A Game Changing Approach to Venus In-Situ Science Missions Using Adaptive Deployable Entry and Placement Technology (ADEPT)

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What is this talk about?

- **Venus, one of the important planetary destination for scientific exploration has presented many challenges**
  - The combination of extreme entry environment coupled with extreme surface conditions have made proposal efforts in the last two decades to be non-competitive.
- **We present an approach where entry environment is made benign and this allows for greater flexibility and lower risk in mission design**
  - greater mass, greater planetary reach,
  - lower cost as a result of much reduced requirements for both instrumentation as well as EDL system development and certification

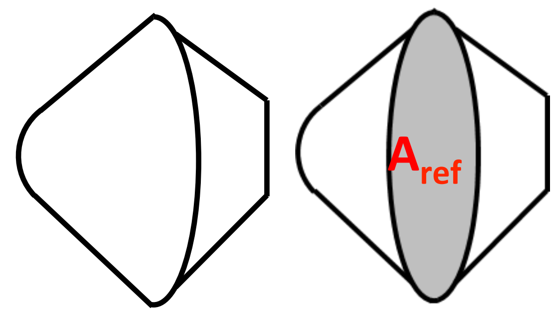
Outline:

- **Background**
- **Venus Mission**
  - Conventional Design and Science Instrumentation Selection to meet NRC Decadal Survey Science Recommendations
- **ADEPT – Mechanically Deployable Aeroshell Integrated Approach and comparison with classical design**
- **Concluding Remarks**

History: Venus Probes, Landers and Balloon Missions

Mission	β (kg/m²)	γ (deg.)	V_{entry} [i] (km/s)	Dia. (m)	n_{max} [ii] (g's)	q_{max} [ii,iii] (kW/cm²)
Venera 4 (1967)	519	-78	10.7	1	450	9.66
Venera 5 (1969)	549	-62 to -65	11.2	1	440-450	13.5
Venera 6 (1969)	549	-62 to -65	11.2	1	440-450	13.5
Venera 7 (1970)	677	-60 to -70	11.2	1	422-452	17
Venera 8 (1972)	670	-77	11.6	1	500	30
Venera 9 (1975)	367	-20.5	10.7	2.4	150	3.04
Venera 10 (1975)	367	-23	10.7	2.4	170	3.37
Pioneer-Venus-North (1978)	190	-68.7	11.5	0.7653	487	10.6
Pioneer-Venus-Night (1978)	190	-41.5	11.5	0.7653	350	7.8
Pioneer-Venus-Day (1978)	190	-25.4	11.5	0.7653	219	5.2
Pioneer-Venus-Large (1978)	188	-32.4	11.5	1.4228	276	6.9
Venera 11 (1978)	376	-18 to -21	11.2	2.4	138-167	4.35
Venera 12 (1978)	379	-18 to -21	11.2	2.4	138-167	4.35
Venera 13 (1981)	387	-18 to -21	11.2	2.4	138-167	4.35
Venera 14 (1981)	387	-18 to -21	11.2	2.4	138-167	4.35
Vega 1 (1984)	412	-18.23	10.7	2.4	130	3.06
Vega 2 (1984)	412	-19.08	10.8	2.4	139	3.29

Ballistic Coefficient:
$\beta = m/C_D A_{reference}$



γ = entry flight path angle

n = sensed acceleration

q = heat rate

[i] Entry velocities have been defined for a 200 km altitude
[ii] Simulations themselves were based on engineering estimates
[iii] Total of engineering estimates for cold-wall convective and radiative heat fluxes

- **Past missions: $\beta > 100$ kg/m²; $|\gamma_{entry}| > 18$ deg.**
- **$N_{max} > 130$ g's and $q_{max} > 3$ kW/cm²**

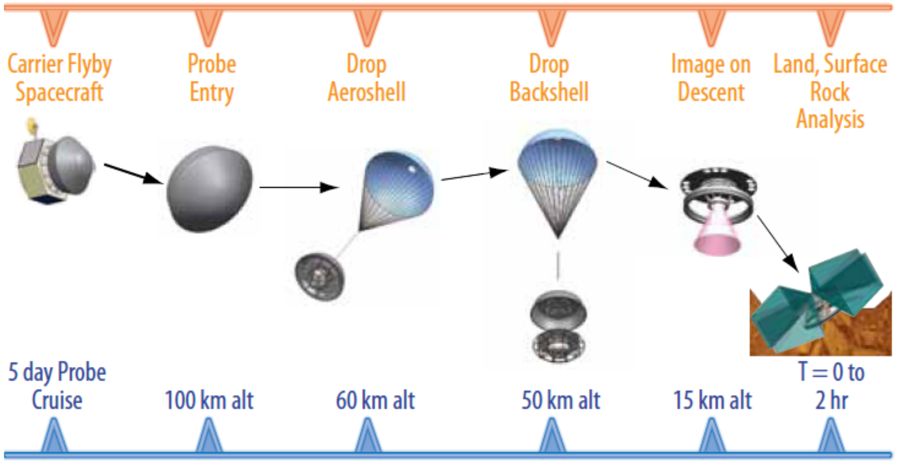
Ref: Dutta, S., Smith, B., Prabhu, D., and Venkatapathy, E., "Mission Sizing and Trade Studies for Low Ballistic Coefficient Entry Systems to Venus," IEEEAC 1343, 2012 IEEE Aerospace Conference, Big Sky, MT, March 2012.

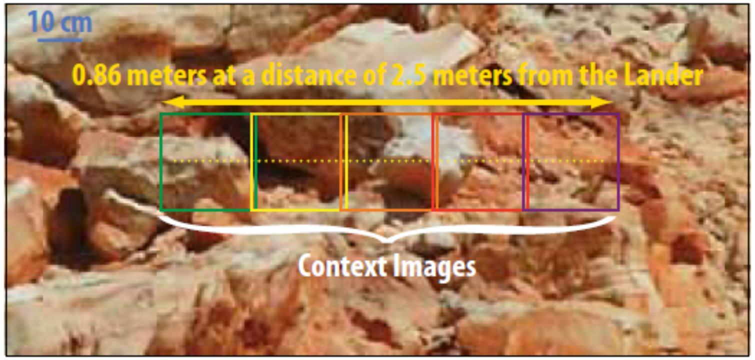
Venus Science Objectives for NASA New Frontiers Program (<$1B, PI-led missions)

