Adaptable Deployable Entry & Placement Technology (ADEPT) for Cubesat delivery to Mars Surface

Briefing for CubeSat to Mars Workshop

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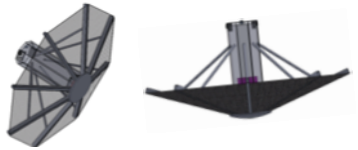
ADEPT: Mechanically-deployable, Low-Ballistic coefficient hypersonic decelerator

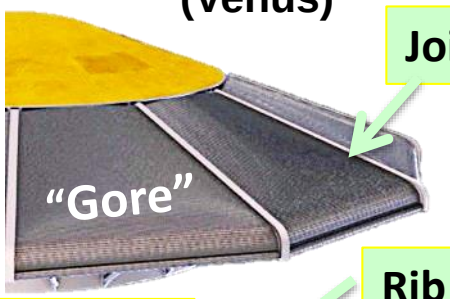
ADEPT is an atmospheric entry *architecture* for missions to most planetary bodies with atmospheres.

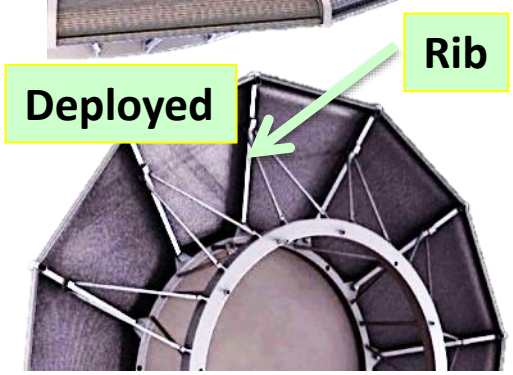
- Current Technology development project funded under STMD Game Changing Development Program (FY12 start)
- Stowed inside the launch vehicle shroud and deployed in space prior to entry.
- Low ballistic coefficient (< 50 kg/m2) provides a benign deceleration and thermal environment to the payload.
- High-temperature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

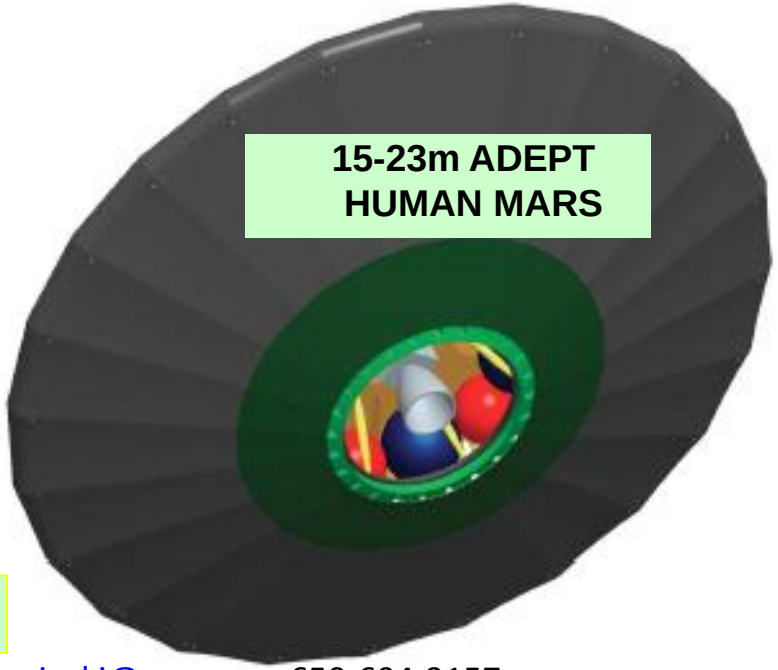
1m Nano-ADEPT (Mars)



6m ADEPT-VITaL (Venus)







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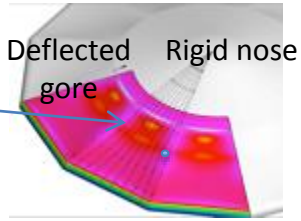
ADEPT Accomplishments to Date (FY12-present)

Carbon Fabric Combined Environment Performance (FY12) and SPRITE Test Methodology

Key Capabilities Demonstrated

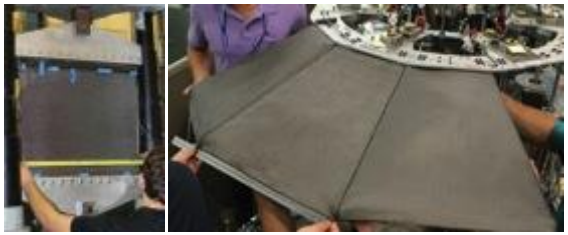
- Successful demonstration of carbon fabric thermal and mechanical performance under relevant testing in arcjets
- SPRITE (rigid configuration) 35 cm diameter, 45 sphere-cone tested as pathfinder for arc-jet facility configuration study
- Design and analysis of larger (up to 0.5 m diameter) SPRITE-C test methodology to "test as you fly, fly as you test" is underway.



