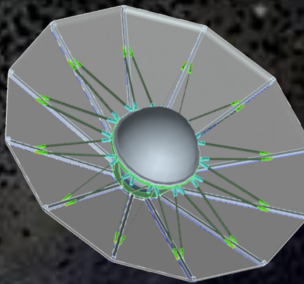
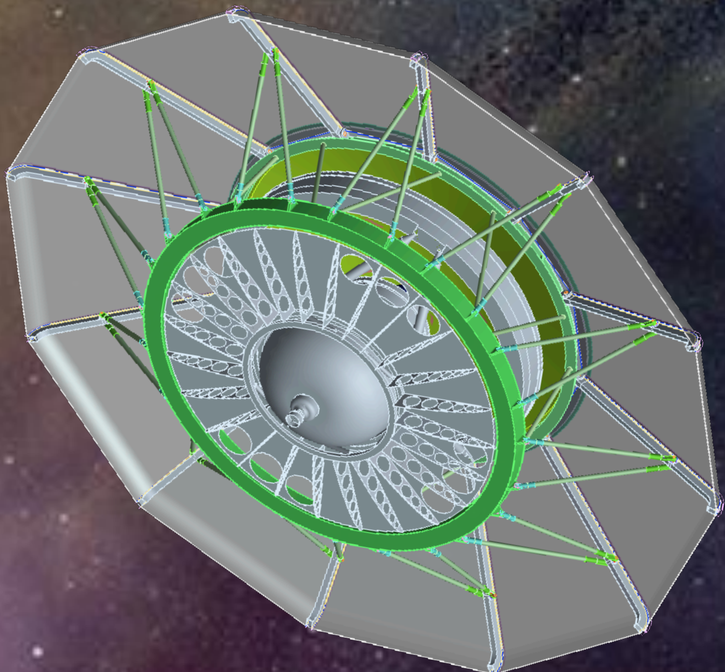
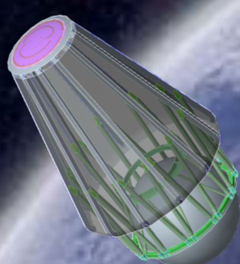
Adaptive Deployable Entry and Placement Technology (ADEPT):

A Technology Development Project funded by Game Changing Development Program of the Office of Chief Technologist



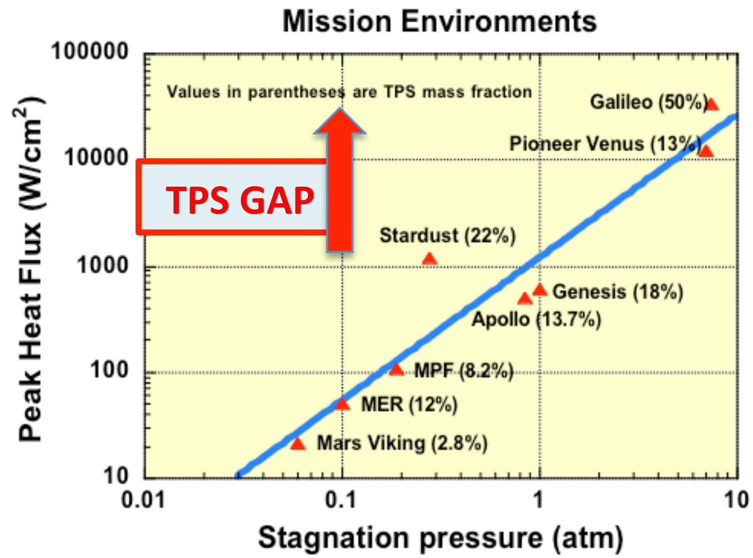


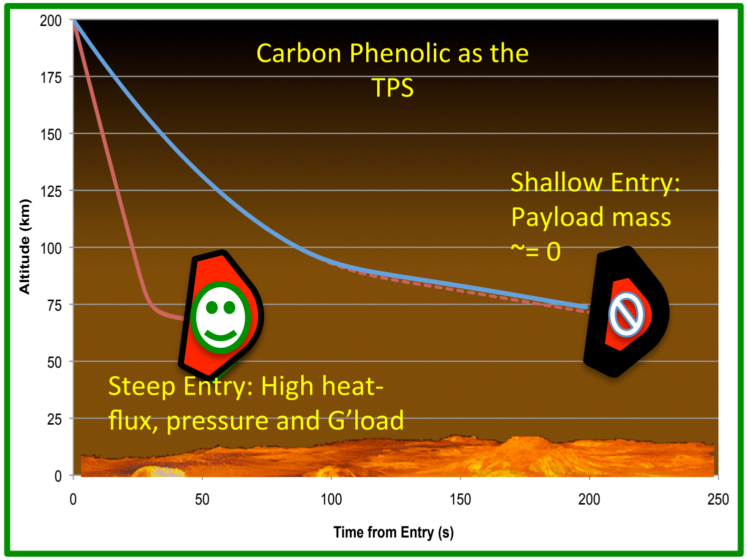


E. Venkatapathy, P. Wercinski, K. Hamm, B. Yount, D. Prabhu, B. Smith, J. Arnold, A. Makino, P. Gage and K. Peterson

Grand EDL Challenges:
Human Mars and Extreme Entry Environment Robotic In-Situ Science Missions

- **Human Mars Missions, landing ~ 40mT at the surface, a grand challenge**
- **In-situ robotic science missions to Venus and Outer planets pose significant challenges – a different kind of challenge.**
- **Mission concepts:**
  - Limited to one and only TPS and heritage Carbon Phenolic (CP) – no longer an option
  - Alternate forms of CP require resources and development time, and higher risk due to
    - Limitations of ground test capability
  - Carbon Phenolic - very capable, but mission constraining - Results in high entry environment (heat-flux, heat-load, pressure)
    - ➢ ground test capability to test
  - And high g'loads – limits science
- **Investment NASA (Office of Chief Technologist) is making to address these challenges – Mechanically Deployable Systems**

