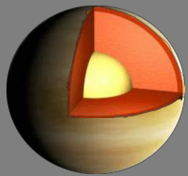
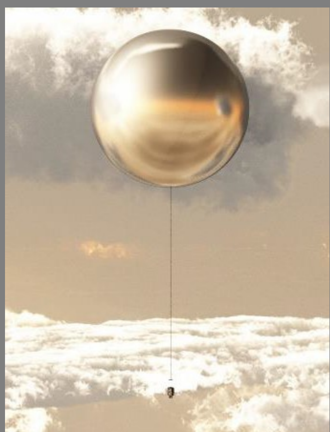
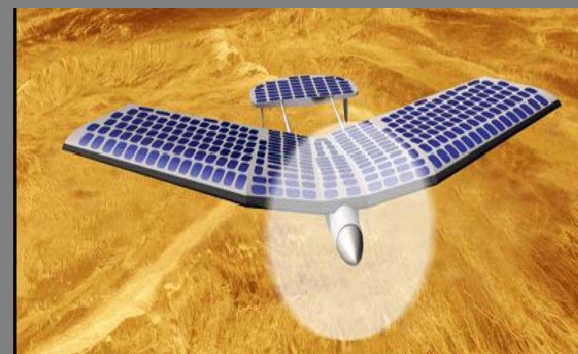


Venus Entry Challenges and Solutions for Aerial Platform Deployment





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Venus Aerial Platform Workshop #2,

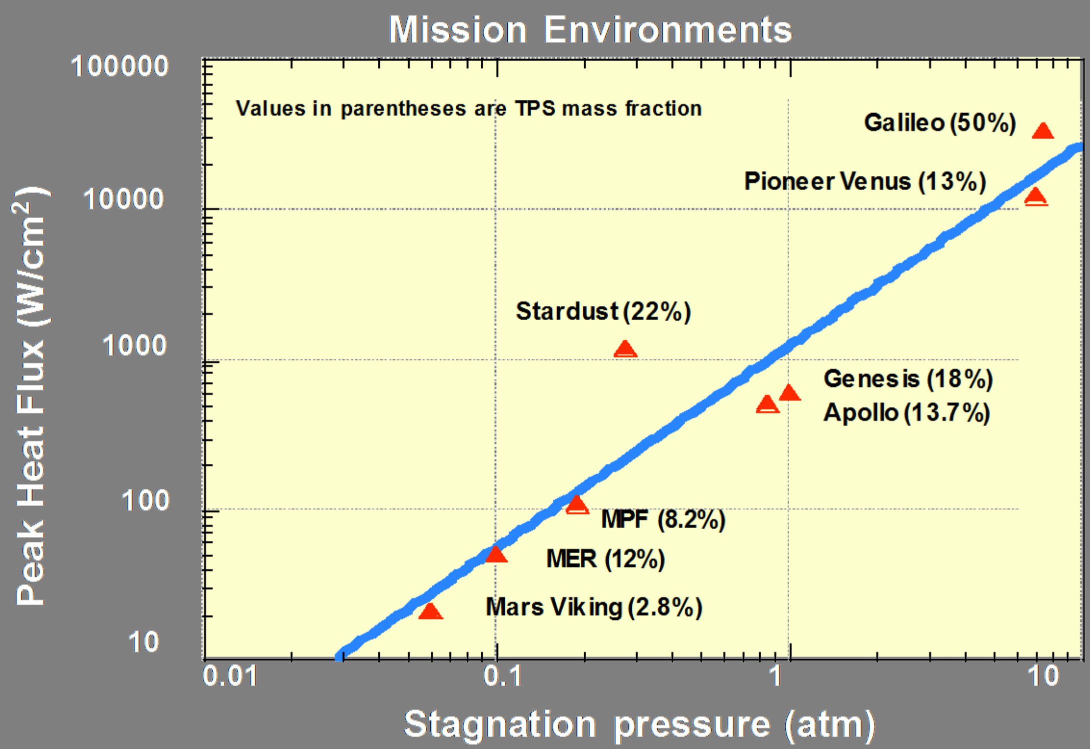
December 6, 2017 Pasadena, CA

Summary

- Entry, Descent and Deployment (EDD) of aerial platforms at Venus **with rigid aero-shell is no more challenging** than at other destinations.
  - Limited only by the availability of efficient heat-shield/TPS technology.
  - NASA is investing in the maturation of “Heat-shield for Extreme Entry Environment Technology (HEEET)” to TRL 6 and is incentivizing its use for New Frontiers - 4 missions
  - Future Venus Aerial Platform missions can use HEEET in place of Carbon Phenolic, which is not currently available
    - HEEET is more mass efficient and permits lower-deceleration entry profile
- Lower ballistic coefficient concepts, ADEPT and HIAD, may offer additional opportunities
  - even lower-deceleration entry profiles
  - Release of multiple probes from open back of EV
- Lowest ballistic coefficient lifting concepts (VAMP) may provide other science benefits but concept and technical maturity are low

NASA has Demonstrated Entry System Capability

- Missions have successfully survived entry environments ranging from the very mild (Mars Viking ~25 W/cm2 and 0.05 atm.) to the extreme (Galileo ~30,000W/cm2 and 7 atm.)
- P-V and Galileo used Carbon-Phenolic (CP) (but heritage CP TPS is no longer viable). HEEET is a mass efficient system that will be available for future Venus missions

