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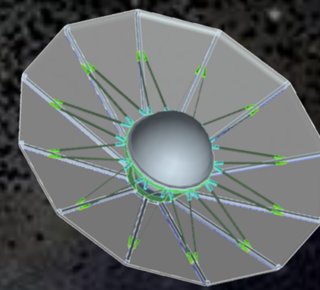
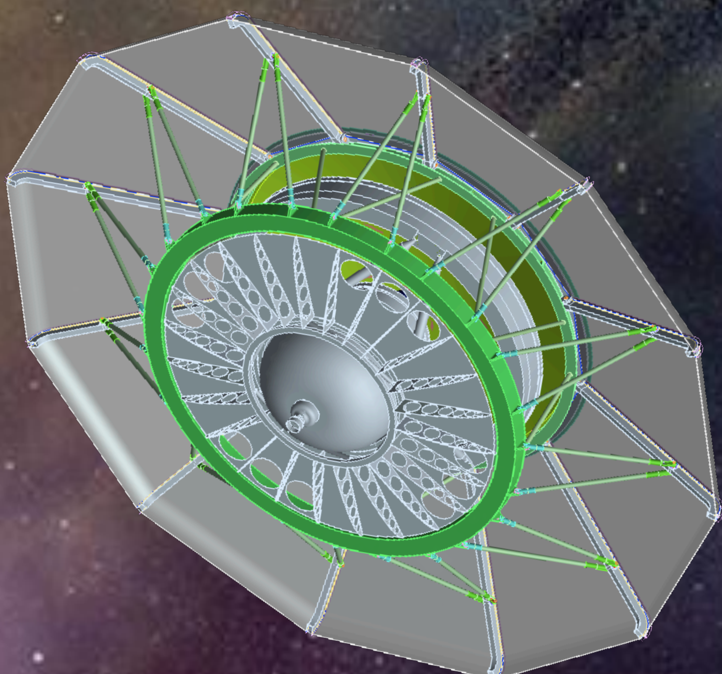
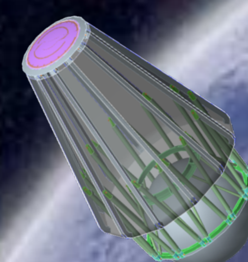
Enabling Venus In-Situ Science – Deployable Entry System Technology, Adaptive Deployable Entry and Placement Technology (ADEPT):



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





P. Wercinski, E. Venkatapathy, P. Gage, B. Yount, D. Prabhu, B. Smith, J. Arnold, A. Makino, K. Peterson, R. Chinnapongse

What is this talk about?

- **Venus is one of the important planetary destinations for scientific exploration, but…**
  - The combination of extreme entry environment coupled with extreme surface conditions have made mission planning and proposal efforts very challenging
- **We present an alternate, game-changing approach (ADEPT) where a novel entry system architecture enables more benign entry conditions and this allows for greater flexibility and lower risk in mission design**

Outline

- **Background: The challenge of entry at Venus**
- **Venus Mission**
  - VITaL: Example Venus Lander mission to meet NRC Decadal Survey Science Recommendations
- **ADEPT – Mechanically Deployable Aeroshell Integrated Approach and Results of application to VITaL mission design**
- **Concluding Remarks**

ADEPT

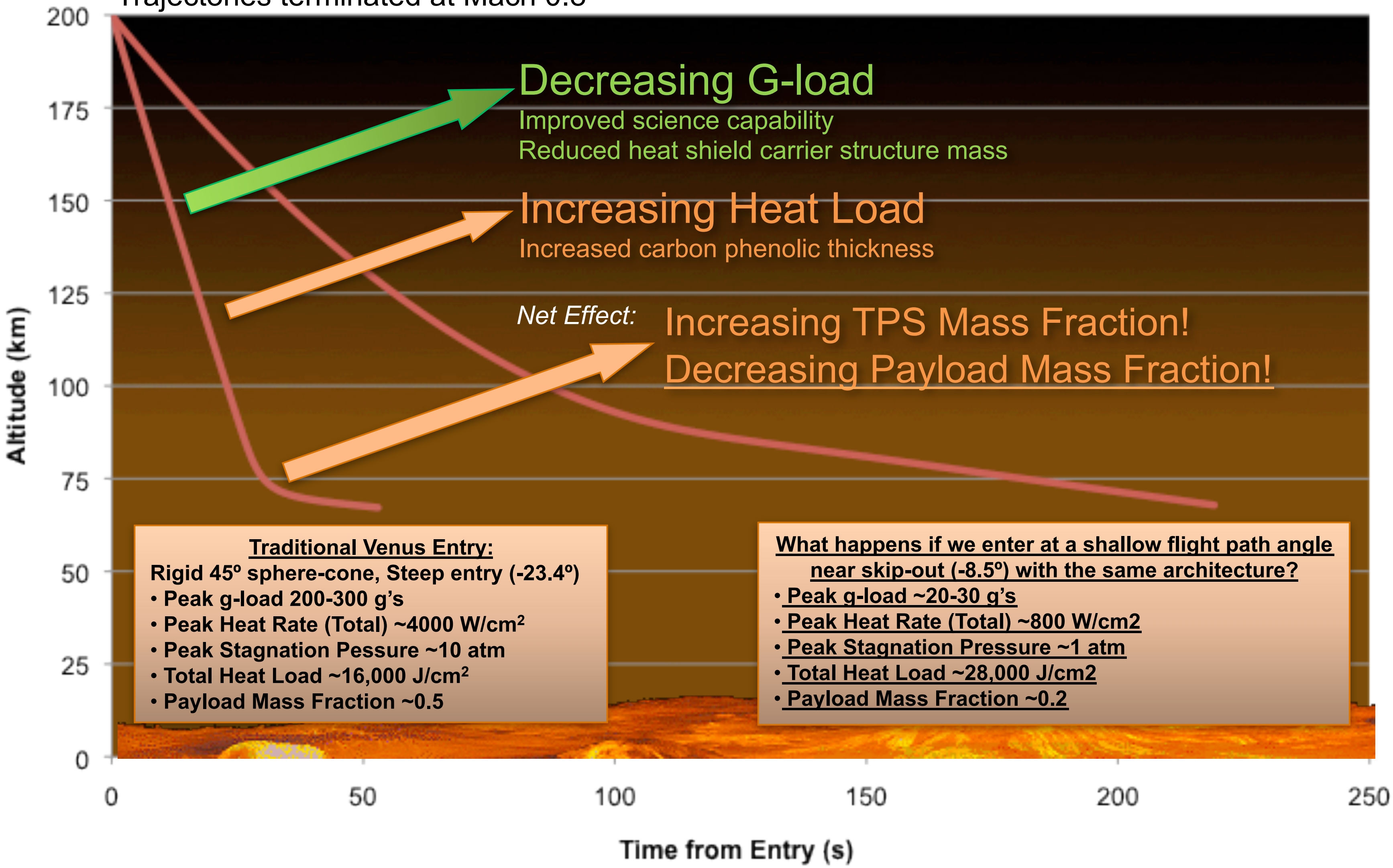
ACKNOWLEDGEMENT

- This work is currently supported by the Game Changing Development Program of the Space Technology Program , NASA HQ.
- NASA Ames Research Center is leading this effort and is supported by NASA Langley Research Center, NASA Johnson Flight Center, NASA Goddard Flight Center and Jet Propulsion Laboratory.
- Content of this presentation was previously given at the IPPW-9 (June 2012) in two presentations by (Venkatapathy, Glaze et al)

