Ballistic and Lifting Nano ADEPT - Flight Testing for Mission Infusion Opportunities

A Briefing to OPAG

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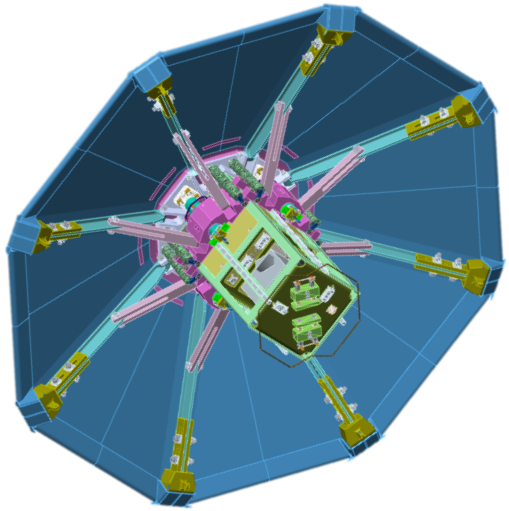
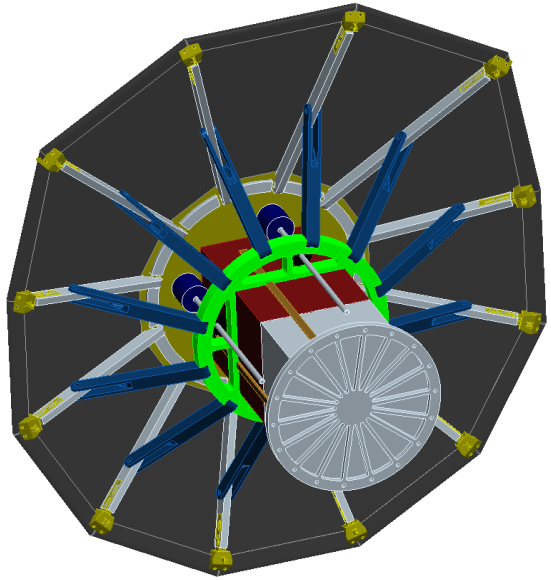
ADEPT SR-1 & Lifting Nano ADEPT





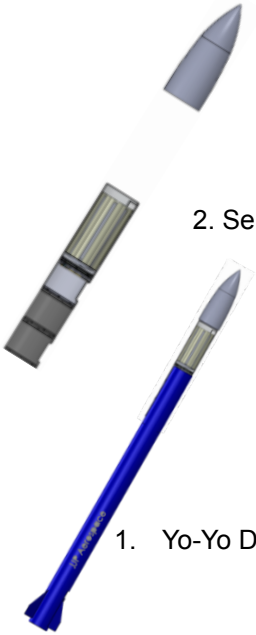
SR-1 Features

- 0.7m deployed diameter
- 8 ribs, 70 deg symmetric shape
- 4 layer carbon fabric system
- Unguided, ballistic entry
- Sounding rocket payload
  - 125 km apogee (Mach 3 peak)
  - Negligible aerothermal heating
- Simple, dual spring deployment system
- Free fall, ground impact, on-board data recovery

LNA Features

- 1.0m+ deployed diameter
- 12 ribs, 70 deg asymmetric shape with trim tab
- 6 layer carbon fabric system
- L/D = 0.19 (AoA = 11 deg), Guided hypersonic flight
- LEO Secondary payload (ULA Centaur ABC)
  - 7.6 km/s entry from LEO (Mach 27 peak)
  - Aerothermal heating (>100 W/cm^2, 3.5 kJ/cm^2)
- Electro-mechanical deployment system
- Parachute terminal descent, air-snatch recovery

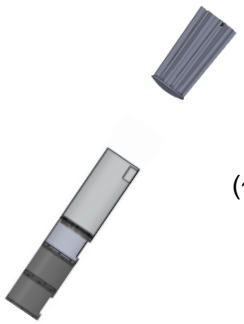
ADEPT SR-1 Sub-Orbital Flight Test
August 2017 Launch



2. Separate Nose & Booster

1. Yo-Yo De-spin

Launch from SpaceLoft XL SR
From White Sands



3. ADEPT Ejection
(~100 km prior to apogee)

4. Deployment

5. Re-entry

M=3.1
Peak Decel= ~4 g
Dyn Pres= ~0.7 kPa
Nominal is chuteless descent
Impact Velocity ~ 25 m/sec

6. Recovery in WSMR (C-band transponder & GPS locator)

Lifting Nano ADEPT Earth LEO Flight Test
NASA Ames & JHU-APL FY16 Study

Problem / Current Solution:

- Large payload delivery to Mars Surface requires guided lift capability to support aerocapture and precision EDL concept of operations
- New capabilities for science missions to other planets (Venus, Titan, Mars) provided by Lifting ADEPT architecture
- Design of the mechanical deployable ADEPT for lifting configurations able to execute hypersonic guided flight
    - Demonstrate low L/D deployable capable of relevant heating environments

Proposed solution:

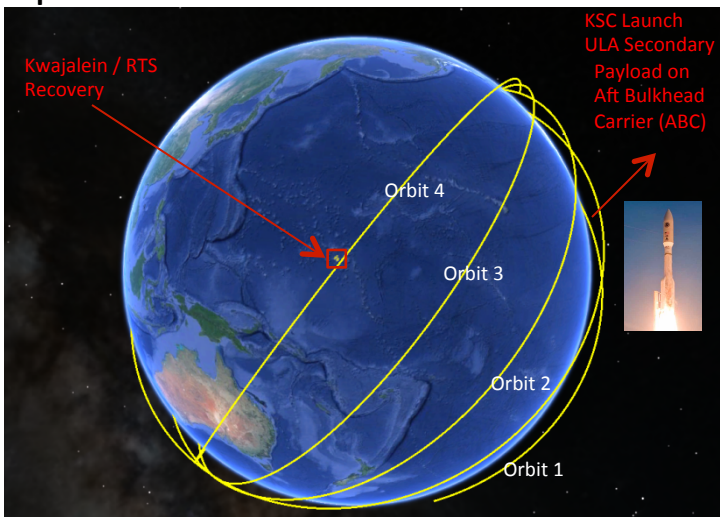
- Perform design studies of an Earth flight test (LEO) of an asymmetric shaped Nano (1m class)-ADEPT
- Leverages design experience from ADEPT SR-1 sounding rocket flight test

FY16 LNA Study Schedule

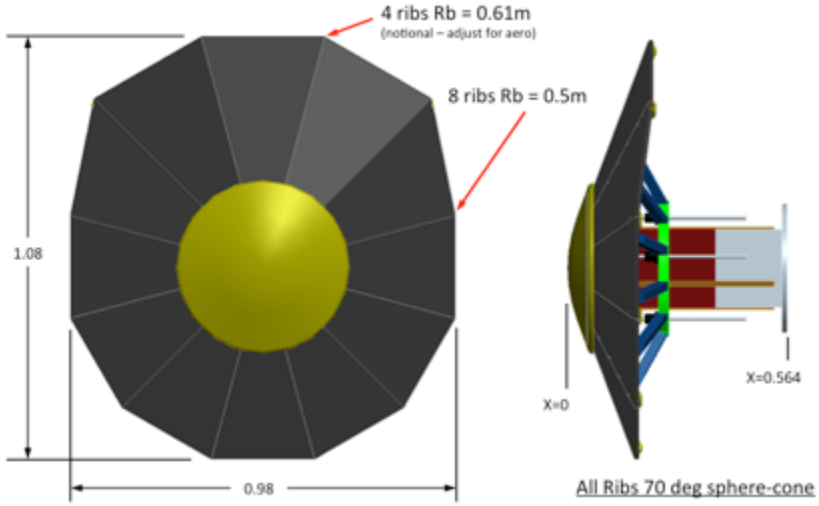
	Q1	Q2	Q3	Q4
Con-ops and Trajectory	LEO entry as Secondary		Robust trajectory design	
Configuration Design	Low L/D shape		Subsystem Layout	
Demonstrator Build up			Deployment Fabrication	

