VENUS MOBILE EXPLORER (VME): NEAR-SURFACE TRAVERSING WITH METALLIC BELLOWS

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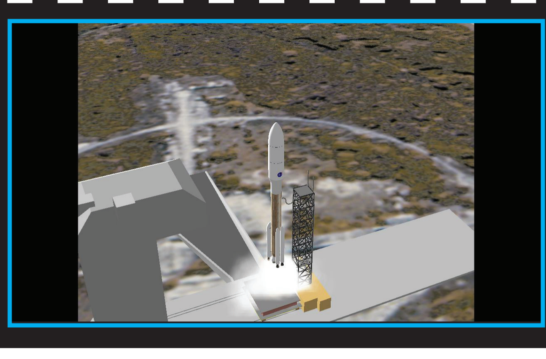
In support of the National Research Council's (NRC) 2010 Planetary Decadal Survey (DS), NASA Headquarters commissioned the Goddard Space Flight Center (GSFC) to perform a Venus Mobile Explorer (VME) study for the DS Inner Planets Panel. The VME mission concept's science objectives required the characterization of surface composition and mineralogy at two different locations within the highlands region of Venus. The measurements are expected to constrain models of the planet's origin and evolution.

Access to the surface at two locations, separated by several kilometers, is best achieved with an aerial mobility platform that can tolerate the local extreme environmental conditions, where the temperature and pressure of the corrosive supercritical CO_2 atmosphere vary from 447°C to 424°C, and 81 bar to 67 bar, respectively, from the surface up to 3 km altitude. Consequently, the study team recommended a metallic bellows system, adopted from the multi-stage balloon concept of a future Venus Surface Sample Return mission. The innovative design of the gondola, surrounded by a toroidal helium tank and capped by the stowed metallic bellows allows for a compact and volume efficient packaging inside the aeroshell. While in situ, the helium inflated metallic bellows system is sized to support the mass of the gondola, which consists of a passive thermal controlled pressure vessel that houses the science payload and subsystems.

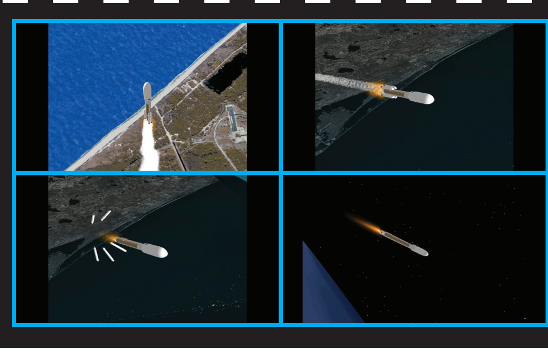
From a bellows operational point of view, following atmospheric entry, the VME would descend to the surface in about an hour, with the bellows stowed. At the initial landing location following a 30 minutes science investigation, the bellows would inflate in about 5 minutes and ascend to a float altitude of ~3 km above the surface, leaving the empty helium tank and connected inflation system on the surface. The bellows system would enable high spatial resolution near infrared mapping of the surface over its ~8 to 16 km float path, riding the low altitude winds. The gondola would be released after 220 minutes of traverse over the second landing location, concluding the bellows system's intended functions.

This paper focuses on the design and sizing of the metallic bellows and inflation systems, including the helium tank, pyro and control valves, and fill lines. These are discussed in the context of the key bellows operational phases, from atmospheric entry, through landing, inflation, ascent to float altitude and buoyancy, aerial traverse, to gondola release at the second landing location. The overall mission description will be given in a companion paper.

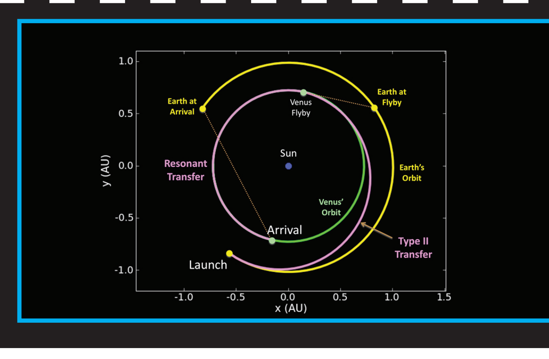
The VME study was one of several dozen commissioned by the NRC's Planetary Decadal Survey to explore the technical readiness, feasibility and affordability of scientifically promising mission scenarios. There is no guarantee that the VME mission concept, or any of the other missions studied, will appear in the Decadal Survey's final list of priorities.