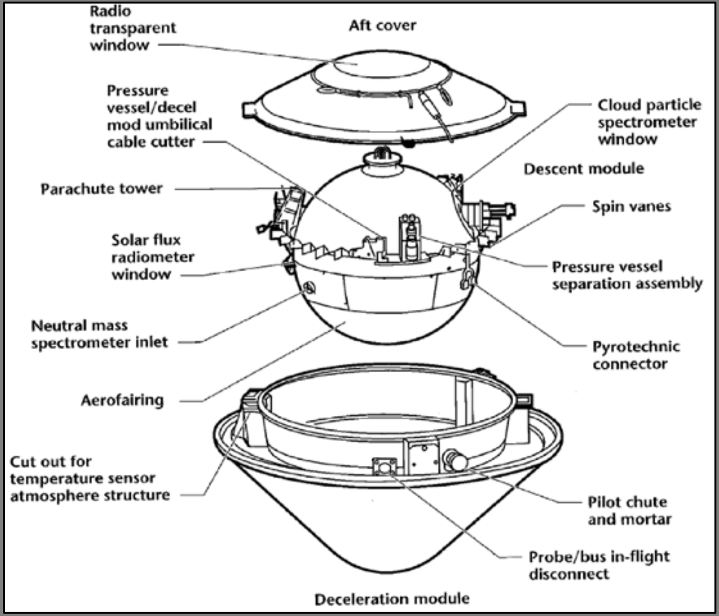


Entry System:
Protects the Scientific Payload and Deploys at the Right Location and Orientation

Entry begins when atmospheric effects start to impact the system

- **Function of Entry System**:
  - Safely deliver the "payload" from outside the atmosphere to a prescribed location within the atmosphere at prescribed condition (altitude, velocity and orientation)
    - Protects from the entry aerodynamic **deceleration loads** due to drag
    - Protects from **entry heating** (TPS)
    - Achieve prescribed trajectory during entry as a result of aerodynamic stability
  - All of the Venus entry missions to-date have been ballistic and non-lifting entry

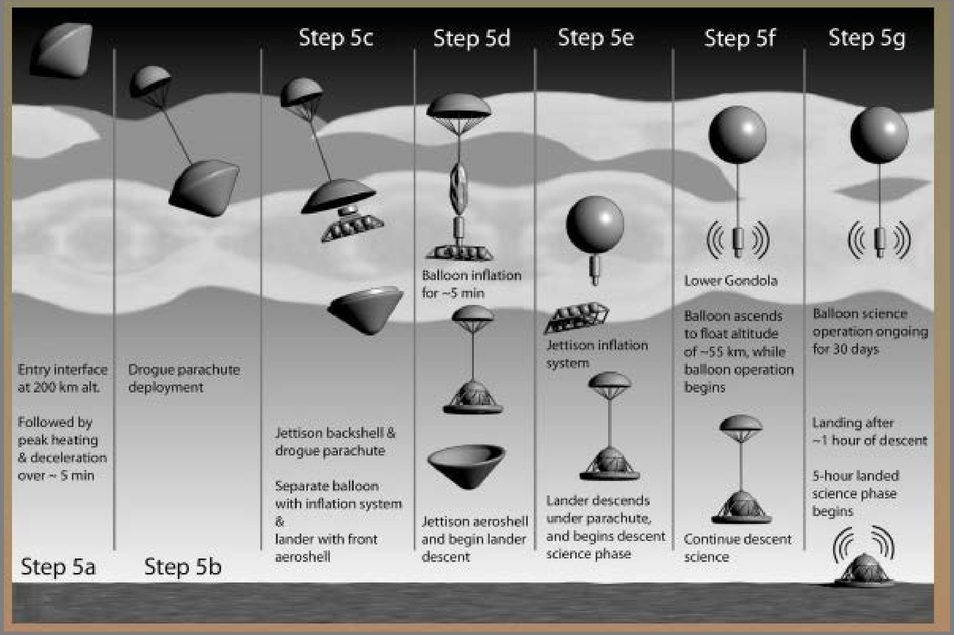
Typical Rigid Aeroshell:



- Heat-shield and Back-shell attached to a structure
- Unguided ballistic entry
- Payload deployment relies on parachute after entry phase

Is Venus Entry, Descent and Deployment more Challenging for Aerial Platforms? No!

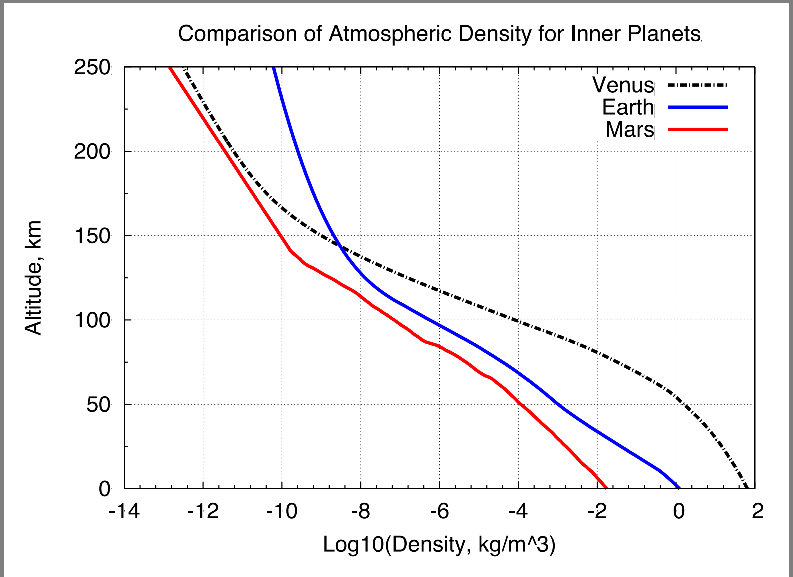
- Venus has had more successful atmospheric entry missions (probes, landers, balloons) than any other solar system destination including Mars.
- The entry challenges into planetary atmospheres are very similar.
  - With matured HEEET technology, the challenge is in engineering.
- To-date all entries into planetary bodies have been performed with rigid aero-shell
  - Emerging deployable and inflatable entry systems, ballistic or lifting, may offer advantages along with their own constraints
  - VAMP is a class of its own and more complex