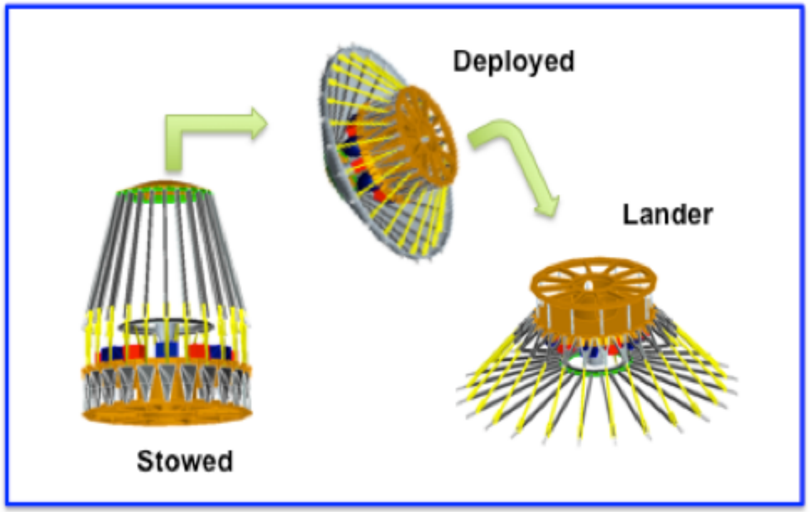


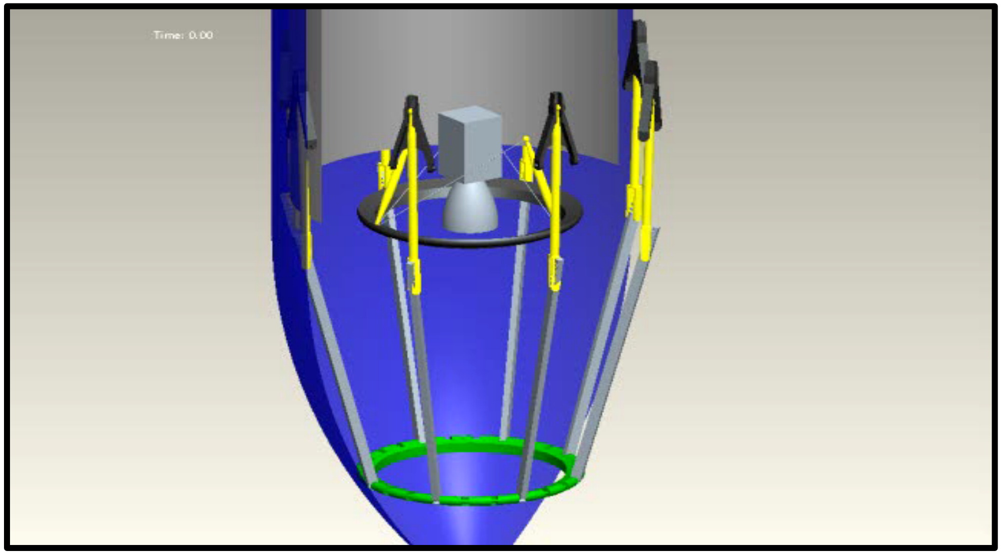


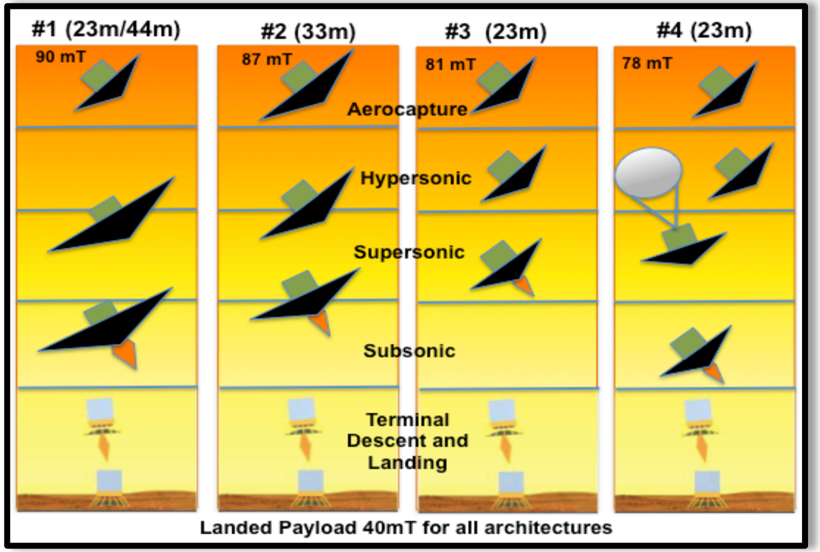
Adaptive Deployable Entry and Placement Technology (ADEPT) for Human Mars Missions

- **A Mechanically deployable, low ballistic coefficient concept developed and demonstrated to be viable (2010-2011) for Human and Heavy Mass Mars Missions**

- Designed like an umbrella with flexible carbon fabric to generates drag and withstand entry heating. Ribs, struts and and mechanisms allow deployment and gimballing of the frontal surface for lift vectoring during aerocapture, entry and descent. During landing, an invert maneuver allows the Aeroshell to be a landing attenuation system.
- Analysis, design, testing as well as mission design performed to prove viability of the mass competitive concept.
- OCT funded a Technology Maturation Project (2012)
- Non-lifting ballistic deployable concept mission enabler for Robotic Science Missions to Mars, Venus, Saturn, etc.