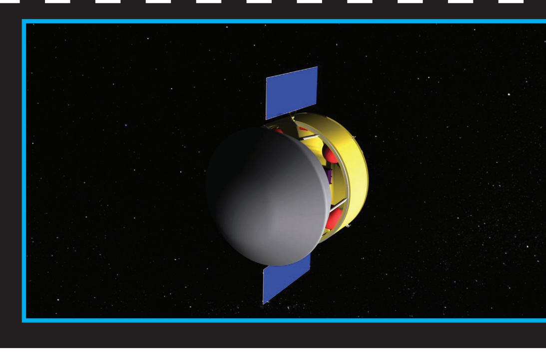
- Proposed launch (L) on May 27, 2023
- On an Atlas V 551 launch vehicle (the Russian Proton-M launch vehicle would also be feasible)



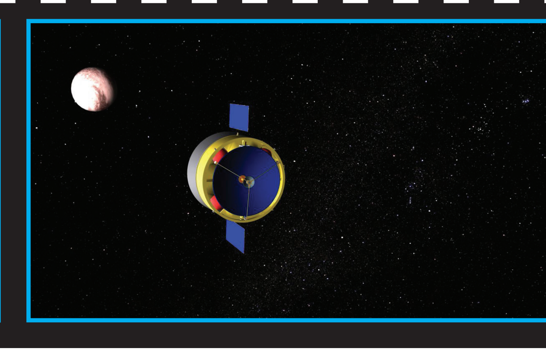
- The spacecraft would reach orbit in ~8 minutes and set out to Venus on a Type II re-encounter trajectory from a parking orbit



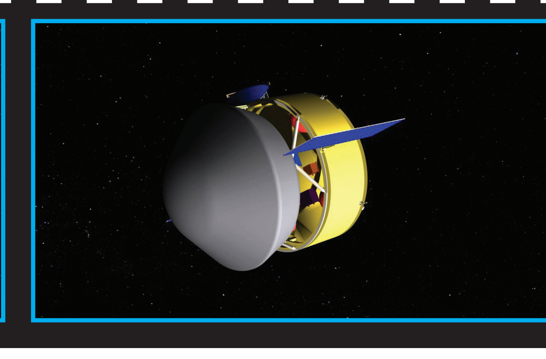
- Venus flyby on Oct. 27, 2023 (L+153 days)
- Venus re-encounter / arrival on Feb. 15, 2024 112 days after the first Venus flyby
- A 2021 launch opportunity is also viable



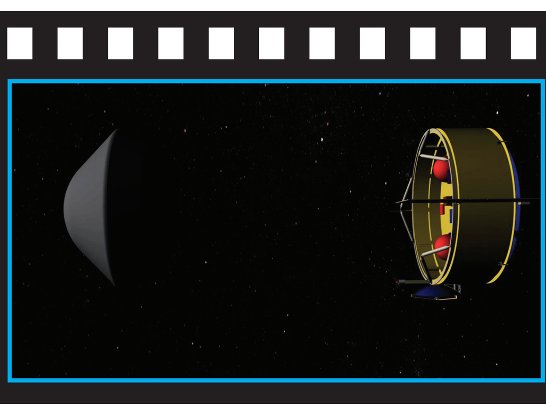
- The Carrier spacecraft is 3-axis stabilized during most of the interplanetary cruise
- Its two solar arrays are ~1.2 m² each



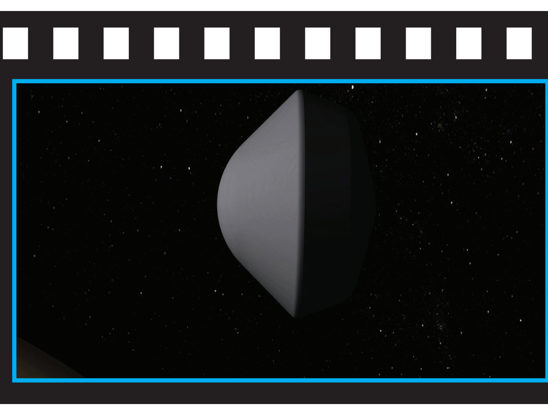
- The interplanetary cruise time is 264 days between launch and atmospheric entry of the Entry System carrying the Venus Mobile Explorer (VME)