ADEPT

High-Speed Atmospheric Entry at Venus : The Challenge

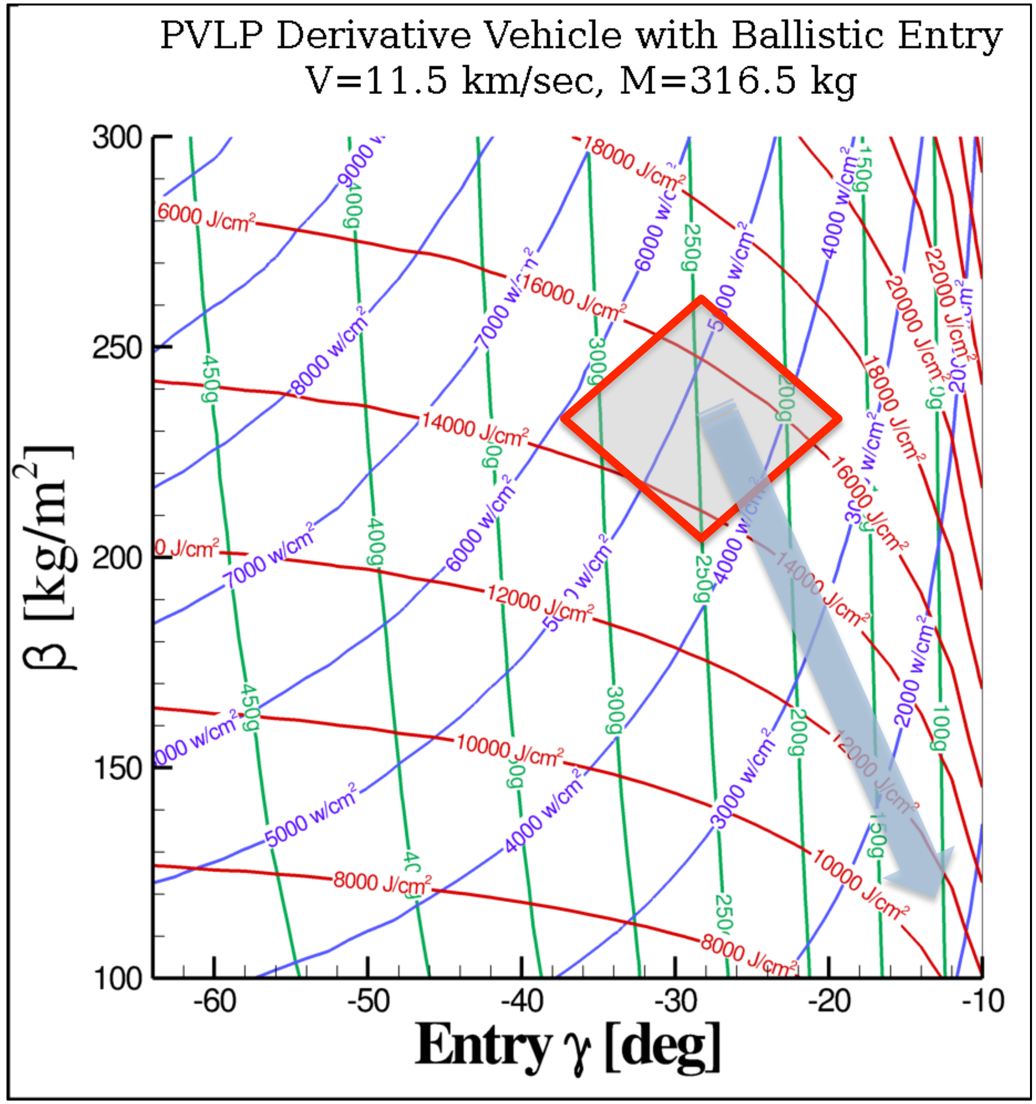
m/CdA(β) = 208 kg/m^2 (3.5m diam, 45º sphere-cone, 2100 kg entry mass)
V_{entry} = 11.25 km/s
Trajectories terminated at Mach 0.8



ADEPT

High-Speed Atmospheric Entry at Venus : The Challenge

- **For rigid aeroshell entry:**
  - Ballistic coefficient 200-250 kg/m^2
  - Size constrained by launch shroud
  - Entry mass constrained by launch vehicle throw capability
- **For Carbon-Phenolic TPS:**
  - Balance between TPS and Payload mass fraction leads to extreme heatflux, pressure and G'load
- **Alternate option:**
  - Design entry architecture that can operate at shallower entry flight path angle (lower g-loads) and a lower ballistic coefficient (lower heat load)

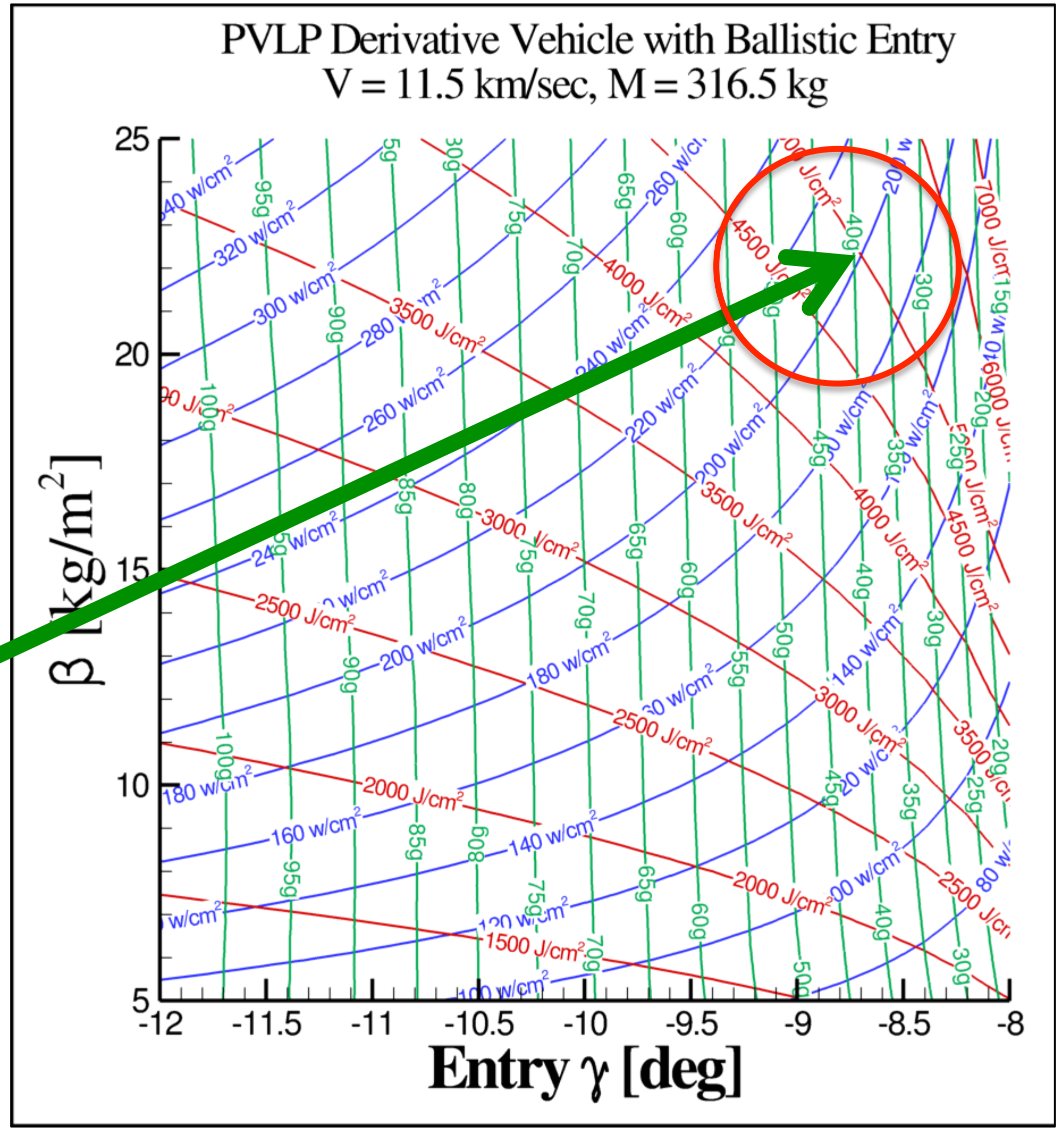


ADEPT

Game Changing Approach to Venus Direct Entry with a Low Ballistic Aeroshell Concept

- **Assume ballistic coefficient can be lowered 10 x**

- **A material that can sustain 250 W/cm^2 is now feasible**
- **Corresponding heatload and pressure are considerably lower as well**
- **Peak deceleration can be reduced by an order of magnitude**



