Adaptable Deployable Entry & Placement Technology (ADEPT)

Presentation for Outer Planet Aerocapture meeting

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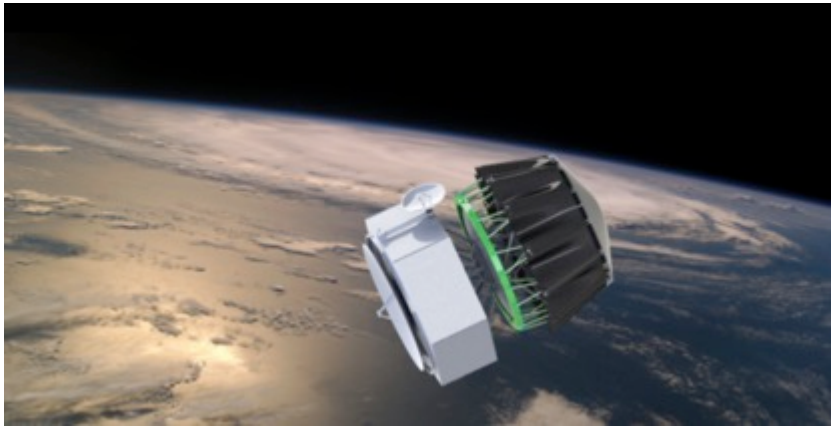
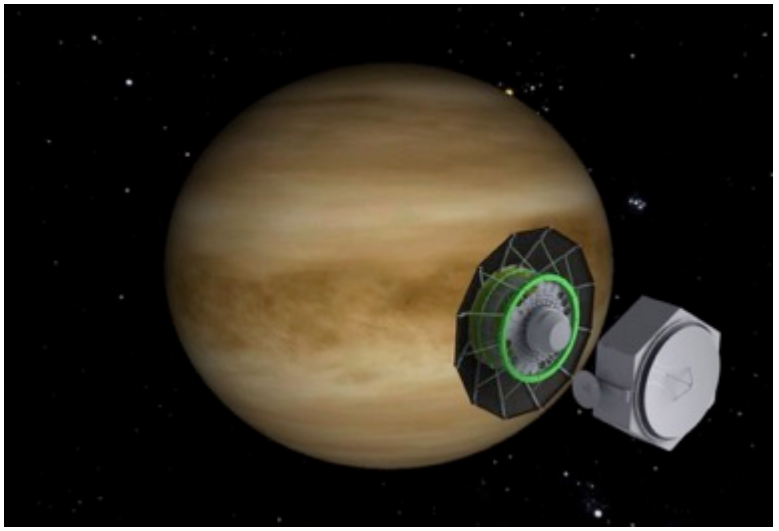
October 7, 2015

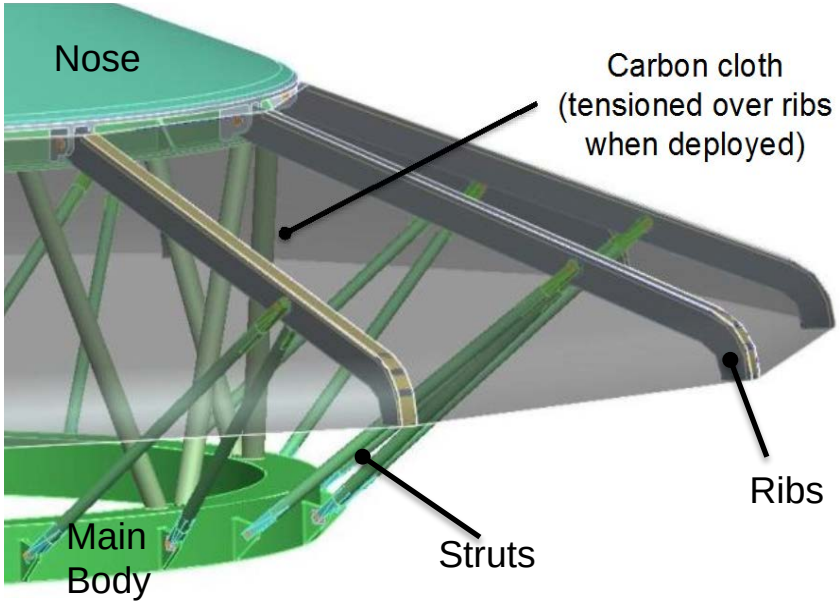
What is ADEPT?
(Adaptive Deployable Entry & Placement Technology)



Earth departure



Arrival at Destination

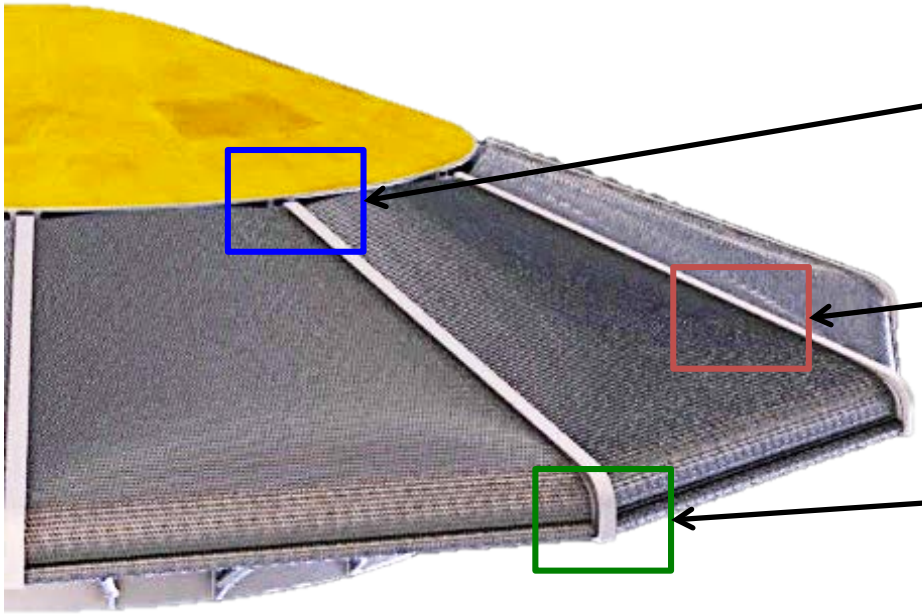


ADEPT is an atmospheric entry *architecture* that is Game Changing for missions to most planetary bodies with atmospheres.

- Provides a benign deceleration and thermal environment to the payload.
- Stowed inside the launch vehicle shroud and deployed in space prior to entry.
- Structural ribs support 3D woven carbon fabric to generate drag and withstand high heating.

2

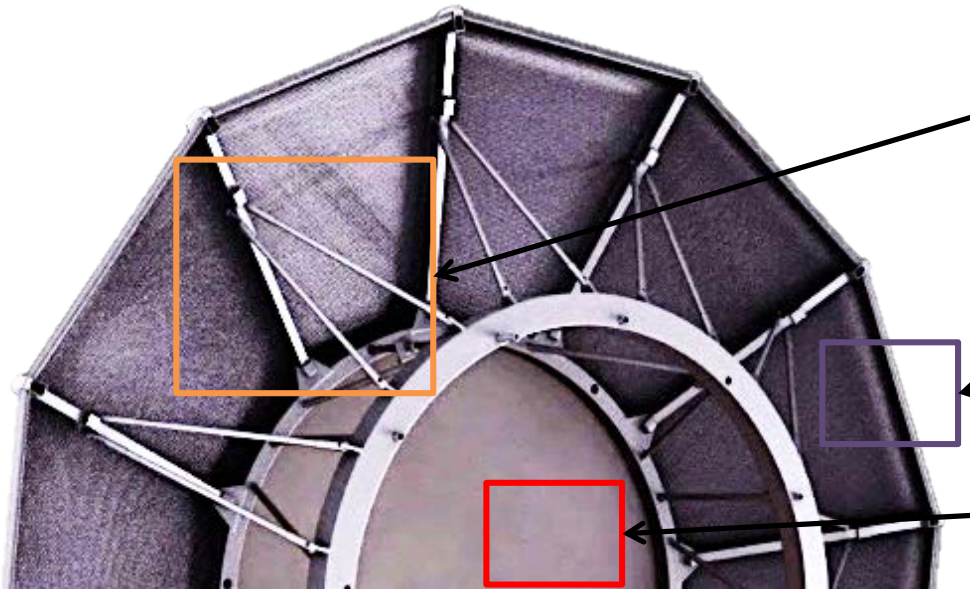
Key Technical Functional Challenge Areas



Carrier Structure/ Forebody TPS/ Fabric/ Rib Thermal Performance

Acreage Fabric/ Rib Interface

Fabric Shoulder/Rib-End Interface



Robust, Reliable Deployment

Mid Gore Shoulder Fabric Close-Out

Payload Thermal Accommodation

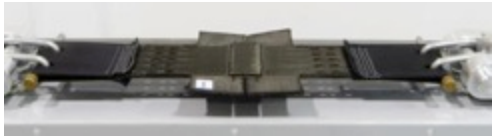
ADEPT

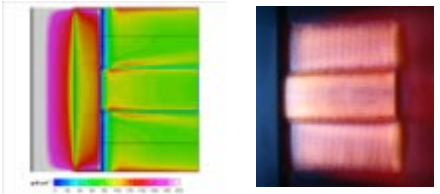
ADEPT Project Overview

- **ADEPT FY12-FY13**
  - Funded under STMD Game Changing Development Program
  - Focus on 6m Venus DRM (Delivery of 1000kg lander with peak decel < 30 g's)
  - Carbon fabric arc-jet tested 100-240 W/cm2.
  - Successful demonstration of 2m Ground Test Article
- **ADEPT FY14**
  - Early year focus continued 6m Venus, Demonstration carbon-fabric stitched joint
  - Mid-year budget reduction forced development goal re-plan -> 1m scale
    - Cost effective approach for key system-level demonstrations
- **ADEPT FY15**
  - Continuation of 'FTE-only' project status
  - Focus on 0.7m aero-loads wind tunnel test, 0.35m SPRITE pathfinder arcjet test
  - Perform risk mitigation and formulation efforts in anticipation of FY16 0.7m sounding rocket flight test
- **ADEPT FY16**
  - ADEPT currently limited to 4 FTE. Tech development limited

Carbon Fabric acreage arcjet testing (2012)

2m Ground Test Article (2013)