More detailed schedule in backup

Con-Ops Overview

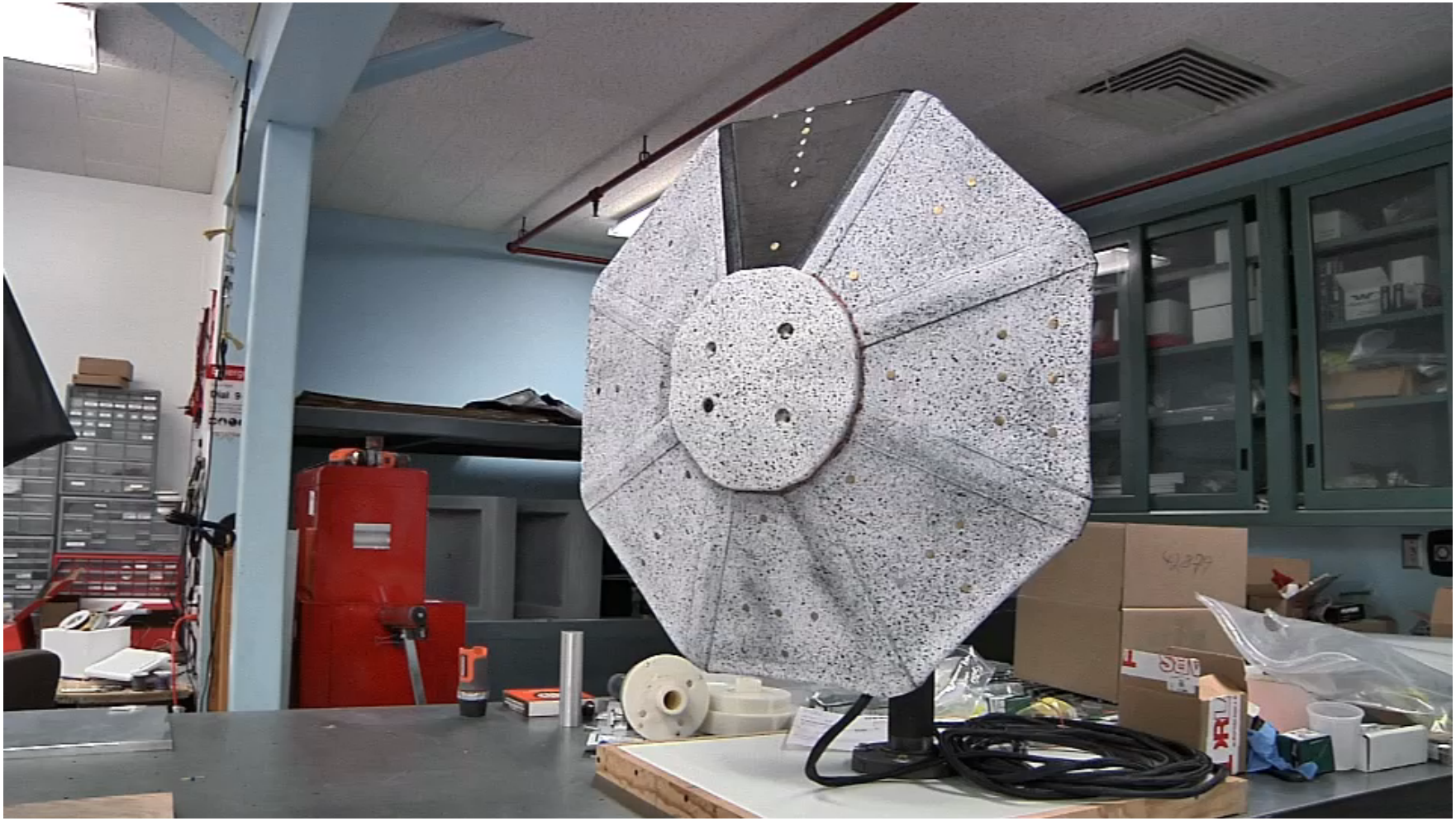


Lifting Nano ADEPT Vehicle Concept



ADEPT 1m Development Overview

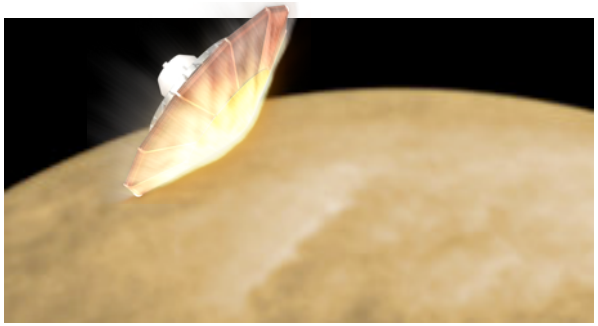
ADEPT



Additional Charts for Poster Presentation

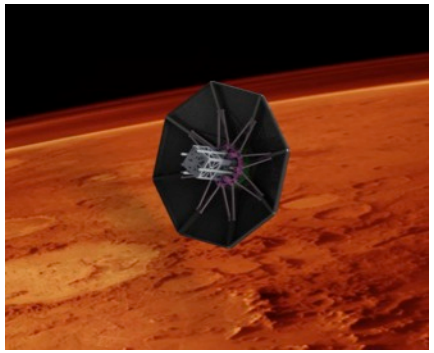
1m ADEPT Mission Pull (Discovery class)

Venus



Science Pull:
- Delivery of In-situ atmosphere science instruments.
- Achieve low deceleration loads for sensitive instruments

Mars

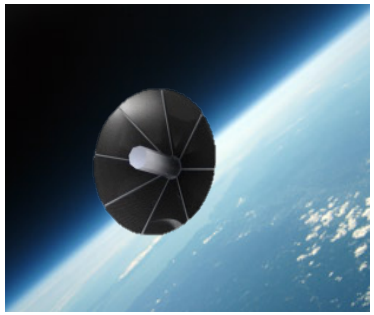


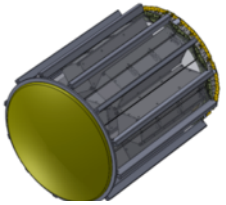
Science Pull:
- Global distribution, low cost
- Numerous landers

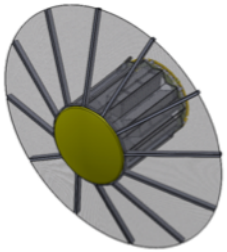
Dandelander (Malin SSS):
Cubesat distributed surface network concept

Earth

LEO Return: Secondary on Upper Stage, ISS Downmass or free-flyer on Super Strypi class LV

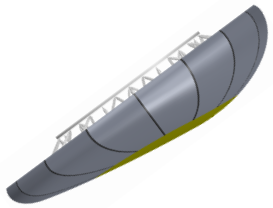






-De-orbit Capability
-22 N thruster incorporated with green propellant
-6 ea, 3U slots for subsystems or payloads

Titan



- Lifting ADEPT configuration allows aerocapture at Titan, effective thermal control with open-back configuration

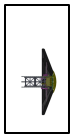
ADEPT Flight Test Timeline

2017 2020 2023 2026

Mars Small (5kg) network landers

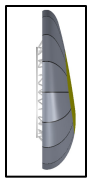
Titan Aerocapture

Venus in-situ Atmosphere science



SR-1

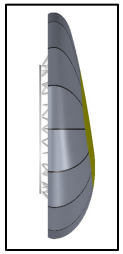
- 0.7m 70deg Ballistic 15kg
- SR-125km apogee (Mach3)



SR-2

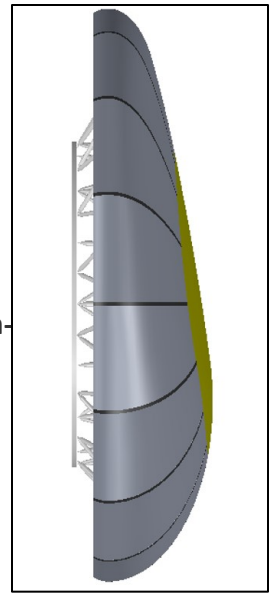
- 2.3m ACV L/D=0.25 80kg
- SR-450km apogee (Mach7)

Nano-Lifting ADEPT CIF 2016



ORB-1

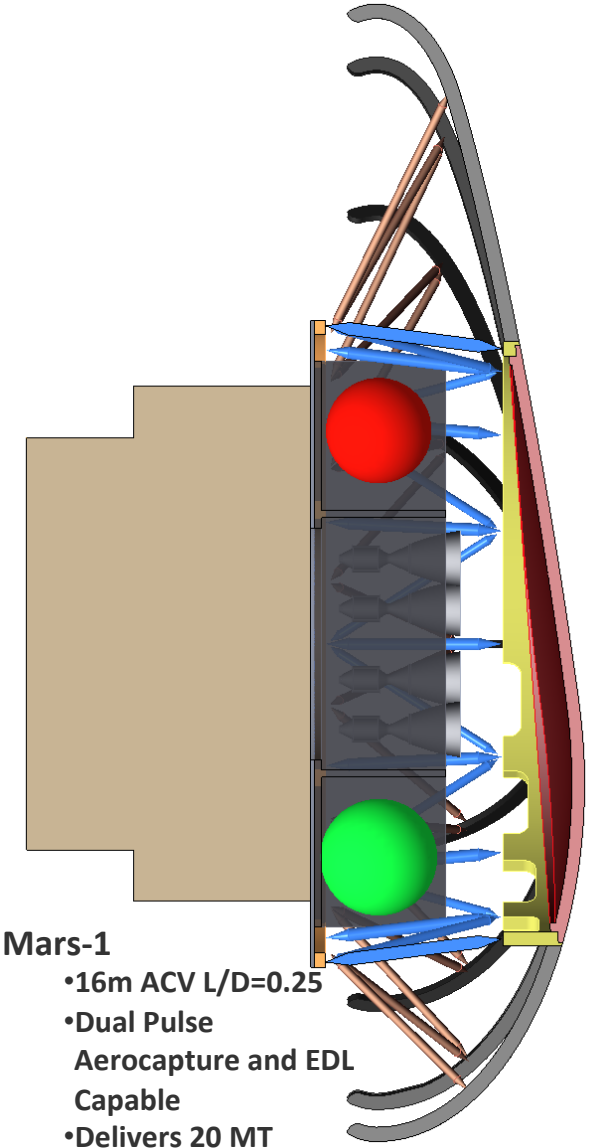
- 3.5m ACV L/D=0.25 150kg
- LEO, Guided hypersonic flight