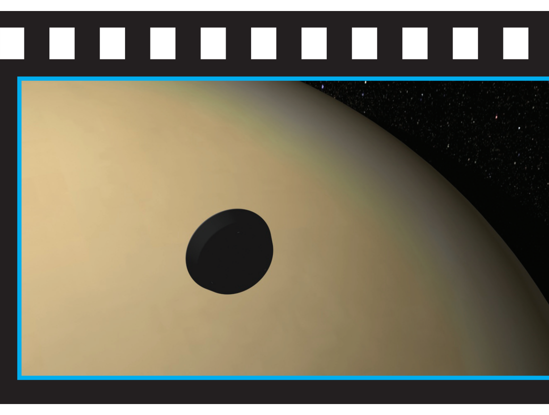
- Before releasing of the Entry System, the Carrier spins up to 5 RPS
- The Entry System is spin stabilized



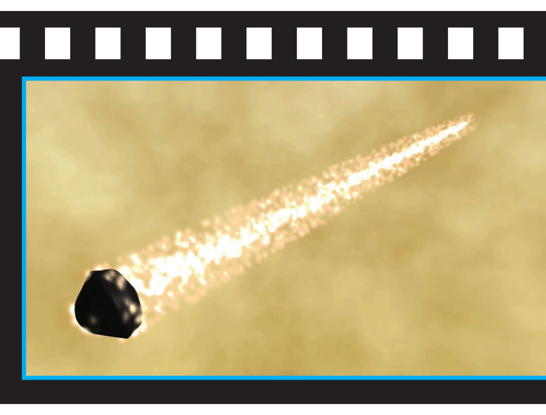
- The Entry System separates from the Carrier 5 days before its atmospheric entry
- The Carrier spins down after separation, then performs a divert maneuver one day later, which is 4 days before the Entry System reaches Venus



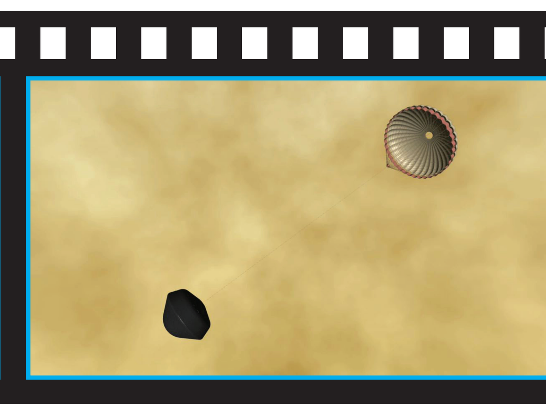
- The spin stabilized Entry System cruises to Venus in 5 days
- During a mostly silent cruise, system checks are performed
- The metallic bellows, gondola, inflation system are stowed inside the Entry System



- The Entry System reaches the atmospheric interface at 175 km altitude on Feb. 15, 2024
- The landing location for this opportunity is latitude N 22.6°, longitude E 8.4° (near Gula and Sif Montes); Time: close to noon
- (Heat shield heritage: PVLP and Stardust)



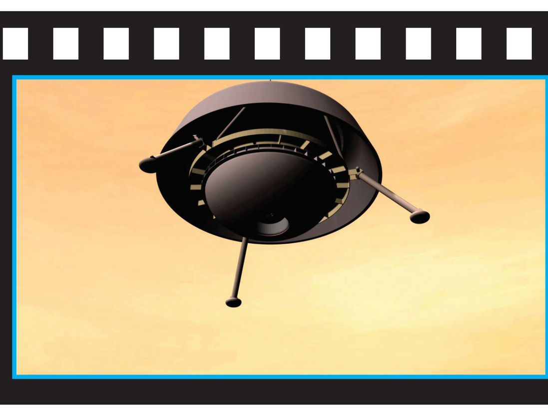
- Atmospheric entry velocity: 11.3 km/s
- Entry Flight Path Angle: 19°
- ~1 min peak deceleration with the aeroshell
- Heat flux: 2.3 kW/cm²; g-load: 167g
- Entry System mass: 2849 kg with 30% cont.
- Aeroshell diameter: 3.5 m



- Parachute opens at ~60 km altitude, about 1-2 minutes after the entry, further slowing down the Entry System
- The load path was designed starting from the aeroshell, through the stowed payload to tolerate the high entry g-loads