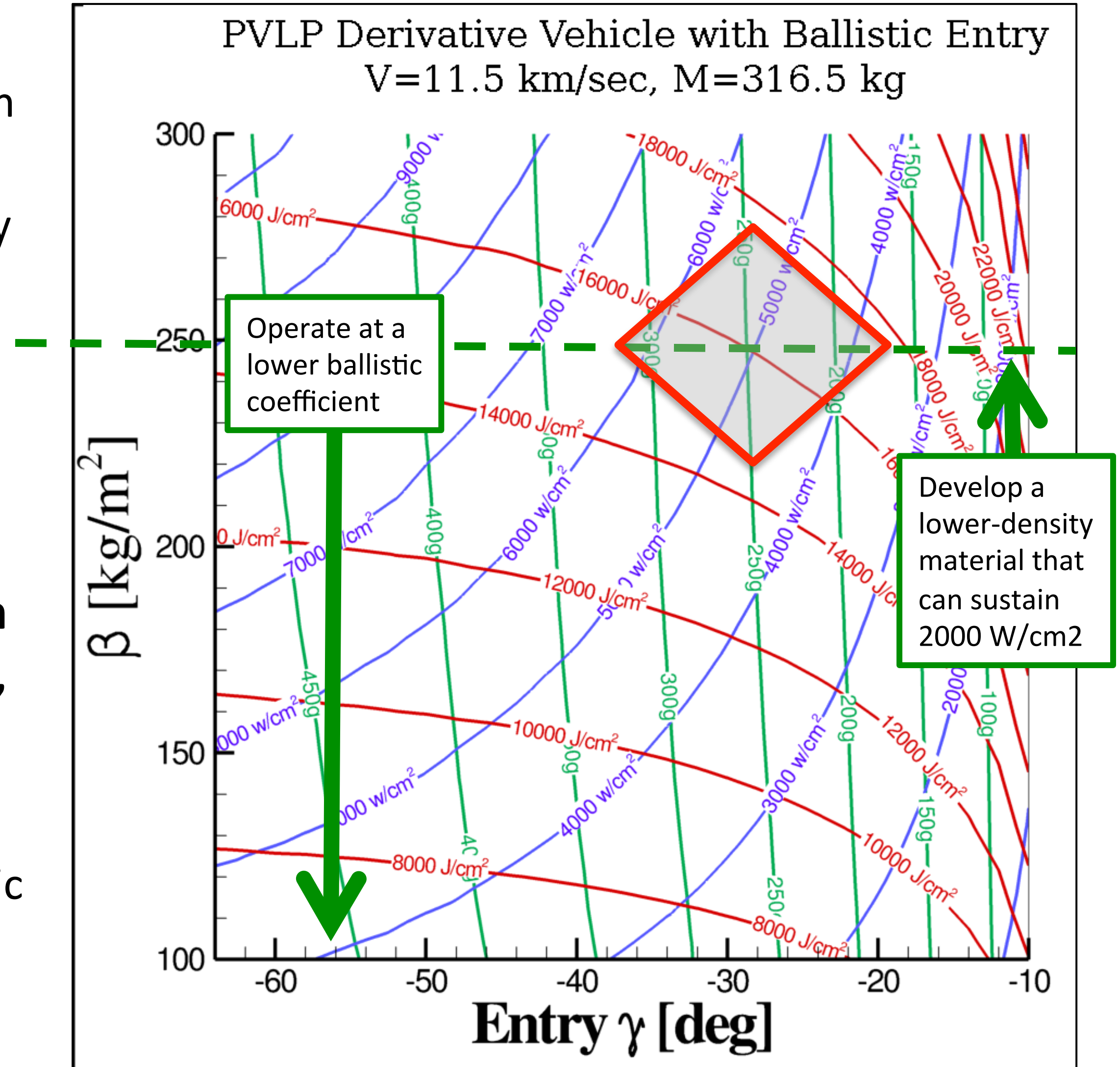






High-Speed Atmospheric Entry at Venus : The Challenge

- **For rigid aeroshell**
  - Size constrained by launch shroud
  - Entry mass constrained by launch vehicle throw capability
- **Ballistic coefficient ~ 250 kg/m²**
- **Balance between TPS (CP) and Payload mass fraction leads to extreme heatflux, pressure and G'load**
- **Alternate options are:**
  - Operate at a lower ballistic coefficient, or
  - Develop a new super efficient TPS



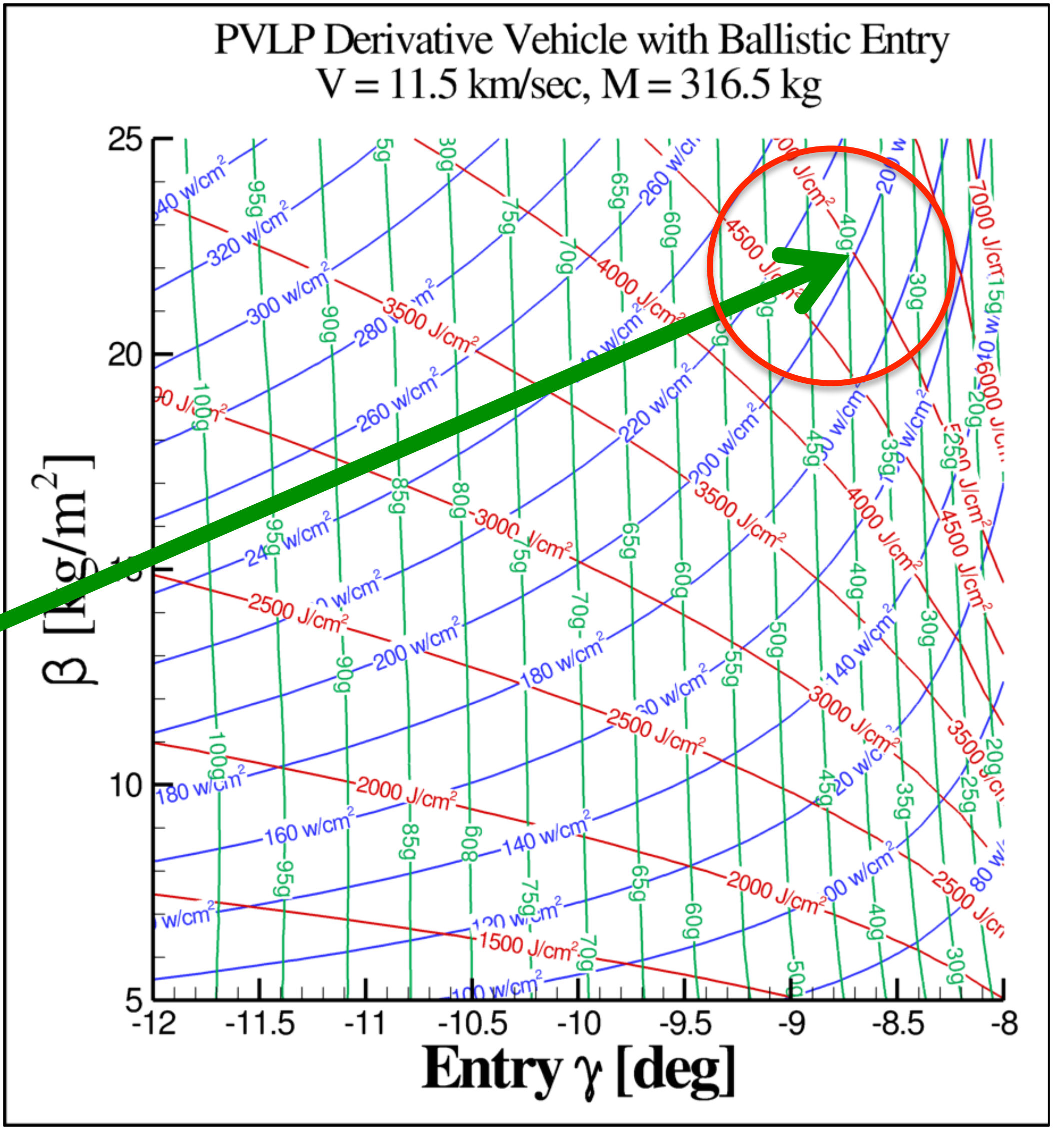
Game changing Approach to Venus Direct Entry with a Low Ballistic Aeroshell Concept

- **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

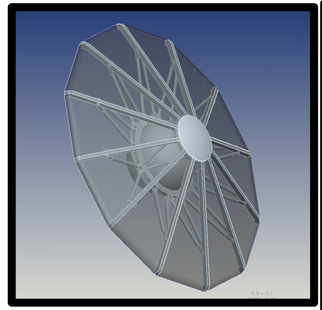


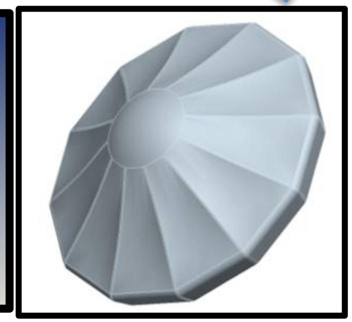
ADEPT (Adaptable, Deployable, Entry and Placement Technology) *is a low ballistic coefficient entry architecture (m/CdA < 50 kg/m²) that consists of a series of deployable ribs and struts, connected with flexible 3D woven carbon fabric skin, which when deployed, functions as a semi-rigid aeroshell system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

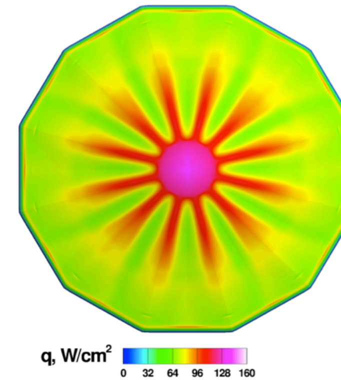
ADEPT is an OCT GCD Project (2+1yr) started in FY12