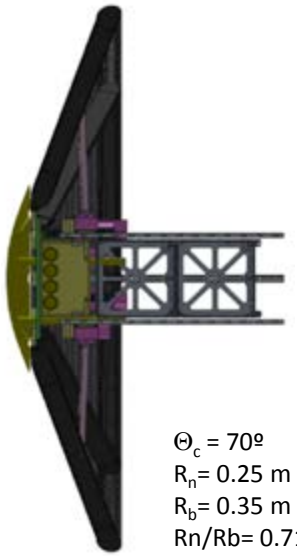


Fabric Joint Design Testing (2014)

ADEPT Development Roadmap (1m scale)

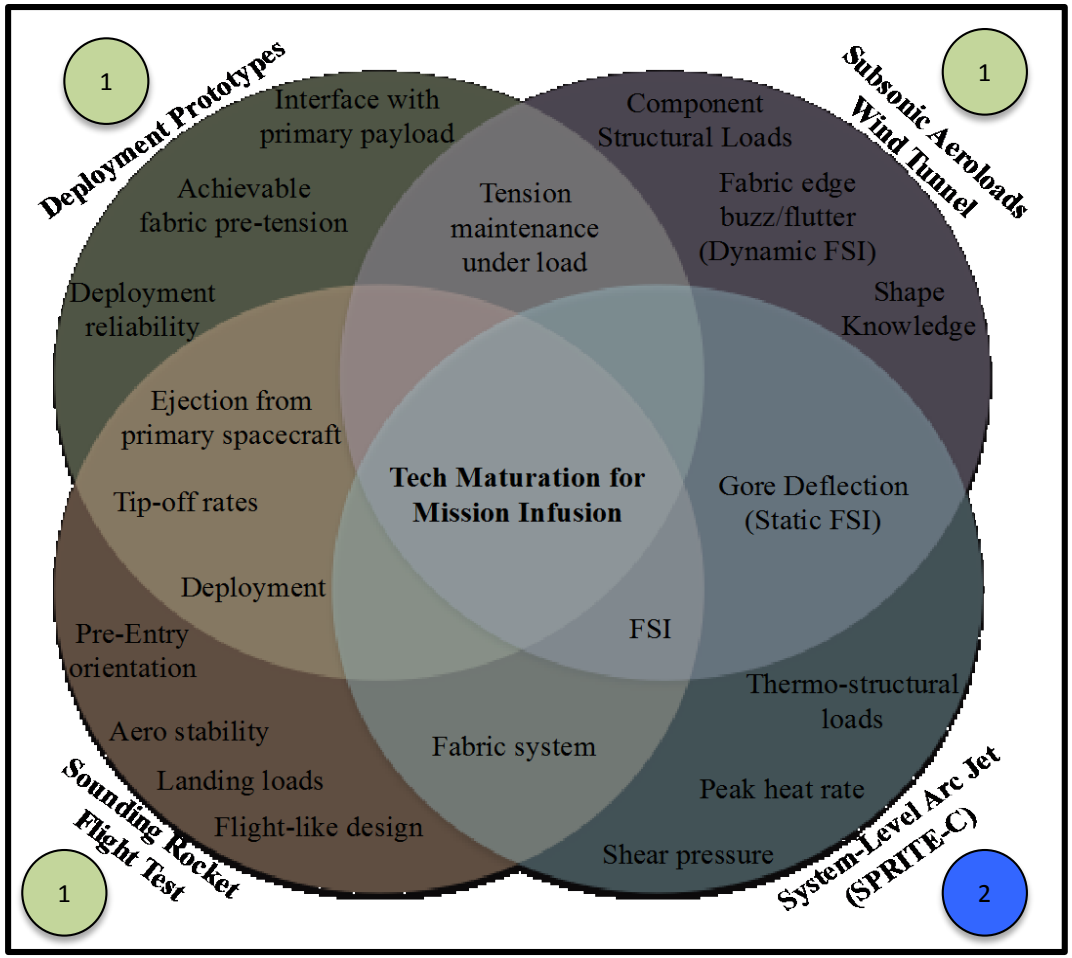
- Strategy addresses technical challenges with four system-level tests
- Common geometric features between design reference missions (DRMs), ground tests, and flight test provide ground-to-flight traceability

Config. 1

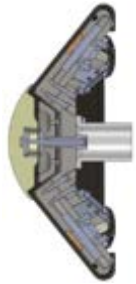


Θ_c = 70º
R_n= 0.25 m
R_b= 0.35 m
Rn/Rb= 0.71

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



Config. 2



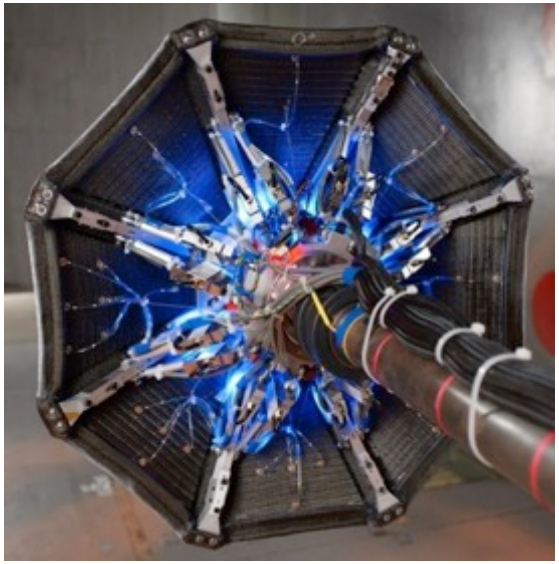
Θ_c = 55º
R_n= 0.13 m
R_b= 0.18 m
Rn/Rb= 0.72

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

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 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. *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; 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

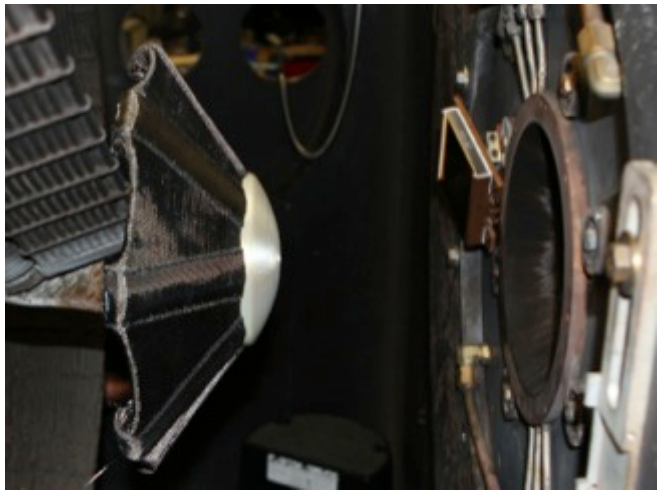


- Flight-like carbon fabric skirt includes key features such as carbon yarn stitching and seam resin infusion
- Central nut moves all struts simultaneously to pre-determined positions to induce a known pre-tension in fabric

Video Highlights from 7x10 Test

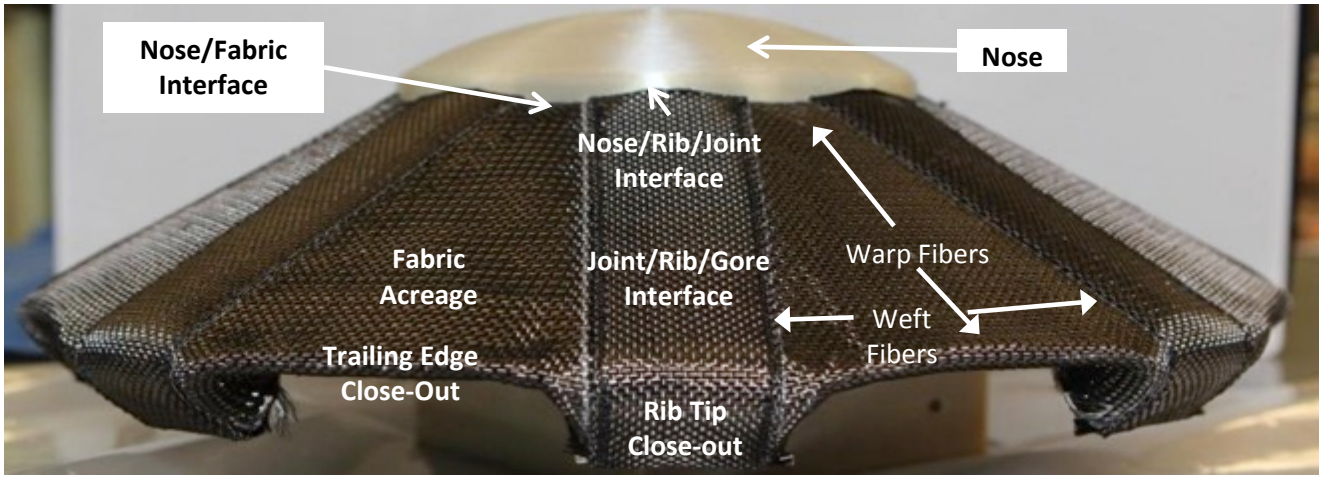
SPRITE-C Arcjet System Level Tests (FY15)

- **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 test article
  - Mars DRM heating conditions (50-150 W/cm^2)
- **IMPACT:**



SPRITE-C Prototype Test Article Fit check in the Ames Interaction Heating Facility

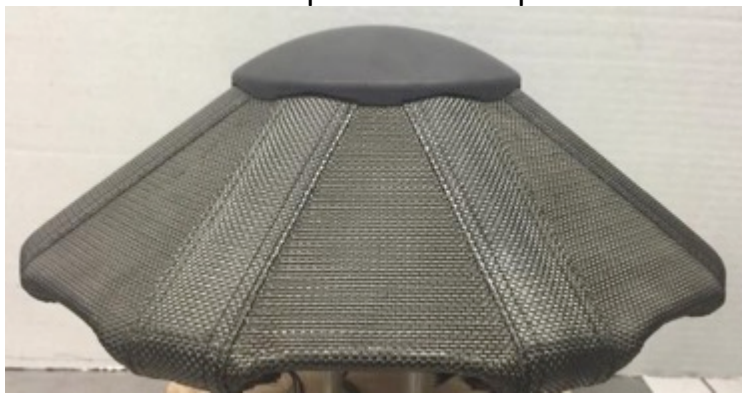
Efficient and cost-effective methodology to achieve system-level aerothermal performance in relevant environments