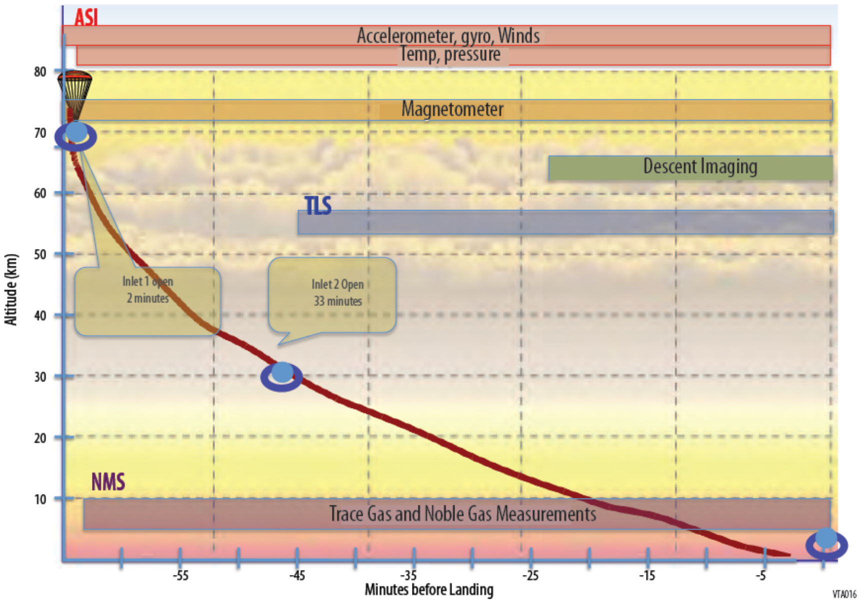
- **2011 Planetary Decadal Objectives for Venus:**
  - **Understand the physics and chemistry of Venus' atmosphere**, especially the abundances of its trace gases, sulfur, light stable isotopes, and noble gas isotopes;
  - Constrain the coupling of thermochemical, photochemical, and dynamical processes in Venus' atmosphere and between the surface and atmosphere **to understand radiative balance, climate, dynamics, and chemical cycles**;
  - **Understand the physics and chemistry of Venus' crust**;
  - **Understand the properties of Venus' atmosphere down to the surface** and improve our understanding of Venus' zonal cloud-level winds;
  - **Understand the weathering environment of the crust of Venus** in the context of the dynamics of the atmosphere and the composition and texture of its surface materials; and
  - **Look for planetary scale evidence of past hydrological cycles, oceans, and life and for constraints on the evolution of the atmosphere of Venus**

Example 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







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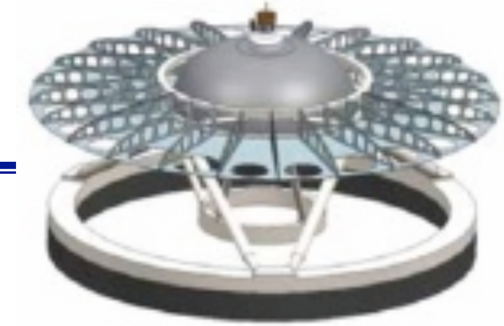
VITaL Strawman Science Instrument Complement

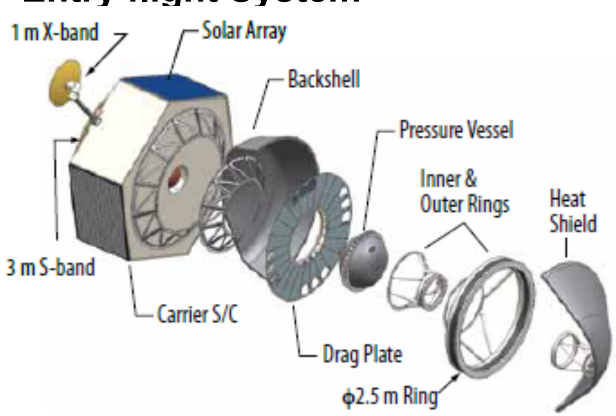


Optimistic with conventional aeroshell: steep entry angle = high g-loads

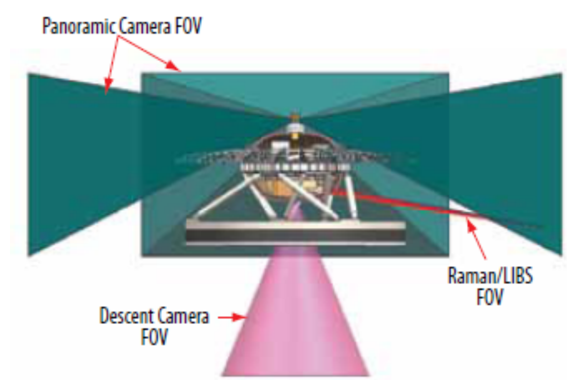
	Mass (kg)	Power (W)	Volume (meters)	Data Rate/ Volume	TRL / Heritage	Comment
Neutral Mass Spectrometer (NMS)	11	50	0.26 x 0.16 x 0.19	2 kbps	High/MSL/SAM	Data rate during descent; reduced to 33 bps on surface
Tunable Laser Spectrometer (TLS)	4.5	17	0.25 x 0.10 x 0.10	3.4 kbps	High/MSL/SAM	Data rate during 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