ADEPT

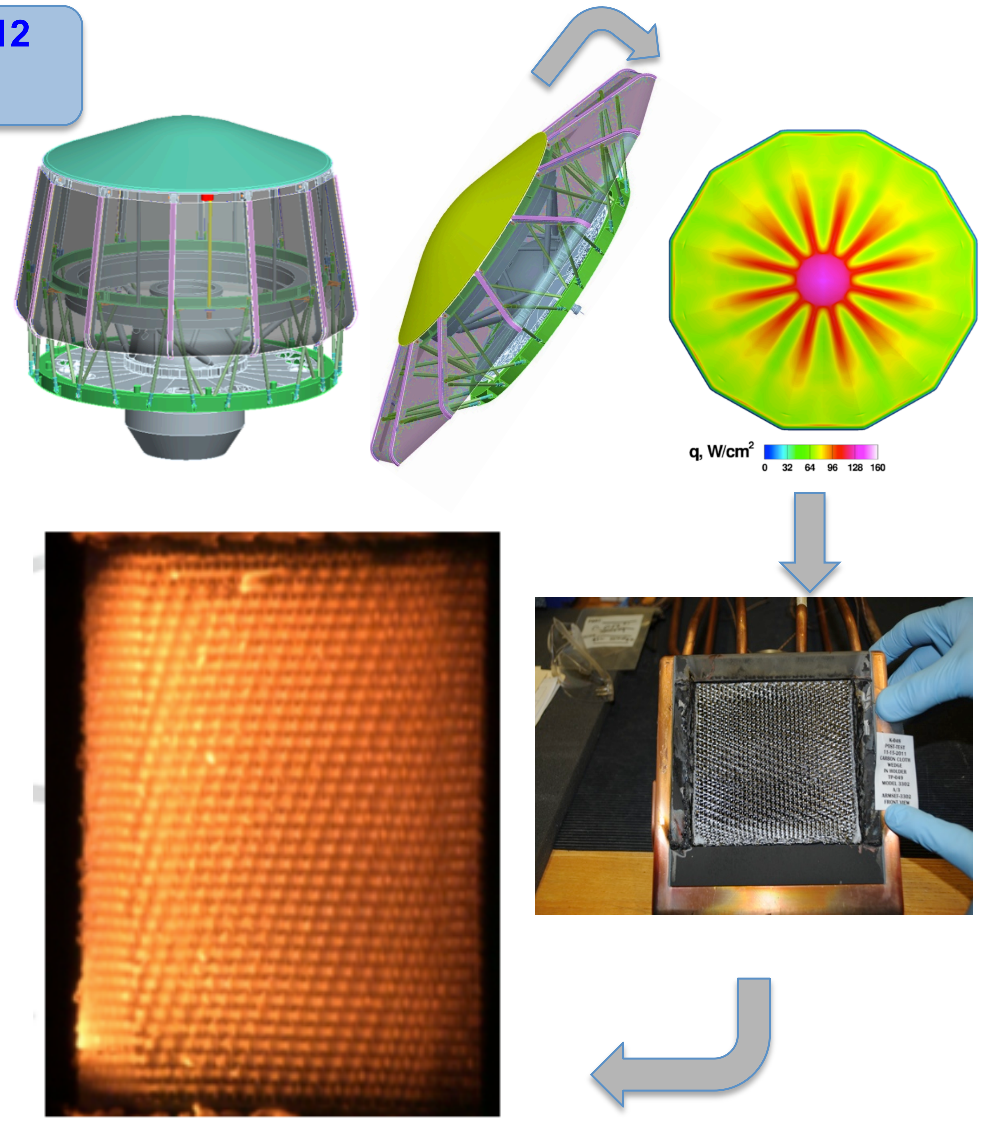
ADEPT (Adaptable, Deployable, Entry and Placement Technology) *is a low ballistic coefficient entry architecture (m/CdA < 50 kg/m²) that consists of a series of deployable ribs and struts, connected with flexible 3D woven carbon fabric skin, which when deployed, functions as a semi-rigid aeroshell system to perform entry descent landing (EDL) functions.*

ADEPT: STP GCD Project (2yr) started in FY12

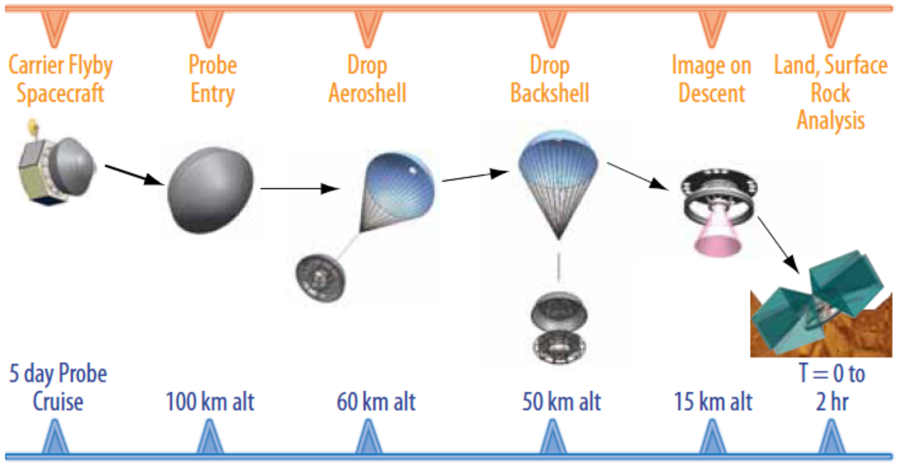
=> Achieve TRL 5 at end of FY13

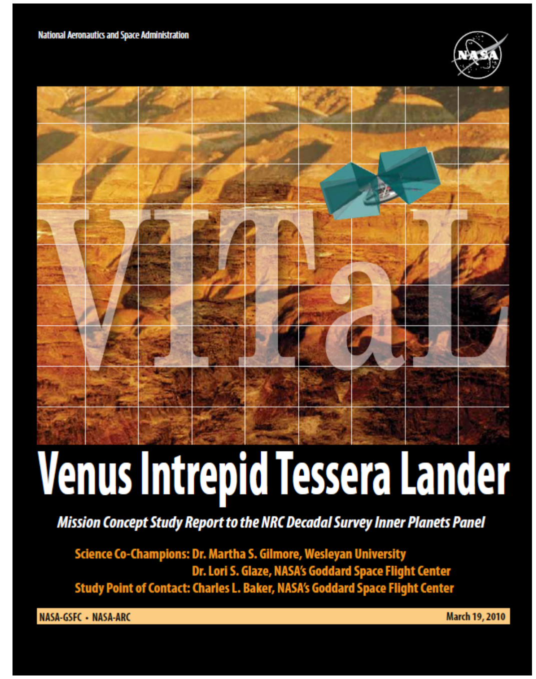
Project Deliverables

- **Characterize thermal and mechanical performance of 3D woven carbon fiber fabric**
  - Produce flight like woven fabric skin for ground test article and integrate with breadboard structural/ mechanical system
  - *Capable to 250W/cm²*
- **Perform mission feasibility study to understand operational requirements/ parameters and sizing calculations**
- **Design, Fabricate and Test sub-scale ground test article (~2m diameter)**
  - Fabricate rib/strut/ring/nose structures using COTS type extruded shapes for breadboard structural support system
  - Design and procure COTS hinge/joint/deployment mechanisms to simulate behavior of ADEPT for ground testing
- **Conduct Mission Concept Assessment for potential flight demonstration**

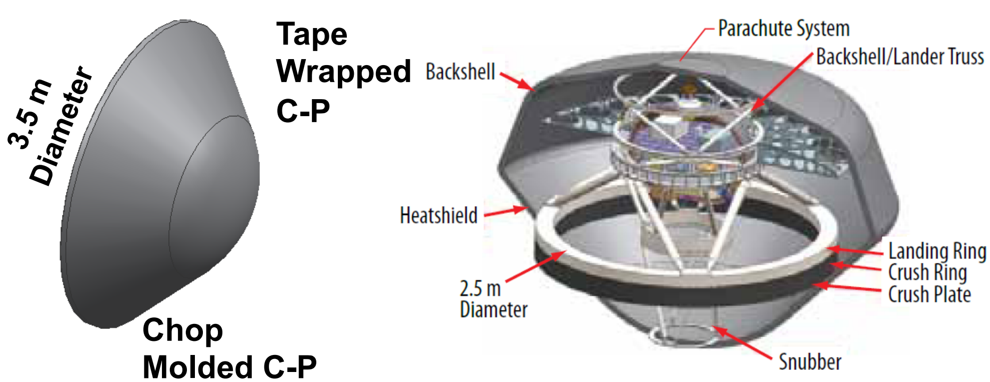


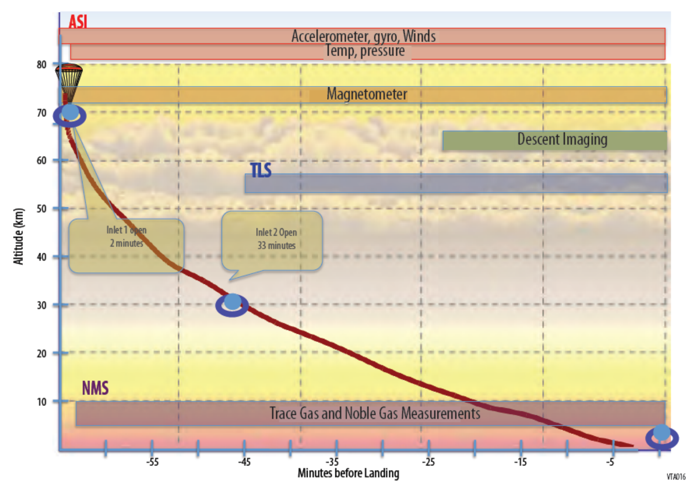
Applying ADEPT to a VISE-like Surface Mission: Venus Intrepid Tessera Lander (VITaL)





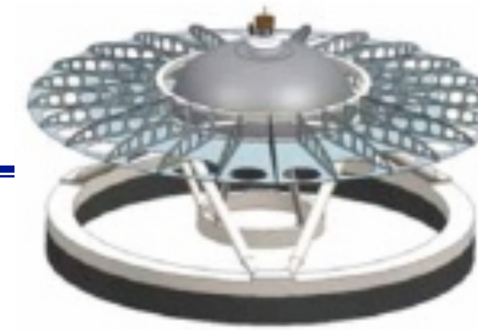
- **1 hour descent science**
  - Evolution of the atmosphere
  - Interaction of surface and atmosphere
  - Atmospheric dynamics
- **2 hours of surface and near-surface science**
  - Physics and chemistry of the crust





