Adaptive Deployable Entry and Placement Technology (ADEPT)

A Technology Development Project funded by Game Changing Development Program of the Space Technology Mission Directorate

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ACKNOWLEDGEMENT

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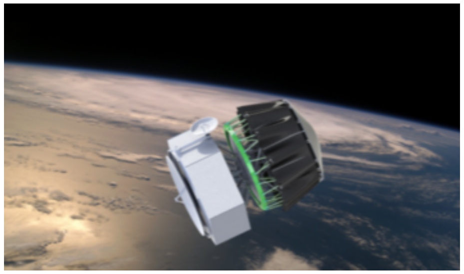
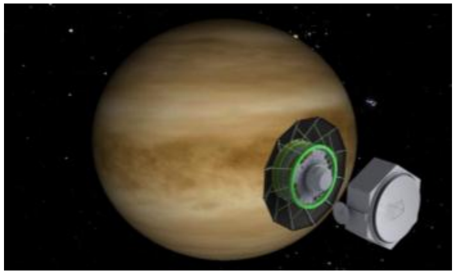
Outline

- What is ADEPT?
- ADEPT Architecture Mission Infusion Strategy
- ADEPT Current Project (FY12-13) Accomplishments
- Key Development Challenges
- ADEPT Full Scale Demonstrator (FSD) Project Plan
- Ground vs. Flight Demonstration
- GCD Technology Insertion into SMD Missions
  - Framework for MUA, MIA, Interaction with Proposal Teams

What is ADEPT?
Adaptive Deployable Entry and Placement Technology



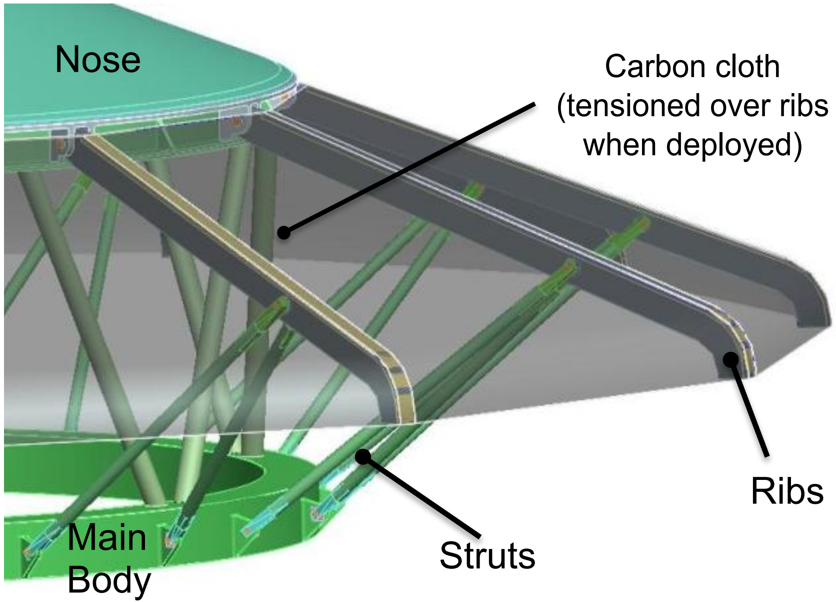
Earth Departure



Venus Arrival

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

- Provides a benign deceleration (~30 g) and thermal environment to the payload.
- Enables Venus in-situ atmosphere and surface science
- Up to 1000 kg delivered payload
- Achieves subsonic speeds at 72 km altitude
- Architecture matured to TRL 6 by mid 2017



What is ADEPT?
Animation

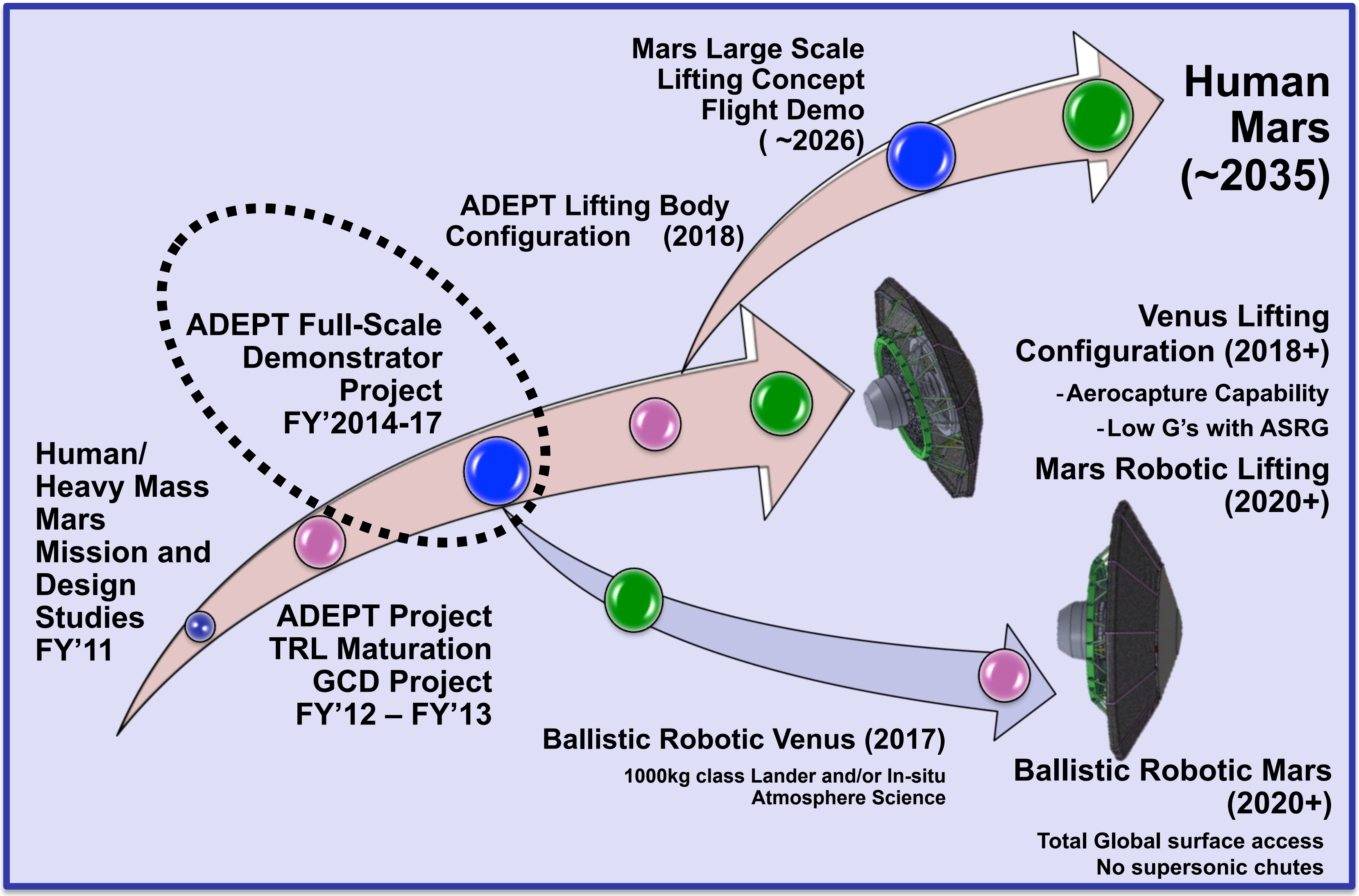
http://www.youtube.com/watch?v=f_eWC7OZx2E