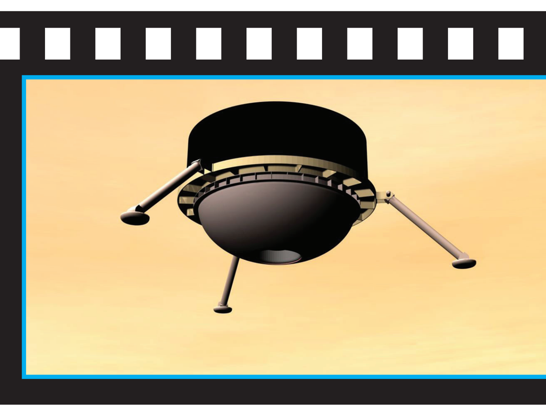
- After parachute opening, the front and backshells separate, using pyros
- The separating heat shield TPS consists of 1-inch (2.54 cm) tape wrapped and chop molded carbon phenolic (TWCP, CMCP)
- Backshell is PICA due to lower heat flux

- The front shell is jettisoned at ~60 km
- Pressure and temperature increases as the system descends to the surface
- The inflation tank's insulation is designed to keep the 10,000 psi Helium below 70°C through descent and bellows inflation

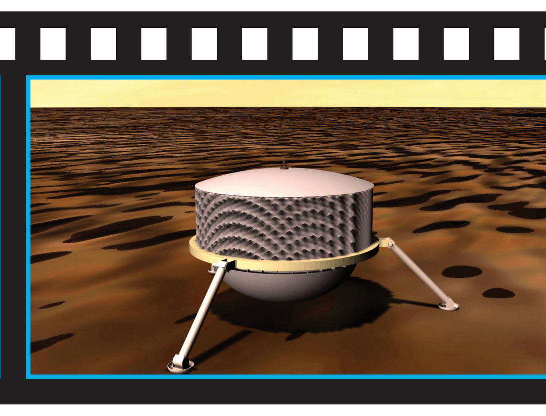


- The landing legs deploy, while the Venus Mobile Explorer (VME) is still attached to the backshell and suspended under the parachute
- These legs allow for a dampened stroke and a landing load of ~34 g

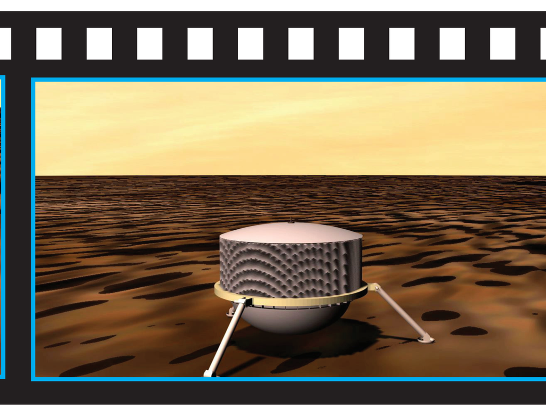
- The backshell and parachute are jettisoned
- An aerodynamically stable descent can be improved by a drag plate, which needs further analysis



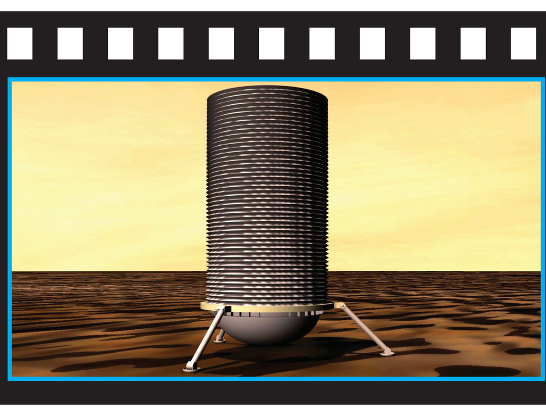
- The Venus Mobile Explorer descends to the surface in about an hour following the atmospheric entry
- The impact velocity is expected ~10 m/s
- During descent the bellows pressure is kept about 0.5 bar below ambient (slow fill)