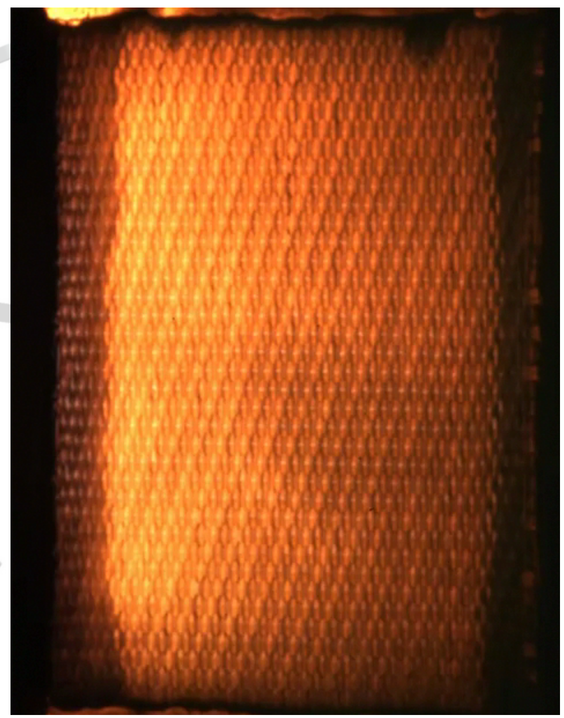
Project Deliverables

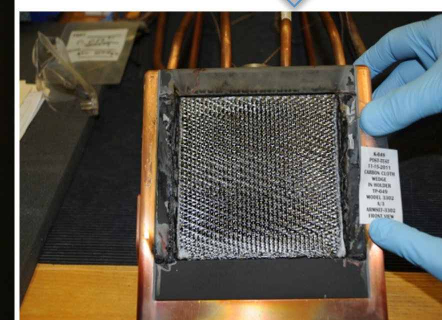
- **Characterize thermal and mechanical performance of 3D woven carbon fiber fabric**
  - Produce flight like woven fabric skin for ground test article and integrate with breadboard structural/ mechanical system
  - *Capable to 250W/cm²*
- **Perform mission feasibility study to understand operational 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 a flight demonstration (Yr 2+)**











ADEPT Project - Major Tasks and Deliverables
2 Years to TRL 5

YEAR 1

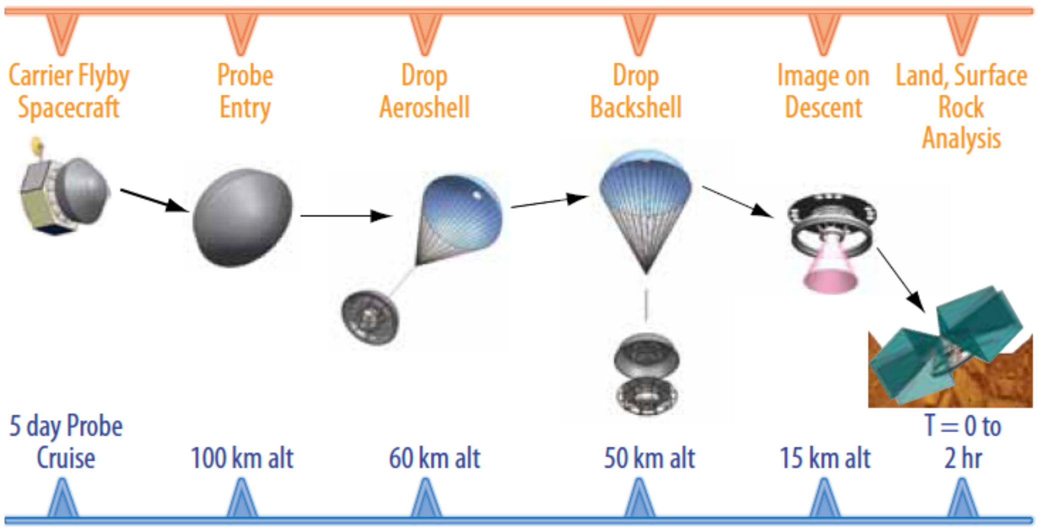
- **Develop ADEPT system requirements**
  - Develop and deliver end-to-end Venus specific mission feasibility study based on operational requirements/parameters and sizing calculations
  - Loads/Reqts. And feasibility report
- **Characterize thermal and mechanical performance of 3D woven carbon fiber fabric**
  - All material-level risks mitigated with test and/or analysis
- **Design for (~2m) ground test article**
  - Flight-like 3D woven carbon fabric and attachments
  - Breadboard representation of structure, hinges/joints, and deployment system

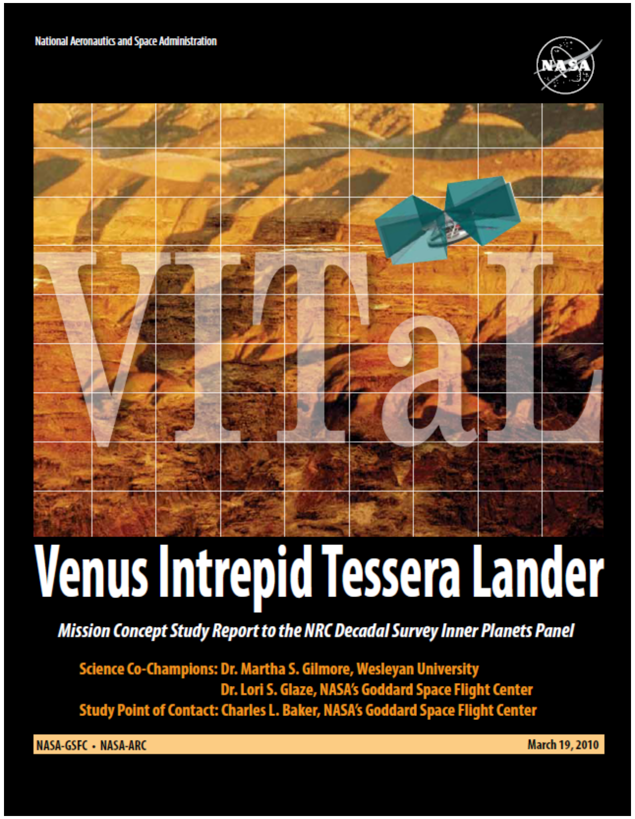
YEAR 2

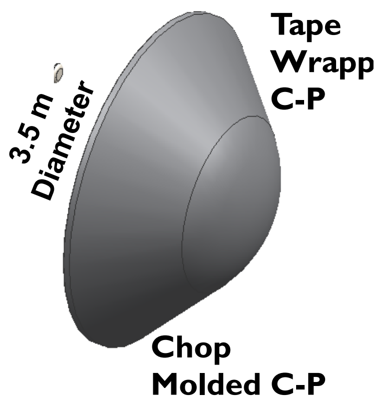
- **Continue 3D woven fabric development**
  - Refine fabrication processes for 3D woven fabric for GTA
  - Produce flight like woven fabric skin for ground test article and integrate with breadboard structural/mechanical system
- **Design, Fabricate and Test sub-scale ground test article (~2m diameter)**
  - 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
- **Develop a mission concept for flight test**

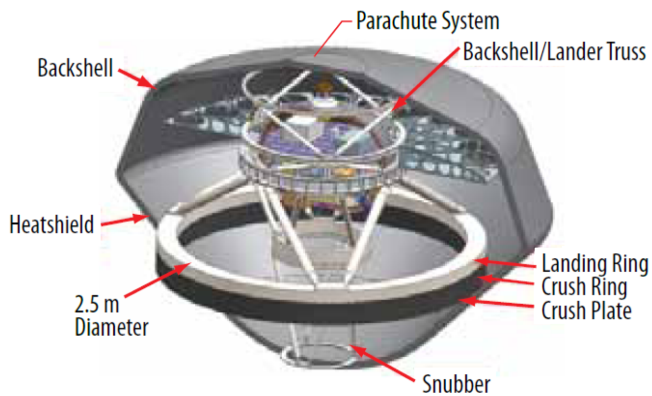
At the end of year 2, in addition to GTA fabrication and testing, prepare a flight test concept study and complete a Mission Concept Assessment Review for a sounding rocket or a sub-orbital flight test of a sub-scale test