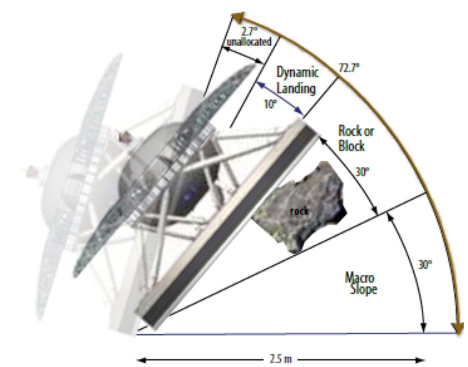
Entry flight System



Camera/Raman/LIBS Fields of View



Stable Landing



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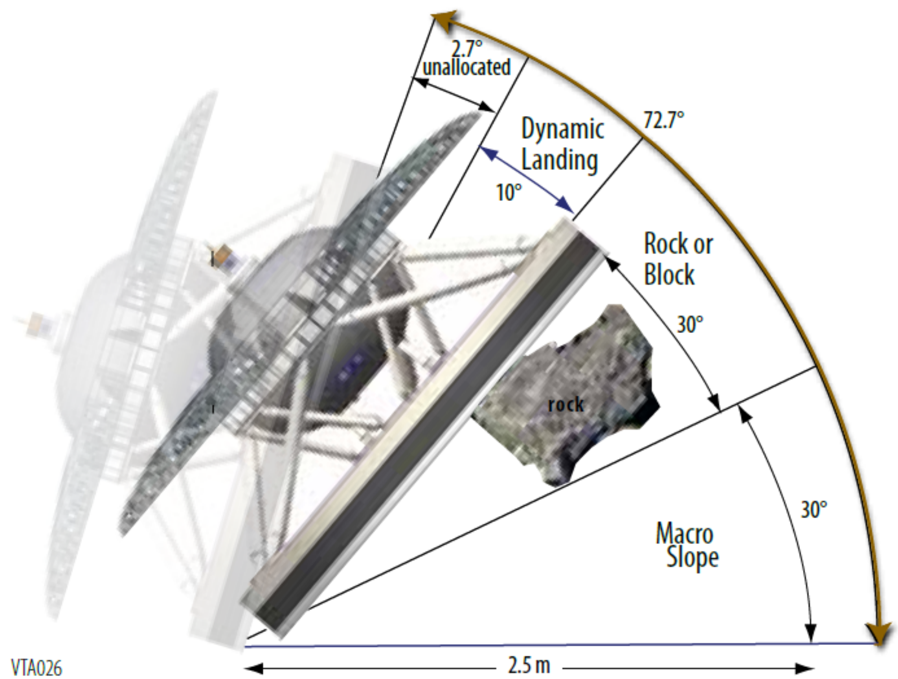
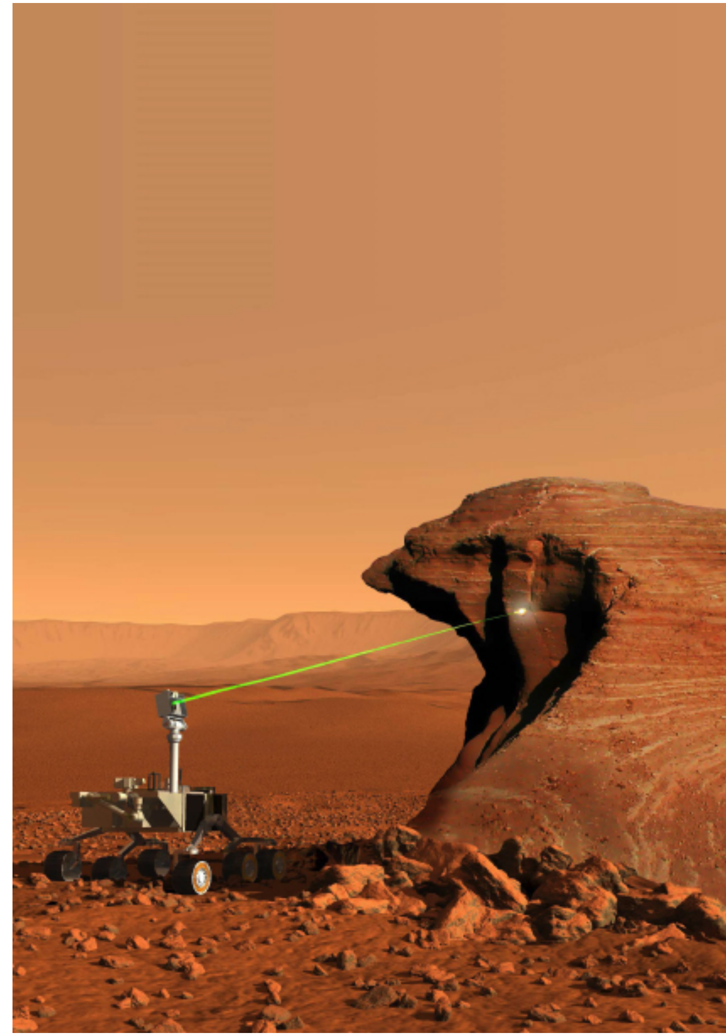
Venus Surface Mission Challenges

- **Landers can be high mass,**
  - Example: VITaL concept is designed to safely land in rough terrain
- **Coupled with high mass entry system:**
  - Limits mass available for science payload and surface survival
  - VITaL science payload mass is only 2% of probe mass!
- **In order to get 2% mass to surface location to perform Science of interest requires 98% of the mass between EDL systems and pressure vessel that allows for science instrumentation survival.**



Venus Surface Mission Challenges

- **Determination of surface chemistry requires either:**
  - Direct sample collection/ingestion
  - "Remote" observation using state of the art sensitive laser system (similar to the ChemCam on MSL)
- **MSL instruments qualified for 25 – 30 g entry loads**
- **VITaL has predicted entry loads of 200 g (required by steep atmospheric entry).**
- **Reduction of entry g-load enables**
  - Less development for state-of-the-art instruments
  - Less mass for the EDL system



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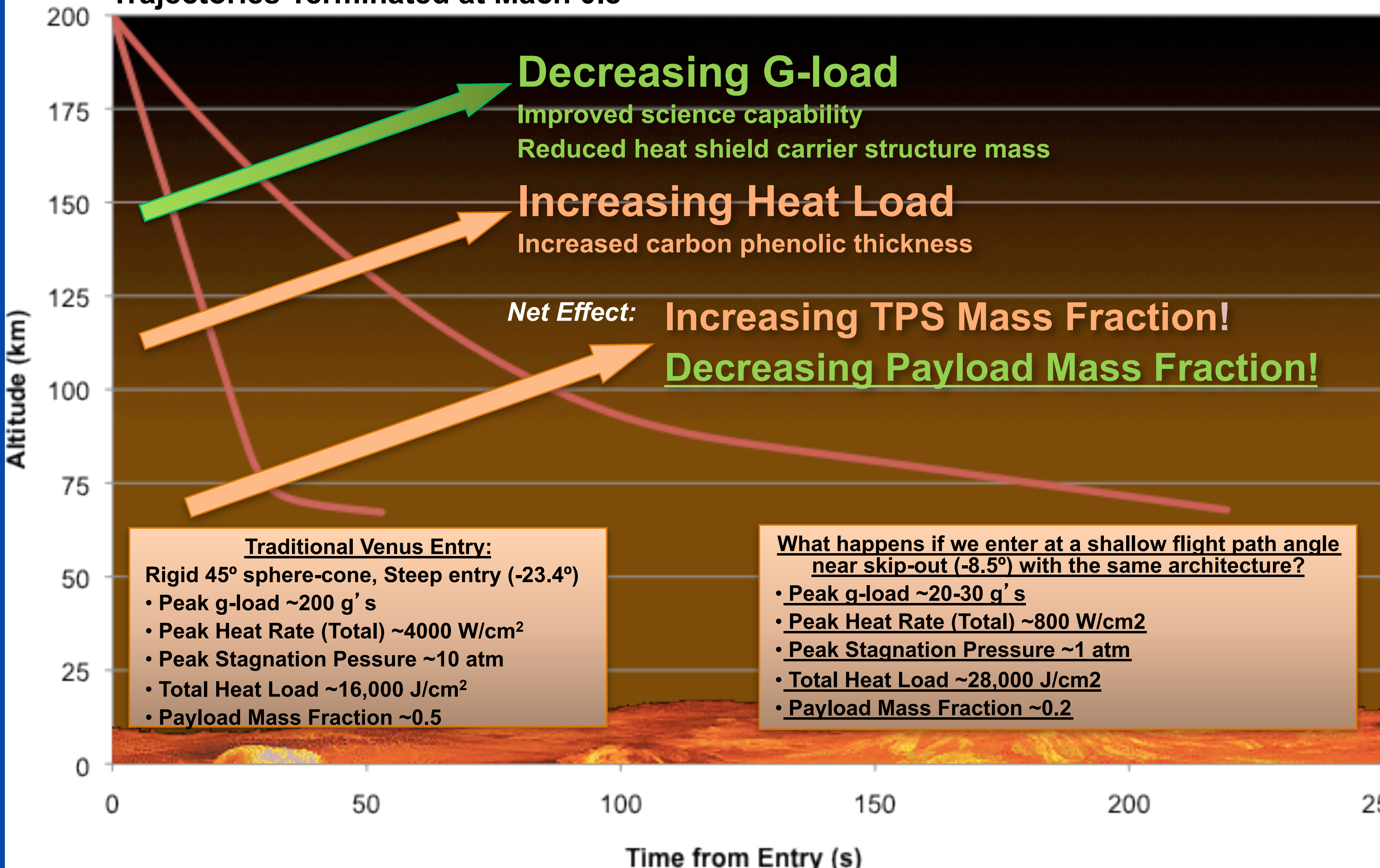
Carbon phenolic TPS places limits on Venus in-situ science due to high entry g-loads

b= 208 kg/m² (45º sphere-cone, 2100 kg entry mass)
V_{entry} = 11.25 km/s
Trajectories Terminated at Mach 0.8