Or search youtube.com for ADEPT

What is ADEPT?
Take Home Message

- Low Entry Environments
  - Flight TPS materials qualification within test facility capabilities (~250 W/cm^2)
  - Low Deceleration loads (30 g) for sensitive payload instrumentation
  - ASRG, when ready could be flown
- Delivered mass
  - Higher delivered mass than traditional entry architecture (comparison with PV)
- Packaging
  - Increased payload volume
  - Access to payload late in integration
- Broad Applicability to a wide variety of destinations
  - Development Venus focused, but applicable to other destinations as well

ADEPT Technology Maturation and Mission Infusion Timeline



Human/ Heavy Mass Mars Mission and Design Studies FY'11

ADEPT Project TRL Maturation GCD Project FY'12 – FY'13

ADEPT Full-Scale Demonstrator Project FY'2014-17

Ballistic Robotic Venus (2017)

1000kg class Lander and/or In-situ Atmosphere Science

ADEPT Lifting Body Configuration (2018)

Venus Lifting Configuration (2018+)

- Aerocapture Capability
- Low G's with ASRG

Mars Robotic Lifting (2020+)

Ballistic Robotic Mars (2020+)

Total Global surface access

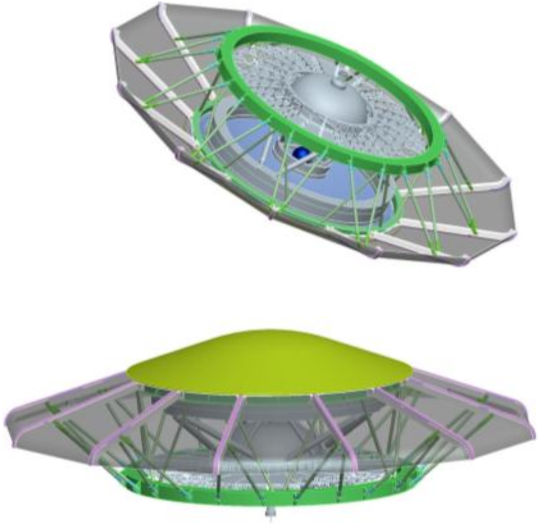
No supersonic chutes

Mars Large Scale Lifting Concept Flight Demo (~2026)

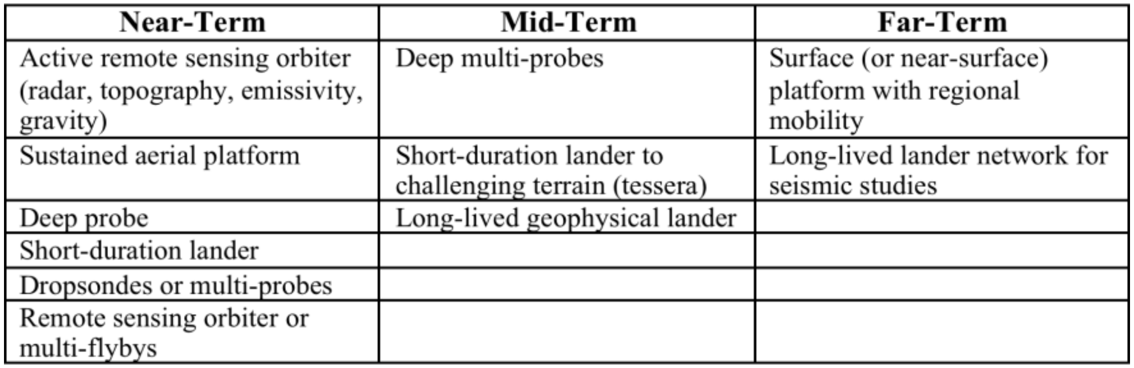
Human Mars (~2035)

ADEPT is an Entry Architecture for a Range of Payload Sizes and Destinations

ADEPT Linkage with VEXAG Tech Roadmap



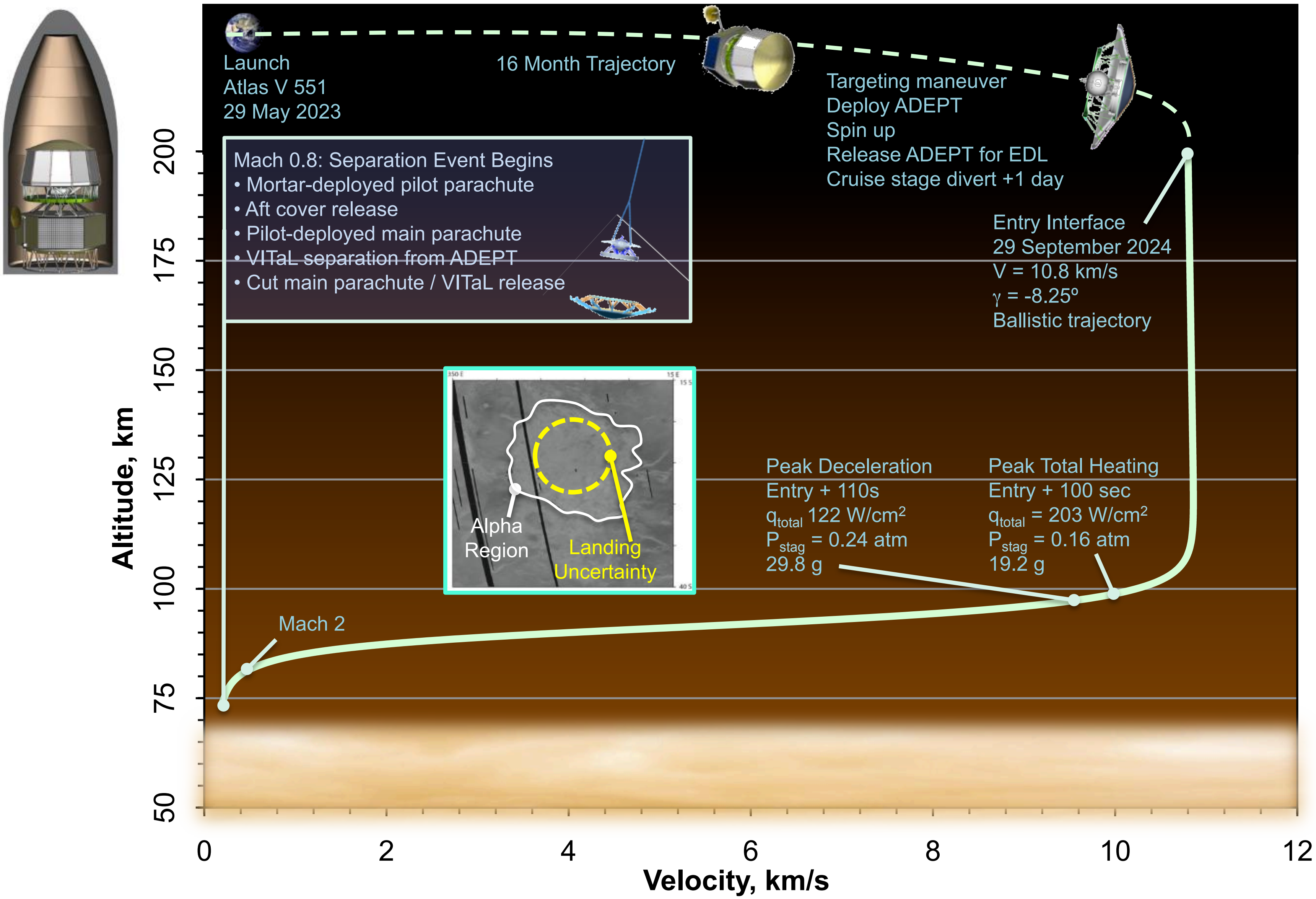
Venus Roadmap Mission Mode Summary (Nov 2013)