ORB-2

- 8m ACV L/D=0.25
- LEO or GTO, Guided hypersonic flight
- Earth Demo Exploration-Class EDL Ops and Mars Entry Environments

16m Scale



Mars-1

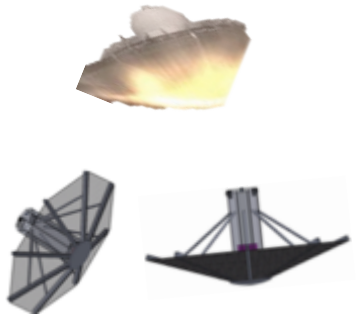
- 16m ACV L/D=0.25
- Dual Pulse Aerocapture and EDL Capable
- Delivers 20 MT Payload

ADEPT: Mechanically-deployable, Low-Ballistic coefficient hypersonic decelerator

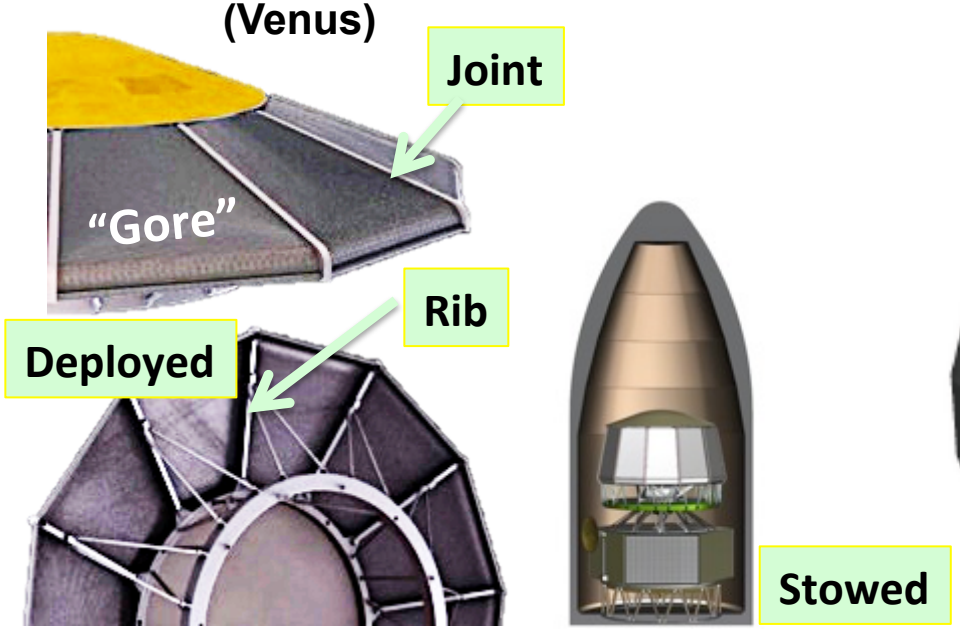
ADEPT is an atmospheric entry *architecture* for missions to most planetary bodies with atmospheres.

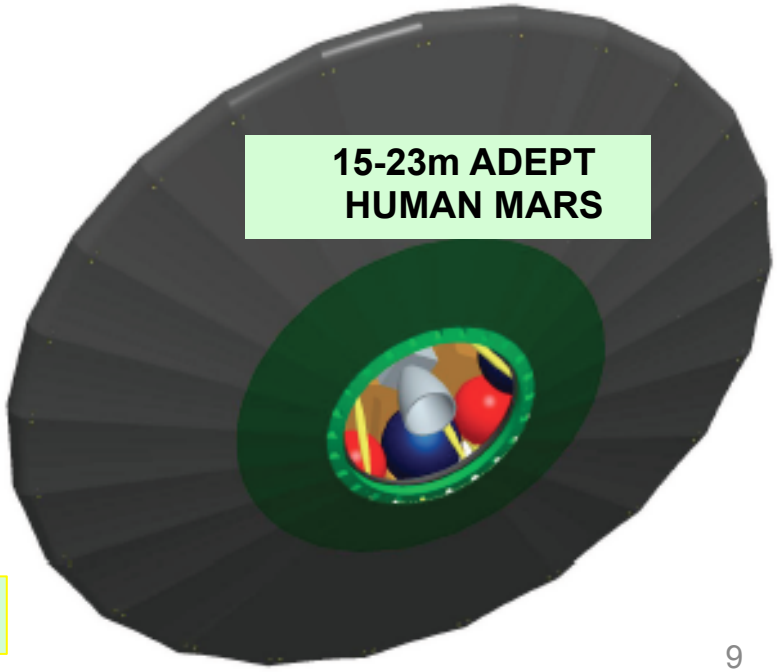
- Current Technology development project funded under STMD Game Changing Development Program (FY12 start)
- Stowed inside the launch vehicle shroud and deployed in space prior to entry.
- Low ballistic coefficient (< 50 kg/m2) provides a benign deceleration and thermal environment to the payload.
- High-temperature ribs support 3D woven carbon fabric to generate drag and withstand high heating.

1m Nano-ADEPT (Mars)

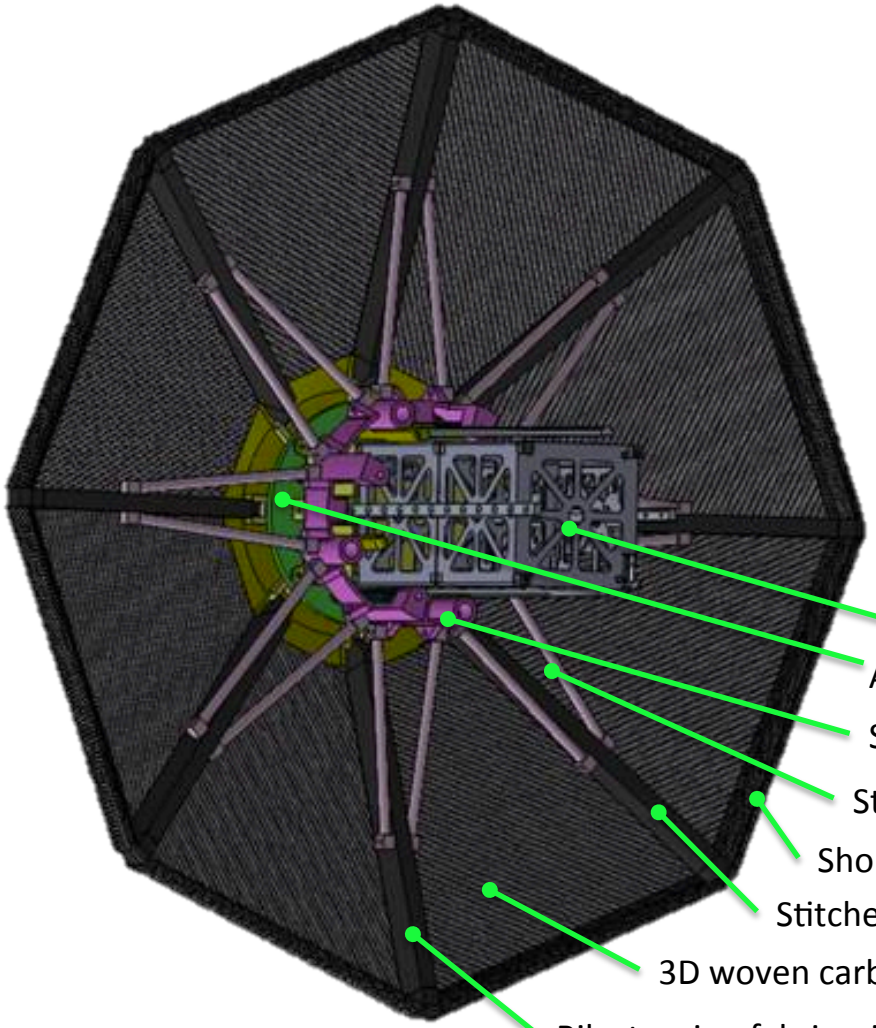


6m ADEPT-VITaL (Venus)