ADEPT

VITaL Strawman Science Instrument Complement

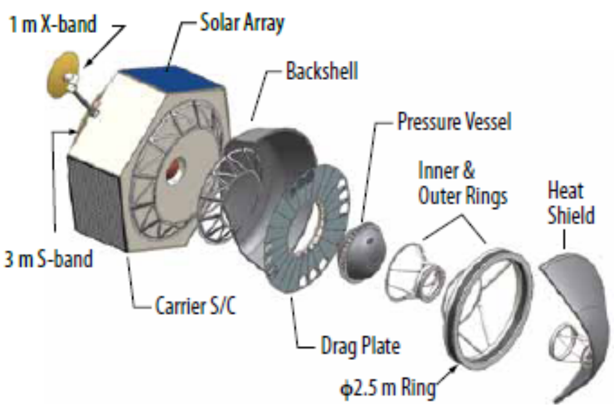


Optimistic with conventional aeroshell: steep entry angle = high g-loads

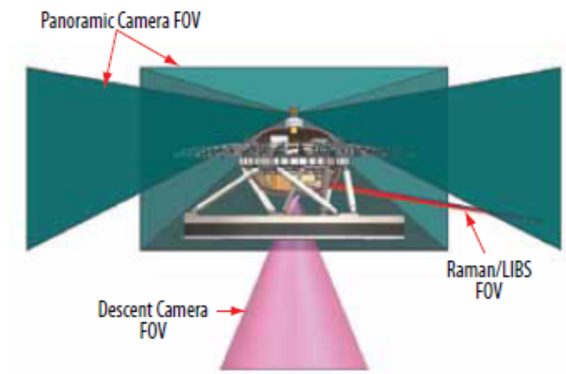
	Mass (kg)	Power (W)	Volume (meters)	Data Rate/ Volume	TRL / Heritage	Comment
Neutral Mass Spectrometer (NMS)	11	50	0.26 x 0.16 x 0.19	2 kbps	High/MSL/SAM	Data rate during descent; reduced to 33 bps on surface
Tunable Laser Spectrometer (TLS)	4.5	17	0.25 x 0.10 x 0.10	3.4 kbps	High/MSL/SAM	Data rate during descent; reduced to 300 bps on surface
Raman/Laser Induced Breakdown Spectroscopy (LIBS)	13	50	Per Optical Design	5.2 Mb per sample	Medium	12 bit, 3 measurements per sample - one Raman and 2 LIBS
Descent Imager	2	12	Per Optical Design	6.3 Mbits per image	High	12 bit, 1024 x 1024
Magnetometer	1	1	0.20 x 0.10 x 0.10	0.064 kbps	High/Various	Data rate during descent; reduced to 6.4 bps on surface
Atmosphere Structure Investigation (ASI)	2	3.2	0.10 x 0.10 x 0.10	2.5 kbps (descent) 0.25 kbps (surface	High/Flagship	
Panoramic Imager	3	12	Per Optical Design	16.4 Mbits per band	High	12 bit, 2048 x 2048 detector
Context Imager	2	12	Per Optical Design	25.2 Mbits	High	12 bit, 2048 x 2048 detector