Near-Term	Mid-Term	Far-Term
Active remote sensing orbiter (radar, topography, emissivity, gravity)	Deep multi-probes	Surface (or near-surface) platform with regional mobility
Sustained aerial platform	Short-duration lander to challenging terrain (tessera)	Long-lived lander network for seismic studies
Deep probe	Long-lived geophysical lander	
Short-duration lander		
Dropsondes or multi-probes		
Remote sensing orbiter or multi-flybys		

- **ADEPT focused on Venus Atmosphere Entry Technology Capability**
  - Full Scale Demonstrator (6m diameter) project funded by STMD GCD (FY14-17)
- **Near-Term (2020)**
  - Capable of Direct ballistic entry at Venus, Delivering Payloads up to 1000kg
  - Not exceeding 30’g deceleration loads
- **Mid-Term (2020-2025)**
  - Expanding capability to perform Lifting Atmosphere Flight trajectories
  - Will enable aerocapture at Venus with Direct entry from orbit

Integrated System Performance
ADEPT-VITaL Mission Quick-Look



Launch
Atlas V 551
29 May 2023

16 Month Trajectory

Targeting maneuver
Deploy ADEPT
Spin up
Release ADEPT for EDL
Cruise stage divert +1 day

Entry Interface
29 September 2024
V = 10.8 km/s
γ = -8.25º
Ballistic trajectory

Mach 0.8: Separation Event Begins
- Mortar-deployed pilot parachute
- Aft cover release
- Pilot-deployed main parachute
- VITaL separation from ADEPT
- Cut main parachute / VITaL release

Peak Deceleration
Entry + 110s
q_{total} 122 W/cm^2
P_{stag} = 0.24 atm
29.8 g

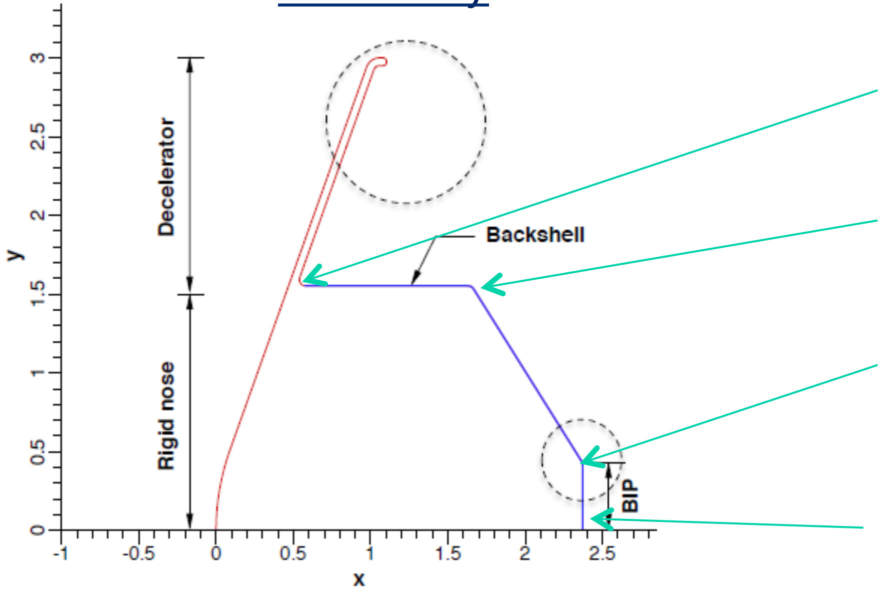
Peak Total Heating
Entry + 100 sec
q_{total} = 203 W/cm^2
P_{stag} = 0.16 atm
19.2 g