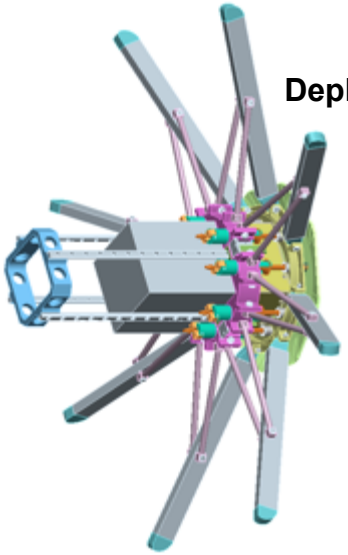




Current Focus on 1m ADEPT



Rear View



Deployed

Stowed

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

Payload volume (2U shown for example)

Avionics unit (IMU, GPS, solid memory, power)

Spring-deployment system

Struts

Shoulder stitching treatments

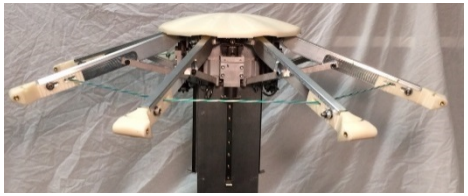
Stitched and resin-infused seams

3D woven carbon fabric

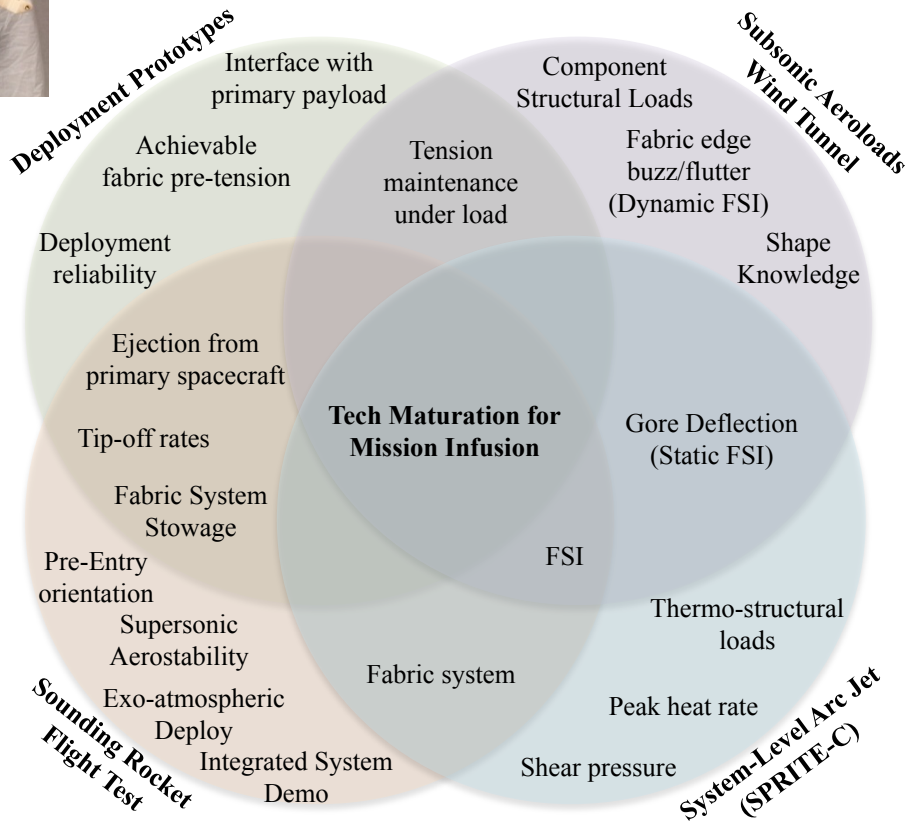
Ribs tension fabric with pockets at tips (like an umbrella)

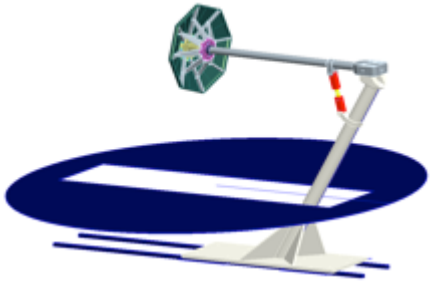
ADEPT

1m ADEPT Technology Maturation Approach



Deployment Prototype Demonstration (FY15)

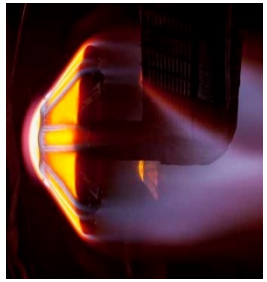




7x10 Wind-tunnel Aeroloads test (FY15)

SR-1 Sounding Rocket Flight Test

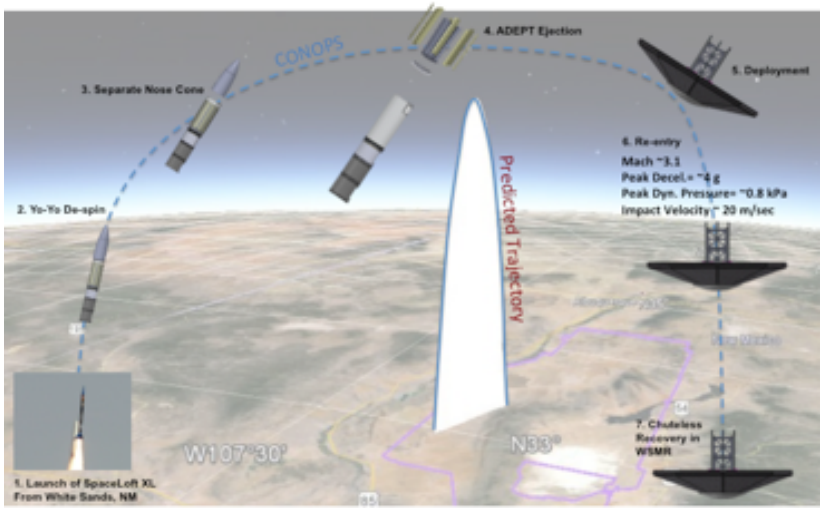
SPRITE C System level Arc-jet testing (FY15)



Each test campaign provides system knowledge in more than one system attribute, and many system attributes are explored by more than one test.

Proposed Sounding Rocket (Mach 3) Flight Test August 2017 Launch

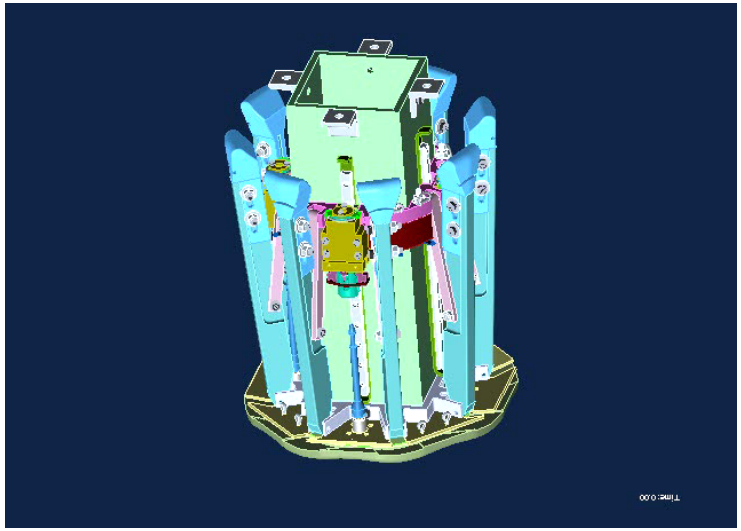
- **OBJECTIVE:**
  - Demonstrate LV separation and exo-atmospheric deployment.
  - Characterize aerodynamic performance from supersonic to subsonic flight regimes.
- **APPROACH:**
  - Demonstrate ADEPT 1 m class system flight performance. TAYF: FAYT
- **IMPACT:**



-Provide flight test experience for ADEPT configuration.