Data volumes include 2:1 compression

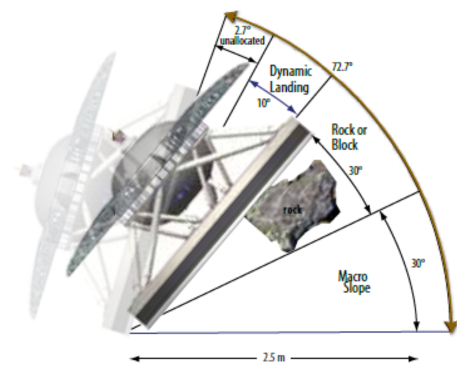
Entry flight System



Camera/Raman/LIBS Fields of View

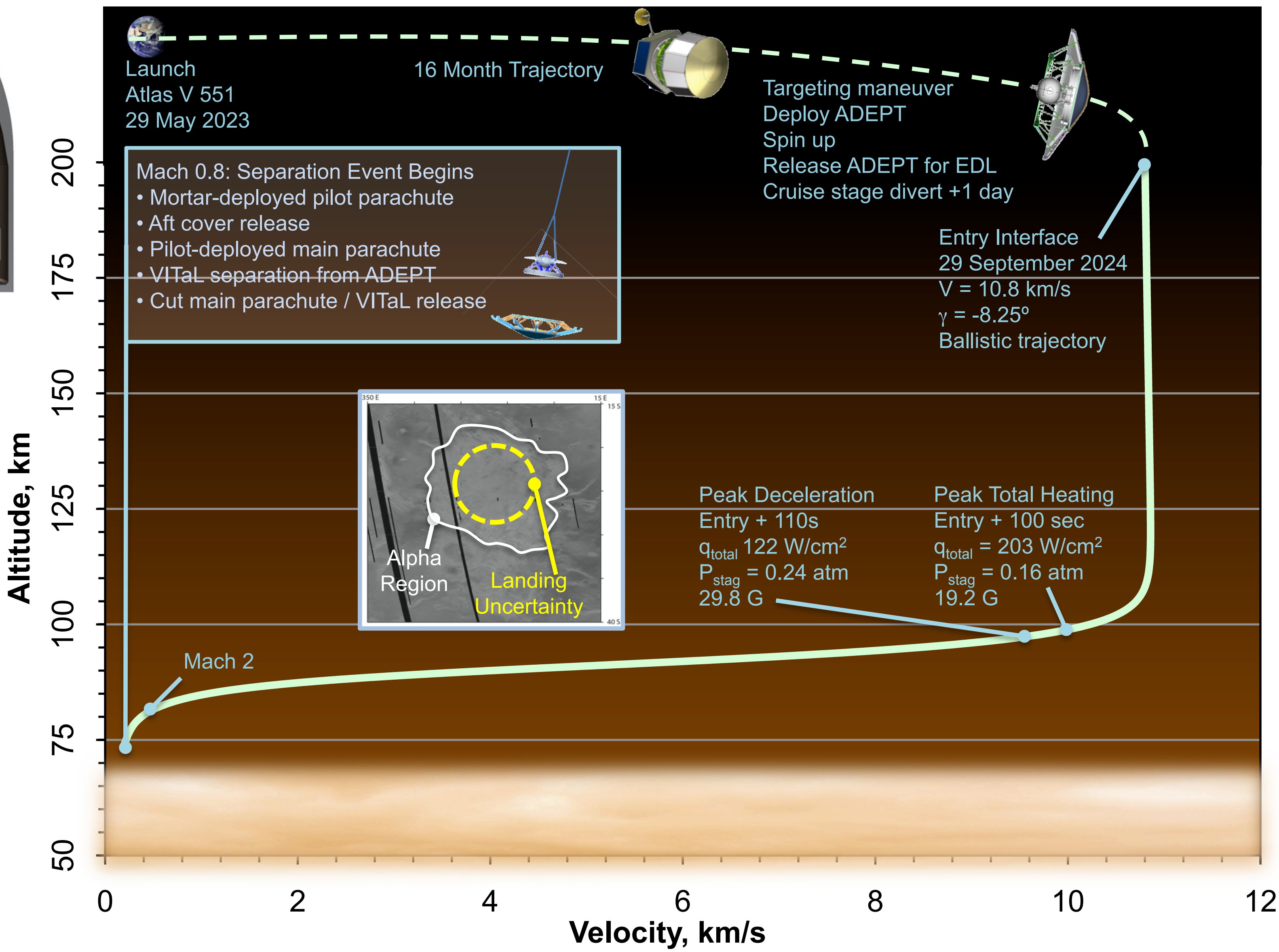


Stable Landing

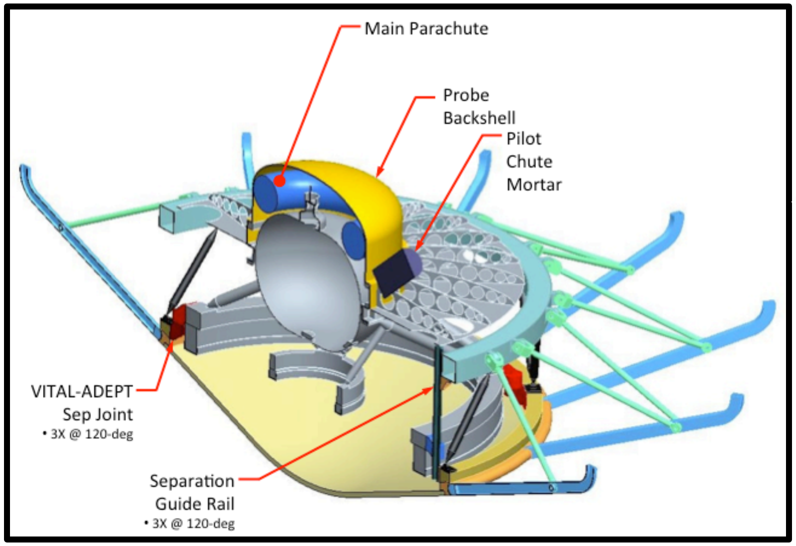


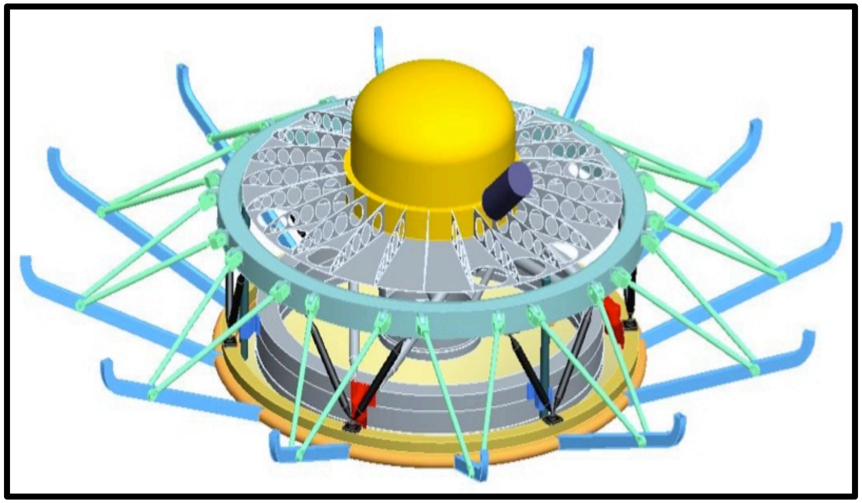
ADEPT-VITaL Mission Quick-Look

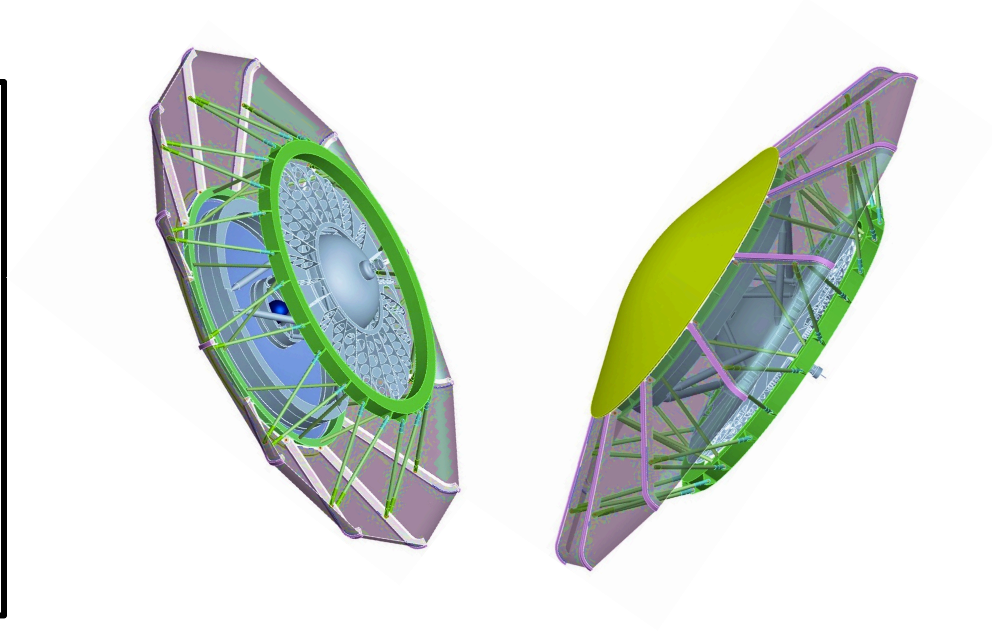
ADEPT



ADEPT-VITaL Design Details







- **ADEPT- VITaL Design Results:**
  - Margined mass estimates for ADEPT-VITaL entry configuration are lower than baseline VITaL

ADEPT-VITaL Mission Feasibility Report

ADEPT

- **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 13 July 2012.**

The ADEPT-VITaL Study Addresses:

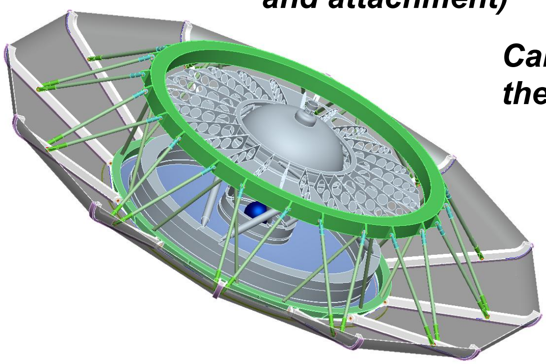
- **Mission Design Elements:**
  - **Launch vehicle**
  - **Interplanetary trajectory design / launch date**
  - **Cruise CONOPS / time of ADEPT deployment**
  - **Carrier spacecraft mods. / mass and power impacts**
  - **VITaL lander modifications and mass savings**
- **ADEPT-VITaL Vehicle Subcomponent 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**

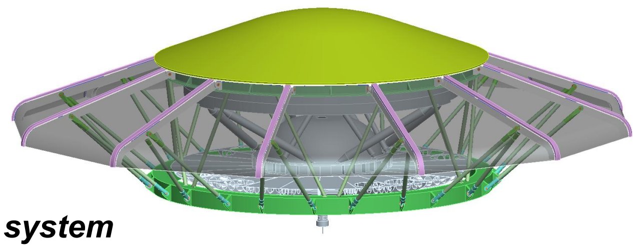
The ADEPT Team used Venus robotic as most challenging class for low ballistic coefficient decelerator applications

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

ADEPT Project Element Vision and Challenges

The ADEPT concept consists of a series of deployable ribs and struts, connected with flexible 3D woven carbon fabric skin, which when deployed, functions as a semi-rigid aeroshell entry system to perform entry descent landing (EDL) functions.





Manufacture of carbon fabric as system (seams and attachment)

Carbon fabric material withstands thermal and mechanical loads

Aero stability of ADEPT entry system

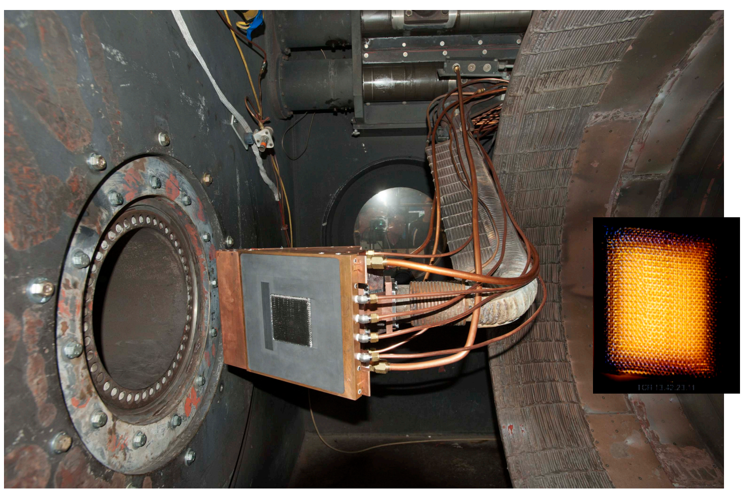
Fluid structure interaction of fabric at supersonic/subsonic conditions

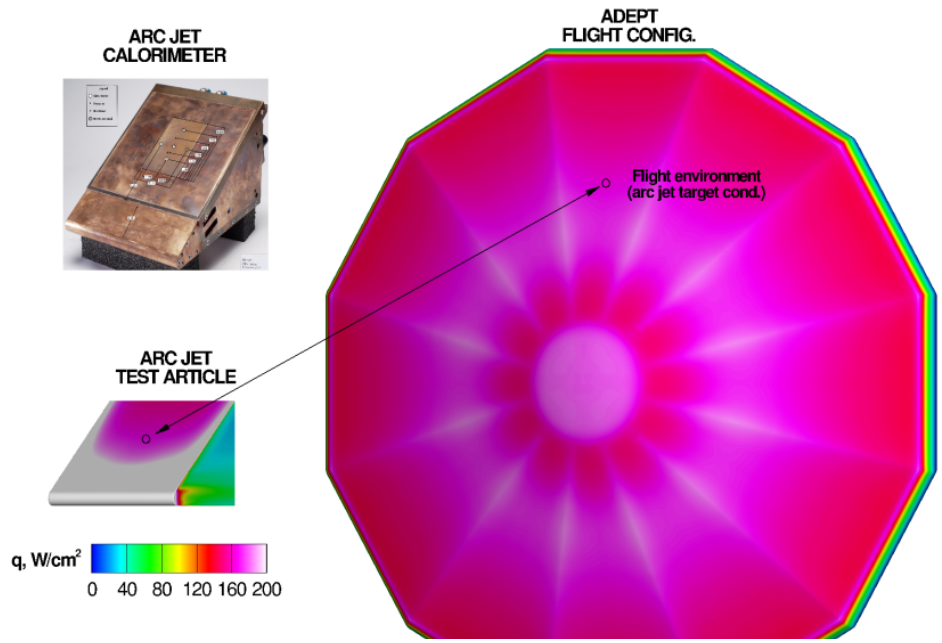
Stowage in launch configuration and deployment