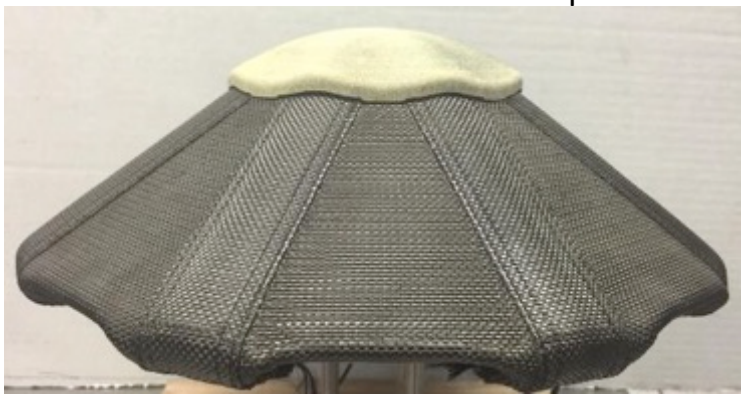
SPRITE-C Arcjet Test Preparations

ADEPT

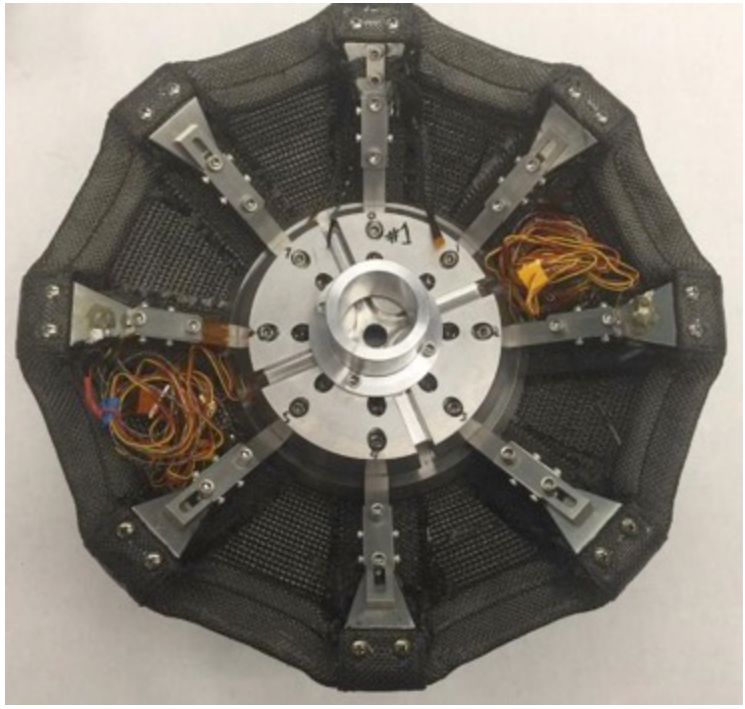
Graphite Nose Cap



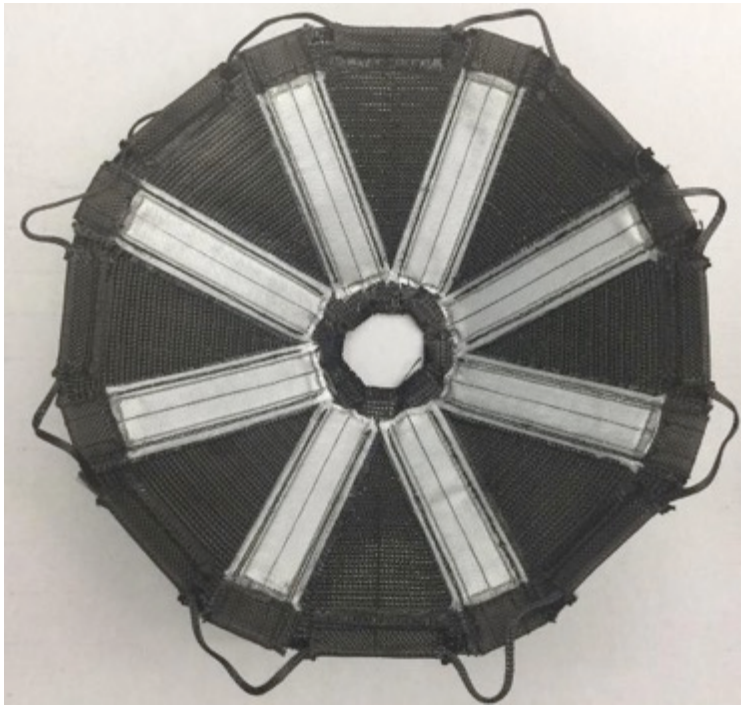
Conformal PICA Nose Cap



Embedded Instrumentation

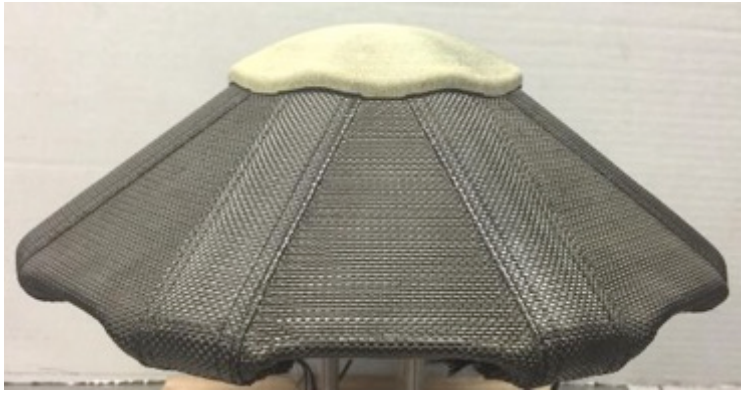


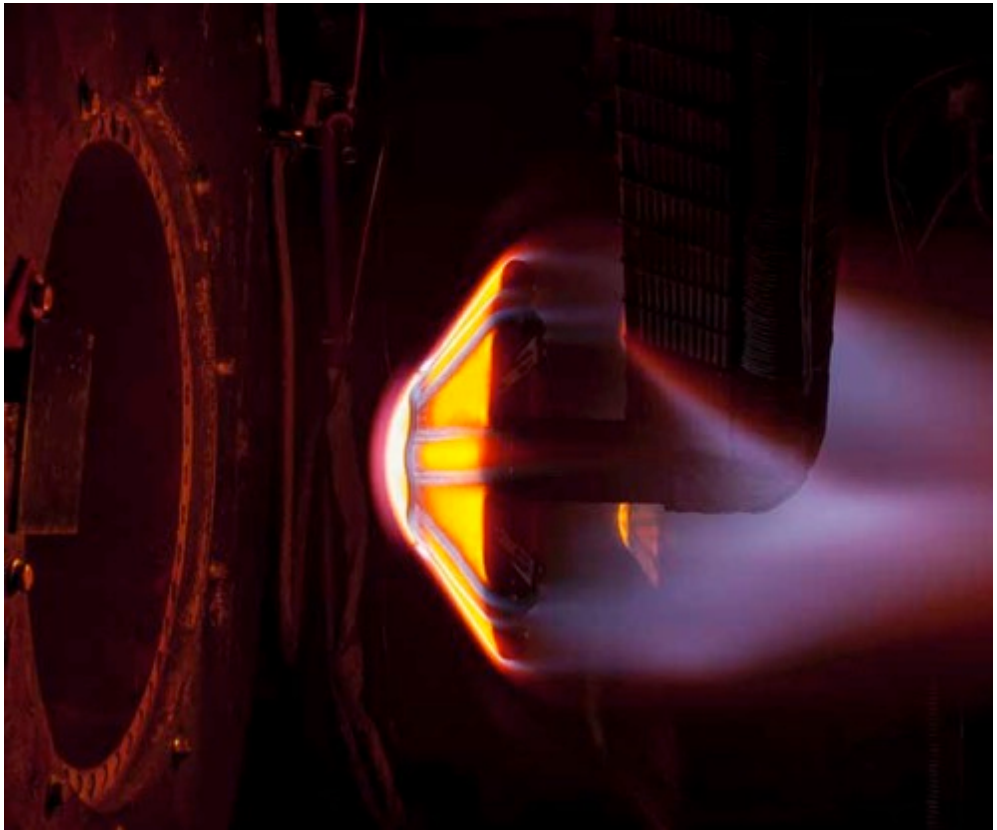
Insulating Fabric Skirt Design



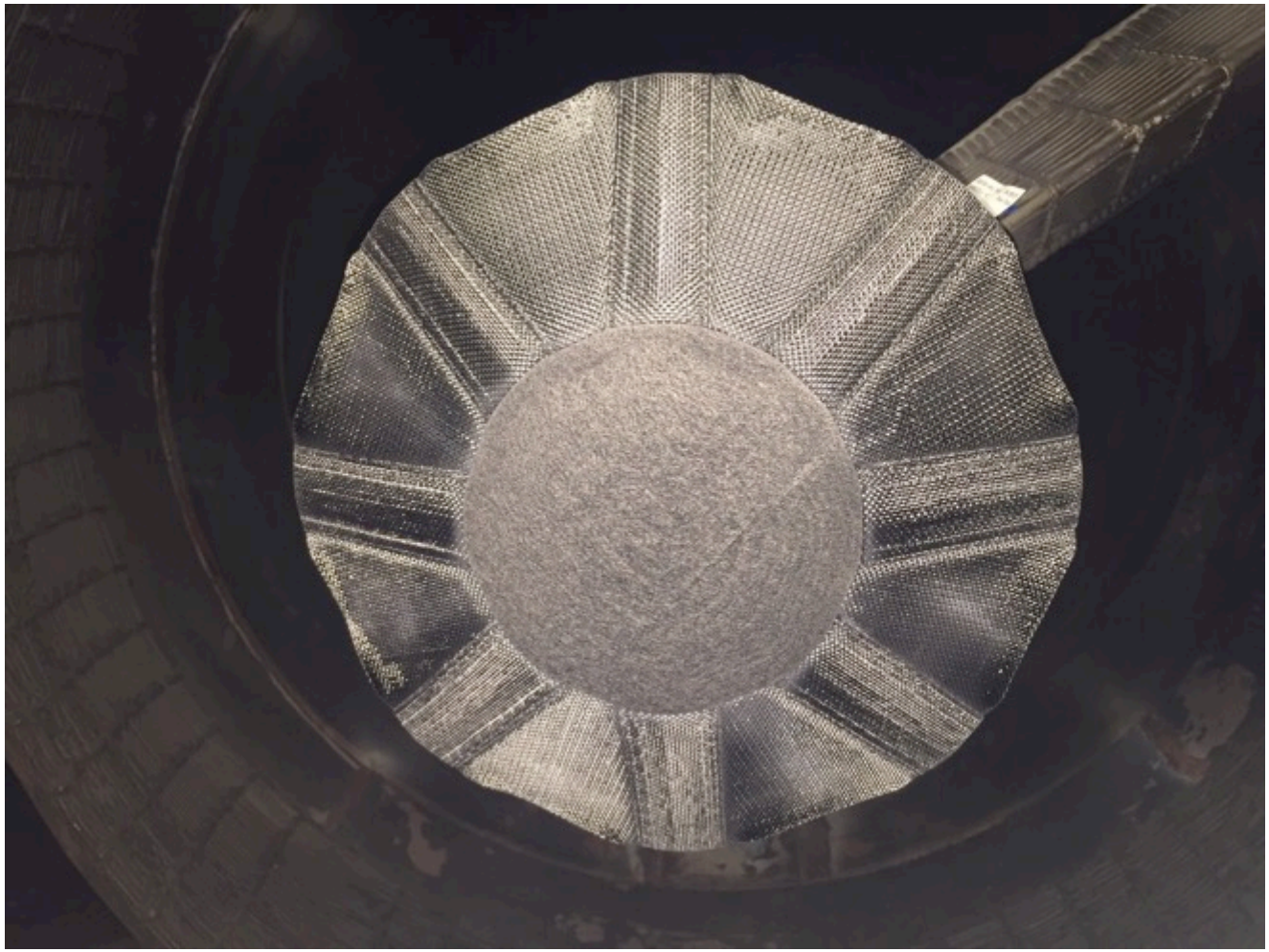
SPRITE-C Pathfinder Arcjet Test Article #2
C-PICA Nose, 6 Layer, Phenolic Resin joint