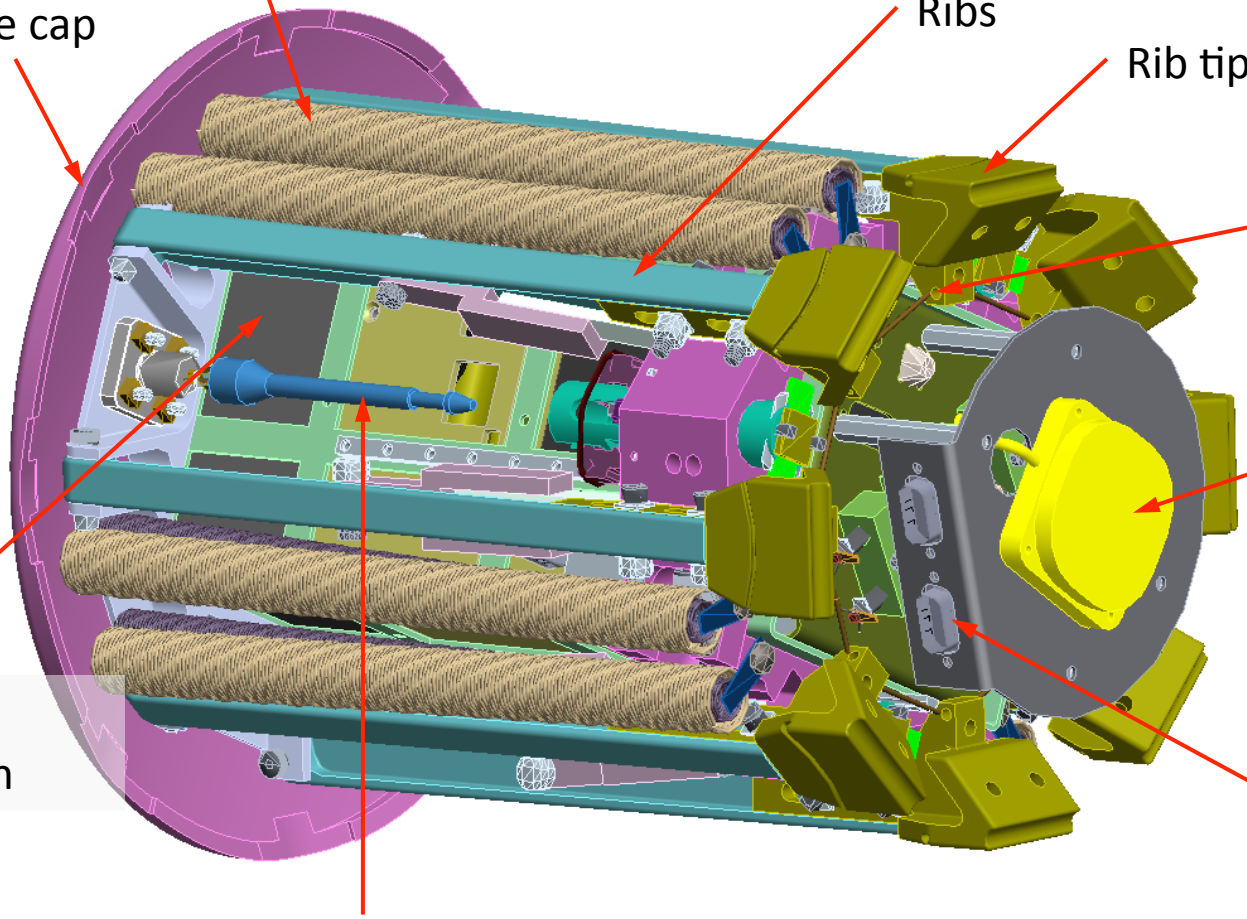
-70deg sphere cone flight supersonic - subsonic

-Critical first step in integrated flight hardware experience for EDL Pathfinder architecture assessments



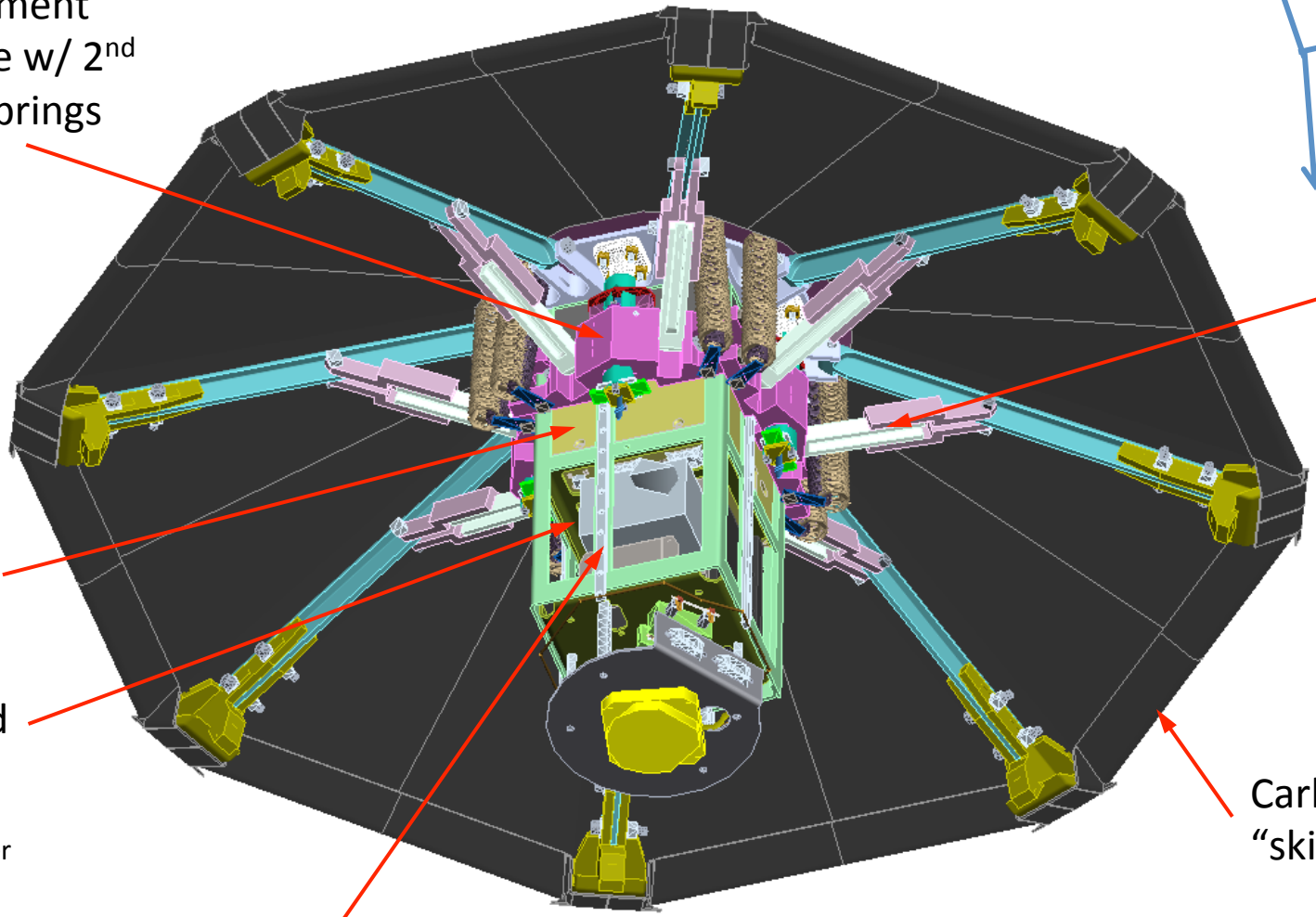
✓ Approved (July 2014) as directed payload from Flight Opportunities Program