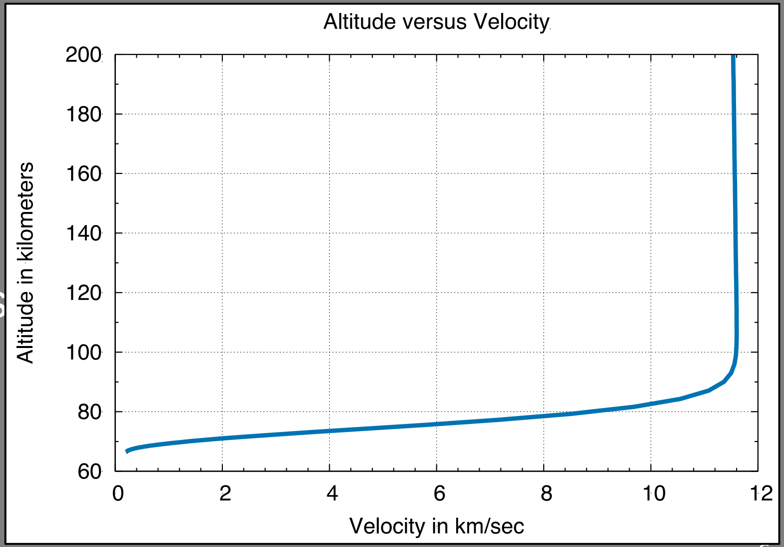


Venus Flagship mission study

What is different about Venus Entry? It's the Atmosphere !

- Entry Velocities for Venus and Earth are similar;
  - Hyperbolic entry velocity at Venus ranges from (10.5 km/s – 12.5km/s)
- Below 150 km atmospheric density at Venus >> Earth >> Mars
  - Deceleration at Venus starts at 100 kms. where density is an order of mag. higher than Earth
- Venus atmosphere composition predominantly CO_2
  - Shock-layer radiation
  - CO_2 Thermo-chemistry
- Atmospheric density profile and composition results in higher heating during entry at Venus compared to Earth.
  - Higher performance TPS required for Venus



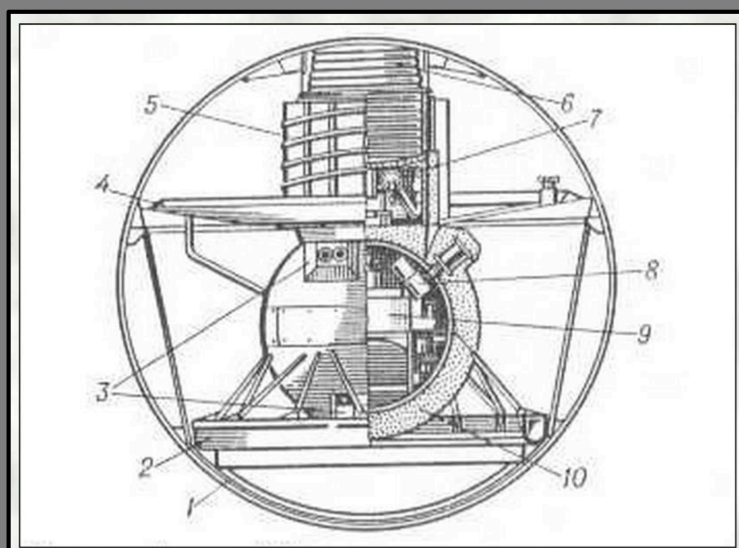


Historical Perspective: Venera and P-V Entry Systems

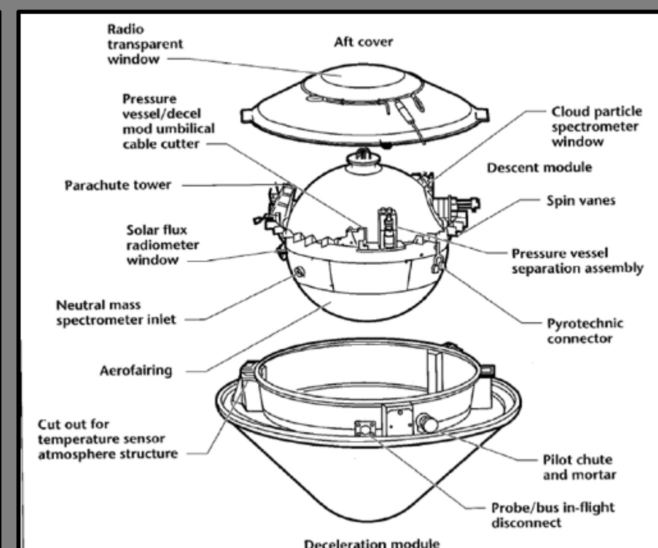
Missions	Entry System Fore-body Shape	Entry Mass, kg	Ballistic Coeff. (kg/m2)	Dia., m	Entry Ang
Venera (3 – 6)	Sphere		~ 450	1	(-62, -78)
Venera (7 and 8)	Circum-Ellipsoid		~ (422/500)	1	~(-60 , -77)
Venera 9 - Vega 2	Sphere	~1600	(370 - 412)	2.4	(-18, -23)
P-V Small Probes	45 deg. Sph-cone	88	180	0.77	(-68.7, -41.5, -25.4)
P-V Large Probe	45 deg. Sph-cone	317	188	1.42	-32.4