Mach 2

Payload Thermal Environment Analysis

Geometry

Environments from CFD

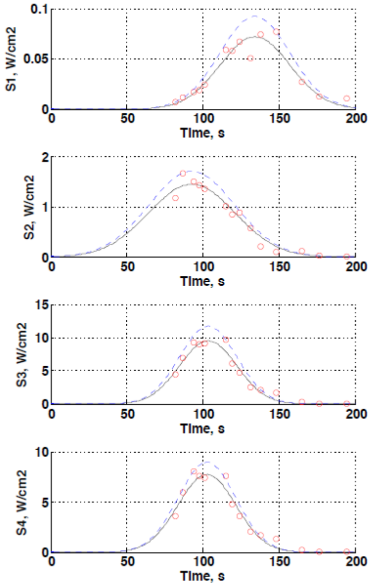


S1
Nose-Fabric Interface

S2
Backshell Transition

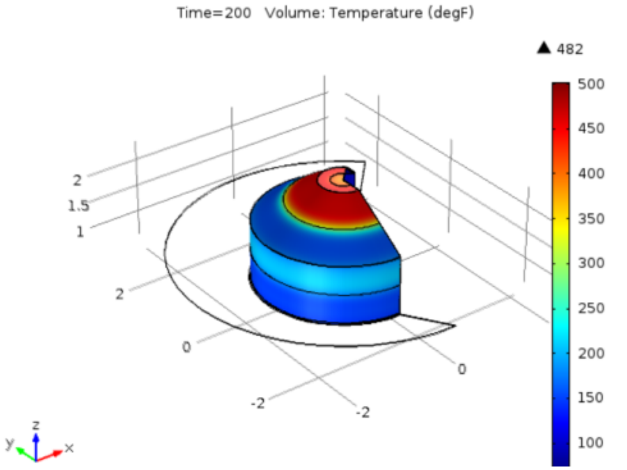
S3
BIP Transition

S4
Aft Stagnation Point



Results

Payload Separation: 200 sec



Summary

- Heat Flux environments applied at various points (S1-S4) along axisymmetric payload volume and combined with fabric radiation.
- Highest heat flux (10-12 W/cm^2) occurs near the aft stagnation point, due to wake flow recirculation.
- Common insulating materials and low emissivity approaches can be used to control payload temperatures
  - Low emissivity coatings or MLI near the cloth nose interface
  - RF-transparent insulator for payload backshell
- Appropriate thermal control techniques are payload specific

ADEPT-VITaL Mission Feasibility Report

- **Study Objective:** ***assess the feasibility of the ADEPT concept by quantifying potential benefits for the NRC Decadal Survey's Venus In-Situ Explorer (VISE) Mission and checking for potential adverse interactions with other mission elements, such as launch and cruise.***

- **The ADEPT project chose to study the Venus Intrepid Tessera Lander (VITaL) design, a VISE lander developed by NASA GSFC for the Decadal Survey's Inner Planets Panel. Results are documented in the *ADEPT-VITaL Mission Feasibility Report*, dated 1 August 2013. Copies are available on DVD or through LFTS to NASA affiliated personnel. Please contact: Alan.M.Cassell@nasa.gov**

The ADEPT-VITaL Study Addresses:

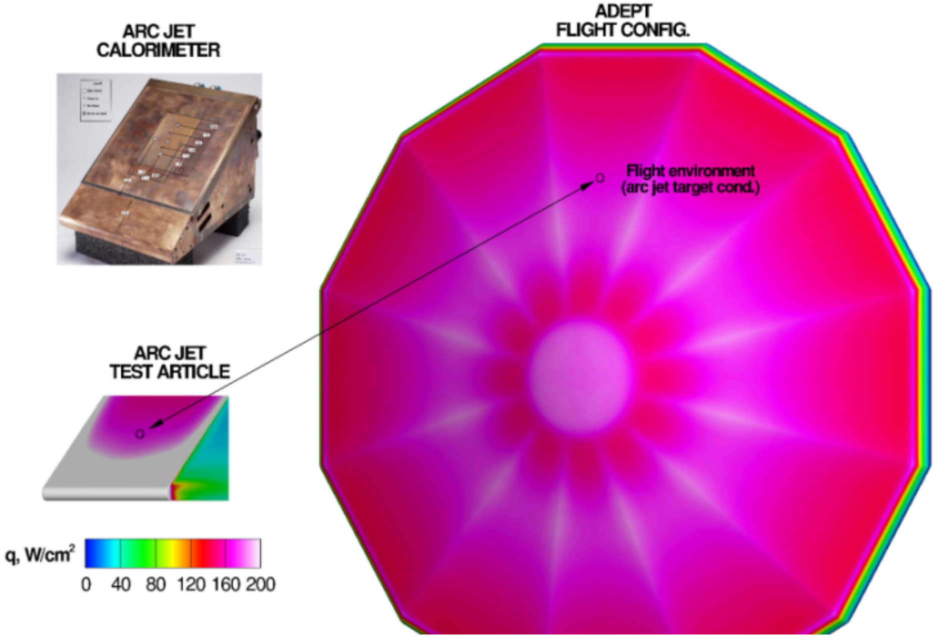
- **Mission Design Elements:**
  - **Launch vehicle**
  - **Interplanetary trajectory design / launch date**
  - **Cruise CONOPS / time of ADEPT deployment**
  - **Carrier spacecraft mods. / mass and power impacts**
  - **VITaL lander modifications and mass savings**
- **ADEPT-VITaL Vehicle Subcomponent Design:**
  - **Structures**
  - **Mechanisms**
  - **Materials**
- **Payload Separation Event**
- **Key Trade Studies:**
  - **Entry shape / trajectory**
  - **Structures and mechanisms trades**
- **Operating environments: stowed configuration**
  - **Launch vibro-acoustic**
  - **Cruise cold soak**
- **Operating environments: deployed configuration**
  - **Aerothermodynamic loads**
  - **Structural and aeroelastic loads**
  - **Aerodynamic stability and flight dynamics**

The ADEPT Team used Venus robotic as most challenging class for low ballistic coefficient decelerator applications