SR-1 DESIGN UPDATE (Cfg. 3.2)
STOWED

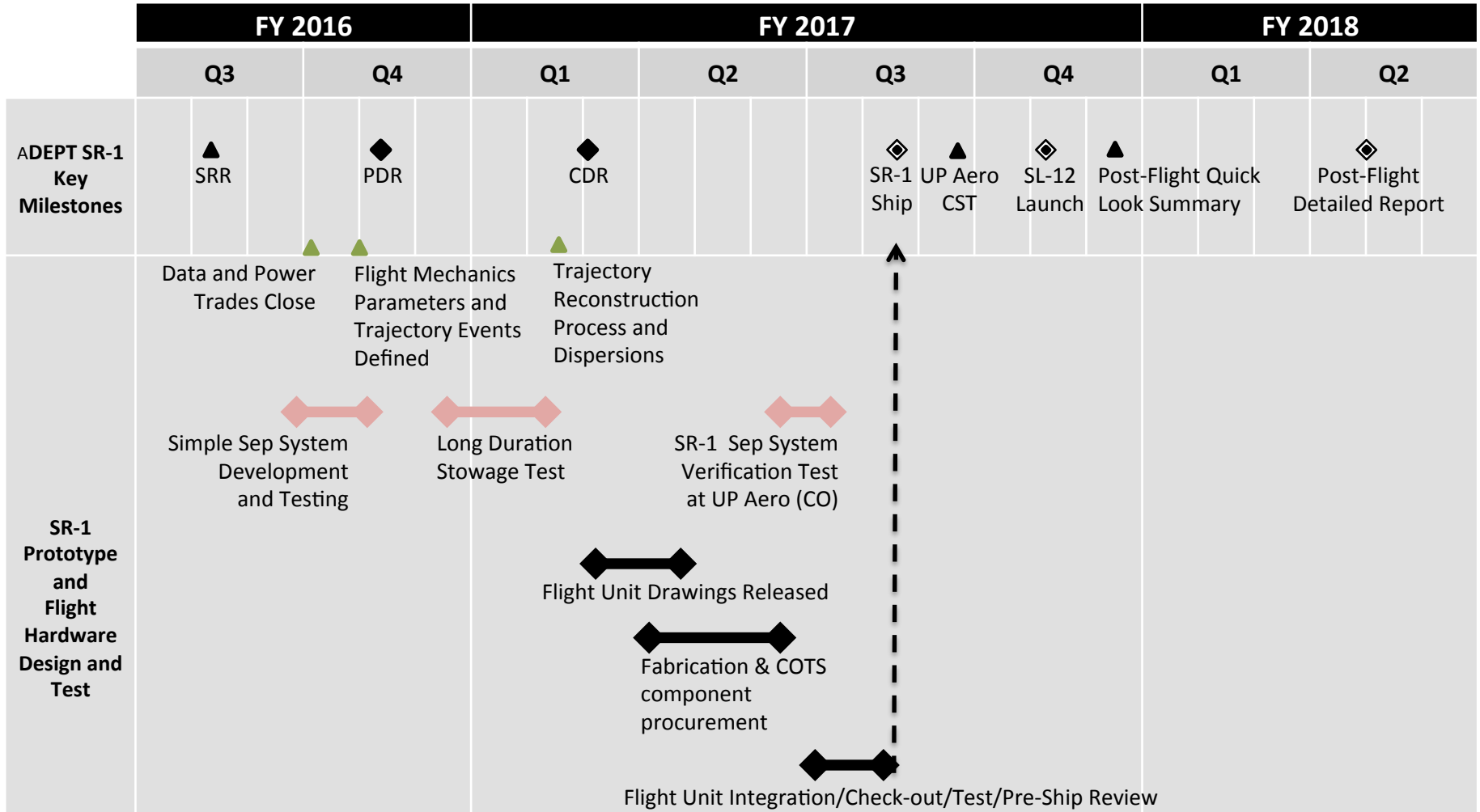


(fabric not shown)

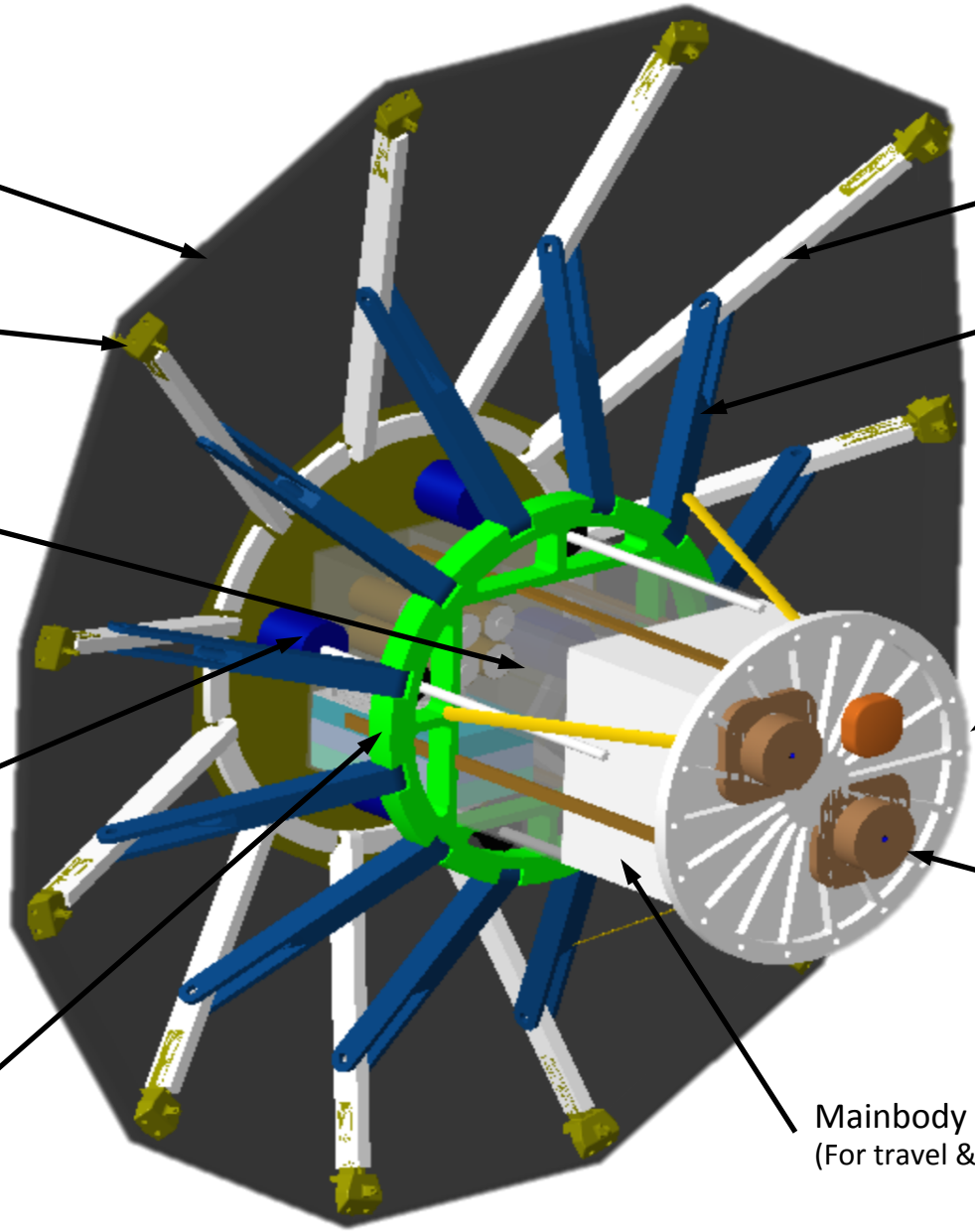
DESIGN UPDATE (Cfg. 3.2)
DEPLOYED



ADEPT SR-1 Schedule
Aug 2017 Launch



LNA Concept (v3) – Features
(70 deg sphere-cone w/ trim tab)



6-layer Carbon Fabric

"Standard" ADEPT Rib Tips

"12 Pack" Cubesat Payload

4 Linear Actuators w/ guide rails

Moving Aft Ring

12 Ribs
(8 normal, 4 long)

12 Struts
(All the same)

Mounting & Separation Ring
(Notional: 11.76" Lightband)

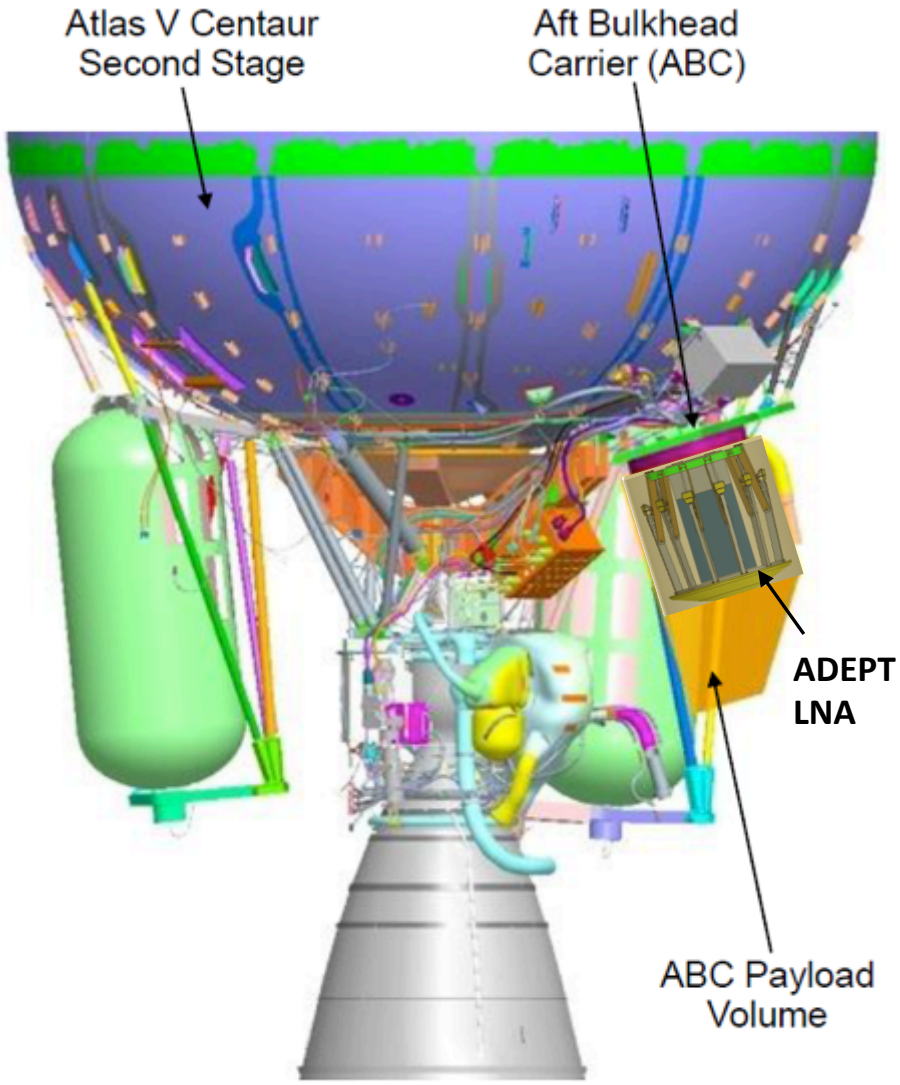
Prop Modules

Mainbody extension
(For travel & to clear ribs)