Venera 4

Venera 7/8

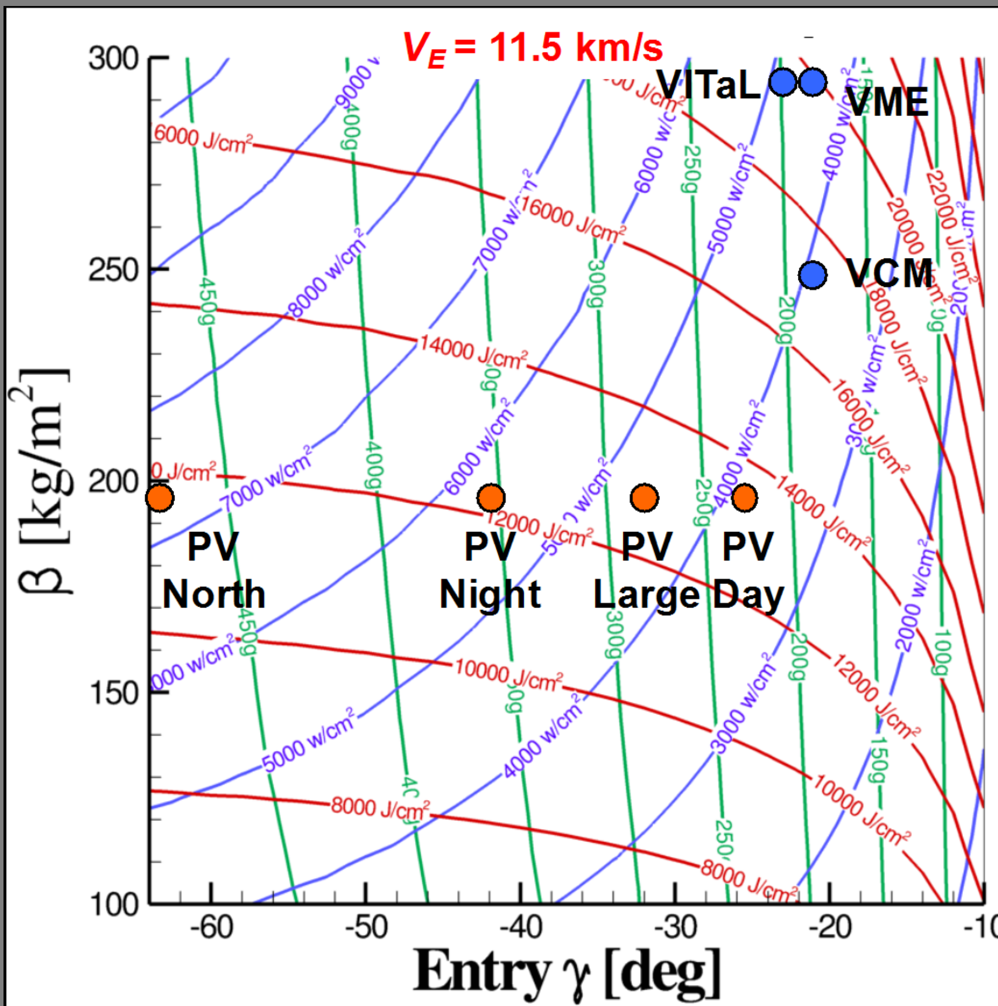


Venera 9 - Vega 2



Pioneer-Venus

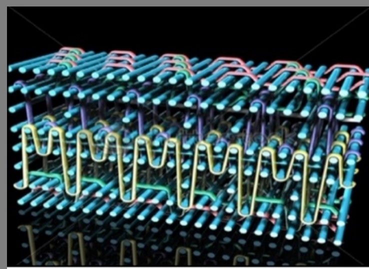
Rigid Aero-shell Design Considerations
Entry Environment and TPS Selection

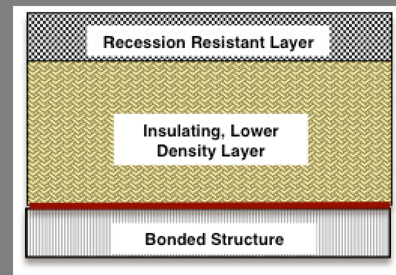


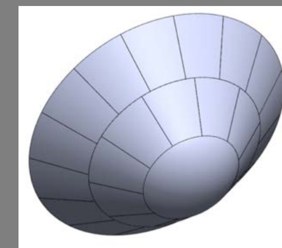
3DOF survey of design space

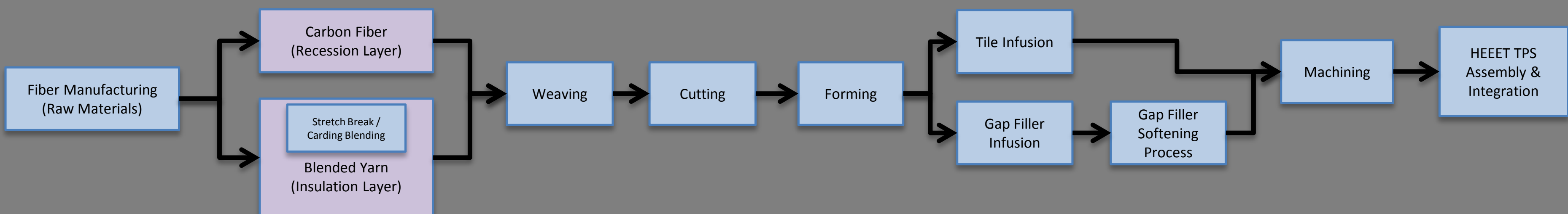
- For entry angles between skip out ~(-8⁰) and −12°, peak deceleration less than 100 g.
- Peak stagnation point peak heat-flux is a function of both entry flight path angle and ballistic coefficient.
  - higher β => higher heat-flux
- Heat-load increases significantly at lower entry flight path angle (proportional to time of flight)
- TPS selection depends on peak conditions whereas TPS sizing (mass) depends on heat-load