ADEPT





SPRITE-C Pathfinder Arcjet Test Article #2 Post-Test Image



ADEPT

SPRITE-C Arcjet Test Matrix and Conditions

Environment Predictions

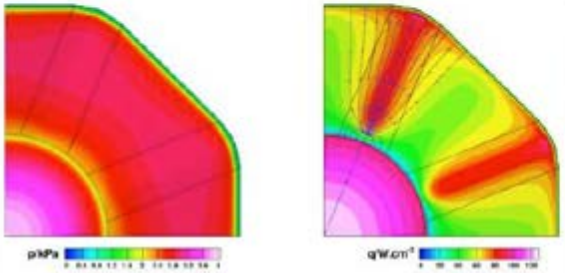
Condition 1

IHF 21.5-in nozzle, 10" from nozzle exit plane

I_{arc} = 2000 A

m_{air} = 200 g/s, m_{air+} = 55 g/s, m_{Ar} = 26 g/s

P_{arc} = 240 kPa



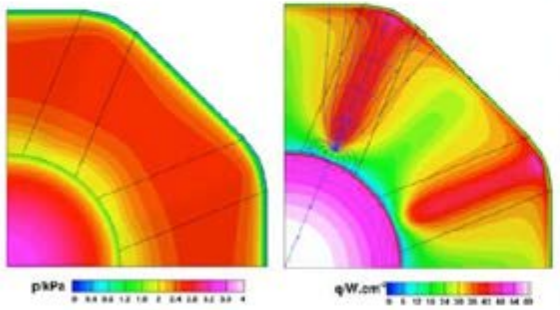
Condition 2

IHF 21.5-in nozzle, 10" from nozzle exit plane

I_{arc} = 2200 A

m_{air} = 110 g/s, m_{air+} = 160 g/s, m_{Ar} = 30 g/s

P_{arc} = 193 kPa

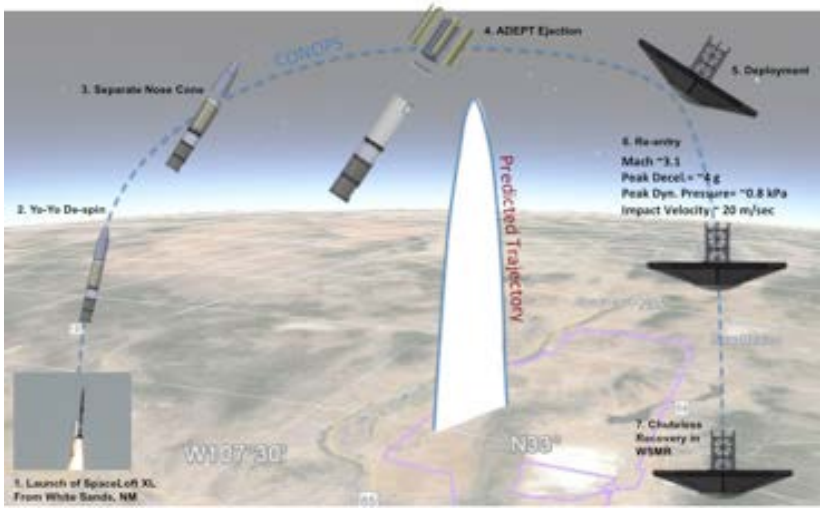


Run Matrix

Run	Condition	Test Article/ Calibration Run	Sting	Stag Pt q_w (W/cm²)	Stag Pt Prs (kPa)	Duration (sec)
1	1	**4" Hemi Calorimeter**	Overhead	245	4.2	-
		SPRITE-C #1 Spherical Graphite Nose w/ Phenolic infused joints	East	124	3.9	60
		SPRITE-C #2 Blended C-PICA Nose w/ Phenolic infused joints	West	124	3.9	40
2	2	**4" Hemi Calorimeter**	Overhead	125	3.4	-
		SPRITE-C #3 Spherical Graphite Nose w/ various resin infused joints	East	63	3.4	60
		SPRITE-C #2 (Re-run) Blended C-PICA Nose w/ Phenolic infused joints	West	63	3.4	40
3	1,2	**4" Hemi Calorimeter**	Overhead	Cond 1 & 2	-	-
		9 mm Pitot Probe	East	Cond 1 & 2	-	-
		SPRITE-C #4 Spherical Graphite Nose w/ various resin infused joints, using insulated 4-layer skirt	West	63	3.4	40

Proposed Sounding Rocket (Mach 3) Flight Test

- **OBJECTIVE:**
  - **Demonstrate LV separation and exo-atmospheric deployment.**
  - **Characterize aerodynamic performance from supersonic to subsonic flight regimes. Tech First for 70deg sphere cone shape!**
- **APPROACH: Demonstrate ADEPT 1 m class system flight performance. TAYF: FAYT**
  - Low cost approach leveraging multiple programs within STMD portfolio. (*GCD, SBIR, Flight Opportunities, Center Innovation Fund*)
- **IMPACT:**



Sounding Rocket Flight Test ConOps: Achieves ~115 km altitude, followed by LV separation and exo-atmospheric deployment. Upon re-entry, ADEPT achieves M=3.1.

-Provide flight test experience for ADEPT configuration.

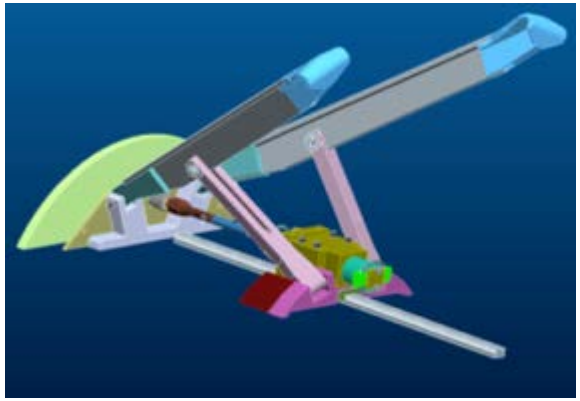
-Critical first step in integrated flight hardware experience to apply to larger scale applications and analytical modeling

-Design capable of delivering ~ 5 kg of cube-sat like payloads

- ✓ **Approved (July 2014) as directed payload from Flight Opportunities Program**
- ✓ **Developed two-stage spring-based passive deployment approach**

Deployment Prototype Development

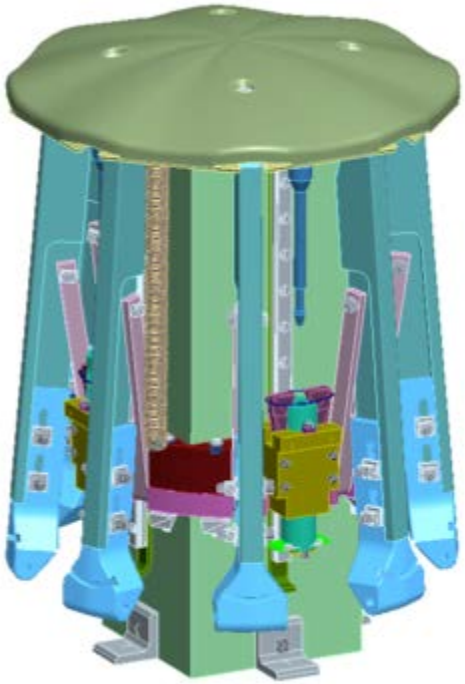
ADEPT in UP Aero Payload Canister
(Folded fabric not shown)