ADEPT-VITaL Study







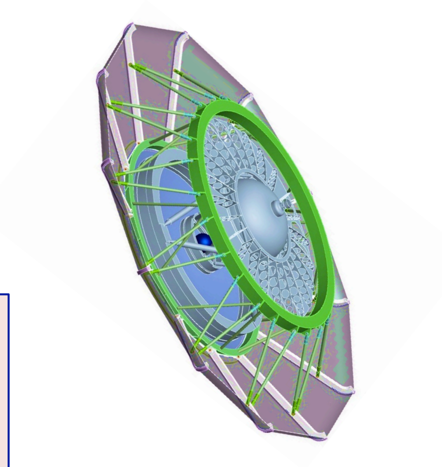


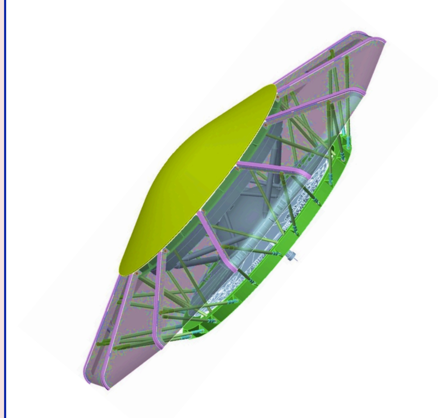
- **Unwrap the payload from VITaL rigid aeroshell study and integrate it with ADEPT architecture and compare architectures, define capability required and requirements**

ADEPT-VITaL Mission Feasibility:
Analysis, Trades and Design Decisions

Mission Feasibility

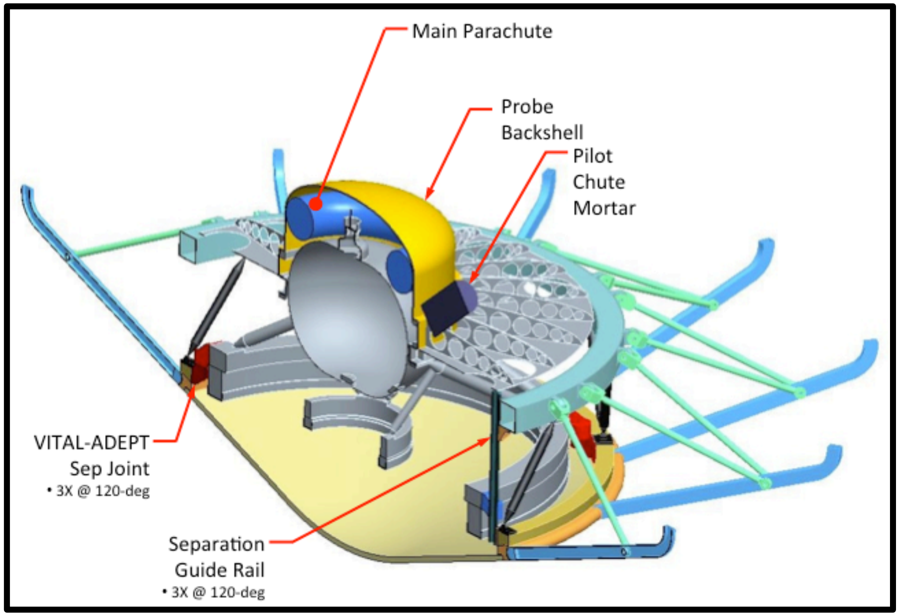
- **Mission Design**
  - Launch Vehicle Fairing Configuration
  - Launch Window
  - Cruise Stage Interface Requirements
  - ADEPT Deployment and Release
  - CONOPS
- **Entry Design Environment**
  - EDL Trajectory
  - Flight Mechanics
  - Aero-stability
  - Loads:
    - Aero
    - Aerothermal
    - Aeroelastic
    - Thermostructural
- **Entry System Design**
  - Geometry
  - Payload Integ. Packaging
  - Structures
  - Mechanisms
  - Materials
  - CG
  - MEL
- **Payload Deployment**
  - Subsonic Separation
  - Parachute
  - Pyrotechnics
  - Near-Field Re-contact
  - Far-Field Re-contact
  - Landing Site Targeting and Uncertainty

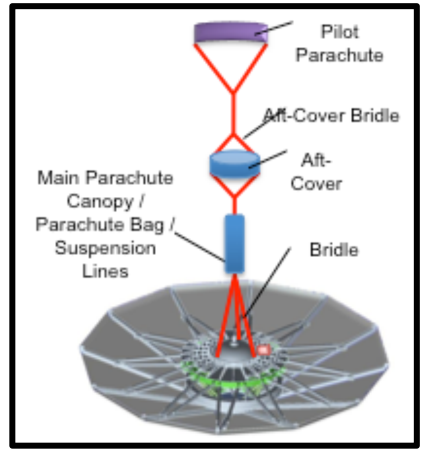


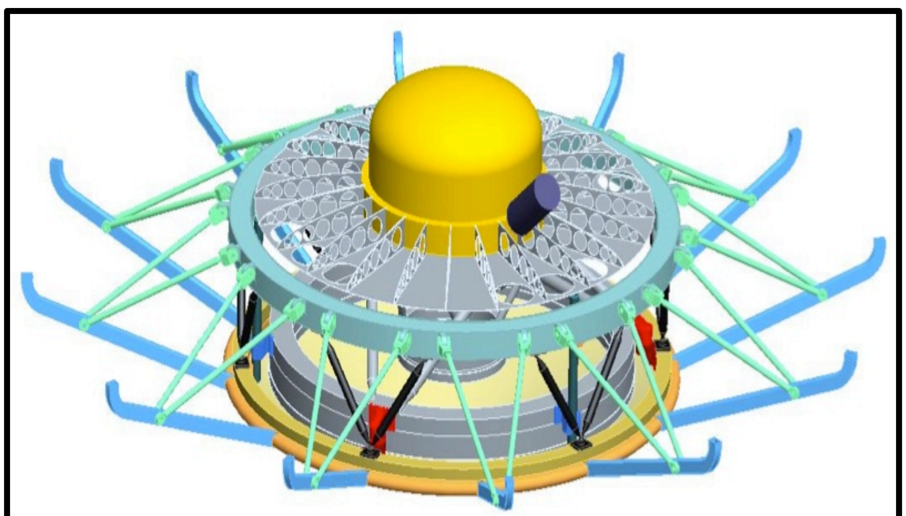


- Mission design and analysis coupled with trades to establish viability of ADEPT Concept loosely coupled with VITaL Payalod .
- Goal is to demonstrate the advantages of ADEPT rather than carry out a closely integrated design exercise