Atlas V Aft Bulkhead Carrier (ABC) Rideshare Payload Accommodation

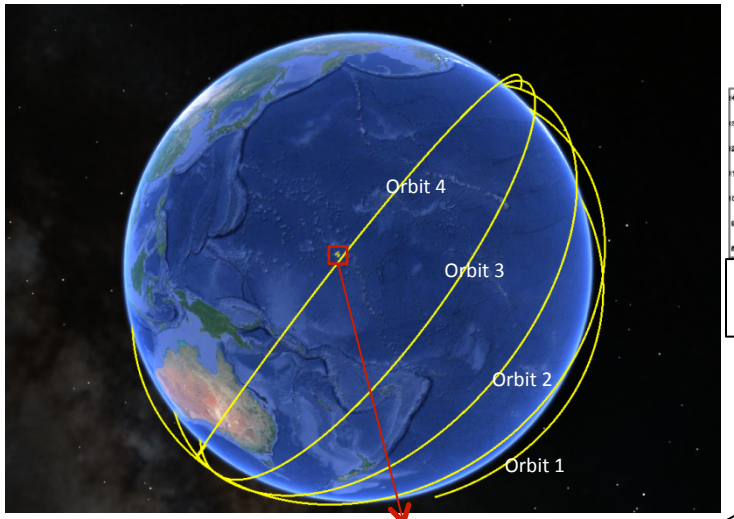
Aft Bulkhead Carrier (ABC)	
Description	An interface located at the aft-end of the Atlas V Centaur second-stage
Vehicle	Atlas V
Capacity	1 ABC per Atlas V
Interface	15-in Bolted Interface
Mass	80 kg (176 lb)
Volume	51 cm x 51 cm x 86 cm (20 in x 20 in x 34 in)
Status	Operational; first launch 09-2012 on NROL-36 (OUTSat - NPSCuL box with 8 P-PODs)

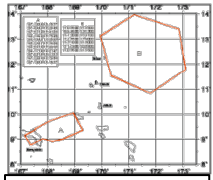
A second ABC mission, GEMSat, launched in Dec 2013, and two additional missions are currently on contract for launch by ULA



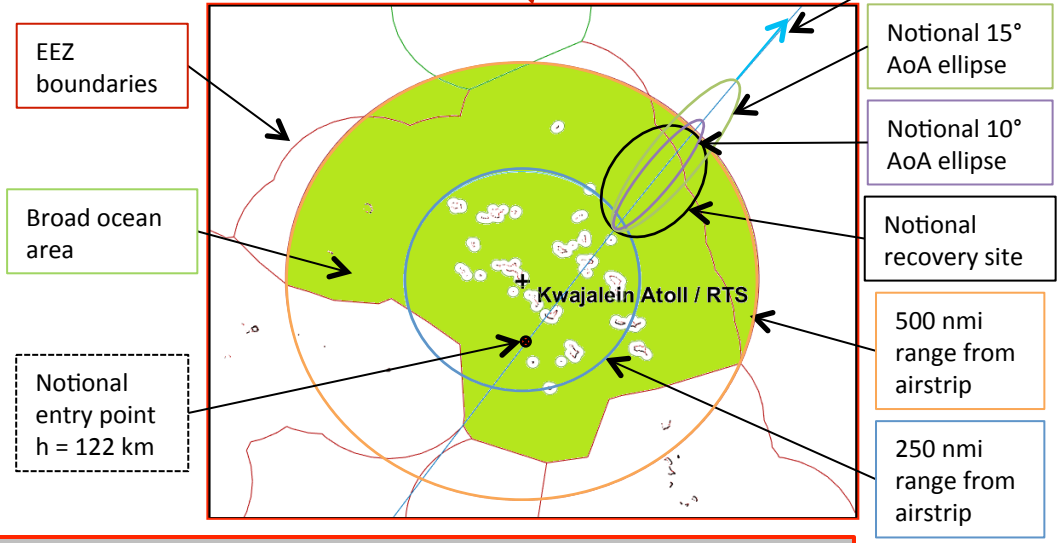
ISS Resupply 51.6° Orbit
Kwajalein / RTS Feasibility

- Roughly Annual ISS Launch Opportunities
- Conditions
  - 51.6° inclination orbit from KSC
  - Assume 500 nmi vehicle capture radius
  - 12 nmi 'Broad Ocean' boundary
  - LNA Concept V1
- Relevant Results
  - Requires 4 orbits (~6 hrs) to overfly Kwajalein
- Need to know
  - Range of recovery aircraft
  - Required overflight altitude
    - How early can we reenter?
  - EFPA / V_i relationship
- Notional Ellipse Assumptions
  - No entry error
  - No breakup (no change in C_L, C_D)
  - 'Worst' case scenarios
    - Fixed 10°, 15° AoA
    - Vi = 7.89 km/s
    - 5°, 7° EFPA
    - Max cross range (62, 102 km)
    - Min down range (573, 563 km)
    - Max down range (1130, 1340 km)





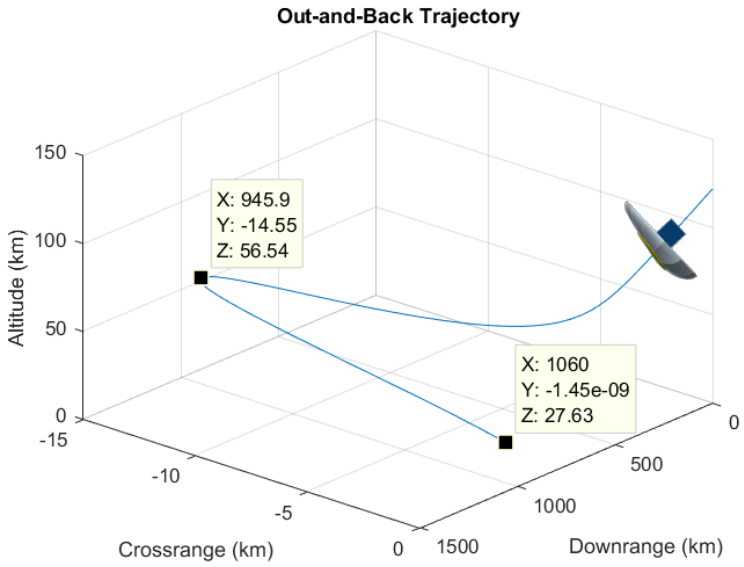
Example caution area according to the Kwajalein Hourglass

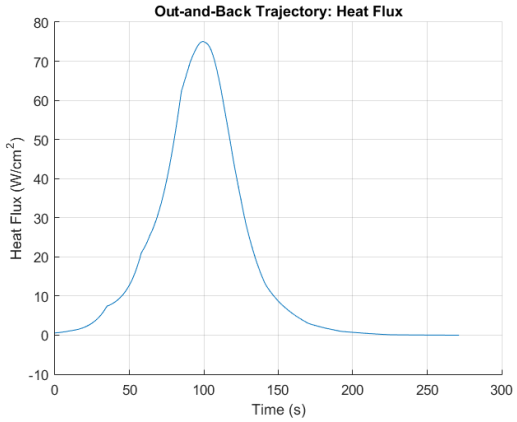


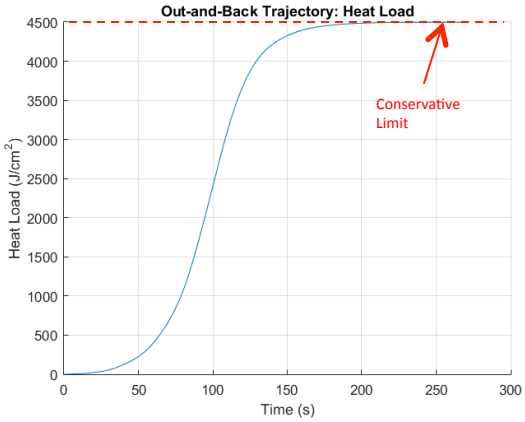
Kwajalein / RTS is feasible depending on overflight restrictions