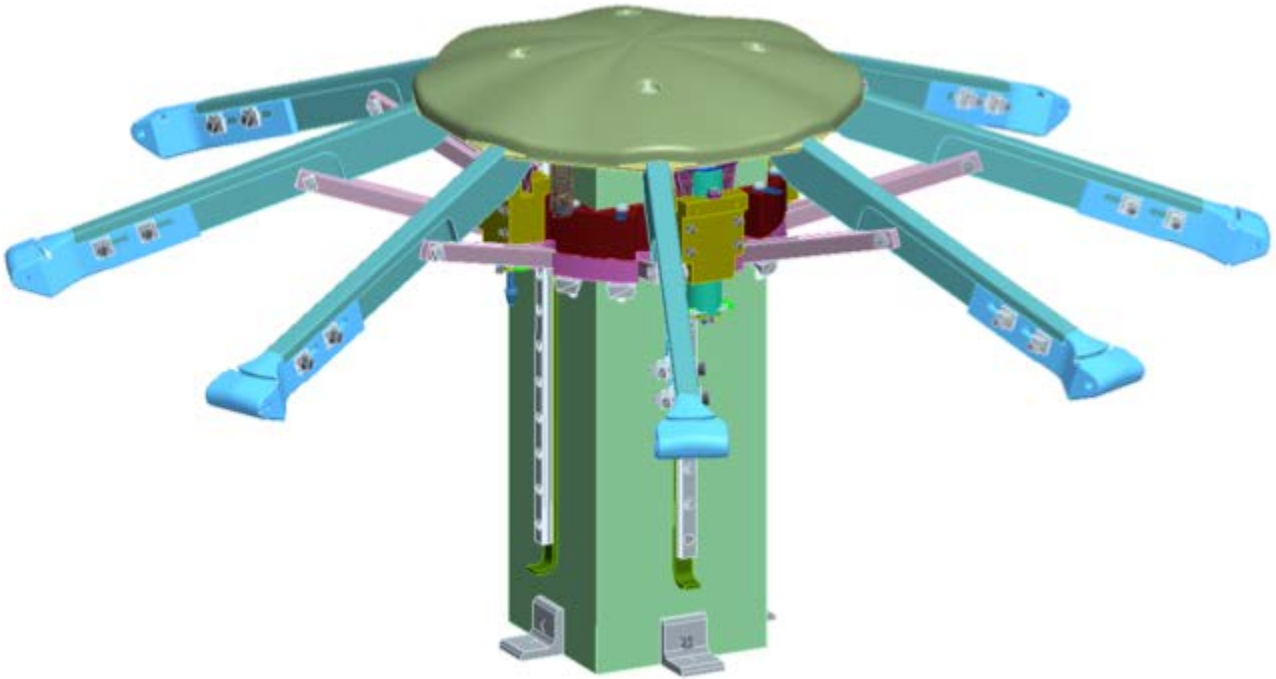
1/4 Model Proof of Concept

- **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 Design

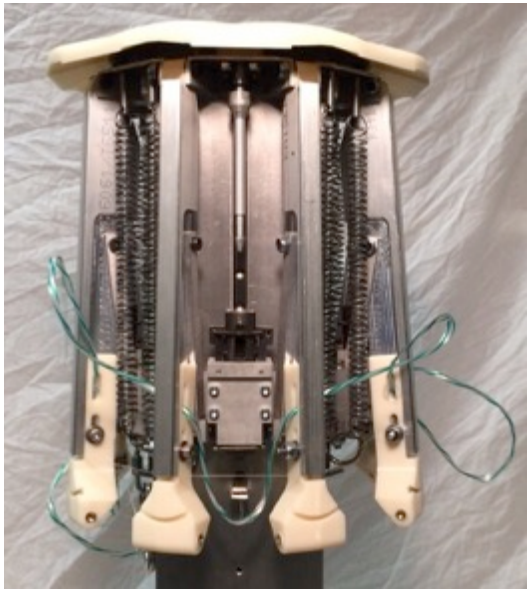


CAD Model - Stowed State

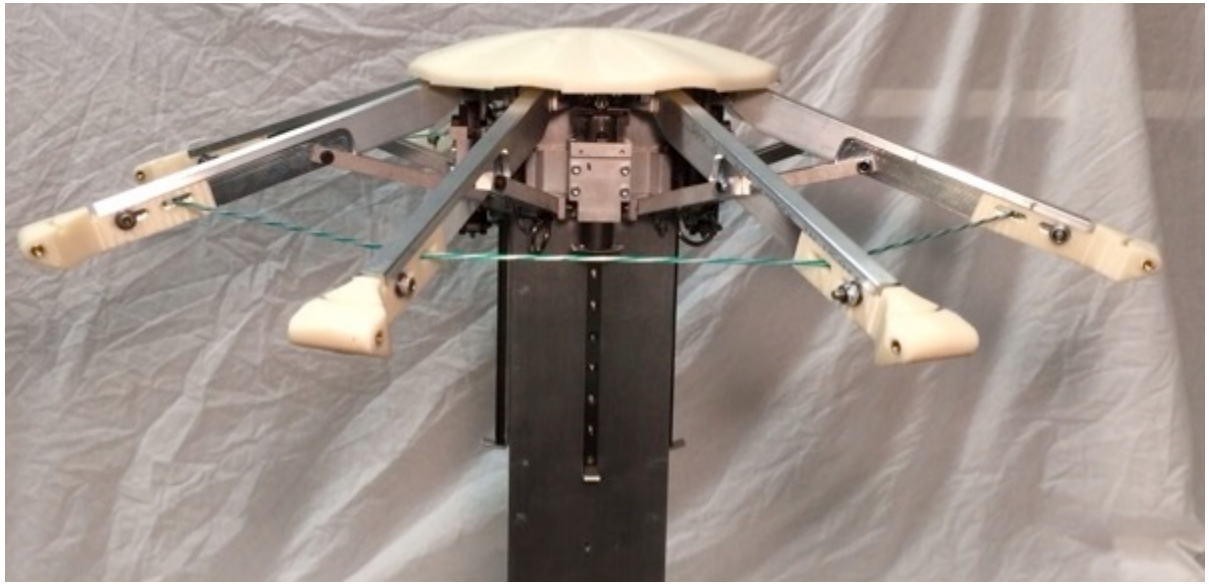


CAD Model - Deployed State

Deployment Prototype Hardware



Stowed State



Deployed State

Deployment Prototype

- 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
    - Initial testing with surrogate fabric (multi-layer laminate material simulating thickness & stiffness)
    - Additional testing planned with updated carbon fabric skirt
  - 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 wrinkles and/or gaps
  - End-of-travel latches lock ADEPT in the deployed state

- Deployment Prototype Deliverables
  - ✓ Deployment prototype hardware has been fabricated and assembled
  - ✓ Deployment prototype has demonstrated consistent deployment function

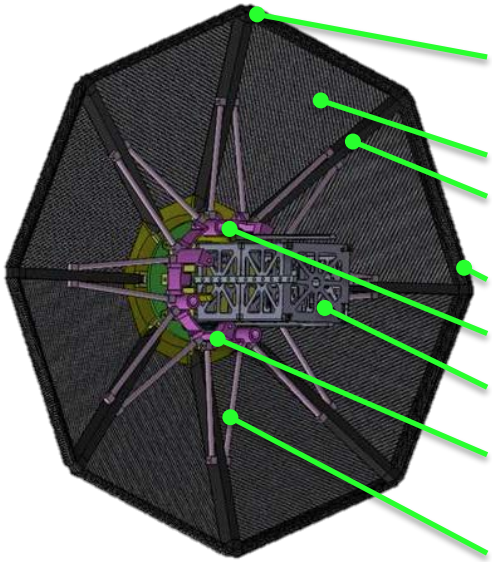
    ➢ ***SEE DEPLOYMENT VIDEO ON NEXT SLIDE***

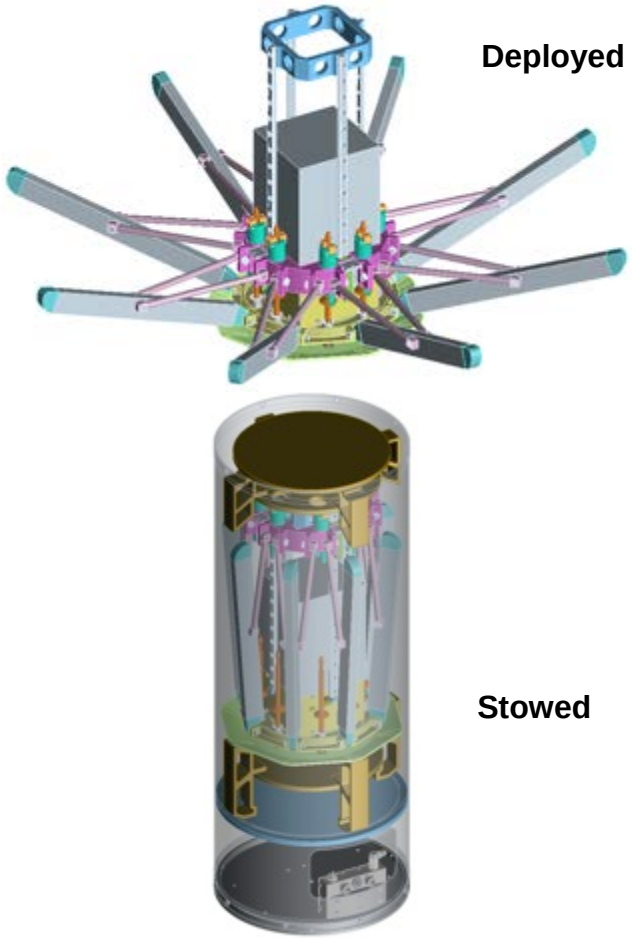
Deployment Prototype Video

ADEPT

Sounding Rocket Flight Test Planning (FY15)

- Sounding Rocket Deployment Prototype Design:
  - Carbon fabric skirts assessed for SR stowage compatibility
  - Deployment prototype demonstration in September

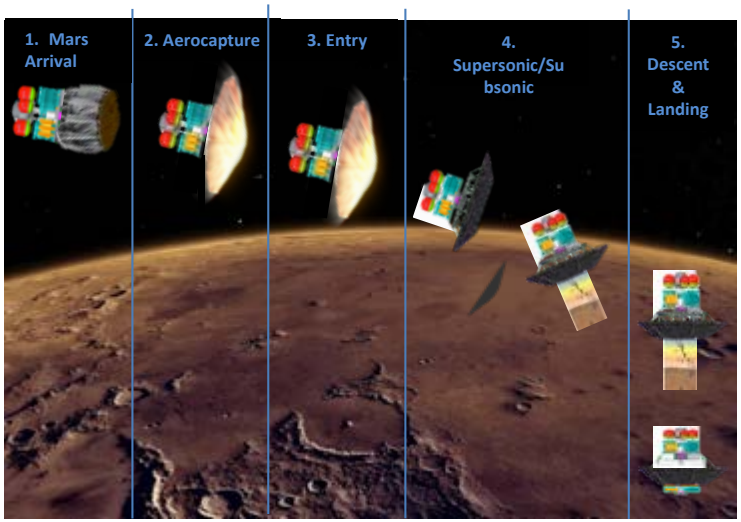


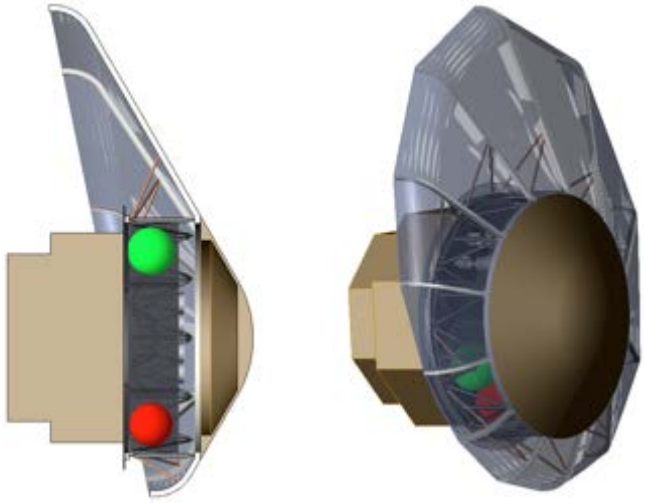


Sounding rocket payload mock-up: Stowed and deployed 0.7m configuration compatible with UP Aerospace payload canister geometry

- Initiated planning discussions with Flight Opportunities Program (FOP) and Sounding rocket provider (UP Aerospace)
- Proposed ADEPT FY16 SR flight test
  - Similar con-ops as IRVE-II which flew in 2009
  - <$4M total budget, this is not a TDM!