ADEPT-VITaL Design Details and MEL

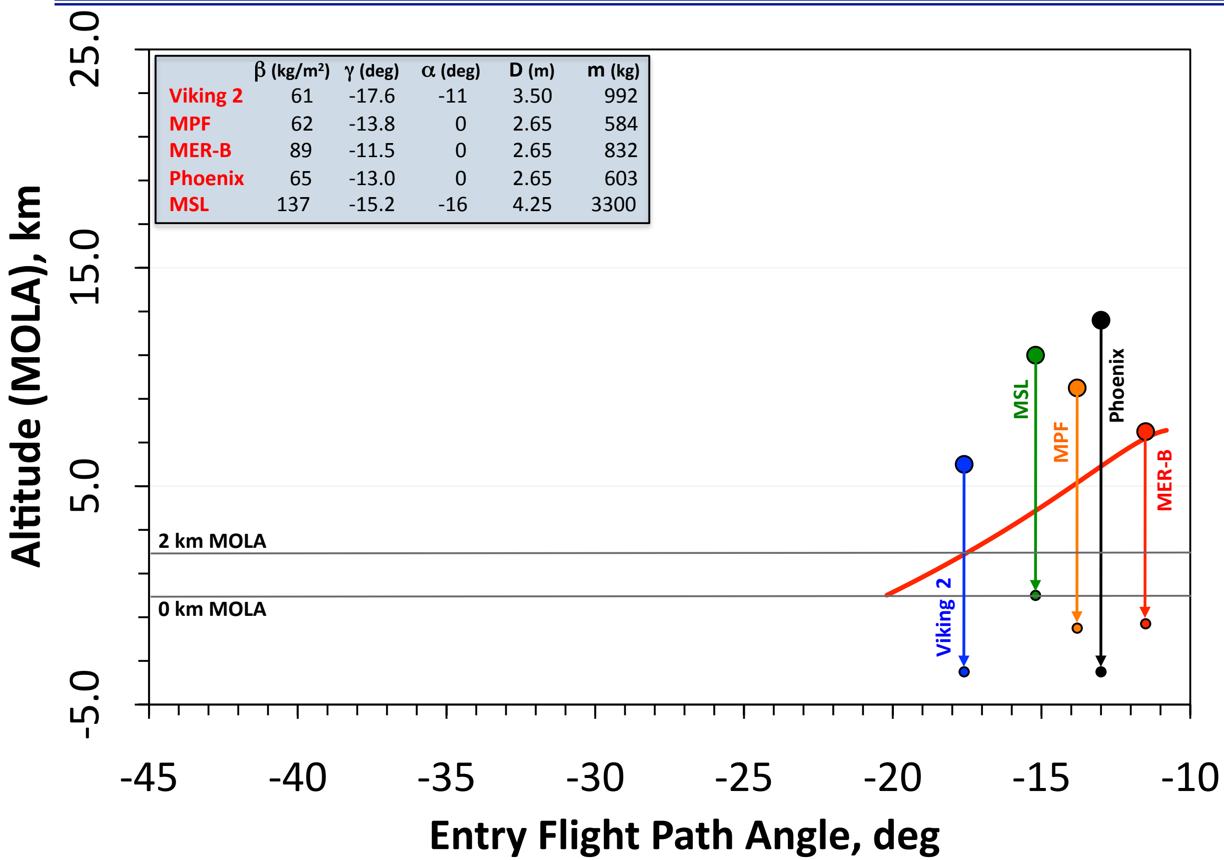






Item	ADEPT-VITaL CBE (kg)	ADEPT-VITaL Margined (kg)	VITaL Baseline Margined (kg)
Probe	1,621**	2,100**	2,758
Spacecraft	797	970	846
Satellite Dry Mass (Probe + Spacecraft)	2,418	3,070	3,858
Propellant Mass	1,111	1,122***	356
Satellite Wet Mass	3,529	4,192	4,214
Atlas V 551 Throw Mass Available to Lift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

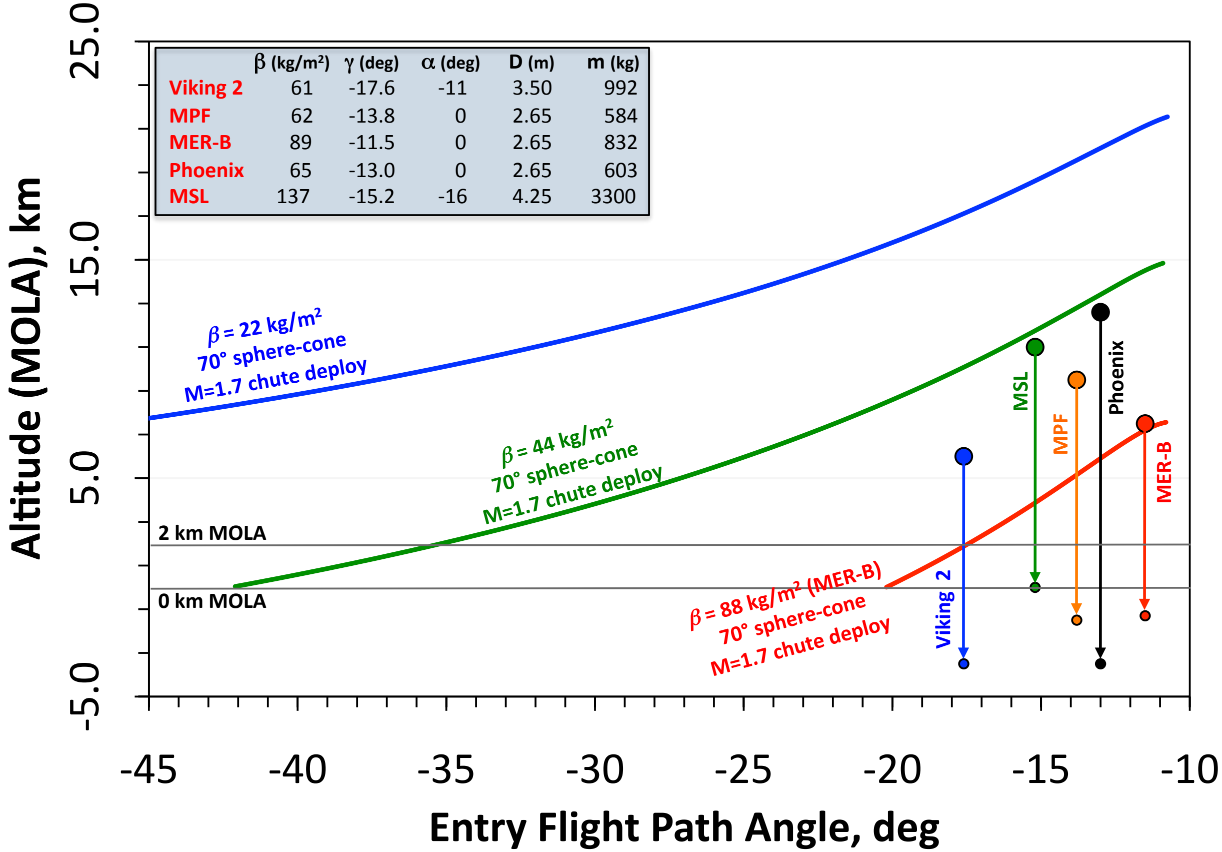
Global Mars Access : Very Challenging with Rigid Aeroshell