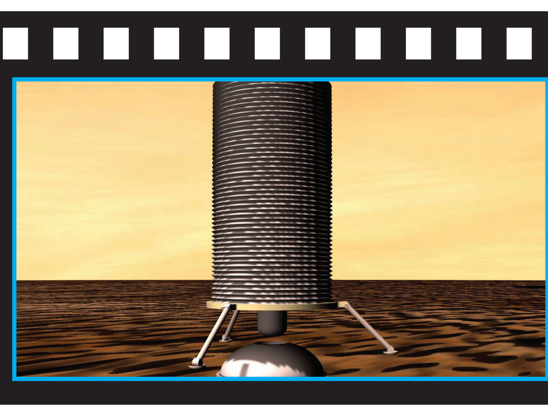
- Successful landing at the scientifically desirable Tessera region requires rugged landing capability, which will require future detailed studies and technology development
- The current landing location is assumed at 2 km above the mean planetary radius



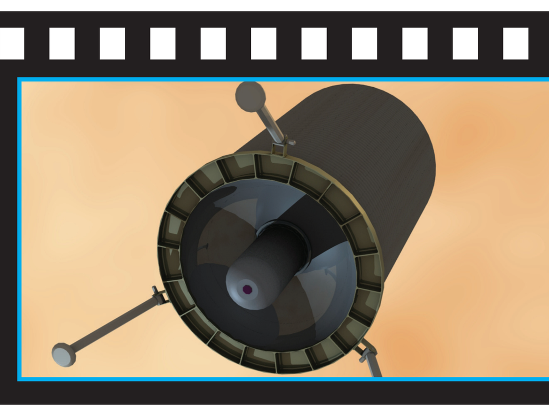
- The VME performs science investigations at this first landing site for about 30 minutes
- At this 2 km surface elevation T = 447°C and p = 81 bar; lower than at 0 km, thus the thermal design requirements for the gondola and He tank are somewhat lower



- Bellows inflation (p+0.5 bar) takes ~5 minutes
- When the inflation is completed, the elastic ratio of the stainless steel bellows is 5, which means that the height ratio of the bellows between stowed inflated configurations is 1:5
- The displaced volume is ~14.8 m³

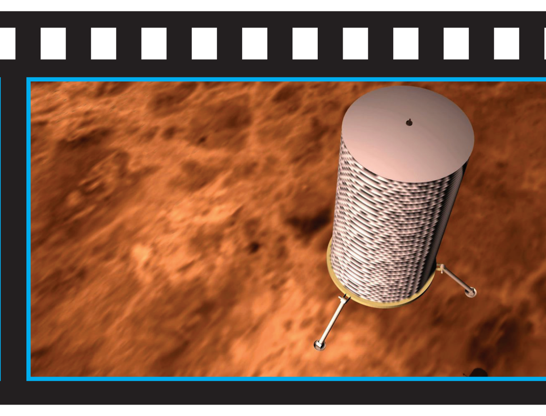


- 81 kg of He is transferred to the bellows; Inflation ends; valve and fill line pyro-cut
- The empty thermally insulated Titanium inflation tank is jettisoned; since the 842 kg tank acts as a ballast, losing it causes the bellows with the gondola to ascend



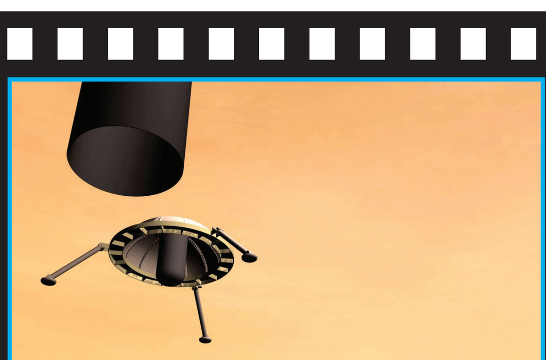
- The VME without the helium tank ascends to a design float altitude in ~20 min
- At this 5 km altitude (i.e., 3 km above the highland surface) T = 421°C and p = 67 bar, lower than at the surface. This is accounted for in buoyancy design & thermal designs

- To maintain the 0.5 bar overpressure in the bellows from the surface to the design float altitude, helium is vented through a pressure relief valve, while keeping the bellows at a constant volume (other approaches exist)
- The vented He volume is 11.5 kg (2 to 5 km)