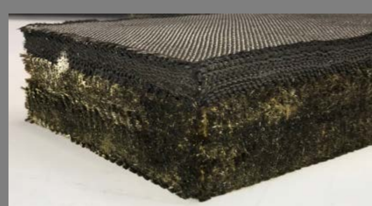
Heat-shield for Extreme Entry Environment Technology (HEEET)

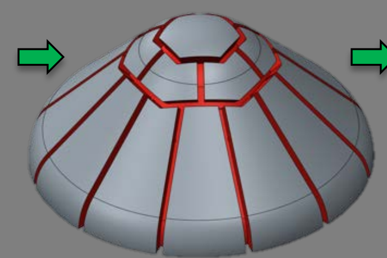


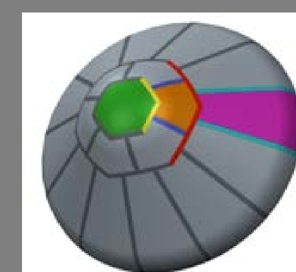








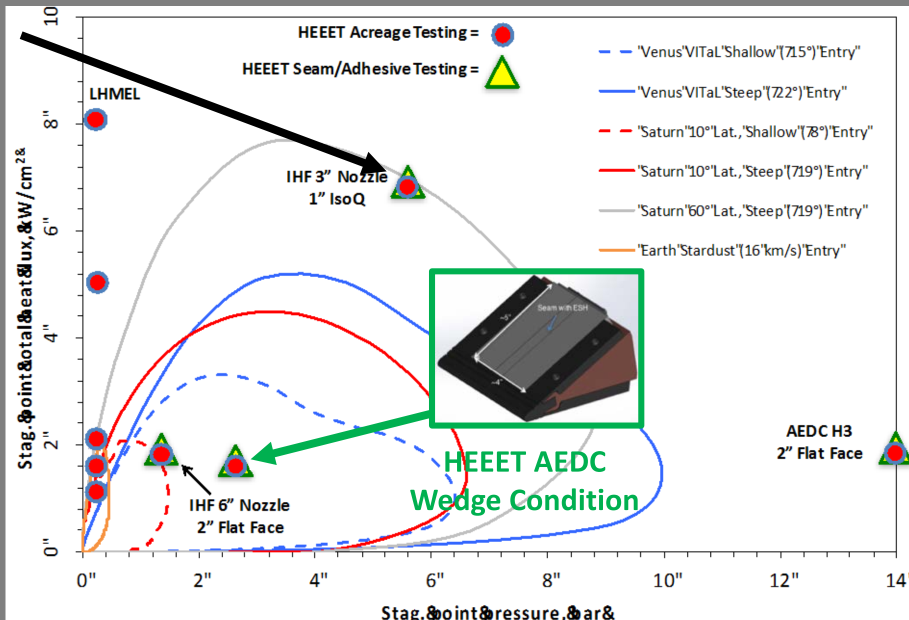




- 3-D, integrally woven, dual layer that is robust, mass efficient and capable of withstanding extreme entry environment
- HEEET to be matured to TRL 6 to support NF-4 and other future missions (Venus, Saturn or very high speed sample Return Missions)

HEEET – Benefits and Limitations

IHF 3” Nozzle



- HEEET has been tested at conditions relevant for NF-4 missions at many different facilities (at facility limits of heating, pressure and shear).

  HEEET’s mass efficiency (40-50% lower than CP for equivalent entry) allows very low entry flight path angles resulting in significantly lower g-loads and peak entry conditions

- Venus entries at entry flight path angles > 25 deg.,Velocities > 11.5 km/sec and high ballistic coefficients (i.e. smaller probes) will carry higher mission risk due to limitations of ground test facilities to allow testing at relevant conditions (True for any TPS not just HEEET)