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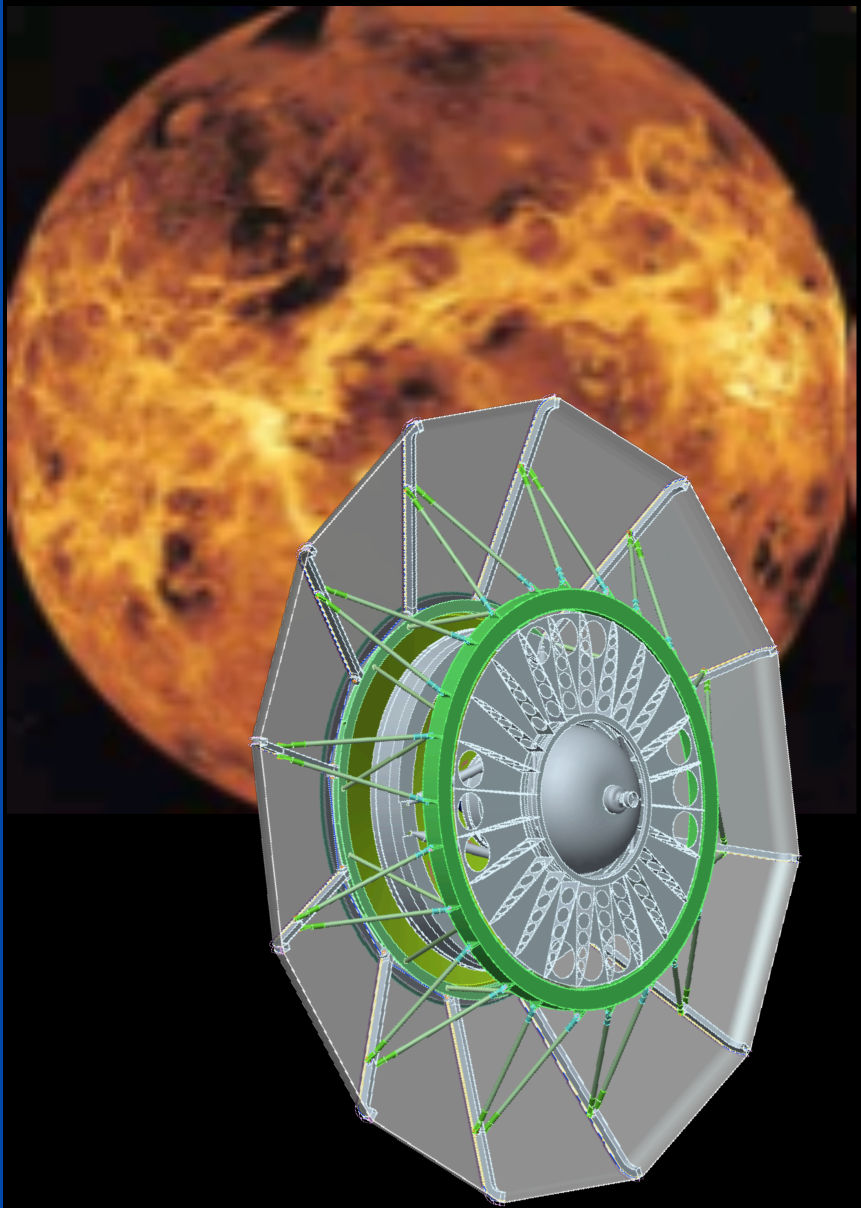
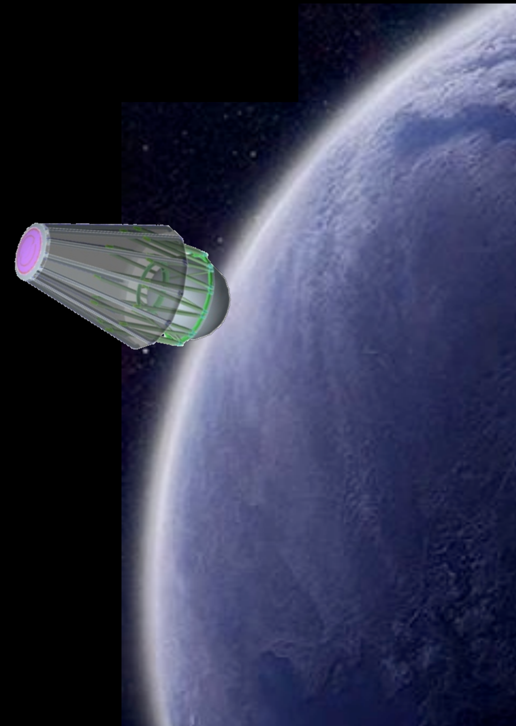
An Alternate EDL Architecture