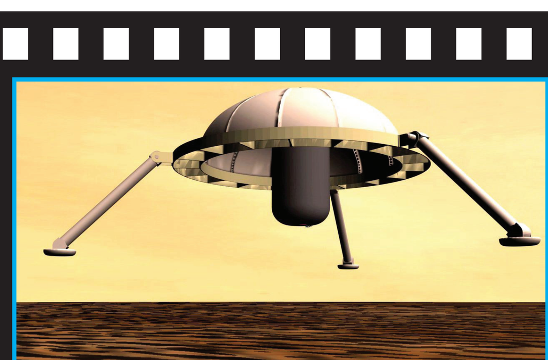


- Once reaching the design float altitude, the VME's bellows design enables unprecedented science investigations near the Venusian surface
- This would include high resolution surface imaging, not possible from orbit

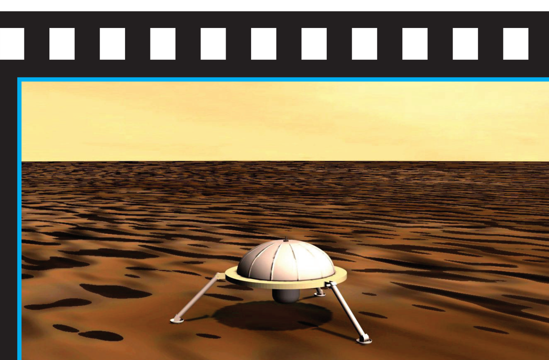
- During its 220 min traverse the VME would cover 8 to 16 km distance from the first landing location, depending on the winds
- This near surface traverse could also improve our understanding of the wind dynamics (hard to measure with a probe)



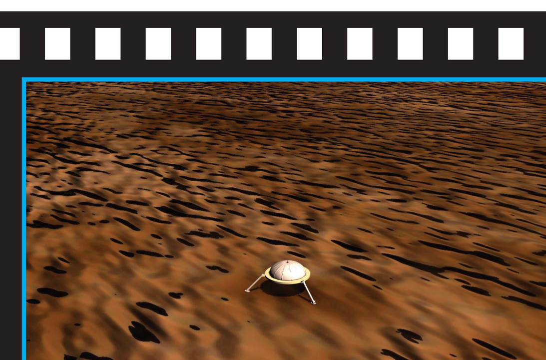
- After ~3 hours traverse at altitude (not counting ascent), the gondola and the bellows are separated autonomously
- This concept is limited to one traverse, due to He tank release at landing and the plastic deformation of the bellows (no re-inflation)



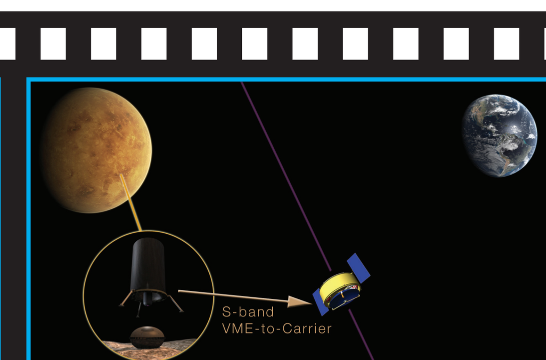
- The gondola descends to the surface in 10-20 minutes at the second landing site
- The attached dome provides aerodynamic stability, while slowing the gondola during descent; the design also allows to re-use the same landing legs as during the first landing



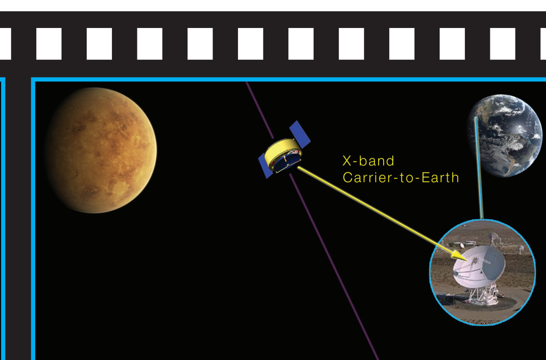
- At the 2nd landing site the gondola would perform the same science investigations as at the first site
- The science payload is housed in a pressure vessel with a passive thermal design, sized to operate through the ~6 hours in situ lifetime



- The metallic bellows design, described in the VME Decadal Survey study, can provide near surface aerial mobility, and access to two surface locations, tens of km apart
- The design also provides feed forward to a Venus Surface Sample Return mission



- The science data from the VME during its ~6 hours in situ lifetime is sent to the Carrier using an S-band telecom system
- The total science data volume is approximately 200 Mbits



- The science data is initially stored on the Carrier until the full data set is received
- Then the data is relayed back to Earth using an X-band telecom system