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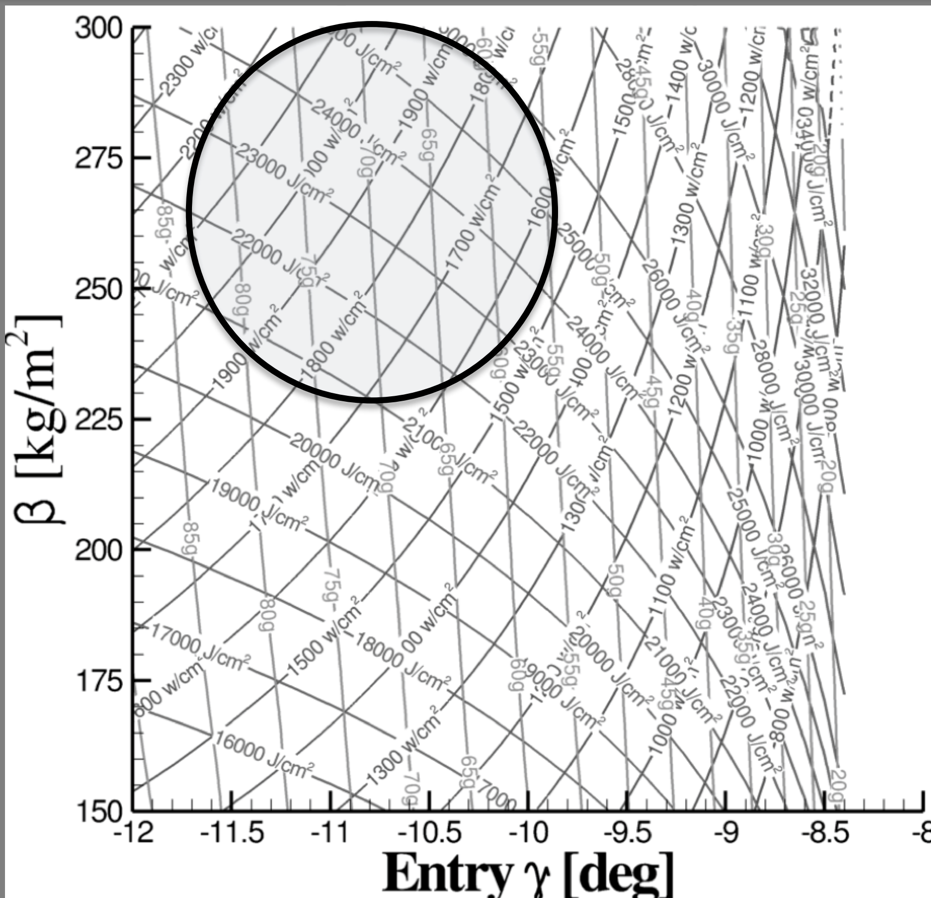
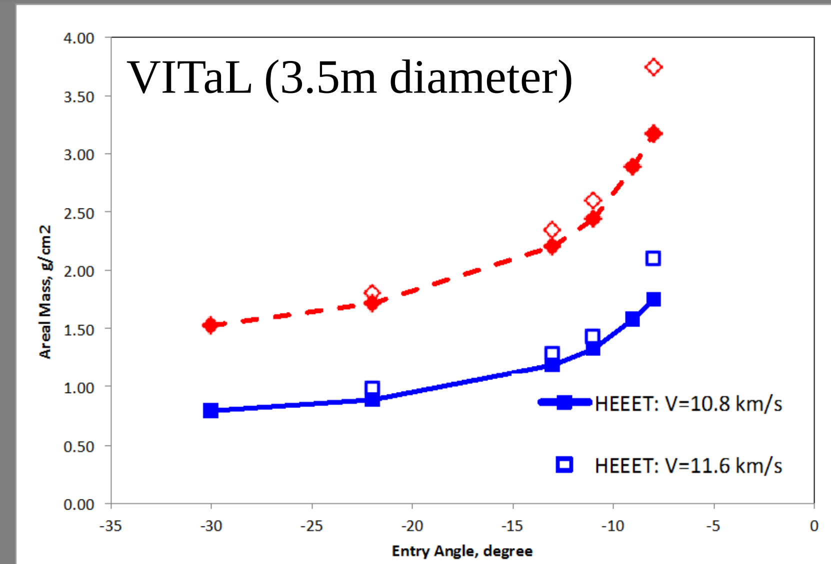
Optimizing Design with HEEET