- **ADEPT Year 1 – Budget ($3.3 M)**
  - Characterize thermal and mechanical performance of 3D woven carbon fiber fabric
    - Arcjet Testing in relevant enviornments
  - Develop ADEPT flight system requirements/capabilities
    - Establish end-to-end mission feasibility to support MOT
  - Start design process for Sub-scale demonstration ground test article
- **ADEPT Year 2 – Budget ($3.5M)**
  - Continue 3D woven material of Thermal and Mechanical characteristics development
  - Design, Fabricate and Test sub-scale ground test article (~2m diameter)
  - Initiate Flight Test Planning and Development

ADEPT Year-1 Major Accomplishment: Carbon Fabric Capability Demonstration

- **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 k above the 11 kJ/cm^2 expected for a Venus mission



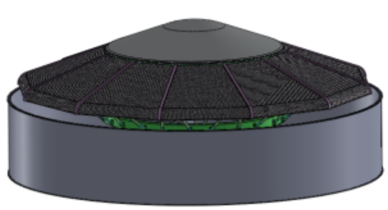


ADEPT

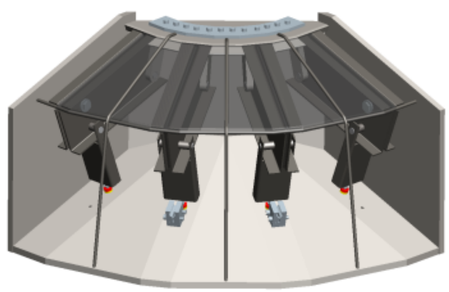
ADEPT Year-2 Technical Plan Highlights

FY 13	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
GTA	SRR		PDR	CDR C-Cloth Procurements	CDR					*Deployment Testing	*Load Testing	
Radiant Testing		PDR			CDR			Radiant Test-1				
Component Testing				C-Cloth Load Tests		PDR BLAM-2	C-Cloth Materials Database	CDR BLAM-2	BLAM-2 Seam Tests			
Flight Test	ADEPT/VITaL Test Plan Kick-off		ADEPT/VITaL		SDR		SRR			ADEPT/VITaL Final Report		MCR

*GTA tests could occur earlier by accelerating procurement of long lead items

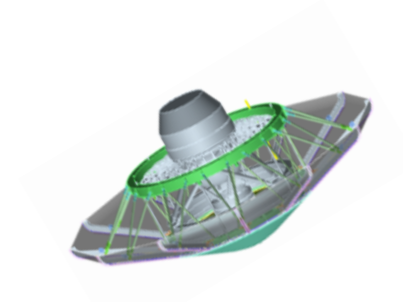


Ground Test Article
Deployment & Load Tests



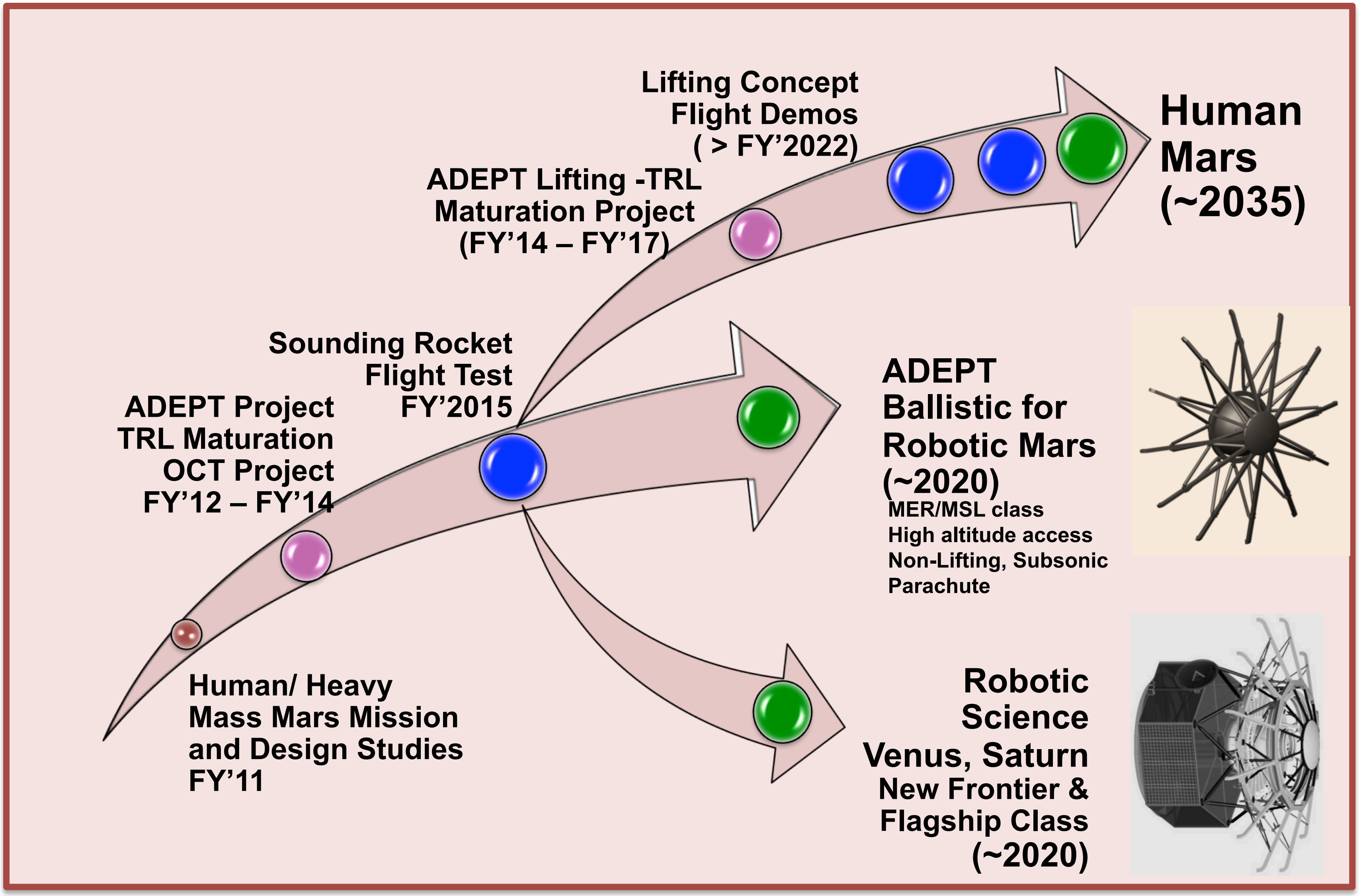
Radiant Testing
Thermal Tests

BLAM-2
C-Fabric Seam Tests



ADEPT/VITaL
Flight Test Planning

ADEPT Technology Maturation and Mission Applications Timeline



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
  - Use of flight qualified instrumentation for lower g-load at Mars and elsewhere
  - Entry mass and the launch mass are considerably reduced
  - 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**
- **Continued Technology Maturation of ADEPT concept by 2015/2016 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

Backup

Design/Analysis Accomplishments
Flight Aerodynamics

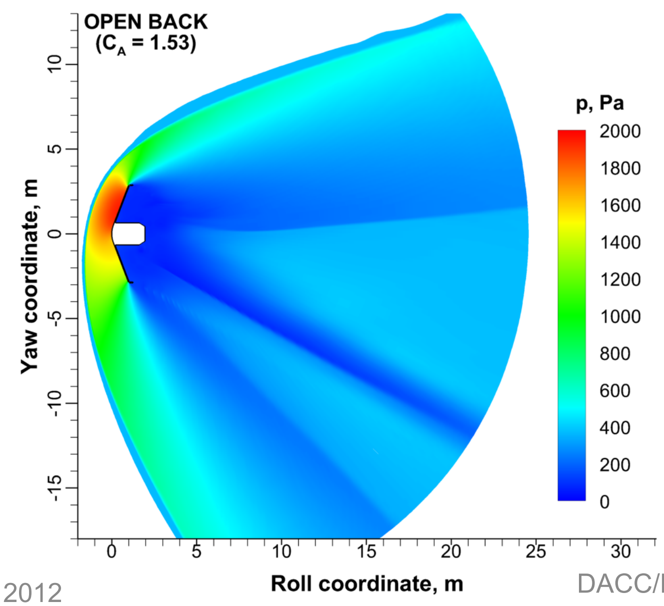
ADEPT

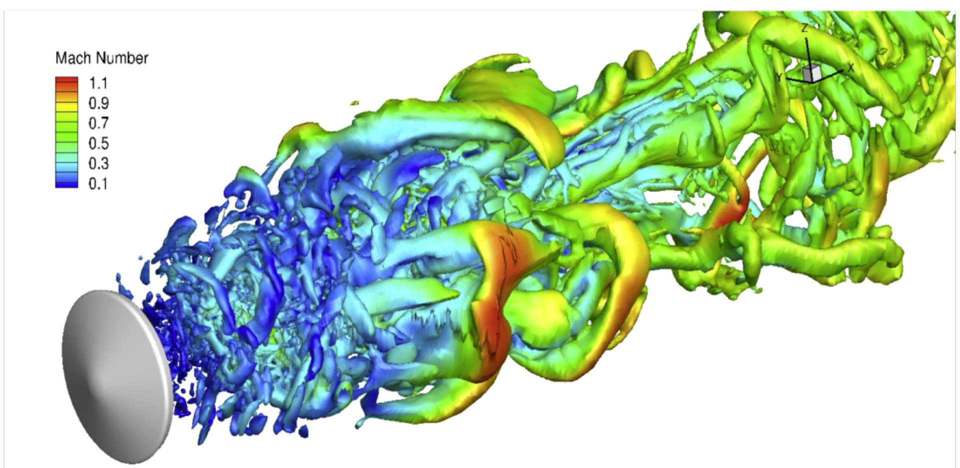
Key Points:

- **Static aerodynamics and dynamic stability of open-back configurations**
- **Flow-structure interaction and determination of "flutter" boundary (if any) at supersonic speeds**

Accomplishments:

- **Static aerodynamic database completed up to Mach 2 using 3D CFD code *DPLR***
- **Wake and vehicle dynamics computations with 3D CFD code *US3D* (pitch damping characteristics)**
- **Model developed for flow-structure interaction and incorporated into 3D CFD code *US3D***



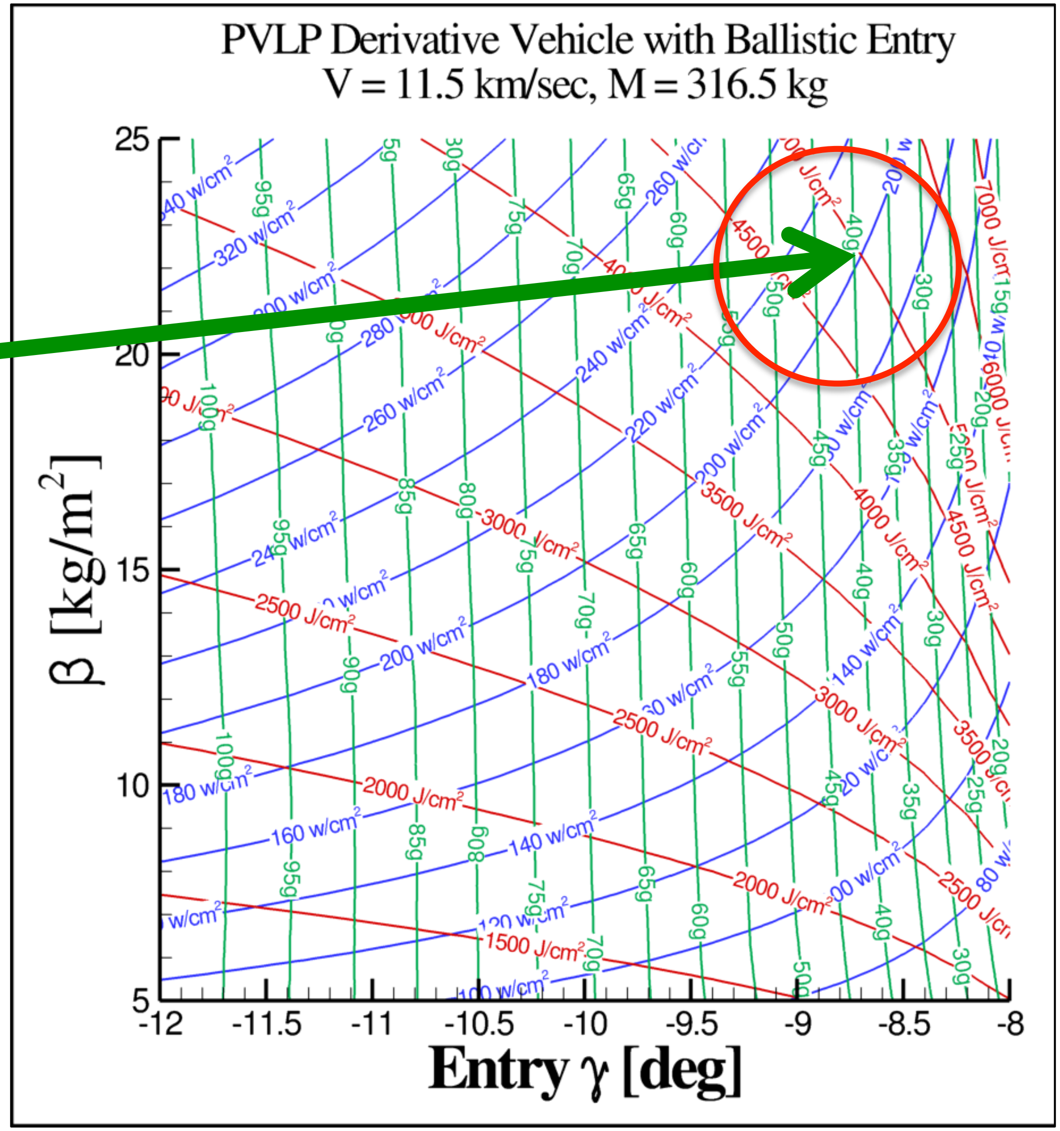


ADEPT

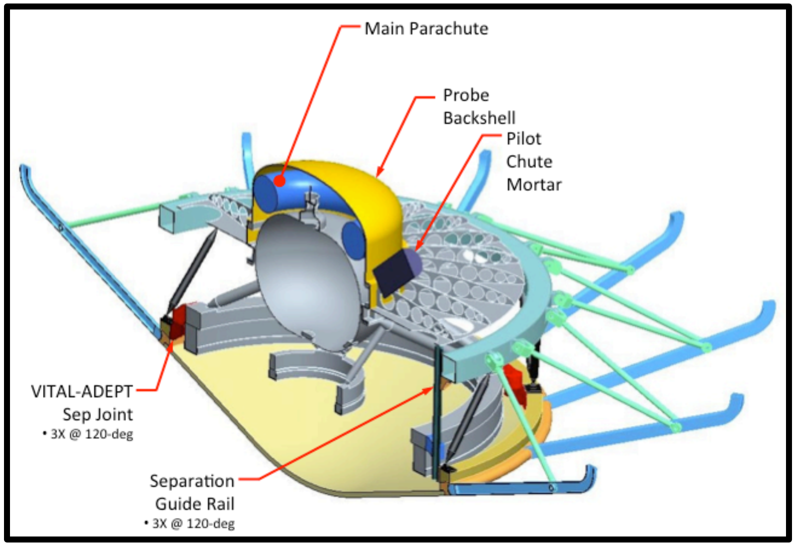
Game changing Approach to Venus Direct Entry with a Low Ballistic Aeroshell Concept

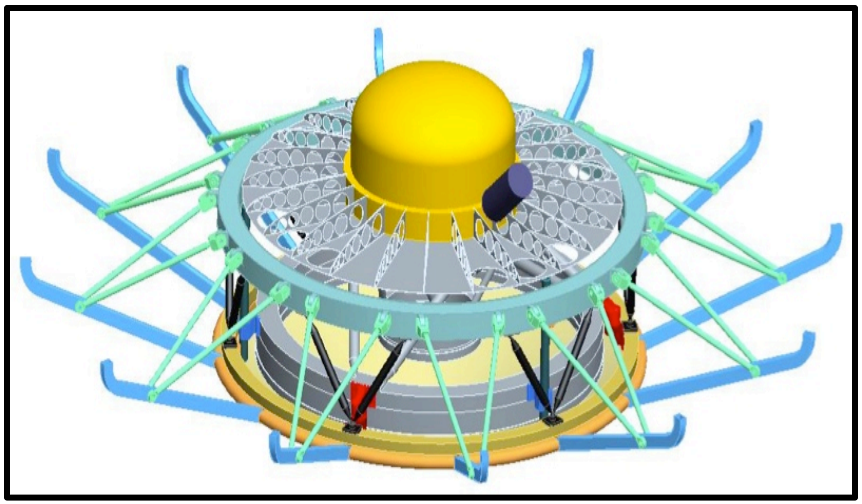
- **Assume ballistic coefficient can be lowered 10 x**

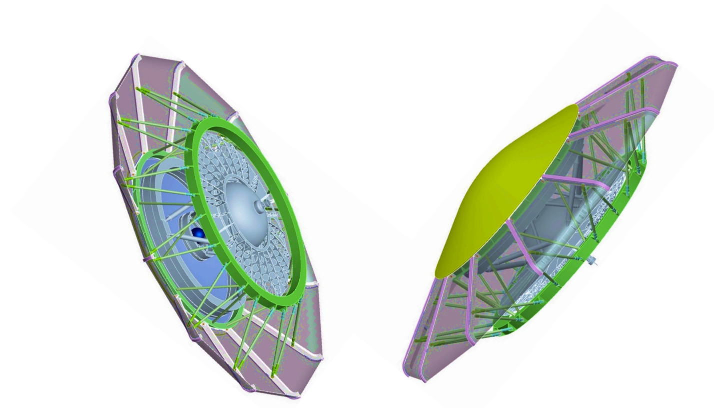
- **A material that can sustain 250 W/cm² is now feasible**
- **Corresponding heatload and pressure are considerably lower as well**
- **Peak deceleration can be reduced by an order of magnitude**