Venus Mobile Explorer Design Summary (without the Carrier)

Item	CBE Mass (+30% cont.)
VME Bellows	**219 kg**
…Diameter	*2.3 m*
…Inflated height	*3.55 m*
…Wall thickness	*0.18 mm*
Bellows mass	*93 kg*
Other structural support	*45 kg*
Helium fill gas mass	*81 kg*
…Compressed helium volume (at 10,000 psi)	*~2 m³*
VME Inflation System	**842 kg**
Single toroidal tank (2 m³)	*764 kg*
Plumbing + valves	*38 kg*
Insulation (1 cm thick)	*40 kg*
VME Gondola:	**649 kg**
Science Payload	*41 kg*
Subsystems total	*608 kg*
Mechanical/Structure	*351 kg*
Mechanisms	*66 kg*
Thermal	*147 kg*
Other	*44 kg*
Aeroshell:	**1139 kg**
Heat Shield	*824 kg*
Backshell	*263 kg*
Parachute	*52 kg*
Entry System & Payload Total	**2849 kg**

All information presented on this poster are for planning and discussion purposes only

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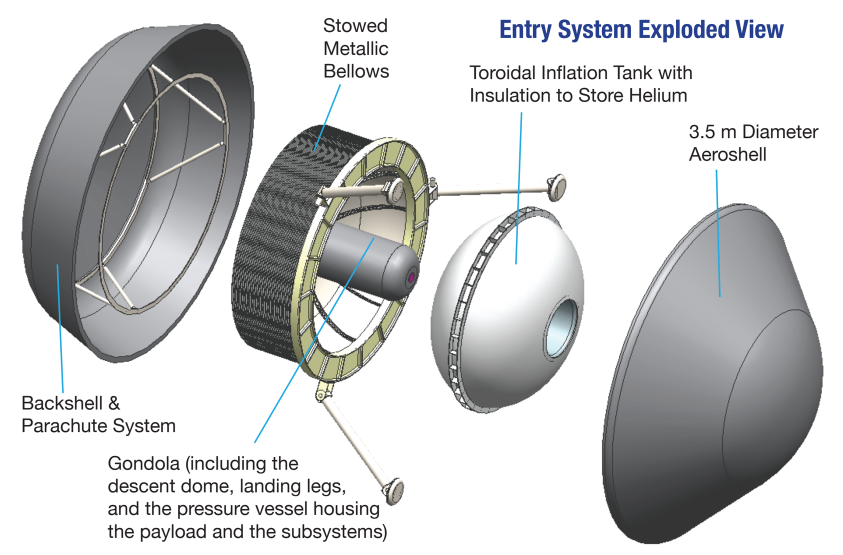
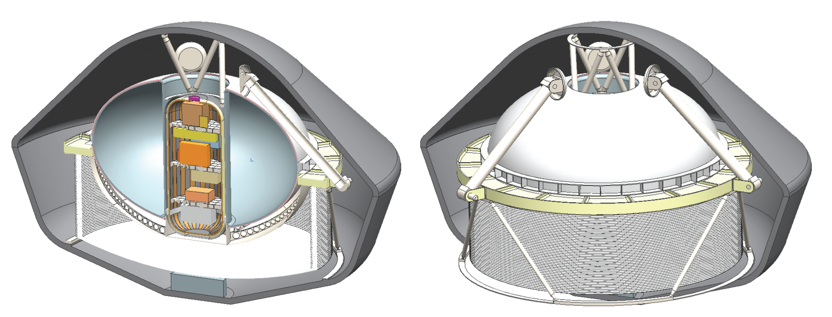
Entry System Exploded View





Entry System Stowed Configuration

NOTE: The filmstrip images of launch vehicle, spacecraft, Entry System (including the exploded view above) are all artist's concepts

Reference:

- Glaze, L., Adams, M., 2009. "Venus Mobile Explorer", Mission concept study report to the NRC Decadal Survey Inner Planets Panel, NASA GSFC/ JPL-Caltech/NASA ARC, Dec 18
- Kerzhanovich, V.V., A.H. Yavrouian, J.L. Hall, J.A. Cutts, K.H. Baines, S.K. Stephens (2005) Dual Balloon Concept for Lifting Payloads from the Surface of Venus, LPSC XXXVI.