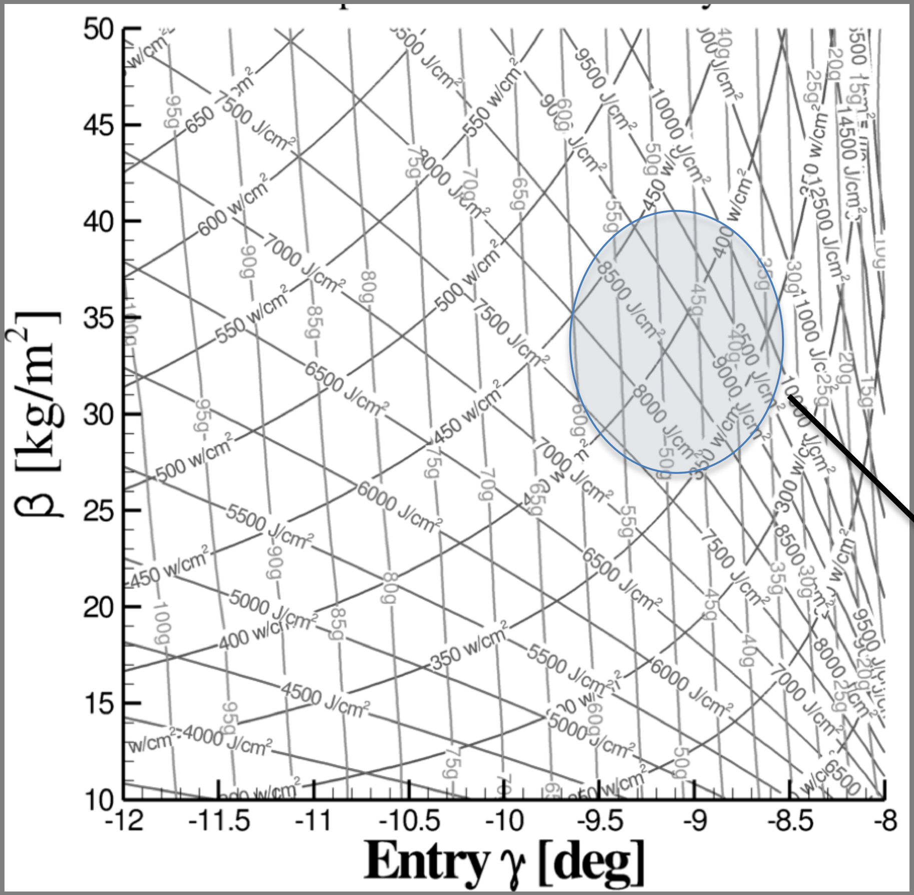


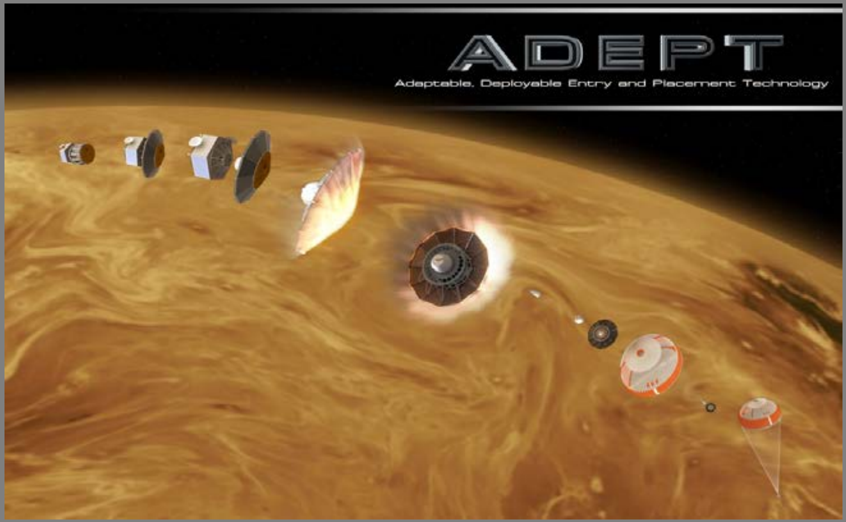
	Ballsitic Coeff.	EFPA	Peak q, W/cm2	Peak G	Heat-load, KJ/cm2
HEEET	225 - 300	-10.5 – 12.5	1600 - 2100	55 - 75	20 - 30

HEEET is ~ 50% mass efficient compared to Carbon Phenolic. Entry at much lower entry flight path angle feasible, resulting in lowers the g-load.

Lower g-load further reduces the mass of the overall system and simplifies design and qualification of science package.

Lower Ballistic Coefficient Systems (ADEPT)



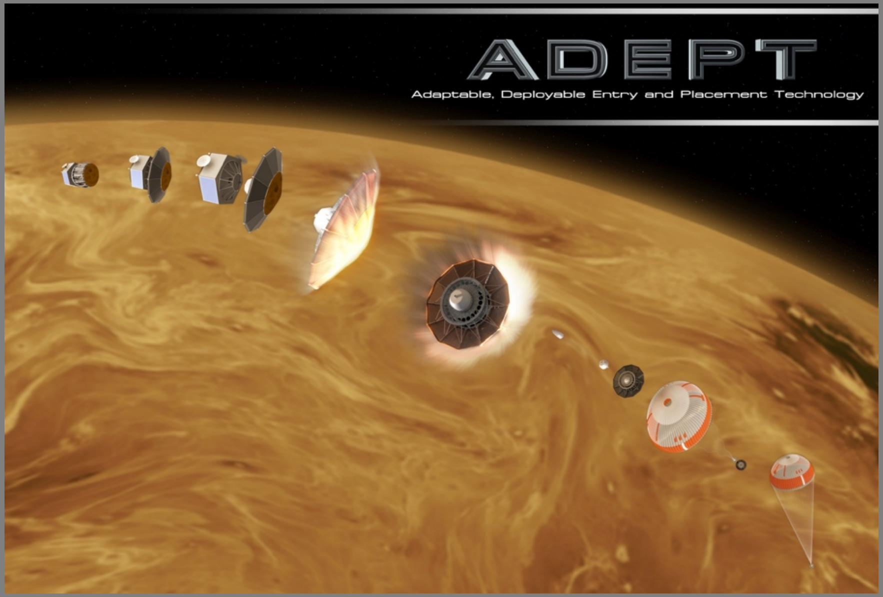


Ballis. Coeff.	EFPA	Peak q, W/cm2	Peak G	Heat-load, KJ/cm2
25 - 40	- 8.5 – 9.5	350 – 400	35 - 45	(7.5 – 10.0)

Lowering both the ballistic coefficient and entry flight path angle furhter lowers the peak heating and pressure. This means, system and TPS verification is simpler based on ground test capabilities

ADEPT-VITaL Study Findings

- ADEPT, a deployable entry system, achieves lower ballistic coefficient by increasing drag area
- In 2013, NASA conducted a study to explore the system benefits of using ADEPT as the entry system for VITaL compared to a rigid aeroshell
- Replacing the rigid CP aeroshell with ADEPT achieved significant mass savings.
  - Lowered peak heat-flux and pressure – well within existing arcjet test capability



References

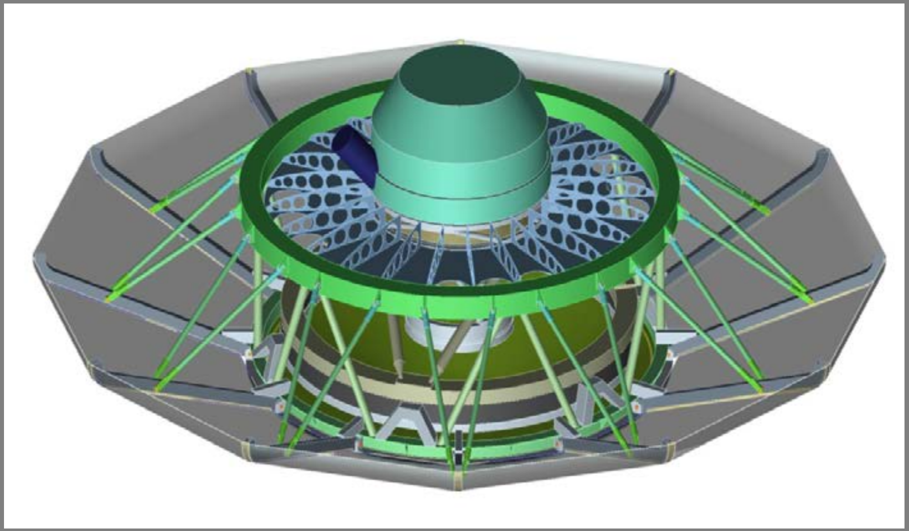
- Venkatapathy, E., Glaze, L., et al, "ADEPT-VITaL Mission Feasibility Report: Enabling the Venus In-Situ Explorer Mission with Deployable Aeroshell Technology," Version 2.1, August 2013. Contact (brandon.p.smith@nasa.gov)
- Smith, B. et al, "Venus In Situ Explorer Mission Design using a Mechanically Deployed Aerodynamic Decelerator," 2013 IEEE Aerospace Conference, Big Sky, MT, March 2013.