Mechanically Deployable Aeroshell





Deployable (Low-*b*), Shallow-*g* Sweet Spot

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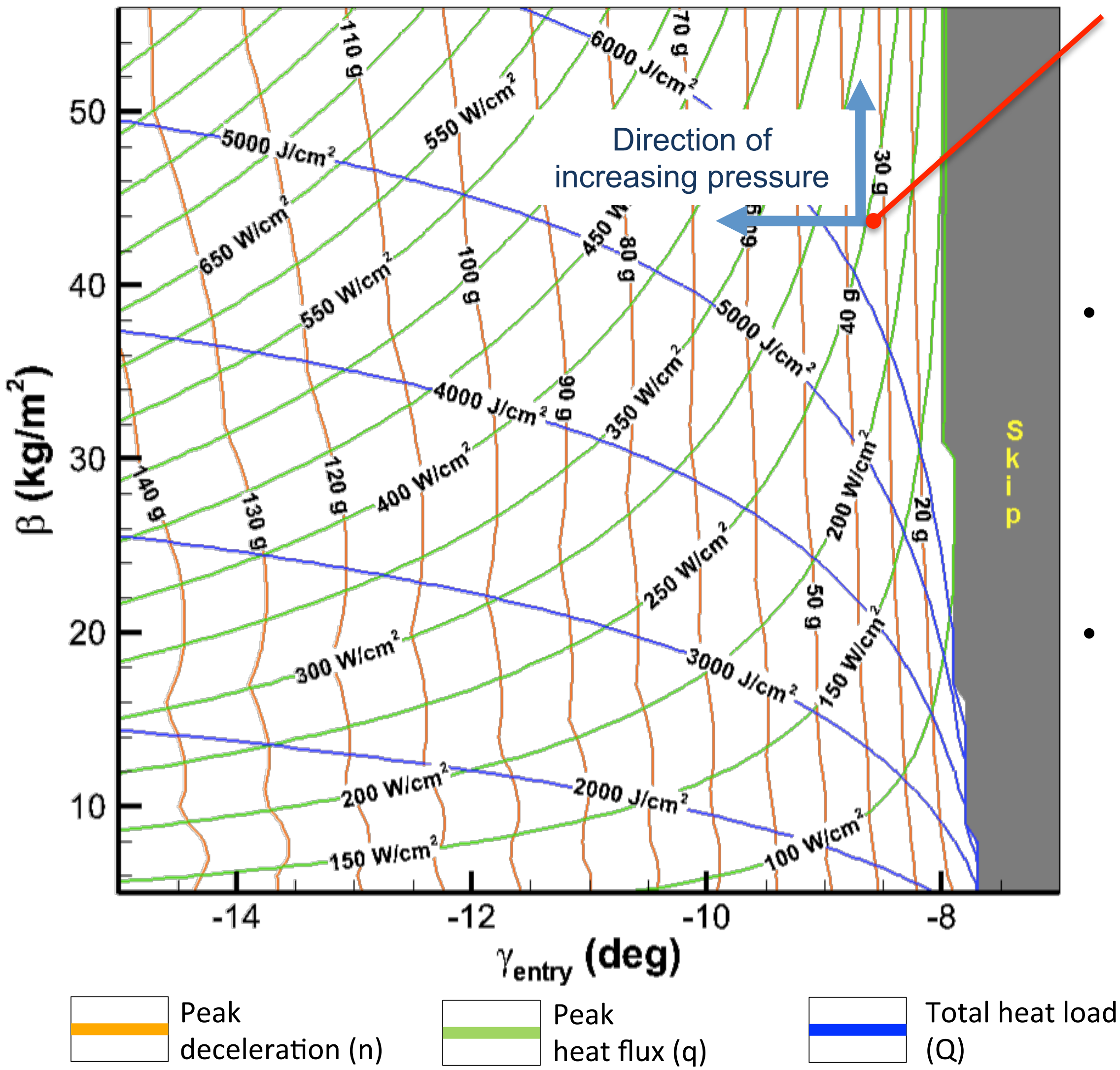
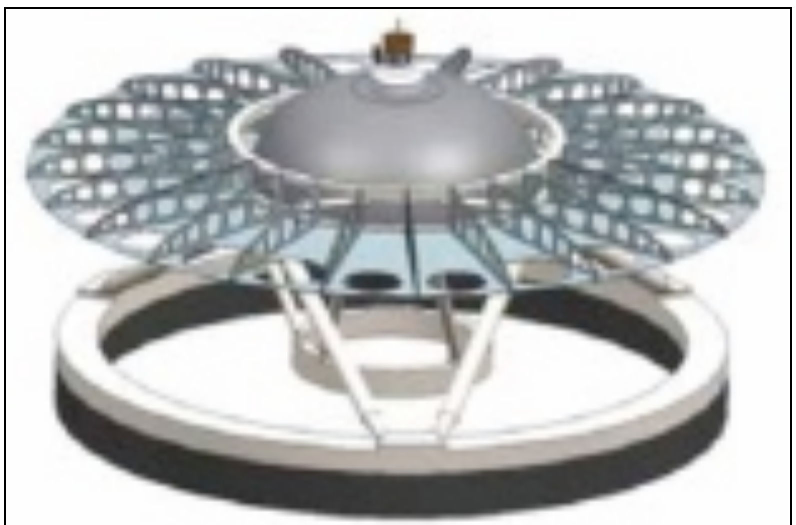


- Low-*b* entry, results in high altitude deceleration where the resulting entry aerothermal environment is benign
  - Well within the capability of carbon cloth
- Furthermore, the low-*b* architecture allows entry with a very shallow flight path angle, dramatically reducing entry G-load

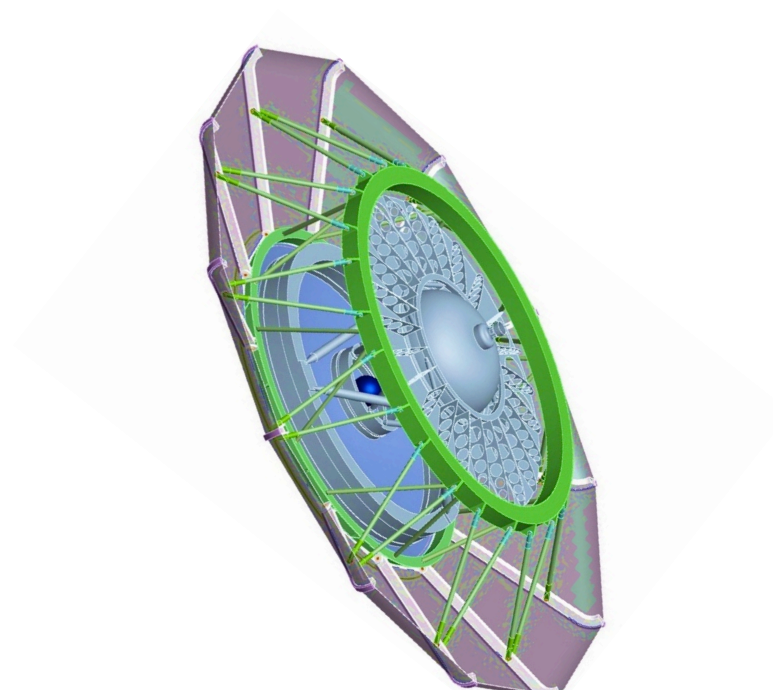
- **ADEPT key benefits:**
  1. No need for carbon phenolic
  2. Benign entry G-load
     - ✓ Simplifies qualification of scientific instruments
     - ✓ Reduced structural mass of payload
     - ✓ Opens doors for improved science return using more delicate instruments

ADEPT Approach to VISE Mission:
Unwrap Rigid Aeroshell and Adapt the VITaL Payload to ADEPT

- **ADEPT-VITaL Approach**
  - What are the benefits, beyond the reduced G'load?
    - Use of rigid aeroshell requires highly coupled design!
    - Can we adapt the payload, without any modification, to the ADEPT concept?
  - Are there challenges? ConOps?