ADEPT-VITaL Design Details and MEL



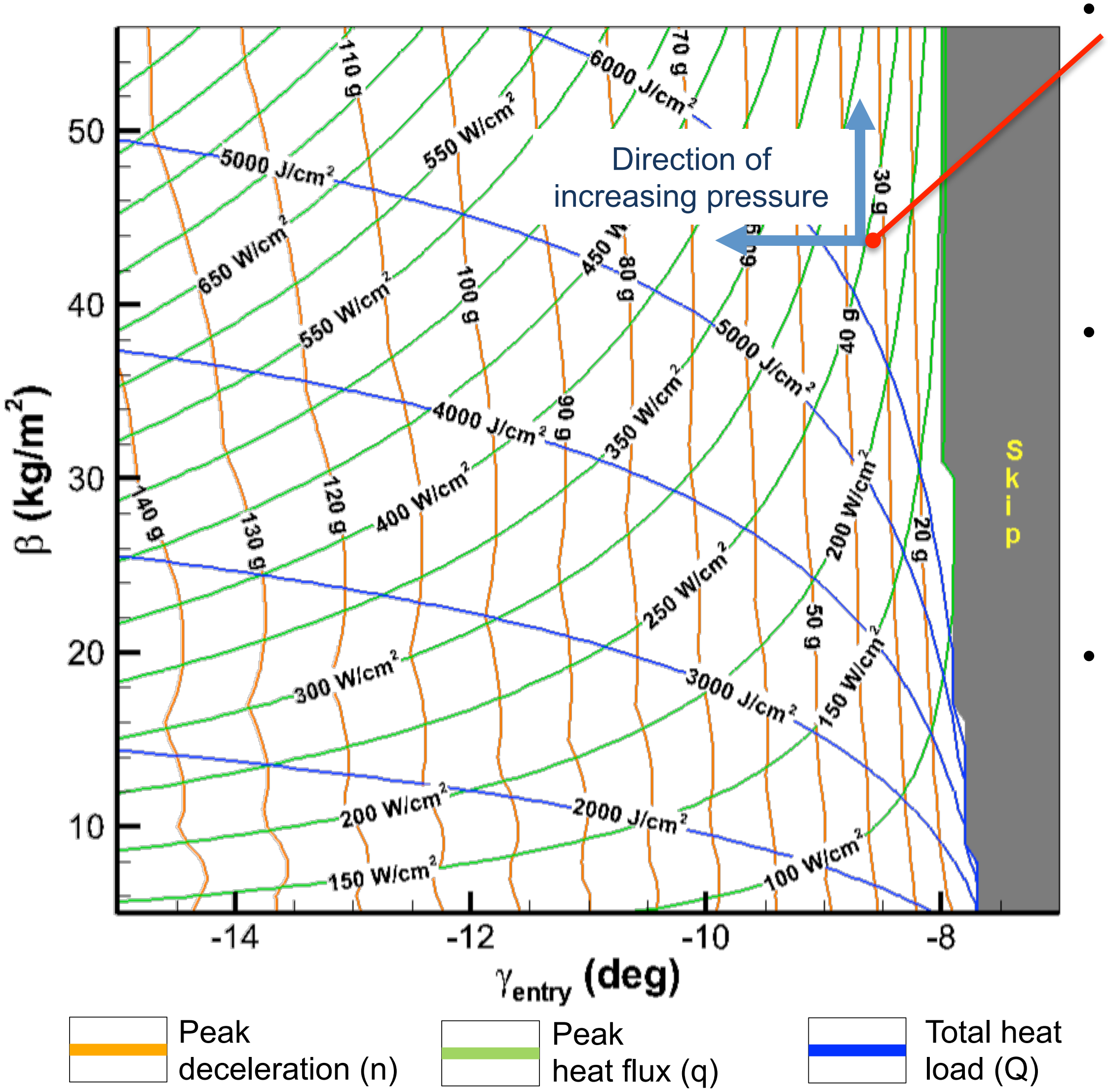




Item	ADEPT-VITaL CBE (kg)	ADEPT-VITaL Margined (kg)	VITaL Baseline Margined (kg)
Probe	1,621**	2,100**	2,758
Spacecraft	797	970	846
Satellite Dry Mass (Probe + Spacecraft)	2,418	3,070	3,858
Propellant Mass	1,111	1,122***	356
Satellite Wet Mass	3,529	4,192	4,214
Atlas V 551 Throw Mass Available to Lift Wet	5,140 kg		

Deployable (Low-β), Shallow-γ Sweet Spot

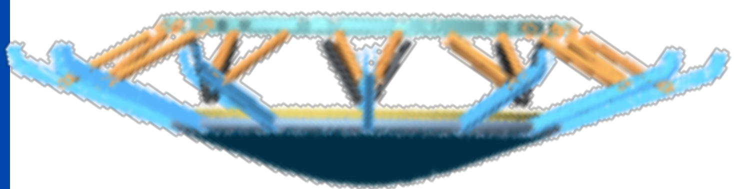
ADEPT

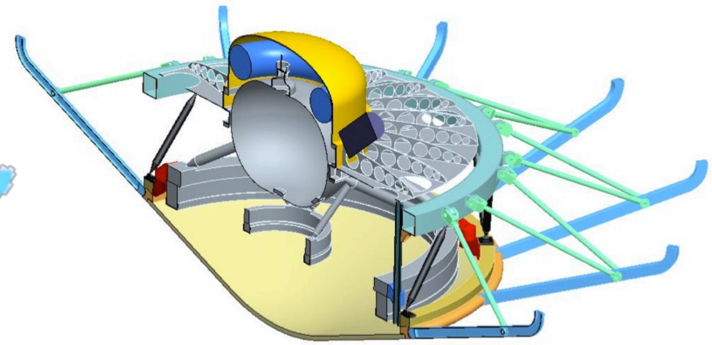


- Low-β entry, results in high altitude deceleration where the resulting entry aerothermal environment is benign
  - Well within the capability of carbon cloth
- Furthermore, the low-β architecture allows entry with a very shallow flight path angle, dramatically reducing entry G-load
- **ADEPT key benefits:**
  1. No need for carbon phenolic
  2. Benign entry G-load
     - ✓ Simplifies qualification of scientific instruments
     - ✓ Reduced structural mass of payload
     - ✓ Opens doors for improved science return using more delicate instruments

ADEPT-VITaL Master Equipment List and Comparison with VITaL

ADEPT





ADEPT Aeroshell	807	30%	1042
Heat Shield	**484**	30%	**629**
Main Body	233	30%	303
Nose cap & Lock Ring	61	30%	79
Ribs & Bearings	46	30%	60
Struts & End Fit	42	30%	55
Joint Hardware	10	30%	13
Carbon cloth	92	30%	120
Rigid Nose TPS	**71**		**85**
-Nose tps	50	20%	60
-Ribs tps	12	20%	14
-Aft cover TPS	9	20%	11
Backshell	**30**		**39**
"Payload" backshell	30	30%	39
Mechanisms & Separation	**205**		**267**
Overall Deployment System	54	30%	70
Stowed/Deployed Latches	19	30%	25
-aeroshell separation ring	30	30%	39
-separation guide rails	45	30%	59
-backshell sep	7	30%	9
-parachute system	50	30%	65
Avionics & Power	**17**		**22**
-avionics unit	4	30%	5
-harness	5	30%	7
-power unit	8	30%	10

ADEPT/VITaL Mass

Item	CBE [kg]	Composite Mass Growth Allow. [%]	ADEPT MEV [kg]	VITaL MEV (kg)
Probe *(Lander + Aeroshell)*	**1620.5**		**2100**	**2758**
VITaL Lander	813.5	30%	1058	1379
Lander Science Payload	**36.9**	30%	**48**	**63**
Mass Spec	8.3	30%	11	14
TLS	3.4	30%	4	6
Atmospheric Package	1.5	30%	2	3
Magnetometer	0.9	30%	1	1
Descent Camera	1.6	30%	2	2
LIBS / Raman Context Camera	1.8	30%	2	3
LIBS / Raman	9.8	30%	13	17
Panoramic Camera	2.3	30%	3	4
Science Payload Accommodation (including Mechanisms)	7.5	30%	10	13
Lander Subsystems	**776.6**	30%	**1010**	**1316**
Mechanical/ Structure	212.3	30%	276	368
Landing System	452.3	30%	588	784
Thermal	65.5	30%	85	100
Power	12.3	30%	16	16
Harness	10.0	30%	13	13
Avionics	6.8	30%	9	10
Mechanism Control Electronics	8.5	30%	11	13
RF Comm	9.0	30%	12	12
ADEPT Aeroshell	807	30%	1042	1379