ADEPT for Mars EDL Pathfinder Study



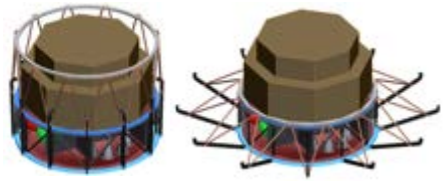


- Dual-Pulse ADEPT Decelerator (Aerocapture and EDL from Mars orbit)
  - ADEPT remains deployed in Mars orbit post-aerocapture, ready for EDL from orbit
- Lifting, asymmetric shape (AFE-like, ACRV shape)
  - Generate L/D 0.2-0.3 without requiring significant offset CG requirements on Payload
  - Assume OML shape remains fixed (static) during hypersonic deceleration
  - Guided trajectory methodology (lift-vector control) TBD, RCS roll control probably lowest risk approach
- Transition to SRP and Terminal Descent
  - Assume retention of ADEPT deployable through initiation of Supersonic Retro Propulsion
    - Vehicle AoA at SRP initiation?, Need to re-trim?, Rigid nose accommodation of SRP nozzles?
  - Ribs can be 'inverted' near landing touch-down to accommodate payload egress
- Other Considerations
  - ADEPT deployed and functionality verified in Earth orbit, prior to Departure

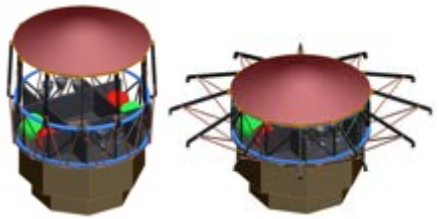
16m ADEPT Concept Configuration Matrix

NAME	CLASS	GEOMETRY	RIBS	STRUTS	DESCRIPTION
SC-01	Symmetric	70° Sphere-Cone	1-Piece (12X)	1-Piece	Aft ring translates forward for deployment
SC-02	Symmetric	70° Sphere-Cone	1-Piece (12X)	1-Piece	Forward ring translates aft for deployment
SC-03	Symmetric	70° Sphere-Cone	Articulated (12X)	1-Piece	Ribs fold forward over nose cap for stowage
AC-01	Asymmetric	60° Sphere-Cone	1-Piece (12X)	1-Piece	AFE mimic: 60° sphere-cone w/ 80.7° trailing edge
AC-02	Asymmetric	Ellipsoid	1-Piece (16X)	1-Piece	ACVe mimic: blended ellipsoid

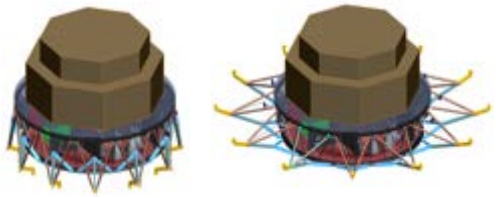
Current Baseline



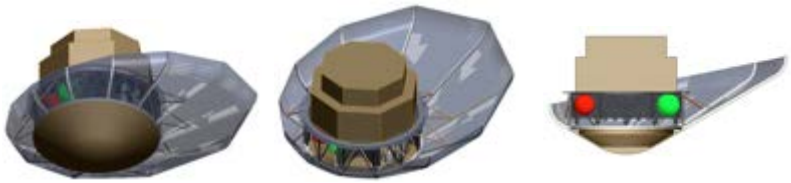
SC-01



SC-02



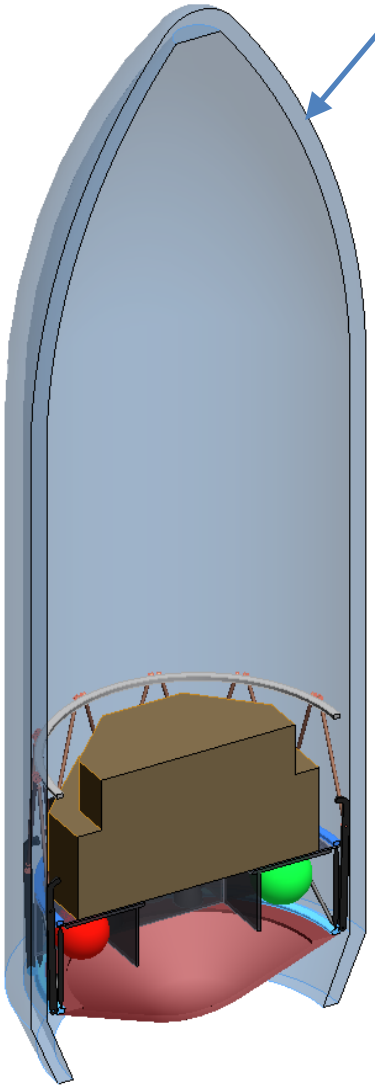
SC-03



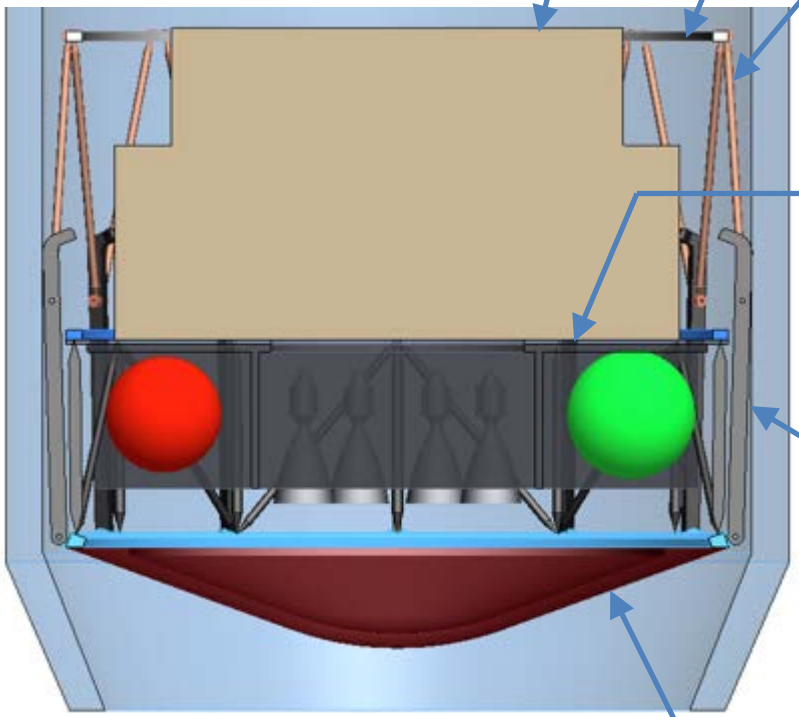
AC-01

AC-02

ADEPT SC-01 Launch Configuration
Rigid Rib & Struts-Translating Ring



PF2-01-56 Fairing



Generic Cargo Placeholder

ADEPT Translating Ring

ADEPT Rib
Support Struts
(Stowed Config)

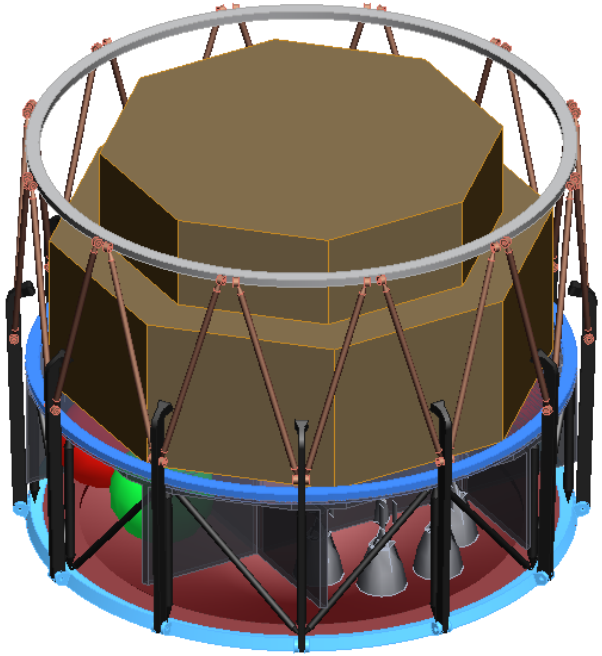
Descent Module Chassis
- Upper Deck Reduced from Ø9.1m to Ø8.5m

ADEPT Rib
(Stowed Config)