2 m Ground Test Article (FY13)

Key Capabilities Demonstrated

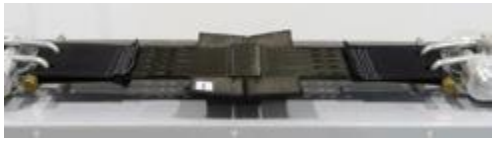
- Developed fabric gore manufacturing & integration process at 2 m scale
- Demonstrated reliable operational functionality of the mechanical design, software control logic, and integration scheme of the ADEPT concept.
- Characterized the system's response to off-nominal conditions during deployment.
- Focused ADEPT GTA team designed, built and tested in < 8 months

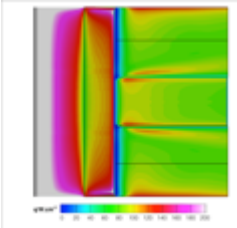


Fabric Seam Development (FY14)

Key Capabilities Demonstrated

- High Strength seams designed and fabricated for the first time with carbon thread, ultimate tensile strength in excess of 3000 lbs/in
- Seam arc jet test methodology developed that simultaneously pulls the seam under load while exposing to aerothermal environments (100 W/cm2 for 220 seconds), heat load in excess of 20 kJ/cm2.
- Phenolic seam infusion process developed
- Tests provide validation that carbon-stitched seams are viable for the ADEPT design





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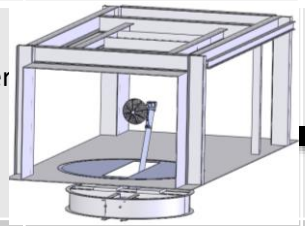
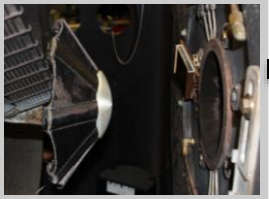
ADEPT-1m Technology Maturation Plan (FY15-16)

Note: FY16 Plans are pending STMD approval

Technology Maturation Activity	FY15 Q1	FY15 Q2	FY15 Q3	FY15 Q4	FY16 Q1	FY16 Q2	FY16 Q3	FY16 Q4
Distributed Load Wind-tunnel test • Demonstrate fabric shape retention under aeroloading in 7 x10 wind tunnel (subsonic) • 0.7m diameter model			Aeroloads Test					
SPRITE-C Arc Jet Test • Demonstrate aerothermal flight environment performance (TAYF/FAYT) • Peak heating rates comparable to Mars, Earth, and potential Venus entry		SPRITE-C Pathfinder				SPRITE-C Interface Test	Response Model Testing	
Sounding Rocket Test • Demonstrate Flight-like deployment in exo-atmosphere (zero-g, vacuum) • Demonstrate critical supersonic aerodynamic stability • Flight-like configuration of 0.7m ADEPT and ~15kg	Sep. System Devel. (Led by UP Aerospace)		SL10 Flight Demo	Deployment Demo		PDR	CDR	ADEPT Flight Test (TBD)





1) Development approach leverages system level testing (SPRITE, W/T testing, Sounding Rocket) to demonstrate performance at flight relevant scale (0.7m diameter) and environments (Mars DRM)
2) Common design configuration between 3 major tasks areas essential for streamlined system level performance demonstration

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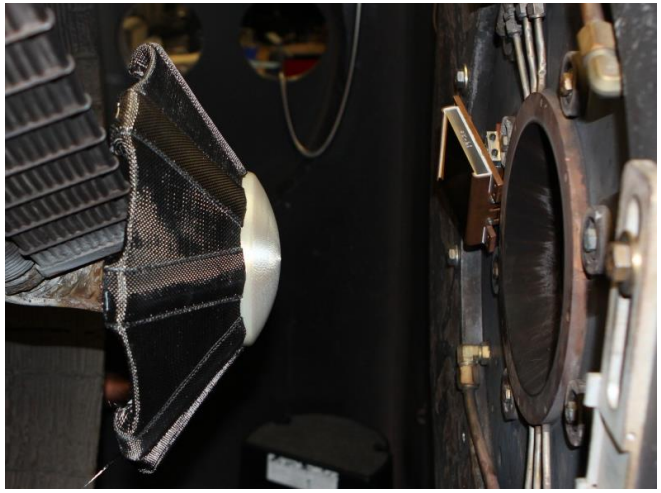
SPRITE-C Pathfinder Arcjet System Level Test