VITaL Lander and Science Payload



ADEPT-VITaL Integrated EDL System

ADEPT-VITaL Mission Feasibility:

Analysis, Trades and Design Decisions

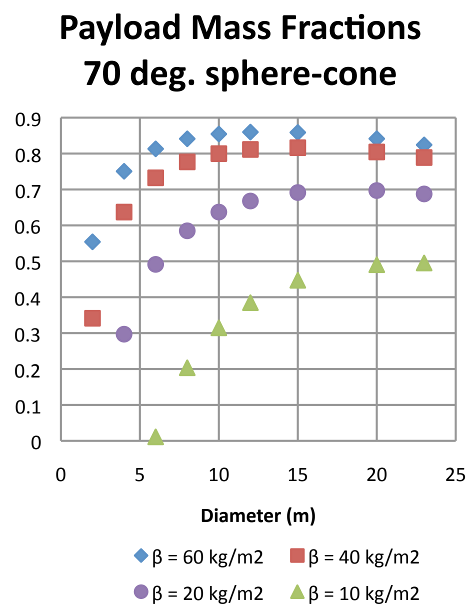
Mission Feasibility

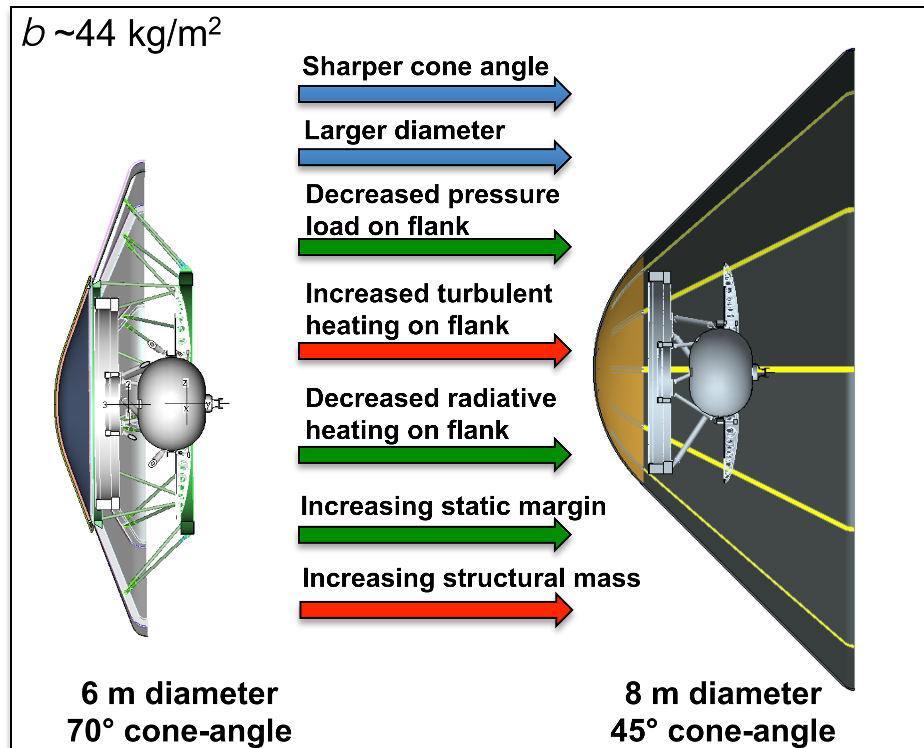
- **Mission Design**
  - Launch Vehicle Fairing Configuration
  - Launch Window
  - Cruise Stage Interface Requirements
  - ADEPT Deployment and Release
  - CONOPS
- **Entry Design Environment**
  - EDL Trajectory
  - Flight Mechanics
  - Aero-stability
  - Loads:
  - Aero
  - Aerothermal
  - Aeroelastic
  - 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
- Goal is to understand the benefits and penalties in order to compare and contrast ADEPT-VITaL (Deployable) with VITaL (Rigid Aeroshell)

Key System-Level Trades (1 of 2)

- **ADEPT-Venus Geometry (Cone Angle and Diameter) for *b* = 44 kg/m^2**
  - System analysis showed this case as an *approximate* point of diminishing returns for the low-*b* ADEPT architecture: structural mass begins to grow faster
  - Stays within the constraints of expected carbon cloth capability for shallow entry flight path angle
  - 70º cone angle / 6-m diameter ADEPT-VITaL baseline is result of trade between ADEPT mass, aerothermal loading, and stability considerations





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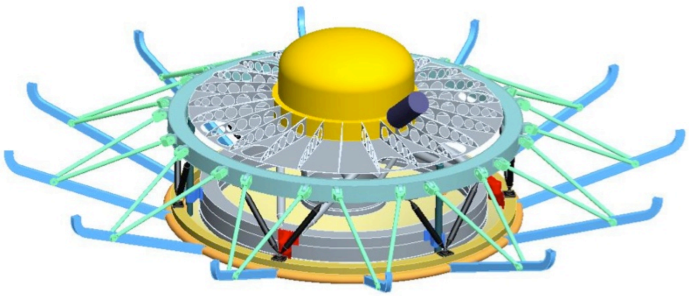
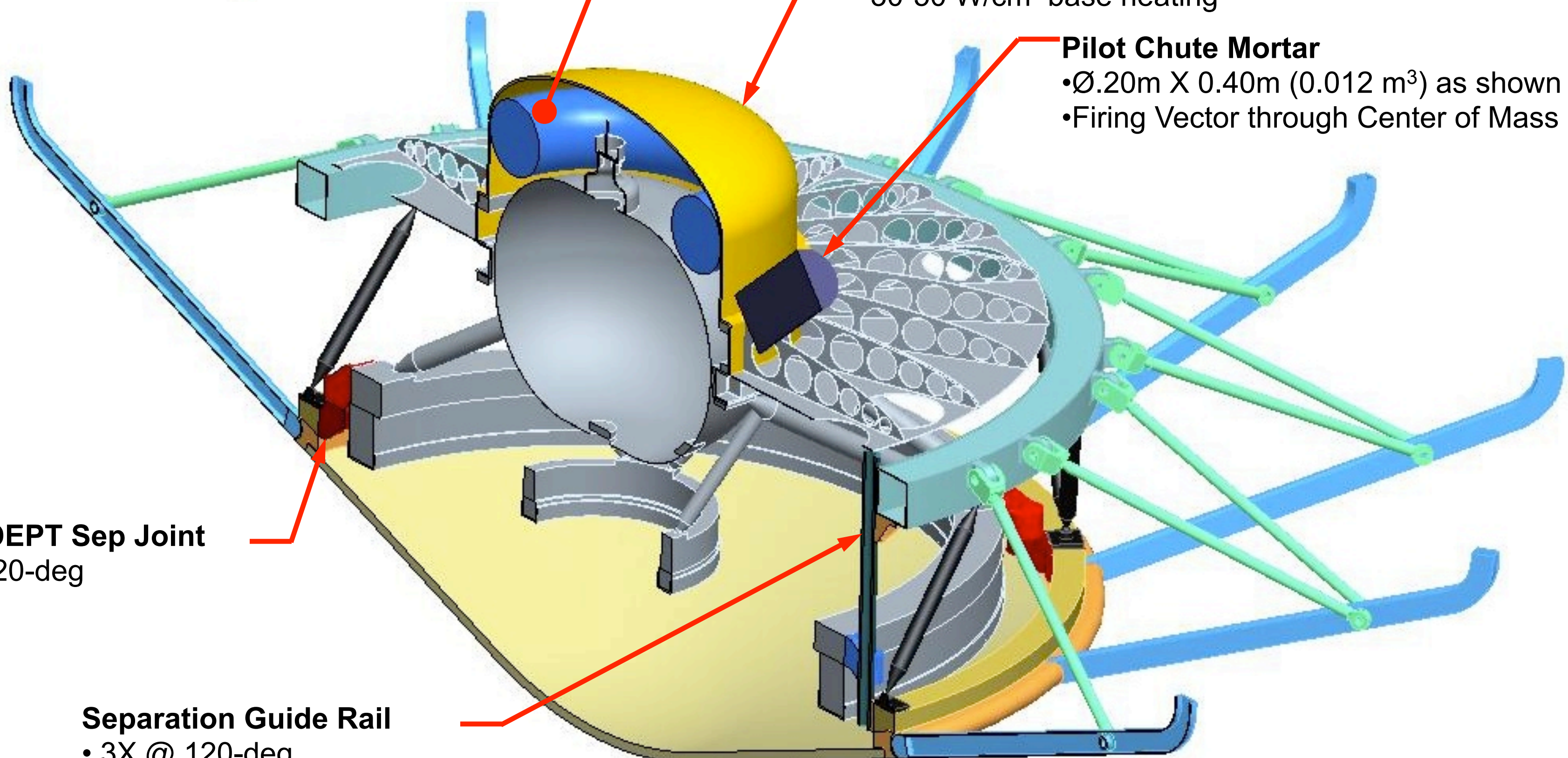
Aft-Separation Concept Details