Simplified In Situ Timeline

- 60 min Entry/Descent/Landing (EDL)
- 30 min 1st Surface science + Inflation
- 20 min Ascent to float altitude
- 220 min Float + science measurements
- 10 min Descent at 2nd lading site
- 30 min 2nd Surface science

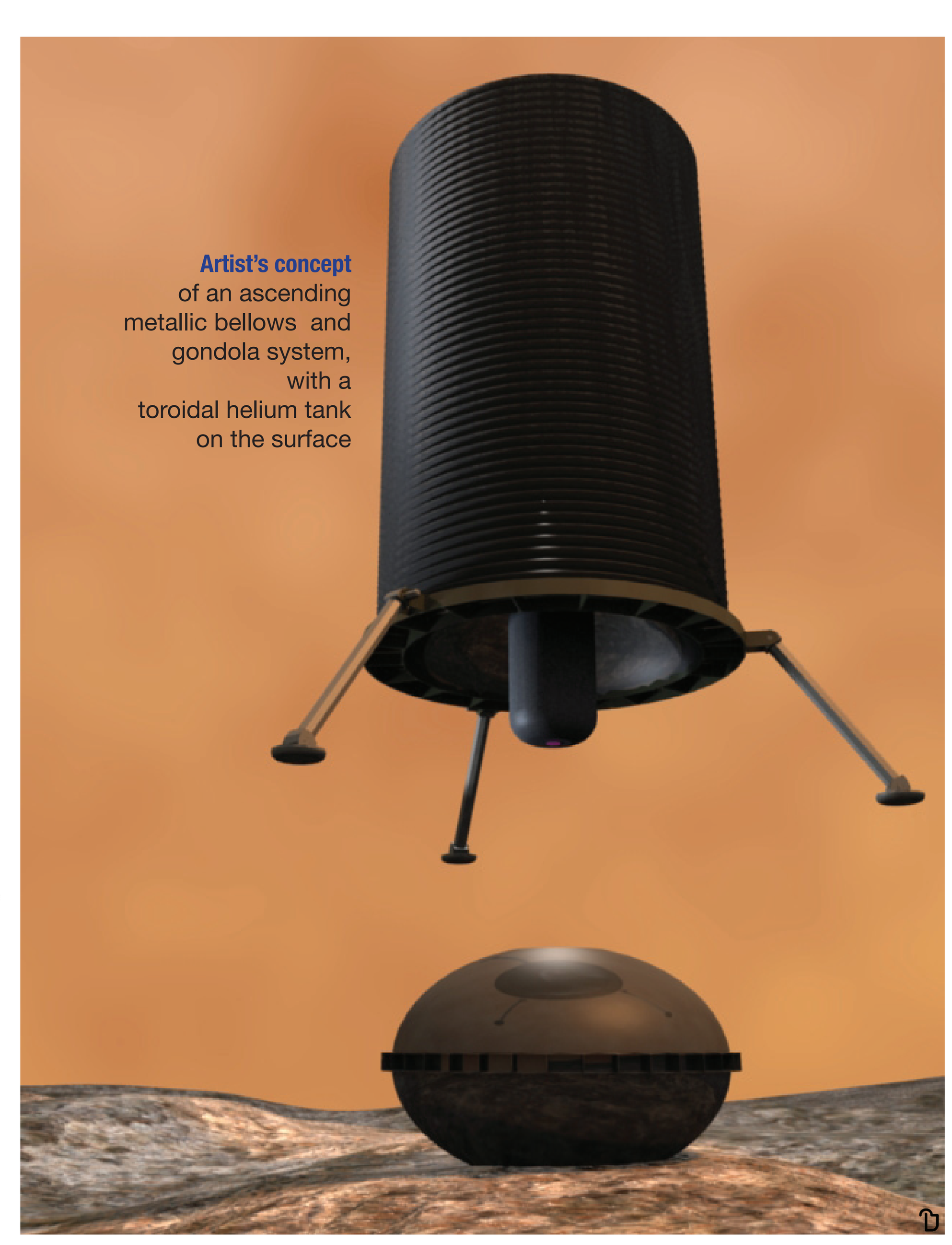
Metallic Bellow Prototype built and tested at JPL

(a) Bellows inflated & tested at Venus surface temperatures;

(b) Semi-inflated bellows;

(c) Stowed (~1:5 ratio);

[Kerzhanovich et al., 2005]



Artist's concept of an ascending metallic bellows and gondola system, with a toroidal helium tank on the surface

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