- **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 multiple design features and their interactions to be characterized for design tool validation.**
  - Heavily instrumented test article allows for multiple flight-like design features to be characterized.
- **IMPACT:**



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

Reduces cost and overall development schedule duration to rapidly mature ADEPT 1 m class

- **FY2014 MAJOR ACCOMPLISHMENTS:**
  - ✓ **Fabricated full-scale prototype to demonstrate skirt manufacturing and tension adjustment (BRM and TRLA)**
  - ✓ **Initial thermal model developed to predict in-depth thermal response of fabric and structure.**

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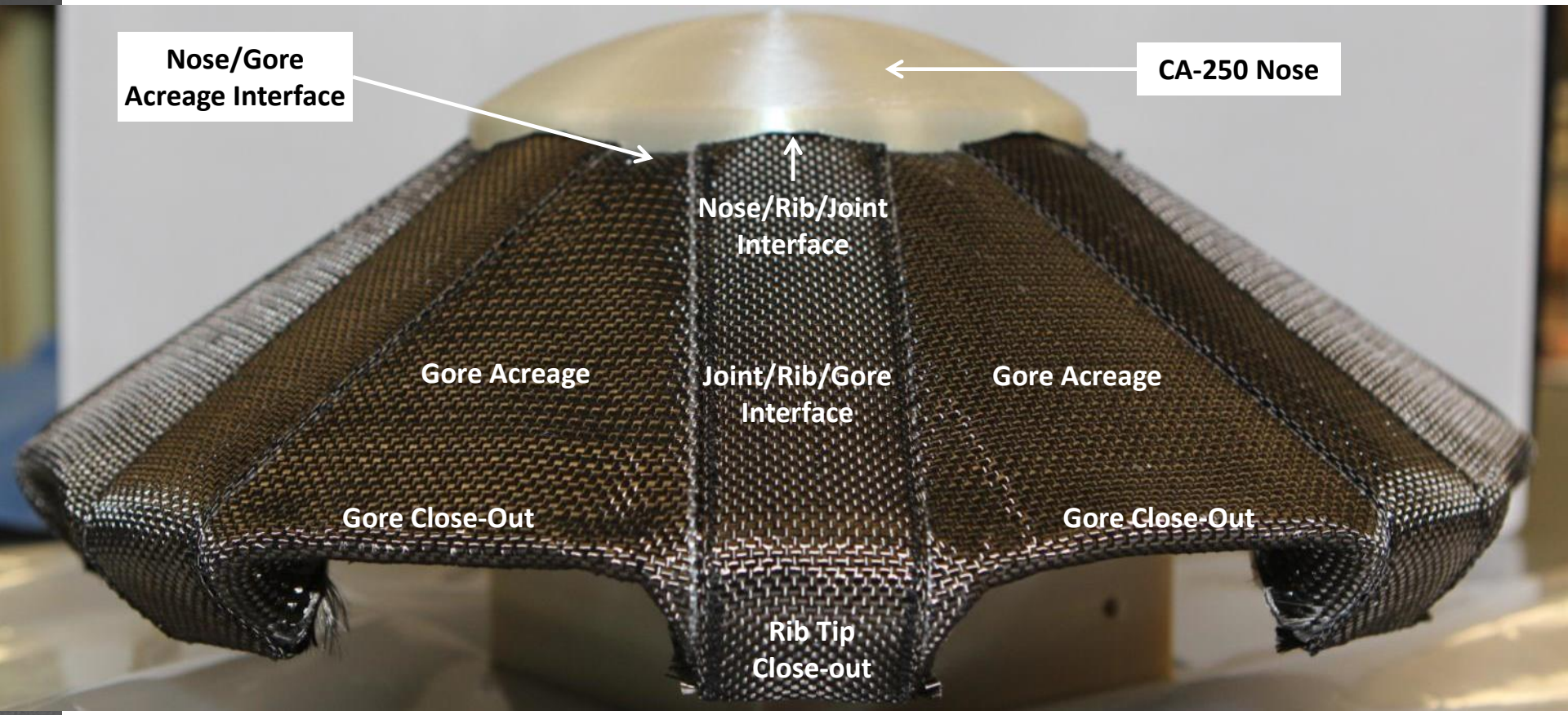
SPRITE-C Pathfinder Test Article
Key Design Features