VITaL and ADEPT-VITaL : Rigid vs Deployable Entry System Comparison

3.5m Rigid Aeroshell with Carbon Phenolic

Entry System Mass 1051 kg/
Total Mass at Entry 2102 Kg

6.0 m ADEPT with Carbon Fabric

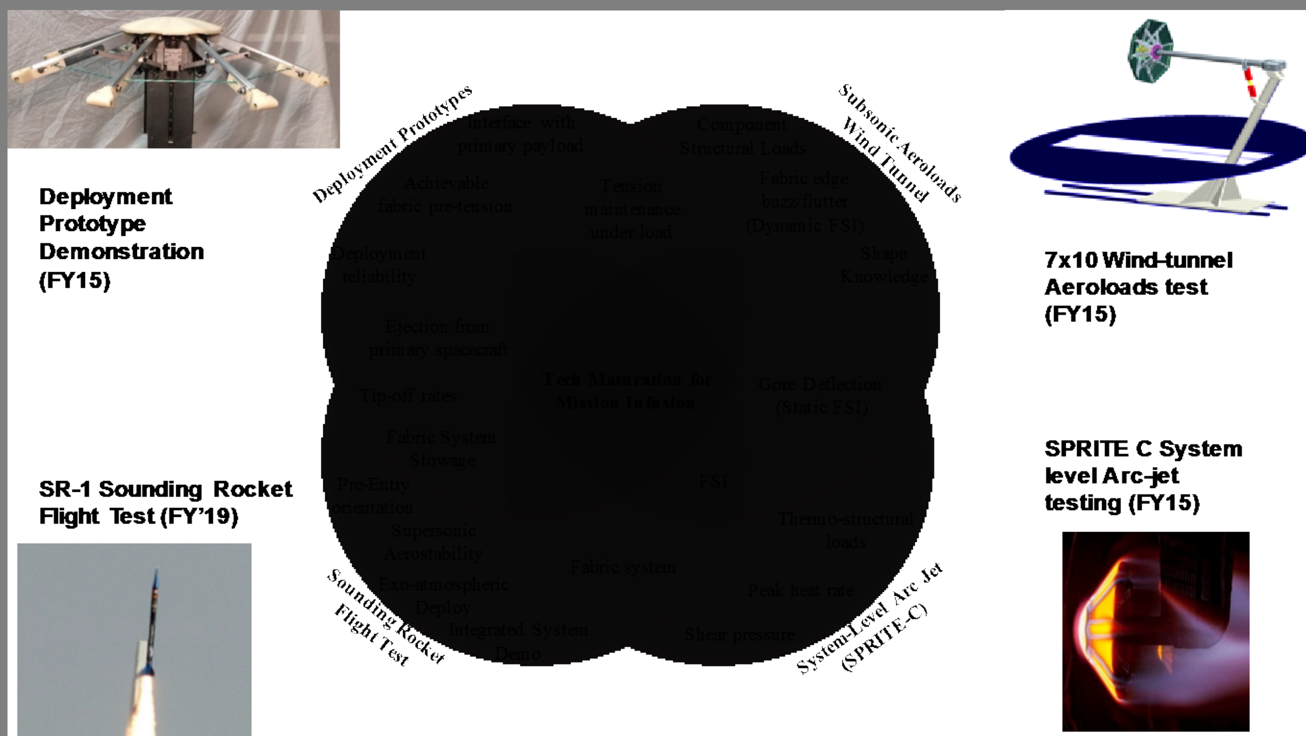


Entry System Mass 807 kg /
Total Mass at Entry 1621 kg

- VITaL mass is reduced by 23% when using ADEPT due to lower structural mass as a result of lower peak g-load
  - Same science capability as baseline VITaL mission
- Replacing CP with HEEET will allow entry at lower flight path angles and reduced g-loads with a similar mass benefit.

Current Status of ADEPT Development

- ADEPT will achieve TRL 5+ for ballistic entry with the sounding rocket flight test of the Nano-ADEPT in FY'19.
  - Technology maturation include wind-tunnel and arc jet test campaigns, ground test article (2m and nano-ADEPT) development testing and design studies in support of Venus, robotic Mars and Human Mars.



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

Concluding Remarks

- With the development of HEEET at TRL 6 for NF-4, entry, descent and deployment of aerial platforms with rigid aero-shell is lowest risk option
- Deployable and inflatable entry systems such as ADEPT (and HIAD) may offer unique advantages
  - More development is needed . Relatively higher TRL level for ballistic entry.
  - More complex lift-guided entry need to be justifiable based on benefits.
- VAMP, a very large-scale multi-functional system will need to tackle numerous challenges at component as well system level.
  - Development challenges, known and unknown, need to be weighed against benefits.