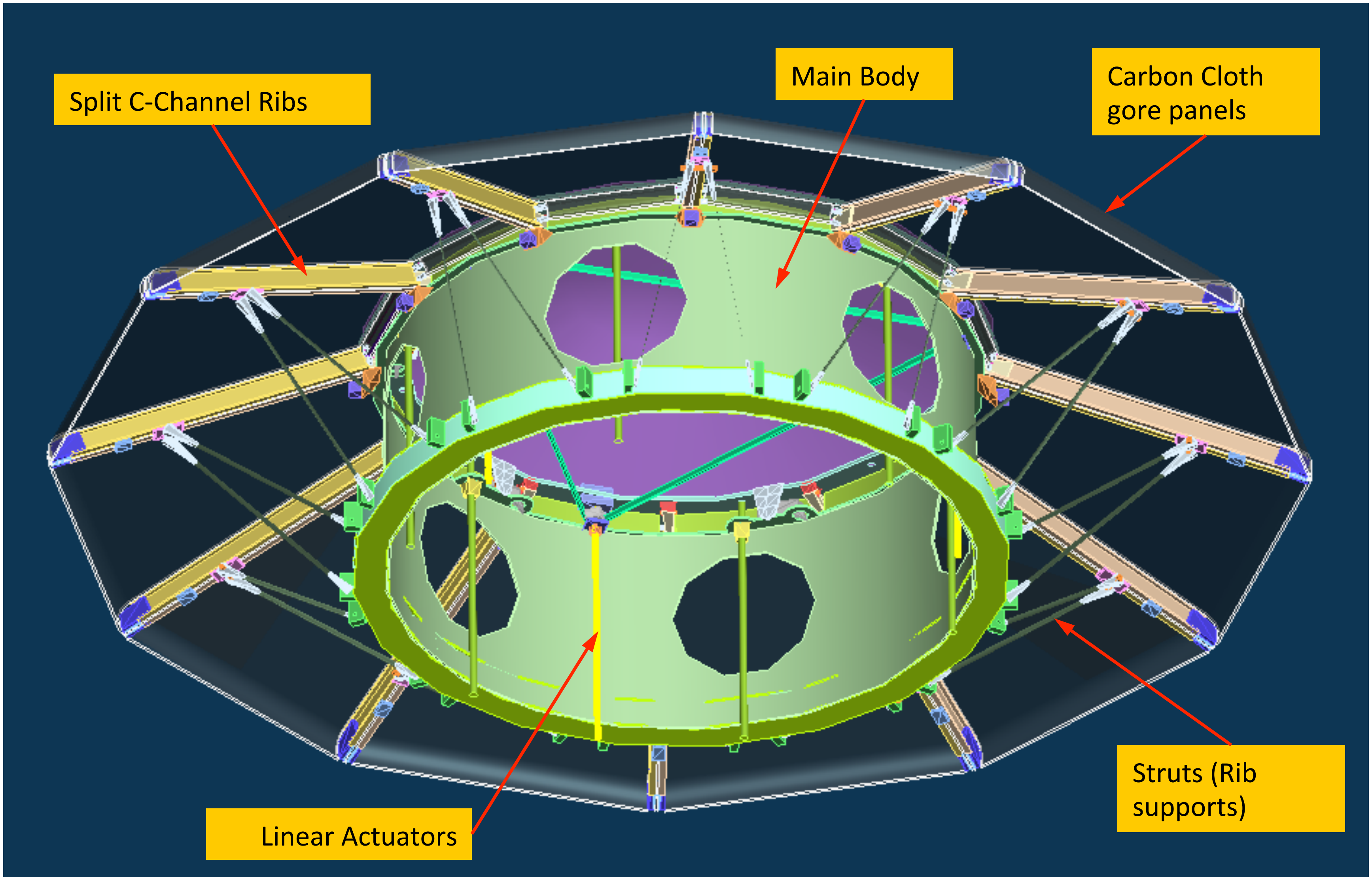
- Fully addressed mission feasibility
- Technology development risks identified
- Close collaboration with Venus Mission Stakeholder (GSFC: Glaze)

Carbon Fabric Thermal Performance Testing Results in Relevant Environments

- **Bi-axial Loaded Aerothermal Mechanical (BLAM) Test Objectives:**
  - Evaluate the carbon fabric's structural integrity under combined aerothermal and biaxial loading. Intended to be a unit test for the acreage of the ADEPT vehicle (far away from the ribs)
  - Evaluate the rate of layer loss as a function of different combined loads.
- **Test Results:**
  - Data shows that the carbon fabric is able to maintain load at temperature.
  - Biaxial load in the cloth from 188 lbs/in to 750 lbs/in has little to no impact on the rate of layer loss of the carbon fabric.
  - Flipping the warp/weft direction had little effect on the rate of layer loss of the carbon fabric.
  - Fabric tested easily withstood a heat load of 15.7 kJ/cm^2. This is well above the 11 kJ/cm^2 expected for a Venus mission.



Manufacturing & Assembly Challenge
2 m Diameter GTA Design Features



Split C-Channel Ribs

Main Body

Carbon Cloth gore panels

Struts (Rib supports)

Linear Actuators

Challenges Remain for FY14 New Start ADEPT Full Scale Demonstrator Project

Risk Area	Description	FY12 Start	FY13 End	FY17 End of ADEPT FSD
Fabric Thermal Performance	Test at and above anticipated peak heating and heat load anticipated for Venus entry	🔴	🟢	🟢
Fabric Interfaces	C-fabric to: 1) rib; 2) nose; 3) shoulder/close-out	🔴	🟠	🟢
Deployment	Deployment function and reliability testing on 2 m GTA and Full-Scale prototype	🟠	🟡	🟢
Thermostructural	Understand thermal design issues- materials selection and performance	🟠	🟠	🟢
Aerodynamic Stability	Blunt body entry vehicles in supersonic to transonic regime may be dynamically unstable	🔴	🟠	🟢
Integrated System	There is no end to end ground test, but the key system test is thermal vac deployment and vibe acoustic of full size vehicle	🔴	🟠	🟢
Fluid Structure Interaction	Flutter of cloth could lead to aerodynamic stability issues	🔴	🟠	🟢
Manufacturing	Establish manufacturing, assembly and integration at relevant scale	🔴	🟡	🟢

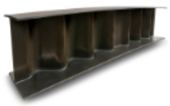
🔴 Little or No Validation
🟠 Minimal Validation
🟡 Additional Validation Needed
🟢 Sufficient Validation
🟢 Fully validated

ADEPT Full Scale Demonstrator Baseline Project Major Deliverables

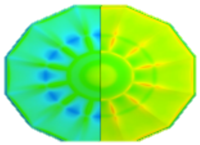
Yr 1 (FY14)

- A/J Interface and SPRITE-C Proto-qual Tests
- Component analysis and tests finalize design:
  - ACC Rib to Fabric attachment (Interface)
  - Rigid nose to Gore attachment (SPRITE-C)
- SRR complete for Full Scale Demonstrator (FSD)
- ACC Component Fabrication
- DAC-1 Completed for FSD
- Control System & Mechanisms Failure Modes & Effects Analysis (FMEA)
- Thermal Model Version 1.0
- Stitched Seams

ACC Component Development

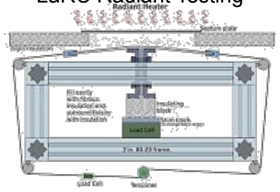


Thermal Model

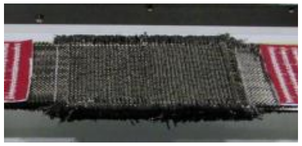


Interface Aerothermal

LaRC Radiant Testing



Interface Component Testing



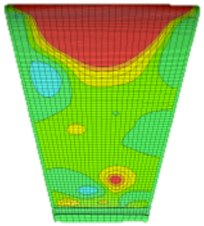
- *Component Design Finalized and risks mitigated*
- *Flight Configuration Loads and Requirements complete*

Yr 2 (FY 15)

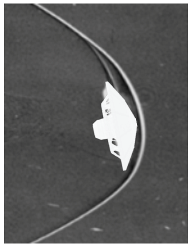
- Ballistic range tests verify flight configuration dynamic stability
- FSI test in 11' Unitary W/T
- Large Scale-Gore Manufacturing Demo
- Solar Tower Test on relevant scale components
- Rigid Nose to Gore to trailing edge design complete
- Aero Model Version 1.0
- ADEPT/Venus FSI Final Report
- PDR/CDR for FSD