	β (kg/m²)	γ (deg)	α (deg)	D (m)	m (kg)
Viking 2	61	-17.6	-11	3.50	992
MPF	62	-13.8	0	2.65	584
MER-B	89	-11.5	0	2.65	832
Phoenix	65	-13.0	0	2.65	603
MSL	137	-15.2	-16	4.25	3300

- Missions have required combination of Supersonic Parachute Deployment and Lifting Entries

Global Mars Access : With ADEPT, landing site elevations is not an issue – Access any site on Mars



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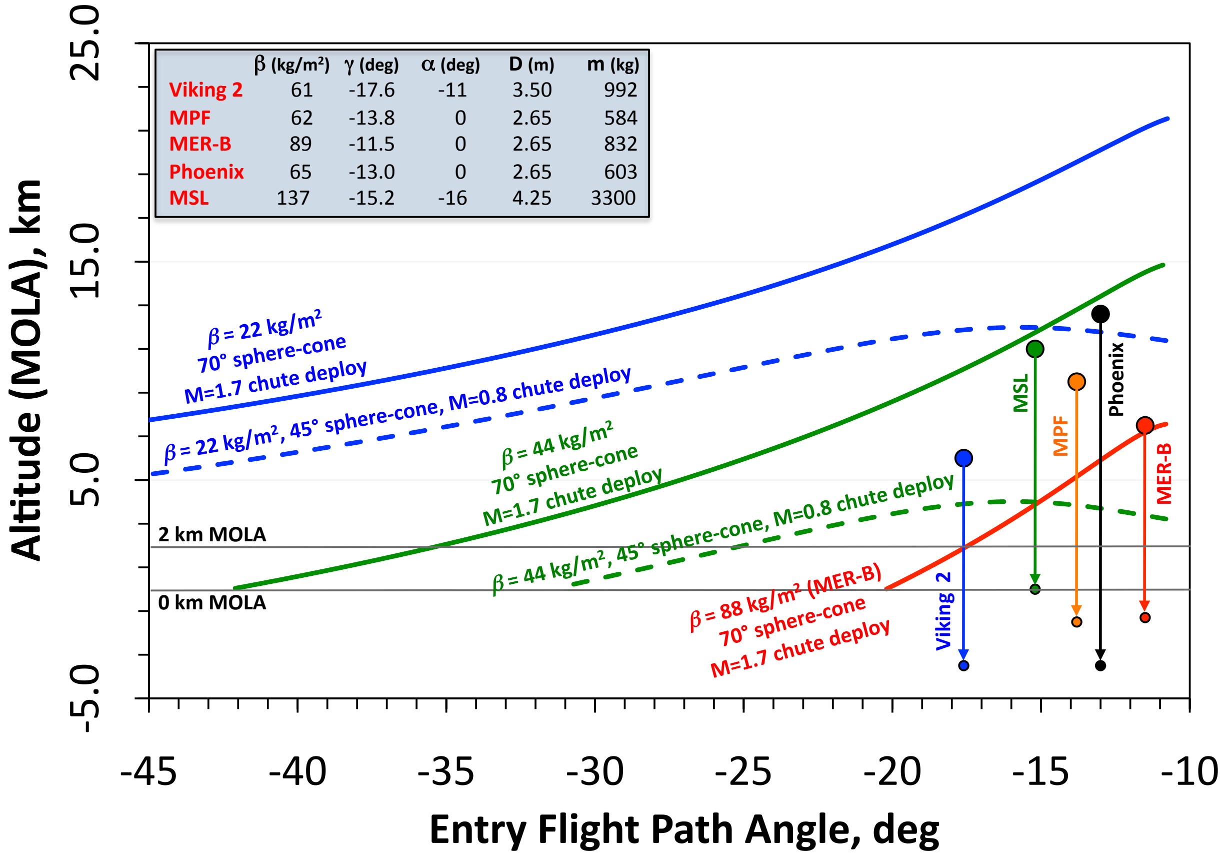
Example:

70° sphere-cone ADEPT

Diameter	= 6.5 m
Entry Ballistic Coefficient	= 44 kg/m²
Entry mass	= 2500 kg
Aeroshell Mass	= ~ 870 kg
Descent/Payload	= ~1630 kg

- Ballistic entry with ADEPT can eliminate risky EDL events for Robotic Mars
- High altitude deceleration results in benign aerothermal environment and g-load's
- ADEPT architecture allows steeper FPA reducing landing dispersion footprint

Global Mars Access : With ADEPT, landing site elevations is not an issue – Access any site on Mars



Decelerator Diameter, m

Entry mass kg	q_c deg	b=22 kg/m²	b=44 kg/m²	b=88 kg/m²
1000	70	5.8	4.1	2.9
2500		9.2	**6.5**	4.6
4000		11.7	8.3	5.8
1000	45	7.4	5.2	3.7
2500		11.7	8.3	5.9
4000		14.8	10.5	7.4

Example:

70° sphere-cone ADEPT
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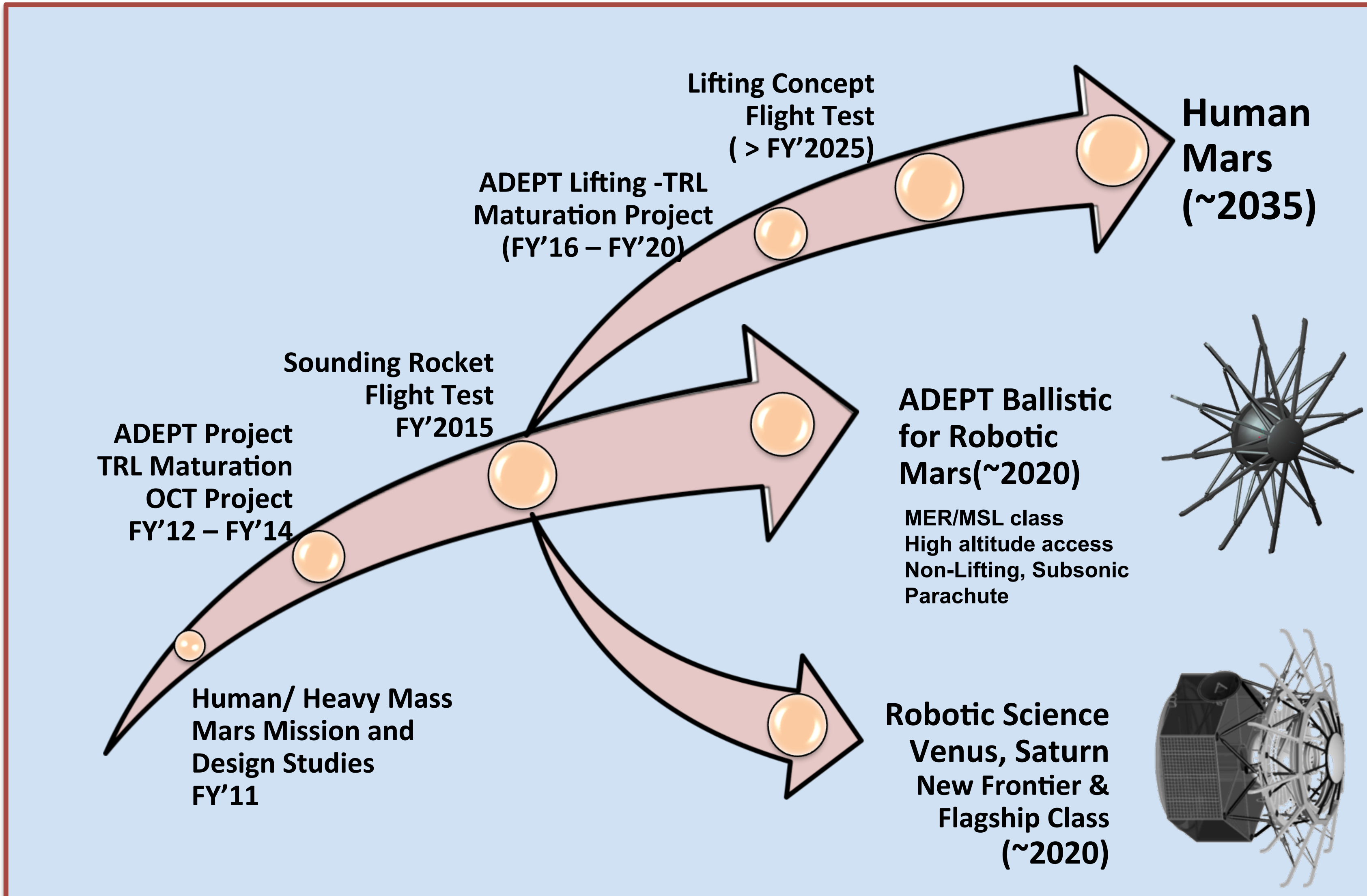
- Ballistic entry with ADEPT can eliminate risky EDL events for Robotic Mars
- High altitude deceleration results in benign aerothermal environment and g-load's
- ADEPT architecture allows steeper FPA reducing landing dispersion footprint
- ADEPT can enable subsonic parachute deployment at high altitudes
    - Does not require either Supersonic Retropropulsion (SRP) or Supersonic Parachute
- With ADEPT, landing site elevations is not an issue – Access any site on Mars