- **Test Articles (3)-** 1 spherical CA-250 nose, 1 spherical graphite nose, 1 scalloped CA-250 nose
- **Arc Heater Settings-** IHF, 21.5-in nozzle, I_{arc} = 2200 A, m_{air} = 110 g/s, m_{air+} = 160 g/s, m_{Ar} = 30 g/s, P_{arc} = 193 kPa
- **Stag Point Heating Prediction-** 63 W/cm^2
- **Test Duration-** 80 seconds
- **Stag Point Heat Load-** 5 kJ/cm^2 (~ 2.5 x the Mars DRM stag point heat load)

Test Scheduled for January 2015

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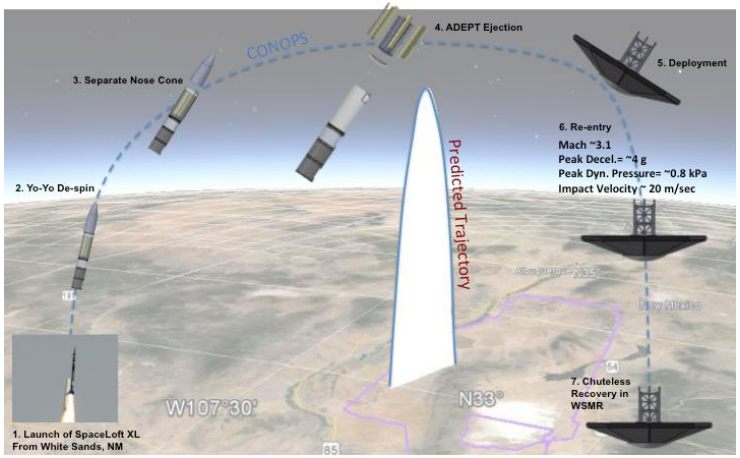
ADEPT Sounding Rocket Flight Test

- **OBJECTIVE: Demonstrate LV separation and exo-atmospheric deployment. Characterize aerodynamic performance from low supersonic (~ Mach 3) to subsonic flight regimes.**
  - Utilize CNAT Avionics and on-board instrumentation to reconstruct trajectory and obtain structural performance data.
- **APPROACH: Demonstrate ADEPT 1 m class system flight performance for potential use as a secondary payload delivery system.**
  - Low cost approach leveraging multiple programs within STMD portfolio. (*GCD, SBIR, Flight Opportunities, Center Innovation Fund*)



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.

- **IMPACT:** **Design capable of delivering ~ 5 kg of cube sat like payloads for low-cost, high-return science with 2-3 U volume.**

- **FY2014 MAJOR ACCOMPLISHMENTS:**
  - ✓ **Obtained approval as directed payload from Flight Opportunities Program**
  - ✓ **Developed two-stage spring-based passive deployment approach**
  - ✓ **Completed DSMC force and moment calculations supporting aero database**

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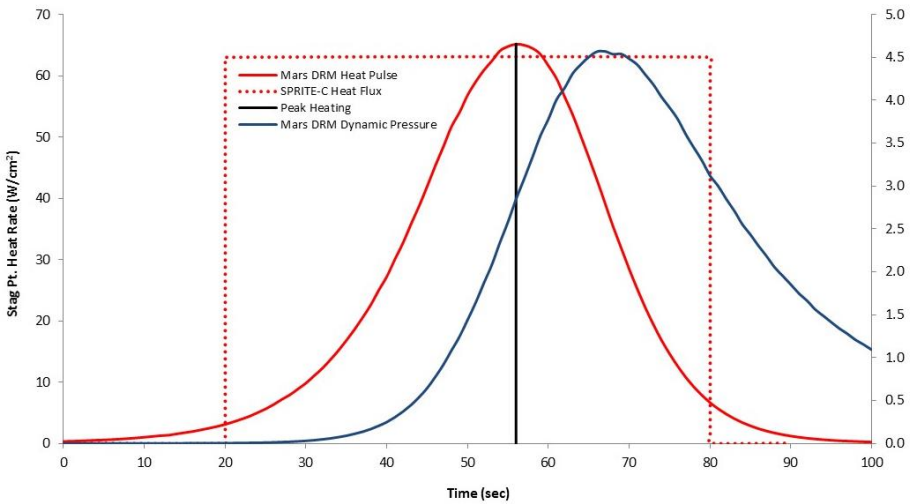
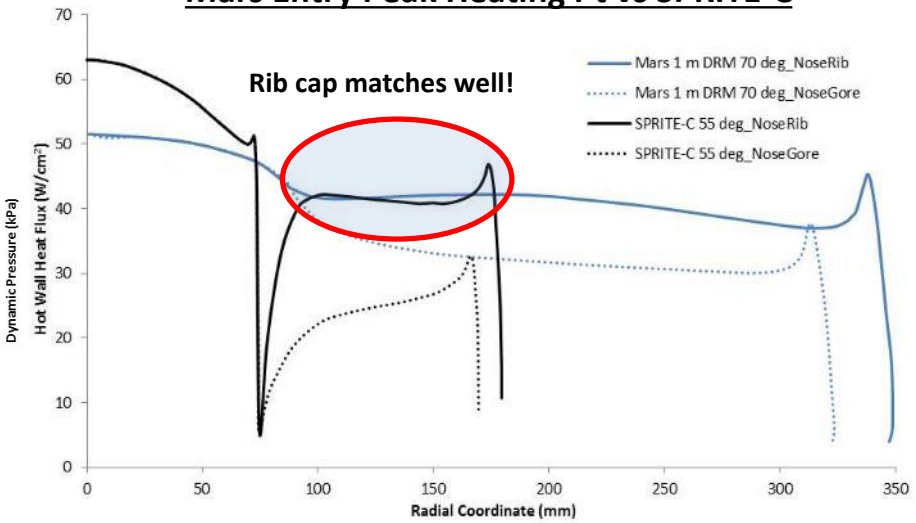
ADEPT 1 m Mars DRM & SPRITE-C Test Aerothermal Environment Predictions