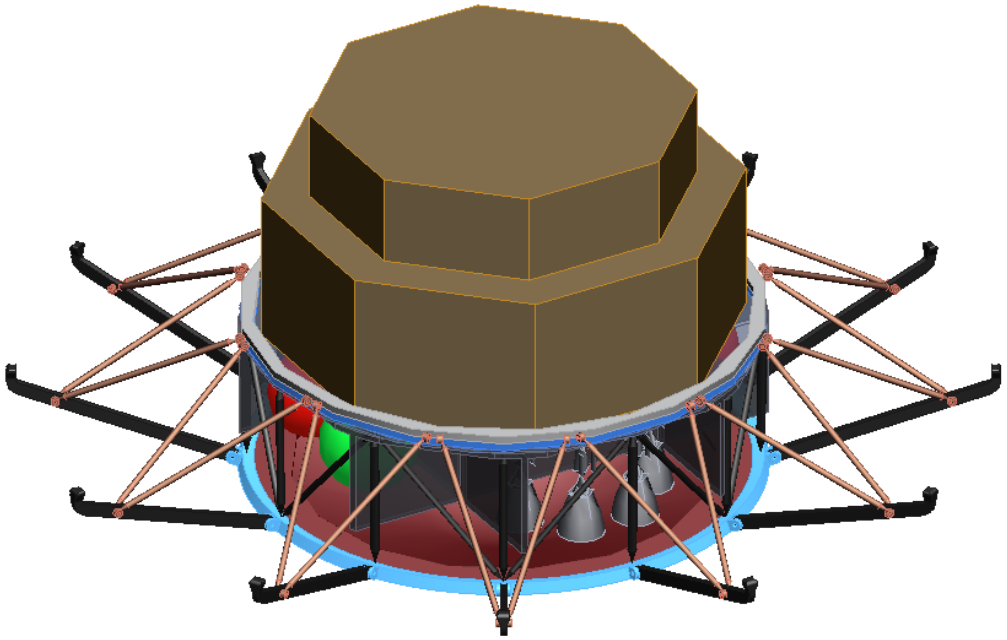
ADEPT Nose Cap

22

ADEPT-SC-01
Rigid Rib & Struts-Translating Ring



ADEPT Stowed Configuration



ADEPT Deployed Configuration

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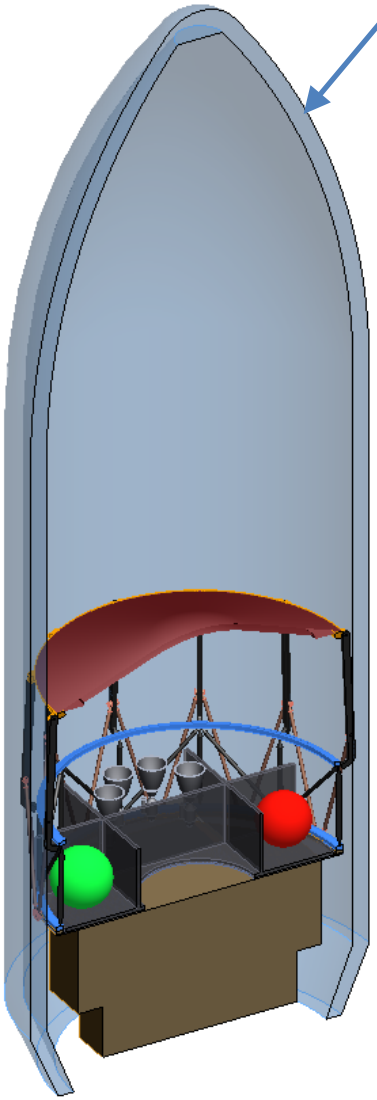
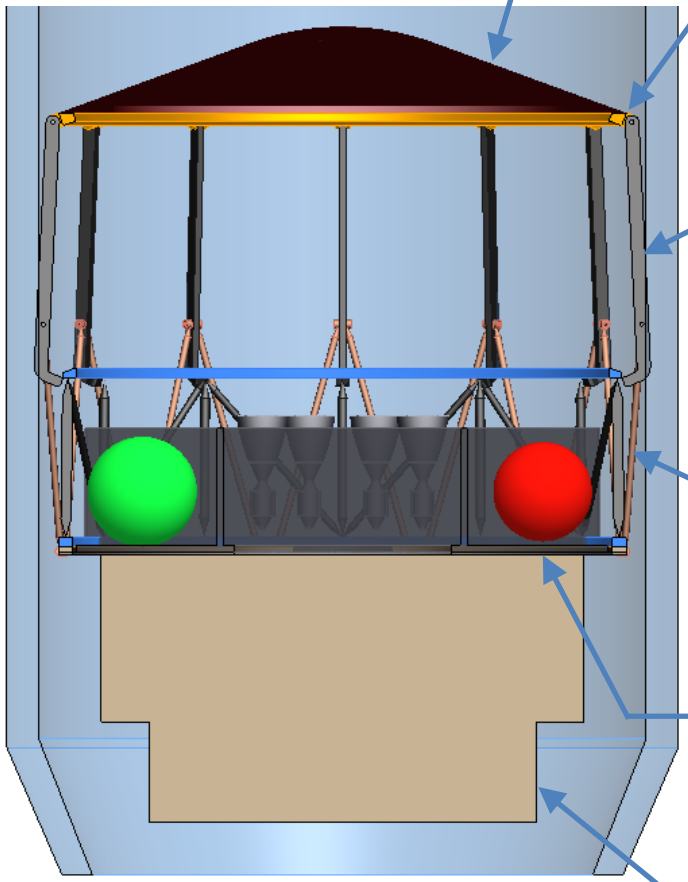
ADEPT SC-02 Launch Configuration



PF2-01-56 Fairing



ADEPT Nose Cap

ADEPT Translating Fwd Ring (Orange)

ADEPT Rib (Stowed Config)

ADEPT Rib Support Struts (Stowed Config)

Descent Module Chassis

- Upper Deck Reduced from Ø9.1m to Ø8.5m

Generic Cargo Placeholder

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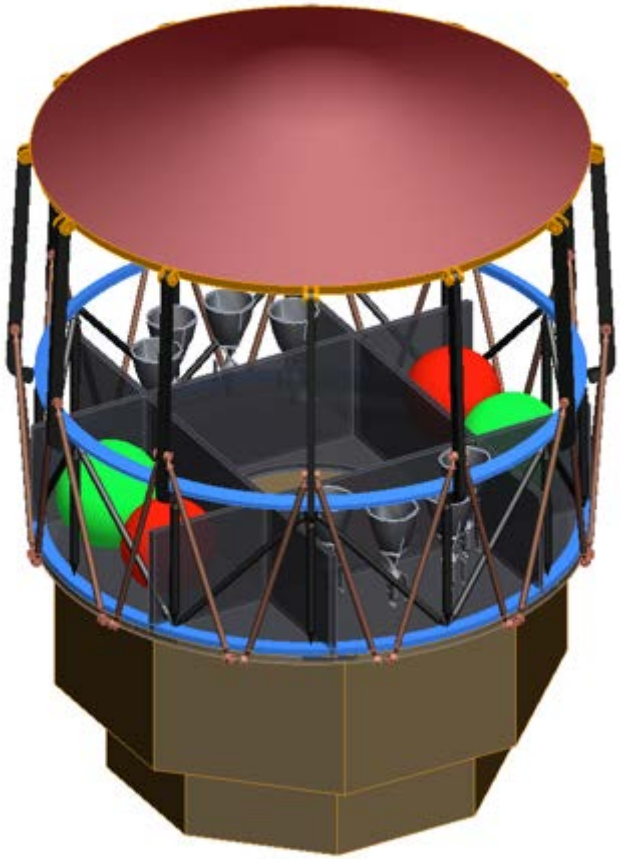
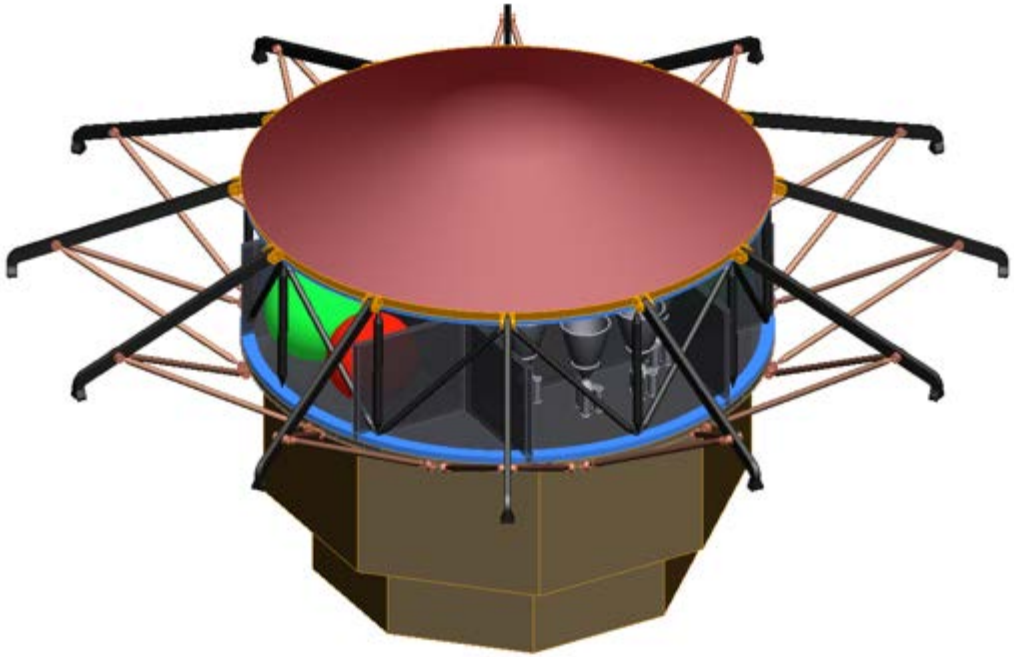
ADEPT-SC-02