ADEPT Technology Maturation & Mission Applications Timeline



Conclusion

- **Low Ballistic Coefficient, mechanically deployable, ADEPT Architecture:**
  - **Developed to address the grand EDL challenges of human Mars mission**
  - **A simpler, non-lifting, ballistic entry architecture potentially capable of**
    - **Science Ennabler for Venus robotic in-situ science missions (& to Saturn, Neptune and Uranus)**
    - **Game changer for near terms Mars robotic and longer term Human Mars missions**
- **A (2+1 =3) year Technology Maturation Project funded by OCT underway**
  - Excellent progress made in a short period of time gives high credibility and confidence
  - Making the case for a 2014/2015 flight test and insertion via mission design studies

ADEPT is a game changer for near term Robotic Mars, Mid-term Robotic Venus, and in the longer term, human Mars missions.

ACKNOWLEDGEMENT

This work is currently supported by the Game Changing Development Program of the Office of Chief Technologist, NASA HQ.

We acknowledge the early support from the Innovative Partnership Program of NASA HQ and the Center Investment Funds from NASA Ames Research Center.

A core team of people, from NASA Centers, Universities and Small businesses have been involved in the concept development (in 2010/2011) and in the currently on going (2012 – 2014) Technology Maturation project.

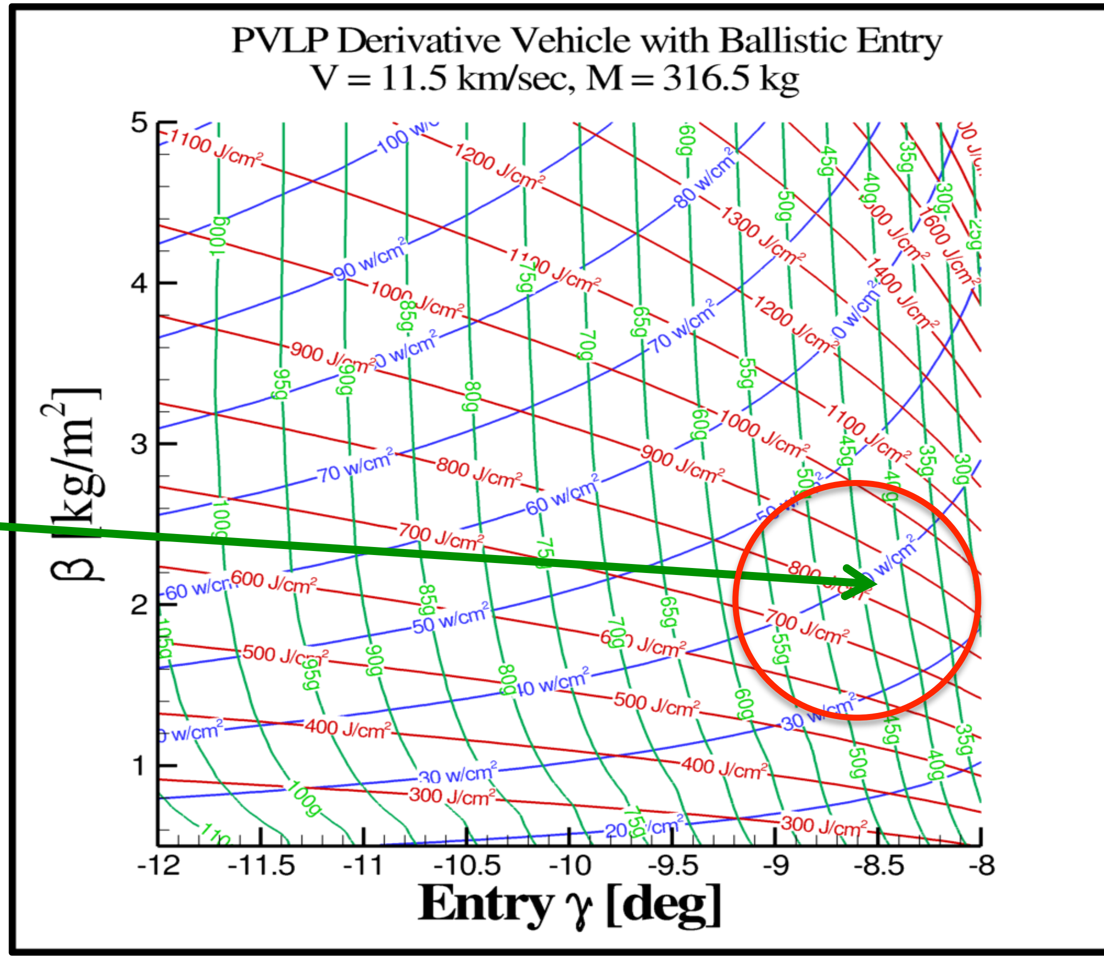
NASA Ames Research Center is leading this effort and is supported by NASA Langley, NASA Johnson Space Flight Center, NASA Goddard Space Flight Center and Jet Propulsion Laboratory.

Back up

Opportunity for High-Speed Atmospheric Entry – Venus Example

- **Assume ballistic coefficient can be lowered 100 x**

A material that can sustain 40 W/cm2 is now feasible.
Entry System Ballistic Coefficient needs to be ~ (2 – 3) kg/m2 which includes the payload
Peak deceleration is invariant with Ballistic Coefficient



Low ballistic coefficient concepts with lower heat-flux capability have to be a) very large, b) extremely low areal density, to have any payload capacity