Optimized Out-and-Back Trajectory

- Vehicle Model
  - Aero data provided by ARC
    - LNA Concept V1
  - Bank as control (+/- 180°)
  - 15°/s bank rate limit
  - m = 40 kg
  - Fixed 10° AoA
- Conditions
  - Approximate LEO reentry
  - Interface velocity, V_i = 7.42 km/s
  - Interface altitude, H_i = 120 km
  - EFPA, γ_i = optimized (from 1-7.5°)
  - Final velocity, M_f = 1.8
- Heating Constraints:
  - Heat flux: 200 W/cm^2
  - Heat load: 4.5 J/cm^2
- Objective:
  - Max in-flight cross range
  - Zero end of flight cross range
- Relevant Results
  - EFPA (γ_i) = 4.32°
  - Heating constraints satisfied



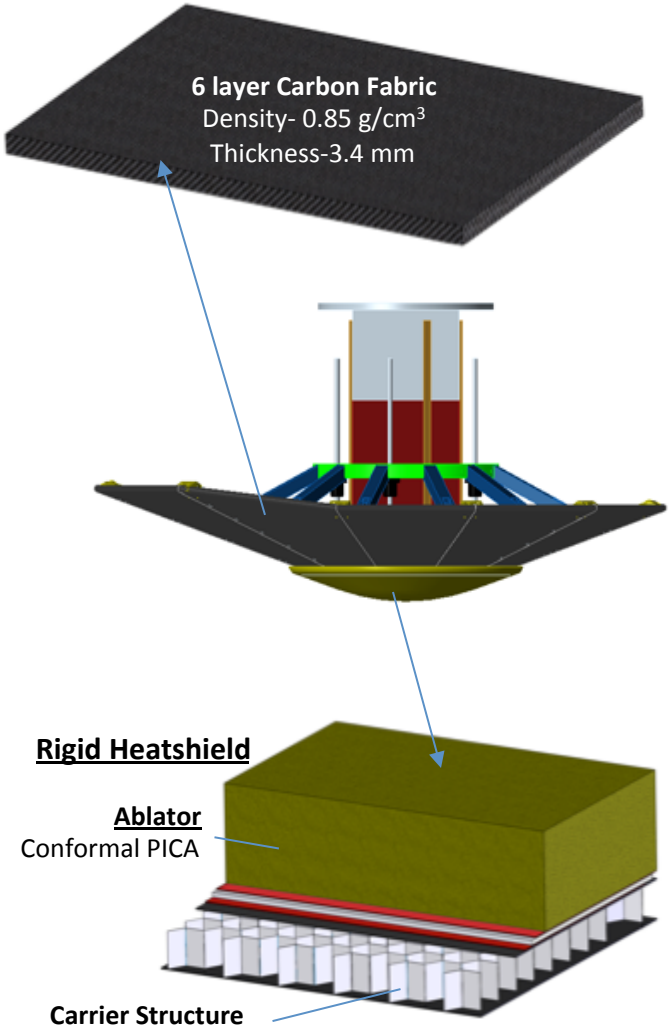




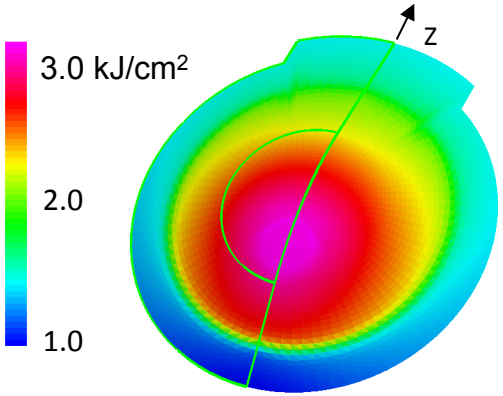
Trajectory demonstrates divert and recovery capabilities

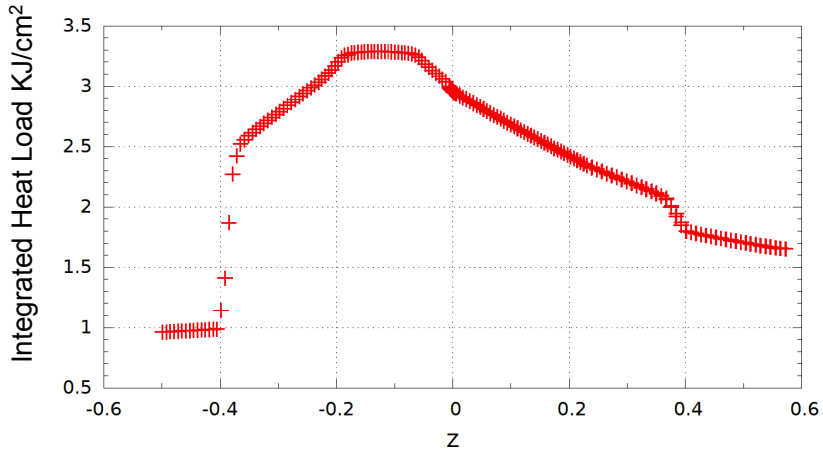
LNA TPS Sizing

Carbon Fabric Acreage



Max Cross Range Trajectory (EFPA = -7 deg, AoA = 11 deg)





- Carbon fabric has been tested over 200 W/cm^2 in earlier ADEPT arcjet tests
- C-PICA has been tested over 500 W/cm^2
- TPS material response expected to be low/med risk for LNA using conservative TPS thickness allocations

Summary

- ADEPT 1m development has strong potential SMD mission infusion. Small payload delivery to Mars surface, In-situ atmosphere science at Venus, Aerocapture at Titan and outer planets
- System level testing in Arcjets and with Sounding Rocket using common configuration – Huge Challenge for EDL!
- LNA Study on schedule to meet CIF study objectives at end of FY16
- LNA Team (NASA Ames – JHU APL) is working very well together
  - Team skills and experience are a great fit!
  - Excellent communication
  - Team is highly motivated to develop a feasible, yet challenging flight test experiment
- Continued Investment including ADEPT Flight Testing will Enable:
  - 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
  - SR-1 Flight Experiment is key step to subsequent ADEPT demonstration of **guided lifting flight**
- Lifting Nano ADEPT is a logical next step from SR-1 (Mach 3) flight experiment for maturing the ADEPT technology architecture

LNA Flight Test Objectives (v1.1)

Test Objectives (Primary):

-Demonstrate *exo-atmospheric deployment* of 1m class lifting nano-ADEPT (LNA) in a flight configuration, and maintain the *deployed shape* under flight conditions.

-Demonstrate LNA configuration maintains a *stable orientation* and is capable of performing *closed-loop guided hypersonic maneuvers*

-Demonstrate that the LNA configuration can survive aerothermal heating rates and heat loads associated with LEO entry conditions.

Test Objectives (Secondary):

- *Obtain flight position and attitude data* to enable reconstruction of best estimated trajectory

- Show that *fabric behavior and surface features* of the ADEPT aeroshell are robust and retain integrity

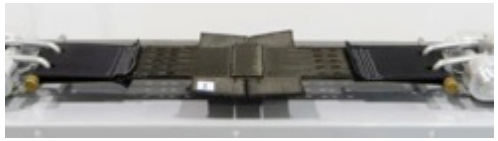
- Recover LNA post-flight to recover payloads and assess overall vehicle performance.

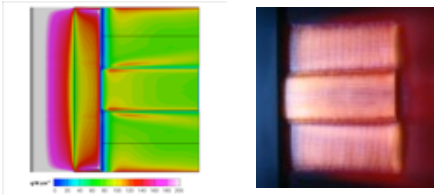
Project Background

- **ADEPT FY12-FY13**
  - 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/cm^2.**
  - **Successful demonstration of 2m Ground Test Article**
- **ADEPT FY14**
  - Continue 6m Venus focus, **Demonstration carbon-fabric stitched joint**
  - Mid-year budget reduction forced project re-plan to 1m scale
    - Potential for 'cubesat class' secondary payload mission infusion
    - 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-C Pathfinder arcjet test**
  - Limited development efforts for 0.7m sounding rocket flight
- **ADEPT FY16**
  - 0.7m development continuing under Task agreement (4 FTEs)

Carbon fabric arcjet testing (2012)

2 m Ground Test Article (2013)





Fabric Joint Design Testing (2014)