Main Parachute
- 0.14 m^3 Stowed
- ~140 kg/m^3 Packed Density

Probe Backshell
- Contains main parachute
- Protects science instruments from 30-50 W/cm^2 base heating

Pilot Chute Mortar
- Ø.20m X 0.40m (0.012 m^3) as shown
- Firing Vector through Center of Mass



VITaL-ADEPT Sep Joint
- 3X @ 120-deg

Separation Guide Rail
- 3X @ 120-deg

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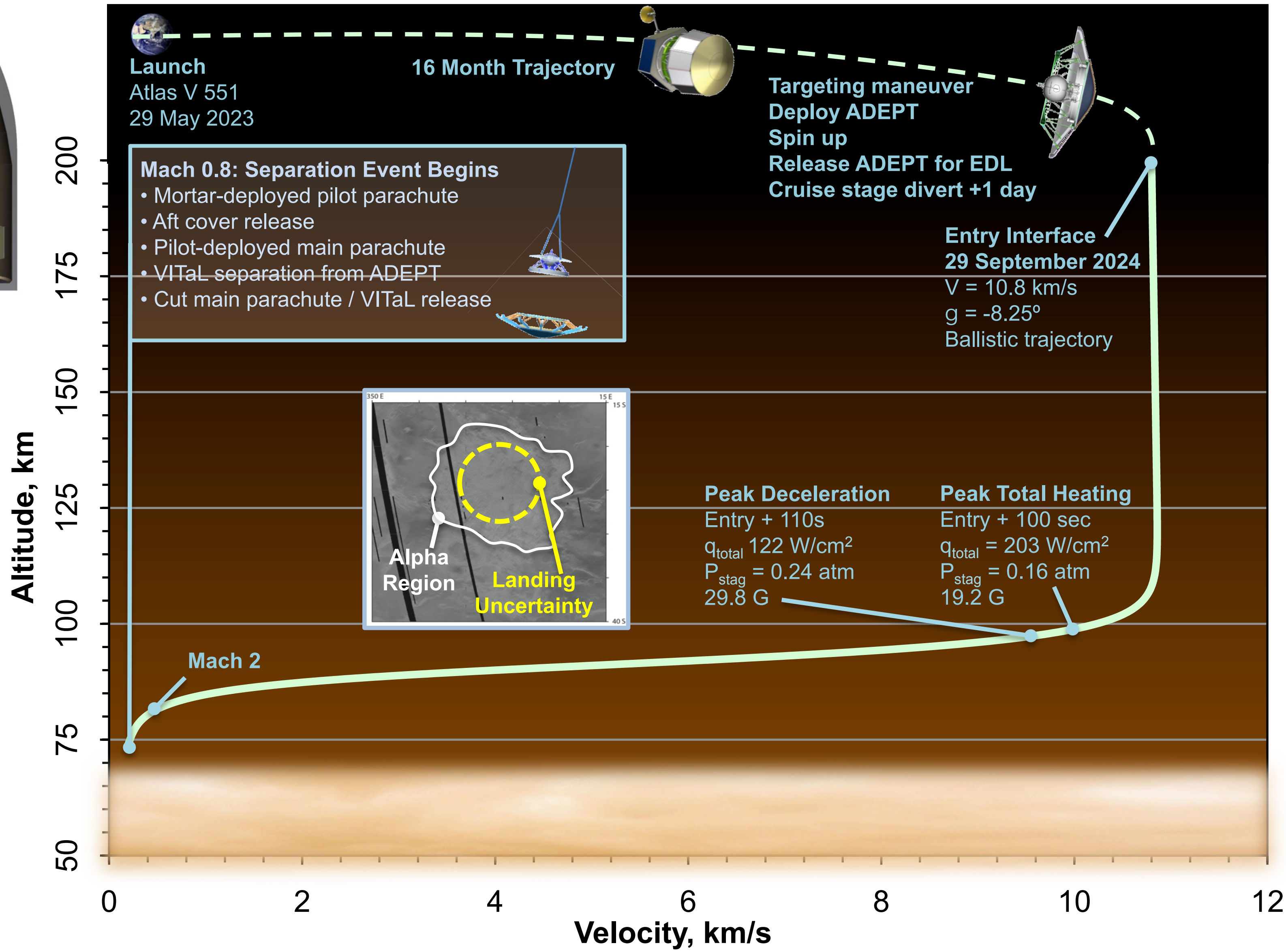
ADEPT-VITaL Mission Quick-Look