ADEPT Stowed Configuration



ADEPT Deployed Configuration

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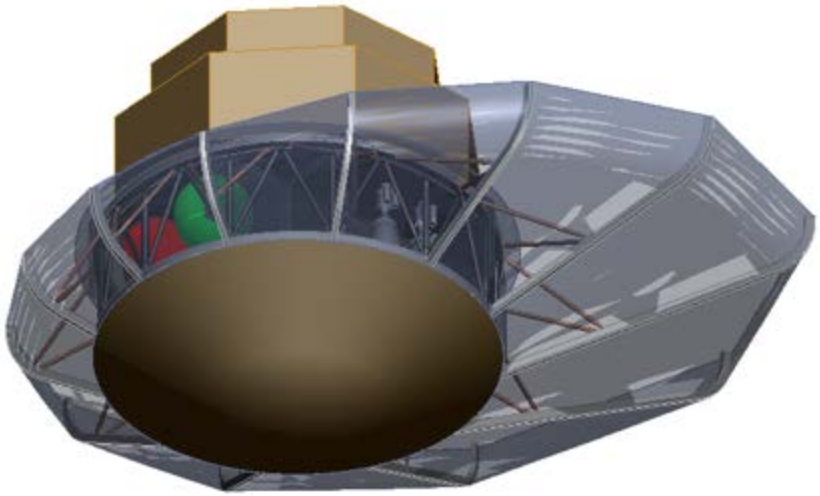
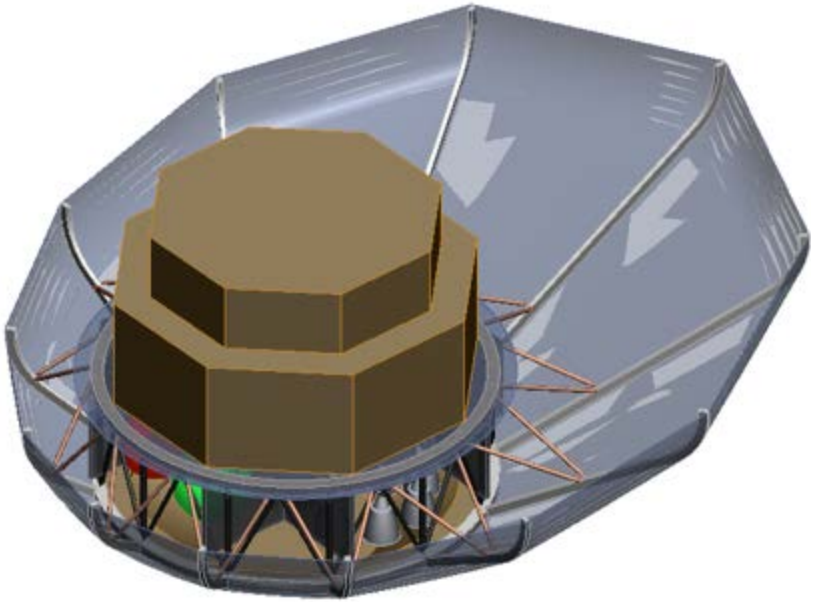
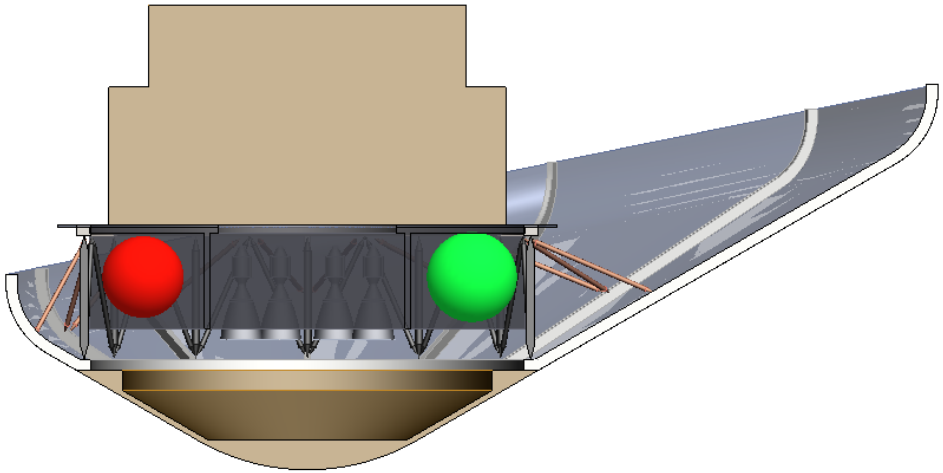
ADEPT AC-01





ADEPT AFE Mimic Configuration:

- 60° offset cone (see early/mid-90s studies)
- Concept shown is highly notional
  - Stowage & deployment schemes TBD



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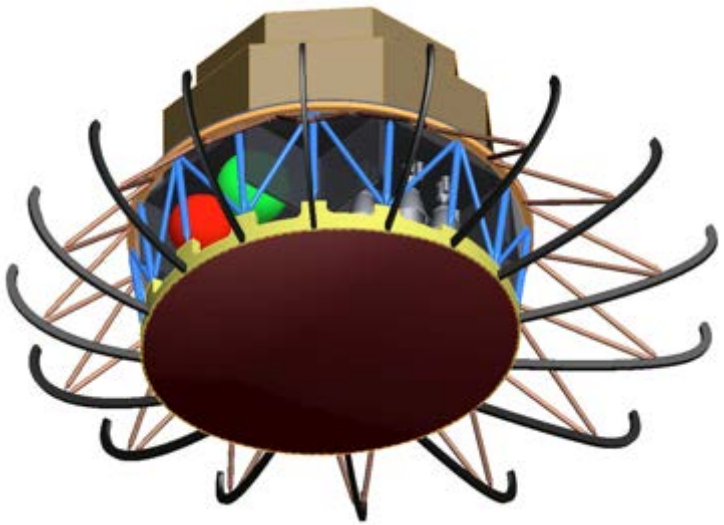
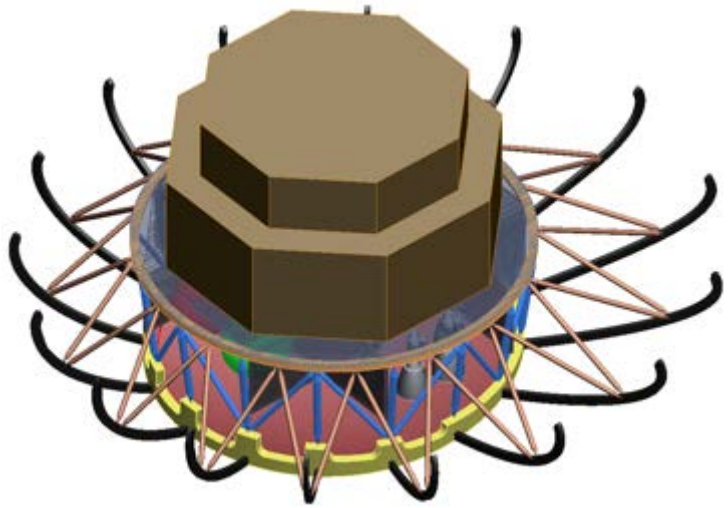
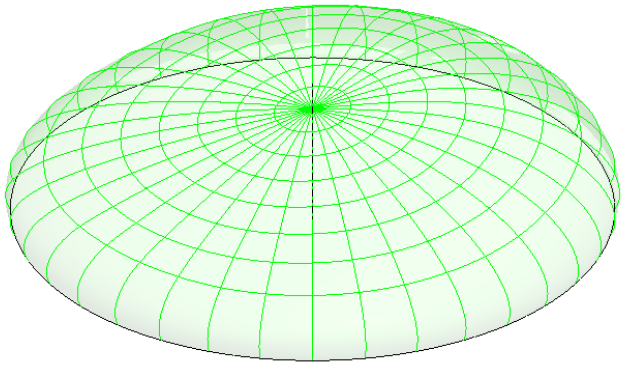
ADEPT AC-02
ACVe Shape stable through Supersonic



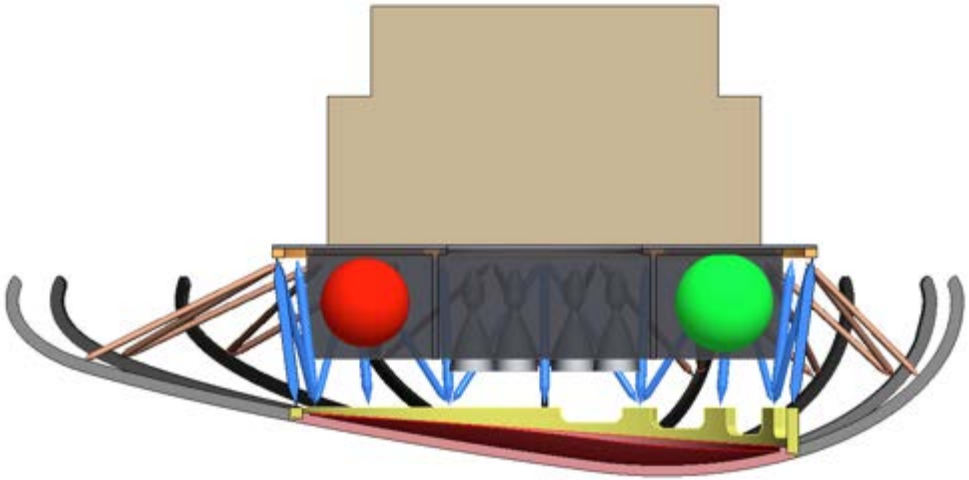


ADEPT ACV Mimic Configuration:

- 1m MDM-ADEPT centerline offset shown



ACV OML Geometry (Reference)



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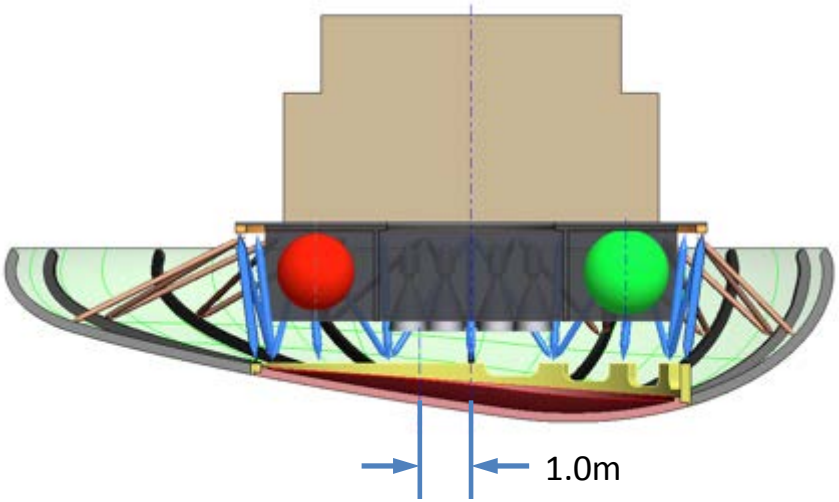
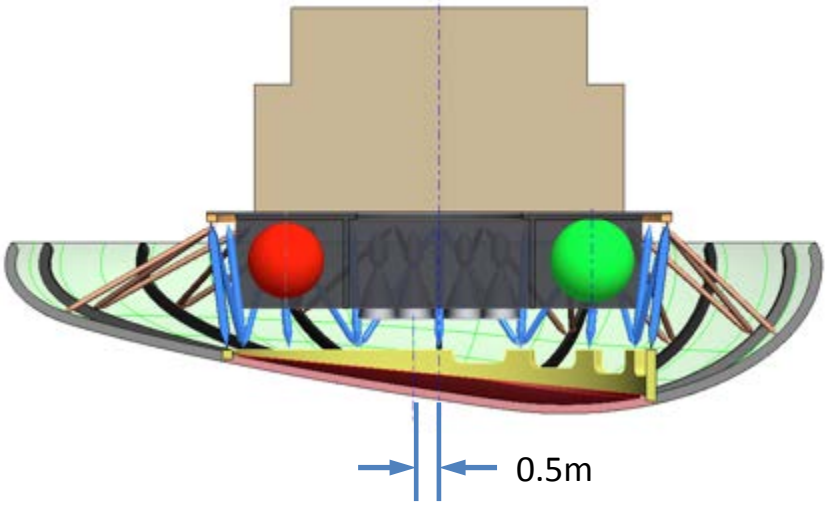
ADEPT ACVe Concept



ADEPT ACVe 1.0m c/l Offset



ADEPT ACVe 0.5m c/l Offset

Extent of centerline (c/l) offset will be set by aerodynamic stability characteristics and by L/D requirements.

- Likely that c/l offset will be less than 0.5m

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