Solar Tower Test

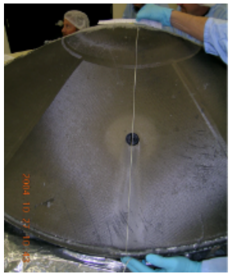
FSI- 11' UWT



Dynamic Stability



Rigid Nose Design

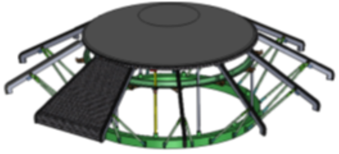


- *Full Scale Demonstrator (FSD) Design Complete*
- *FSD Fabrication Started*

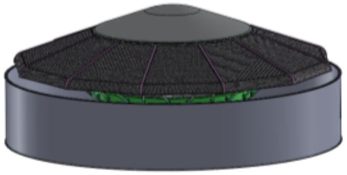
Yr 3/4 (FY16/17)

- 6m Gore Assembly Process
- FSD Assembly and Integration Complete
- Vibro-acoustic Testing
- T/V Deployment Testing
- Static Load Testing
- Verification Report

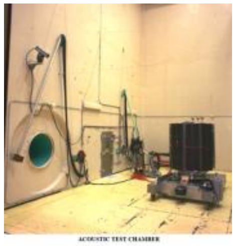
Gore Assembly Process



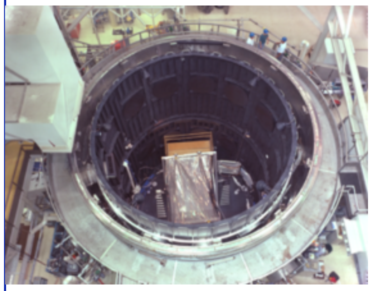
Static Load Test



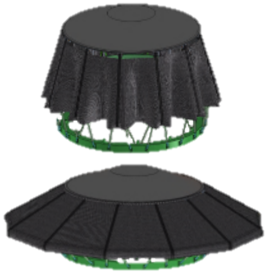
Vibracoustic



27' x 40 ' Thermal Vac Chamber



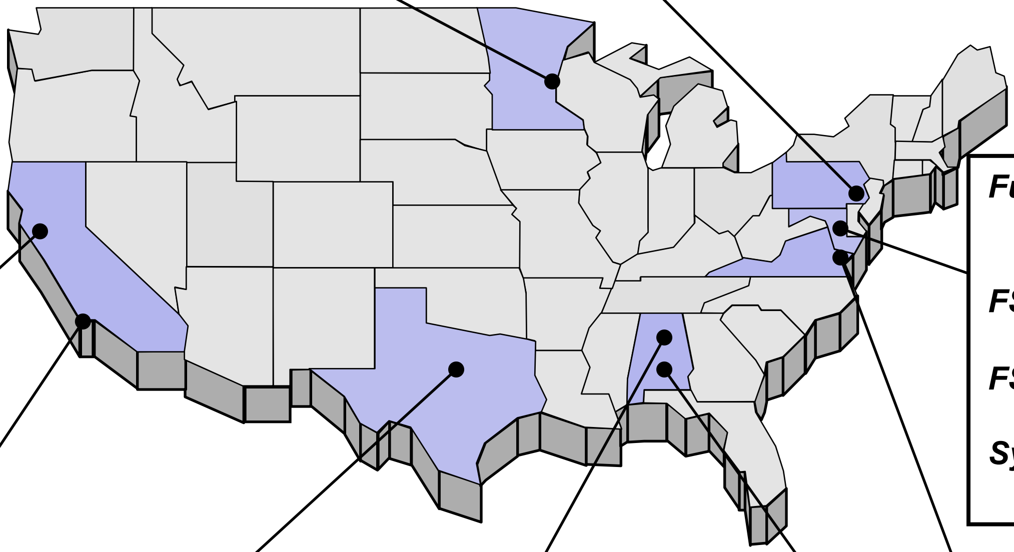
GSFC 290 SES T/V Facility



6 m Stowage & Deployment Testing

- *FSD Assembly, Integration, and Test Complete*
- *Thermal testing of Nose-Rib-Fabric Complete*

ADEPT FSD NASA & Industry Team Roles and Responsibilities



Univ. of Minnesota, Minneapolis, MN
Flow-Structure Modeling/Analysis

Bally Ribbon Mills, Bally, PA
Woven Fabric Manufacturer

NASA ARC

- ***Project Mgmt***
- ***Systems Engineering***
- ***Thermal Mechanical Hardware Design, Fab, Test***
- ***Aero/FSI Analysis and Testing***
- ***Full Scale Demonstrator design and analysis***

NASA GSFC

- ***Full Scale Demonstrator (FSD) Structure Design, Fab, Test***
- ***FSD mechanisms and actuators***
- ***FSD A,I,&T incl: T/V and Vibe/Acoustic***
- ***Systems Engineering support***

NASA JPL

Reliability Engineering and Mission Design Support

CFDRC Huntsville, AL
Carbon fabric stitching (SBIR ØII-e)

C-CAT Fort Worth TX
Advanced Carbon-Carbon supplier

Southern Research Institute, Birmingham, AL
Material Property Testing

NASA LaRC

- *Hot structure (ACC) design and analysis support*
- *Radiant facility testing*

FY14- Critical Interfaces & Rib Development


ACC-6 Ball Joint & Strut Prototype

☐ Technical Objectives

- Demonstrate ACC-6 component manufacturing and structural performance
- Demonstrate stitched seam aerothermal performance
- Validate thermal structural models for rib/fabric, nose/fabric , nose/rib interfaces
- Define Performance Specs (PS) for all Ames/Goddard structural interfaces. Develop mechanical interface drawings (MIDs).