Mars Entry Trajectory & SPRITE-C Test Condition



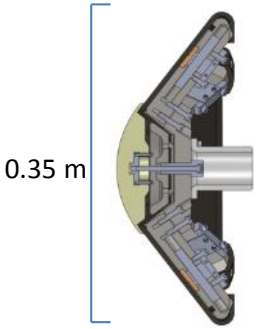
Mars Entry Peak Heating Pt vs SPRITE-C



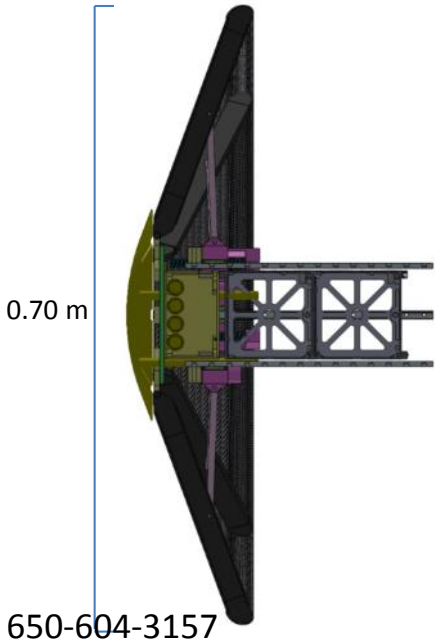
Nominal Mars Ballistic Entry Trajectory

Parameter	Value
Mass	20 kg
Half Cone Angle	70 deg
Rn	0.25 m
Rb	0.35 m
EFPA	-15 deg
Inertial Velocity	6 km/sec
Peak Deceleration	15.5 g
Heat Load	2.0 kJ/cm^2

55 deg SPRITE-C Geometry



70 deg Flight Geometry



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Recent Publications (2014)

- 5 ADEPT publications at the International Planetary Probe Workshop in Pasadena, CA (June 2014), including 2 non-affiliated publications from academia
  - *ADEPT for Secondary Payloads* (Smith et al, NASA)
  - *Deployment Testing of the ADEPT Ground Test Article* (Yount et al, NASA)
  - *A versatile 3D-Woven Carbon Fabric for Broad Mission Application of ADEPT* (Kazemba et al, NASA)
  - *Enabling Venus In Situ Missions Using Mechanically Deployed Aerodynamic Decelerator* (Saikia et al, Purdue University)
  - *Trajectory Optimization with ADEPT Architecture* (Saranathan et al, Purdue University)

Summary

- Three major test campaigns in Sounding Rocket flight test, Arcjet testing, and Wind Tunnel testing are planned for FY15-16.
  - Maximize common configuration and design features
  - Mitigate major challenge areas sufficiently to enable credible infusion potential for Secondary Payload class missions.
- ADEPT is proposing a Mach 3 sounding rocket flight test with hardware delivery in FY16. Actual flight depend on SR manifest schedule.
- ADEPT 1m class development will see clear tech maturation and end-user confidence with successful sounding rocket flight test
  - Exo-atmospheric deploy with flight relevant hardware
  - Aerodynamic stability (open-back 70 deg sphere cone) through critical transonic flight regime
- Simple deployment design (spring-based) with chute-less delivery to Mars Surface
- Viable options exist to take advantage of mass and volume available on Mars 2020 cruise stage to deliver multiple ADEPTs (in stowed configuration)