fabric
  - Two-stage deployment mechanism triggers high-force springs near end of travel to tension fabric
  - Linear guide rails (4) maintain even deployment
  - Nose cap movement is integrated with 2nd stage of deployment mechanism
    - Pulls nose cap down against fabric at end of travel to eliminate gaps
  - End-of-travel latches lock ADEPT in the deployed state



CAD Model - Deployed State



Prototype Stowed State



Prototype Deployed State

Prototype Deployed with Surrogate Fabric