☐ Approach

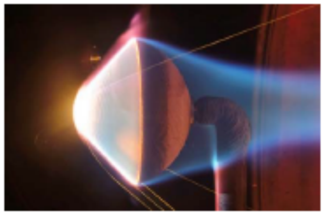
- Perform arc-jet tests on rib-fabric interface and nose/fabric interfaces
- Design and manufacture various alternative rib, nose, fastener, and strut attachment designs and test in combined thermal/load environment
- Perform preliminary analysis and sizing for all primary components

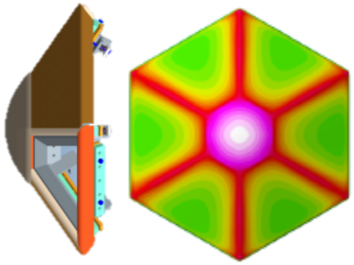
☐ Technical Challenges

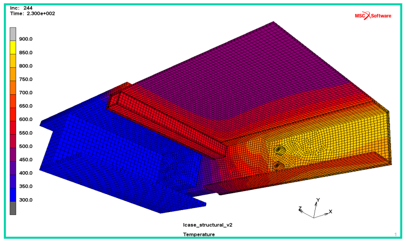
- Manufacturing of ball and socket strut ends and fasteners from advanced carbon-carbon (ACC), CCAT, Inc.
- Early interface definition may constrain design changes
- Loads must be selected that will envelope potential missions

☐ Risks Addressed

- Rib-Fabric Interface Attachment
- Nose-Fabric Interface
- Trailing Edge
- Manufacturing of complex and/or large ACC components







Interfaces & Attachments	FY 14											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Seams/Interfaces	◇ Stitched Seam Test				◇ Test CDR		◇ Arc JetPathfinder				◇ Arc Jet Key Interface Test	
ACC Components			◇ ACC Comp Design		◇ ACC Component Fab		◇ ACC Component Load Test					◇ ACC 3 d lay-up
DAC-1		◇ Define Perf Specs		◇ Elephant Prelim Sizing			◇ Interface Definition Review			◇ MID Drawings		

Full-Scale Demonstrator Planned End State

Advanced Carbon-Carbon Structure

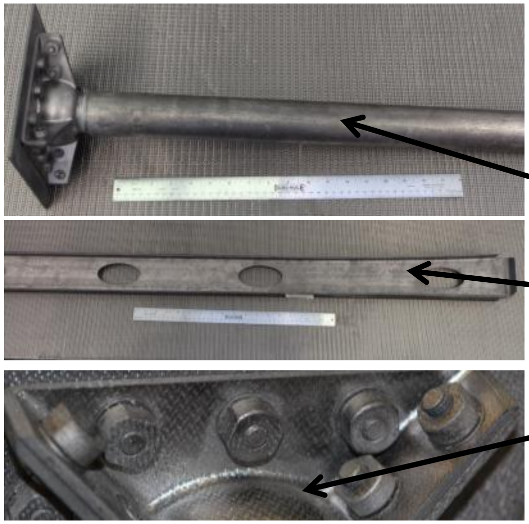
- ACC Ribs, Struts, pivots & Fasteners

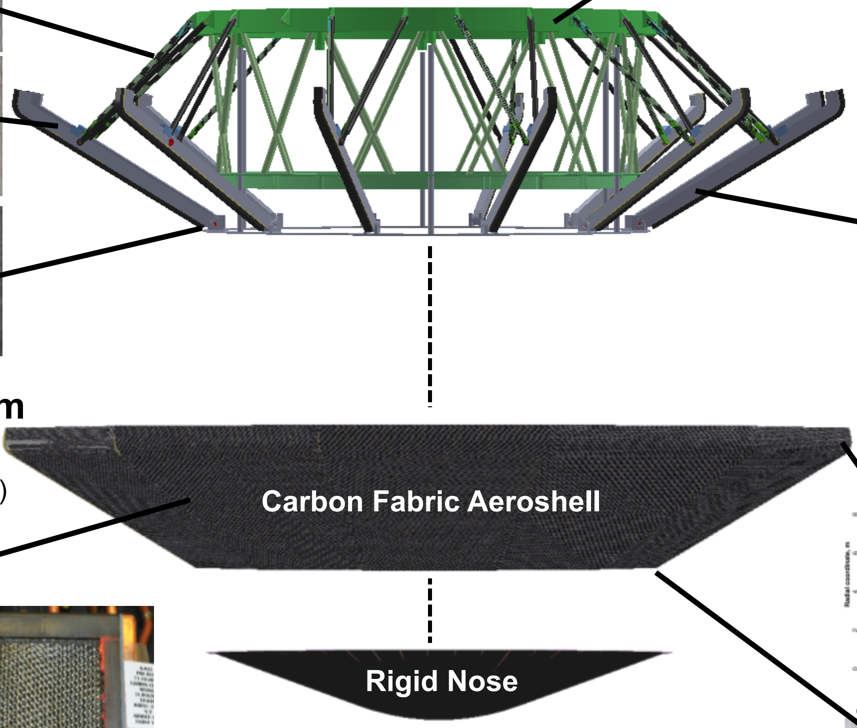
Deployment System

- Fault Tolerant Deployment
- Precision aero dynamic shape

Payload Adapter Ring

- Adaptable to any mission payload

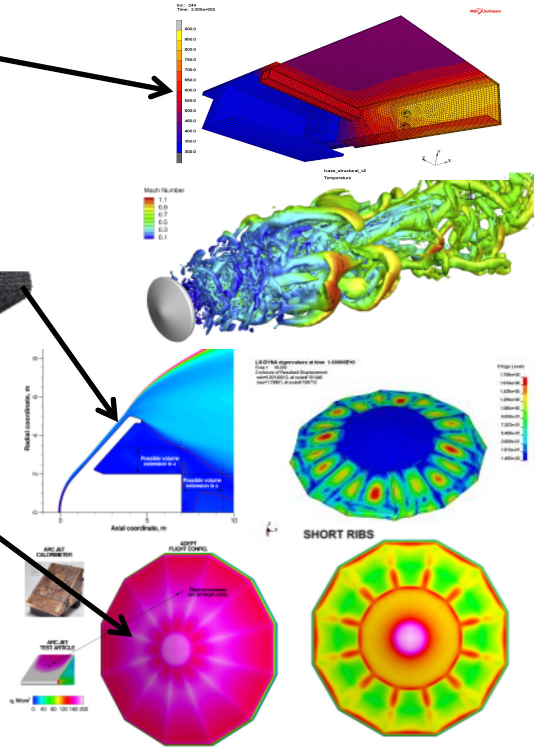




Modeling Tools

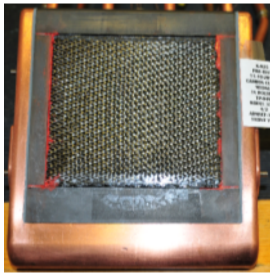
Certified for Flight Design

- Aerothermodynamic
- Aerodynamic
- C-Fabric Thermal Response
- Structural
- Thermal Structural
- Fluid Structure Interactions



Carbon Fabric Aeroshell System

- 3-d woven Carbon Fabric
- Medium Heat Rate Capability (250 W/cm²)
- High Structural Load Capability (3 psi)
- Interfaces , Seals & Close-Outs