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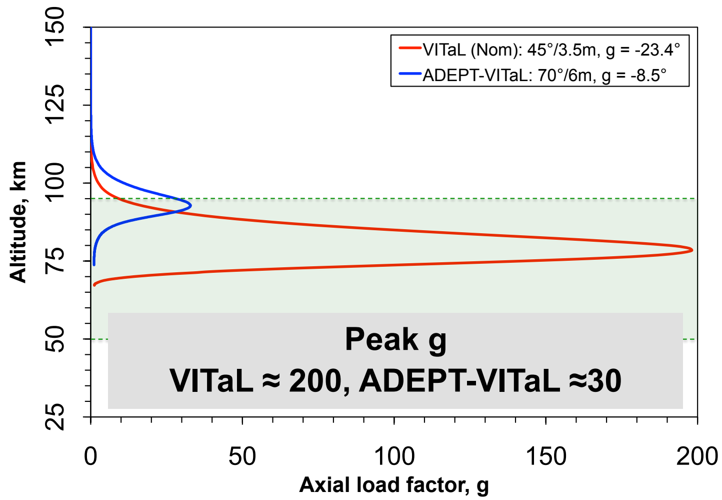
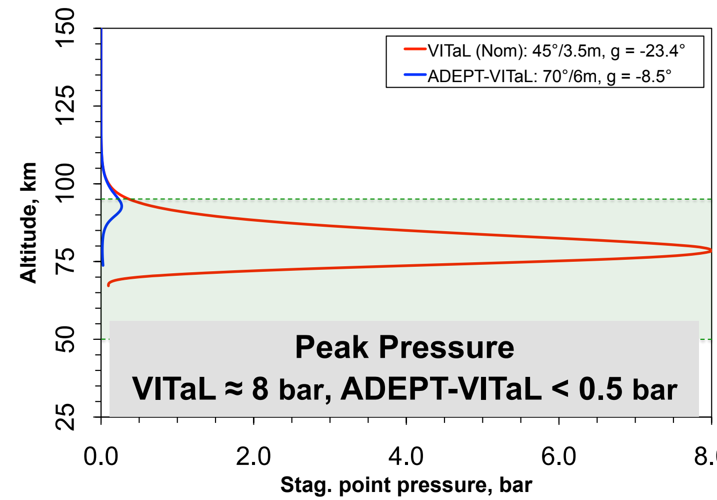
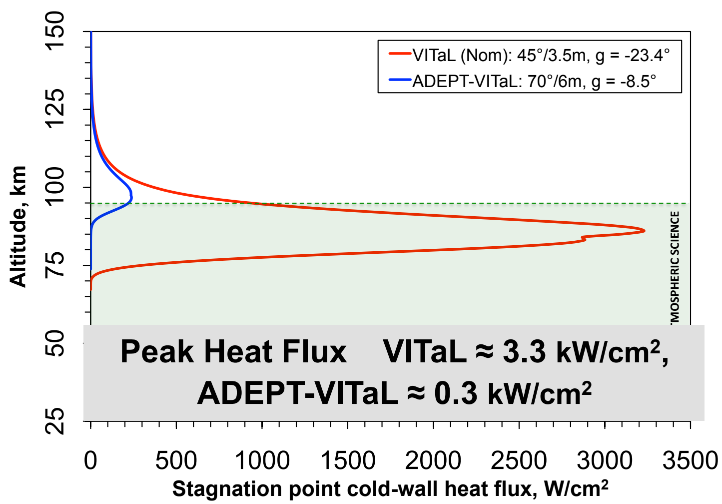
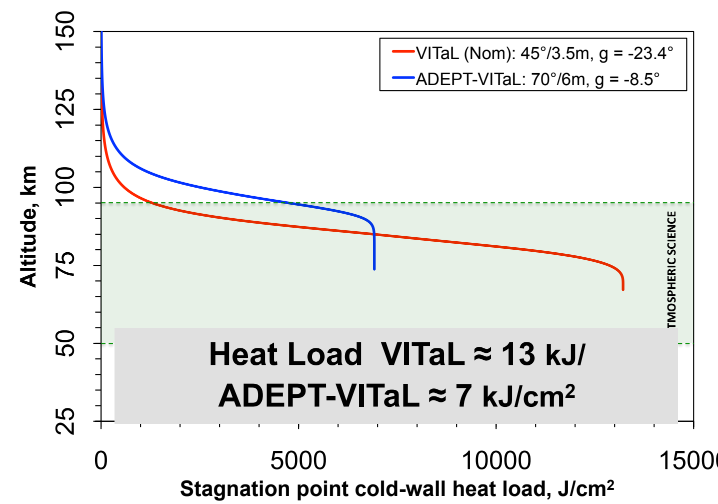
VITaL and ADEPT-VITaL Entry Environments





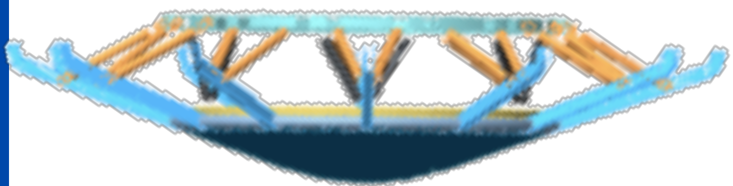


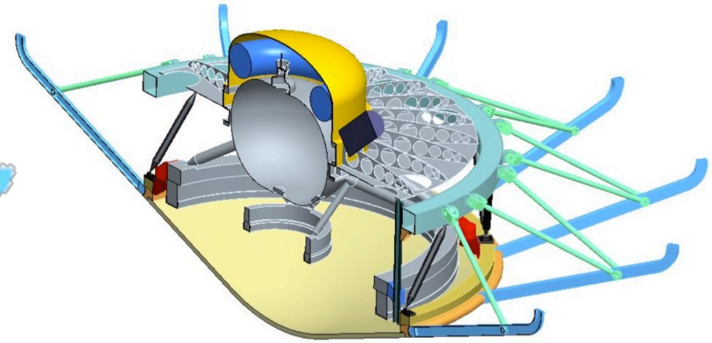


ADEPT-VITaL Entry Environment is very Benign and well within Ground Test Capabilities. VITaL Entry Environment is extreme and is a challenge for certification

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

ADEPT-VITaL (Deployable) vs VITaL (Rigid Aeroshell)

Launch MEV MEL Comparison

ADEPT

OPTION 1: Ovda Regio 2021 Landing Site

Item	ADEPT-VITaL Margined (kg)	VITaL Baseline Margined (kg)
Probe	2,100	2,745
Spacecraft	970*	1100
Satellite Dry Mass (Probe + Spacecraft)	3,070	3,845
Propellant Mass	283	355
Satellite Wet Mass	**3,353**	**4,214**
Atlas V 551 Throw Mass Available	**5,140 kg**	

Spacecraft Mass has 22% contingency versus VITaL baseline of 30%

OPTION 2: Alpha Regio 2023 Landing Site

Item	ADEPT-VITaL Margined (kg)	VITaL Baseline Margined (kg)
Probe	2,100	2,745
Spacecraft	970*	1100
Satellite Dry Mass (Probe + Spacecraft)	3,070	3,845
Propellant Mass	1,117**	1,399
Satellite Wet Mass	**4,192**	**5,244**
Atlas V 551 Throw Mass Available	**5,140 kg**	

****Higher propellant mass than VITaL baseline because a new landing site was chosen that requires a deep space maneuver***

- **ADEPT architecture can lower the Launch Mass by 25%, or**
- **New Landing Site feasible only with ADEPT Architecture**

Concluding Remarks (missing testing decreases and lower mass)

ADEPT

- **ADEPT, a Low Ballistic Coefficient, Mechanically Deployable Entry System Architecture is a Game Changer:**
  - Dramatically decreases the entry environment due to high altitude deceleration (200 gs to 30 gs)
    - 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
- **New Frontier and Discovery Class Missions to Venus become highly Competitive with Missions to Other Destinations recommended by Decadal Survey**
- **OCT's investment in ADEPT, mechanically deployable aeroshell technology has broad payoff including Venus**
- **Continued Technology Maturation and Flight Test of ADEPT concept by 2015/2016 will**
  - Enable Venus Missions to be a top contender for the next round of New Frontier AO.