- 3 m diameter rigid nose -CA 250 Conventional technology

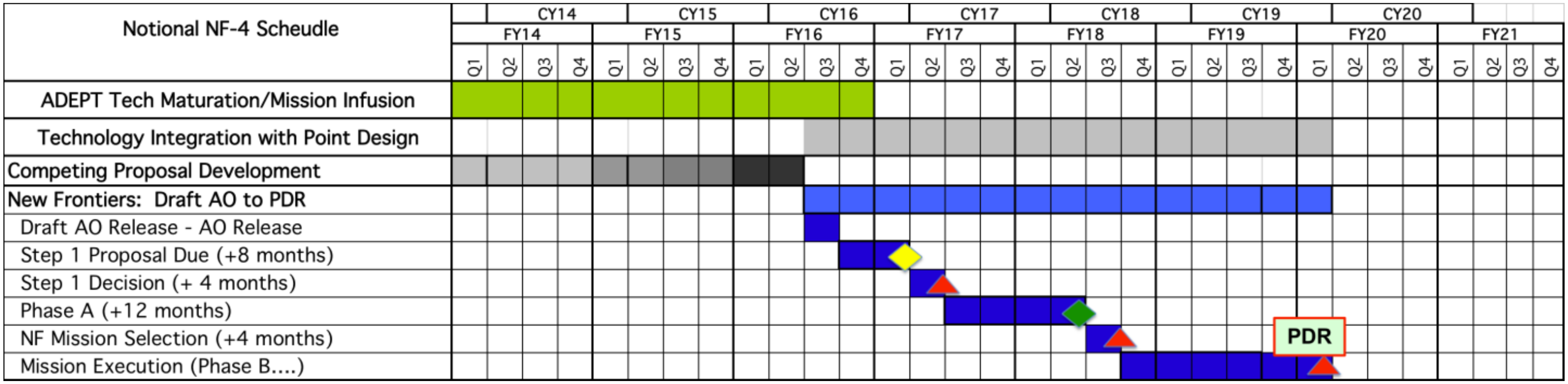
ADEPT Comprehensive Ground Development vs Flight Test Assessment

Characteristic	ADEPT-VITaL	ADEPT Relevant Scale Aeroshell Ground Test Campaign		ADEPT Sounding Rocket Experiment	
		Value	Comments	Value	Comments
Vehicle Scale (diameter, m)	6	6 🟢	Flight-like components at appropriate scale	≤ 3 🟡	Key components such as C-fabric and ribs/struts would not be at appropriate scale
Peak Heating (W/cm²)	250	>250 🟢	Qualification Testing in Arc Jets establish performance	59 🟡	Additional testing needed to qualify for heating rates expected for Venus entry
Integrated Heat Load (kJ/cm²)	11	> 12 🟢	Radiant and arc jet testing establish upper bounds on performance & characterize failure mechanisms	0.60 🟠	Benign entry environment would not thermally stress the system
Deployment	Reliability & Repeatability	>99% Confidence Interval 🟢	Thermal Vacuum Chamber establishes reliability and repeatability in cold soak environment	>95% Confidence Interval 🟡	Flight acceptance testing would require cold soak environment
Aerodynamic Stability	Demonstrate dynamic stability	Stable 🟩	Ballistic Range testing is flight relevant	Specific to SR 🟡	Determine bounding stability values specific to SR Experiment
Fluid Structure Interaction	High Fidelity Model	Mid Fidelity Model 🟩	Validation of FSI simulation tool in 11' UPWT on relevant scale C-Fabrics	Flight data down to M=0.8 🟩	Minimal information on C-fabric performance unless SR expt is appropriately instrumented
Manufacturing, Assembly & Integration	6 m, 70 deg sphere cone	6 🟢	Establishes manufacturing, assembly & integration processes at Mission relevant scales	≤ 3 🟡	SR experiment only partially addresses

🔴 Little or No Validation 🟠 Minimal Validation 🟡 Additional Validation Needed 🟩 Validated but some room for improvement 🟢 Fully validated

- **Ground test development has superior relevance for technology maturation**
- **Community involvement in the development pathway**
- **Analysis of alternative sub-orbital flight tests are underway**

ADEPT Project Plan for Mission Insertion to NF-4



- Technology maturation progress and mission usage need to be periodically reviewed
- What are the key products the proposal team needs and by when?
- ADEPT technology development team provides a) data and b) insights into technology use and limitations
- ADEPT technology development team is not an extension of the proposal team
  - Trade studies specific to mission design need to be carried by the proposal team
  - Proposal Strategy, proposal writing and data preparation are all the responsibilities of the proposal team
  - ADEPT tech development team needs to provide data needed by the proposal team
- Technology transfer beyond the tech maturation is a topic of discussion and planning by
  - SMD, STMD, ADEPT and Proposal Teams

Mission Usage For ADEPT

- Proposal teams are encouraged to take a close look at ADEPT-VITaL mission design study report
    - Recommended as the basis for ADEPT technology evaluation
    - Venus missions requiring ED alternate to rigid aeroshell is the primary target.
        - Depending on the mission / payload, ADEPT-VITaL study may be directly applicable
            - ADEPT-VITaL delivered payload mass ~ 1300 kg, ~65km altitude parachute delivery and entry environment tailored to a G'load of ~30'g and a entry mass of 2800 kg
            - The ADEPT full scale demonstrator project end deliverable is compatible with the ~1300 kg class payload delivery at Venus
        - If the mission/payload is different than VITaL, then
            - ADEPT team need to support assessment studies
    - Other mission proposers, interested in ADEPT technology
        - ADEPT project team need to understand and can provide a preliminary evaluation of the benefit and cost (mass, integration challenges) of integrating ADEPT
        - Detailed evaluation studies, if ADEPT is chosen, will require careful planning and resources
- Current project plan is aggressive with key challenges
- Continued community engagement is necessary
- Mission infusion challenges will require:
    - Dialogue between ADEPT project and proposing organizations
    - Dialogue between STMD and SMD-PSD
    - NASA developed technology infusion in a competed process.

Concluding Remarks

- ADEPT, a Low Ballistic Coefficient, Mechanically Deployable Entry System Architecture is a Game Changer:
  - Dramatically decreases severity of the entry environment conditions due to high altitude deceleration
  - Enables use of delicate and sensitive instrumentation and instrumentation already flight qualified for lower g-loads
  - Entry mass and the launch mass are reduced compared to rigid heatshield designs
  - Mission Risk and Cost, once the technology is matured and demonstrated, will be reduced considerably
- GCD investment in ADEPT, mechanically deployable aeroshell technology, has broad payoff for Solar System Exploration and Science including Venus
  - VEXAG and PSD have identified and recommended this technology for NF
- Continued Technology Maturation of ADEPT concept by 2016/2017 will
  - Enable Venus Missions with more comprehensive science to be a top contenders for the next round of New Frontier AO
  - Continue Deployable Entry Concept development for Mars robotic and eventual human exploration missions
- ADEPT will engage the mission proposers and will participate in SMD/STMD reviews to ensure New Frontiers mission infusion relevance.