Venus Surface Sample Return: A Weighty High-Pressure Challenge

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A mission to return a sample to Earth from the surface of Venus faces a multitude of multidisciplinary challenges. In addition to the complications inherent in any sample return mission, Venus presents the additional difficulties of a deep gravity well essentially equivalent to Earth's and a hot-house atmosphere which generates extremes of high temperature, density, and pressure unmatched at any other known surface in the solar system. The Jet Propulsion Laboratory of the California Institute of Technology recently conducted a study to develop an architecture for such a mission; a major goal of this study was to identify technology developments which would need to be pursued in order to make such a mission feasible at a cost much less than estimated in previous. The final design of this mission is years away but the study results presented here show our current mission architecture as it applies to a particular mission opportunity, give a summary of the engineering and science trades which were made in the process of developing it, and identify the main technology development efforts needed.

Mission overview

A single launch with a medium-to-large expendable launch vehicle (in the Delta IV M+ class) suffices to launch the spacecraft on a ballistic transfer to Venus, where it will spend a year before beginning the return journey to Earth. After aerocapture at Venus, the mission adopts a strategy reminiscent of the Apollo manned missions to the Moon. A propulsive plane change and aerobraking put the spacecraft into a circular equatorial orbit. A lander separates from the orbiter and descends to the surface to collect a sample, which is placed in a sample carrier at the tip of a three-stage Venus ascent vehicle (VAV). A variety of passive thermal and pressure protection techniques are used to protect the landed hardware and the VAV during a rapid descent and 90-minute stay on the surface. The lander inflates a balloon which carries the VAV with the sample to a high altitude (60 km – 70 km) in a few hours, from whence the VAV puts the sample carrier into orbit around Venus. Then the orbiter which brought the lander to Venus uses a beacon on the sample carrier and its own telescopes to rendezvous with the sample carrier. After transferring the sample into an Earth entry vehicle (EEV) on board, the orbiter deploys solar arrays to power a solar electric propulsion (SEP) system which is used to spiral out from Venus and travel back to Earth, taking two and a half years in total for the return.

Mission Alternatives

The multitude of mission phases and relatively large number of system elements make for a large number of engineering trades which must be considered. A table showing

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the main trades is attached. In particular, the mission architecture baselined here depends on the ability of solid rocket motors to withstand the pressure at the surface (they will be protected from the heat). An alternative approach also studied in some detail would be to keep the VAV suspended by a powered blimp at a high altitude and use smaller balloons to acquire a sample from the surface and bring it back to altitude where the blimp would rendezvous with it and transfer the sample to the VAV.

Previous studies have focused on similar but distinct architectures for this mission (Refs. 1-3). These studies in general have concluded that two launches are necessary, delivering the lander and the orbiter to Venus separately. In this study we have seen that use of advanced technologies may make it possible to perform the mission with a single launch.

Science Considerations

The primary science goals of the mission are to determine the mineralogical, chemical, and isotopic composition of Venus's crust and to investigate its structure and evolution. The minimum requirements on the surface sample to satisfy these science goals were that it include a small (on the order of 1 cm^3), intact, unweathered rock sample, with good contextual information in the form of images of the sample site, and a sample of the lower atmosphere to help in understanding the interaction between the crust and the atmosphere.

A Closer Look at the Mission

Transfer to Venus is accomplished by conventional launch into a direct ballistic transfer trajectory. SEP was considered as an alternative and while it does offer some mass advantage (adding perhaps 5% to 10% to the delivered mass), the cost of the SEP system didn't seem worth the mass gain.

Aerocapture at Venus is done using an inflated hypersonic drag device (also known as a ballute, a hybrid of balloon and parachute). Because of the relatively low ballistic coefficient of the ballute the atmospheric heating is spread over a much larger area making an ablative heat shield unnecessary and offering a significant mass advantage. In addition the drag device can be released when the desired ΔV has been achieved, which replaces the the more complicated guidance and control system needed by conventional aeroshells to remove the errors due to navigation and uncertainty in the atmosphere.

Staging Orbit for Lander Deployment is equatorial and circular to give equal access to a variety of terrains and keep the orbiter coplanar with the lander and the balloon ascent after sample acquisition. Also, a low circular orbit minimizes the entry velocity for the lander. The orbit is achieved by a plane-change maneuver near the apoapse of the initial capture ellipse, followed by aerobraking to circularize the orbit.

Landing must be quick to minimize exposure to the extreme atmosphere. Another hypersonic drag device (perhaps with the same inflation hardware as was used by the first one) is deployed to remove the entry velocity for landing and then released to allow the lander to fall as quickly as possible. Because the high density near the surface the terminal velocity at landing may be as low as a few meters per second; a small parachute may be deployed near the surface to reduce the velocity further and to provide stable orientation for landing. Like Viking and Pathfinder, this mission is accepting the risk of landing "in the blind," though pictures will be taken during the descent of the landing site for later transmission to the orbiter. The VAV is thermally isolated within an insulated bag which is maintained at ambient pressure through the descent, landing, and balloon ascent.

Sampling must also be done quickly but with limited power. An ultrasonic coring device which is at an early stage of development looks like the best prospect for doing the sample acquisition. A mechanism to deploy and control the drill and transfer the sample to a canister was designed to operate at ambient conditions.

Balloon Ascent to an altitude of 66 km offers the opportunity to rocket the sample into orbit; a lower altitude would require a larger rocket, a higher altitude a larger balloon — the minimum total is achieved somewhere around 66 km, depending on the detailed characteristics of the balloon and the VAV. The balloon would operate at zero-pressure but would still need to survive the ~~and~~ harsh environment. One candidate material is polybenzoxazole (PBO) for strength at high temperature, with a Teflon coating for protection against sulfuric acid and possibly another coating over that to prevent the balloon from sticking together while it's packed up. The balloon would be inflated from helium tanks which would stay on the lander.

Venus Ascent Vehicle designs were simulated with a variety of stage combinations and guidance schemes. A successful ascent was simulated for a three-stage combination of off-the-shelf solid rockets, using inertial guidance and control (which need to be developed) to steer the first two stages and to orient and spin up the third stage to do the final insertion burn at altitude. A cartoon of the VAV and ascent design is attached.

Rendezvous and Capture would be done using hardware and techniques being developed in the Mars Surveyor Program for sample return from Mars.

Return to Earth is very demanding because of Venus's size. A comparison between conventional chemical propulsion and SEP showed a large mass advantage to SEP. In contrast to the use of SEP considered for delivery of the spacecraft to Venus, the closer proximity of the Sun and the lower mass of the returning vehicle both implied a smaller, less costly SEP system.

Mass and ΔV Summary charts will be included in the paper.

Conclusion

The technologies which provided the greatest advantages in reducing the total system mass for a Venus Surface Sample Return mission were the use of hypersonic drag devices instead of aeroshells and the use of SEP for the return from Venus to Earth. One other technology which is a *sine qua non* for this mission is a hardware system for controlling the direction of the VAV's first two solid stages as directed by a small self-contained inertial measurements unit (IMU).

Acknowledgment

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References

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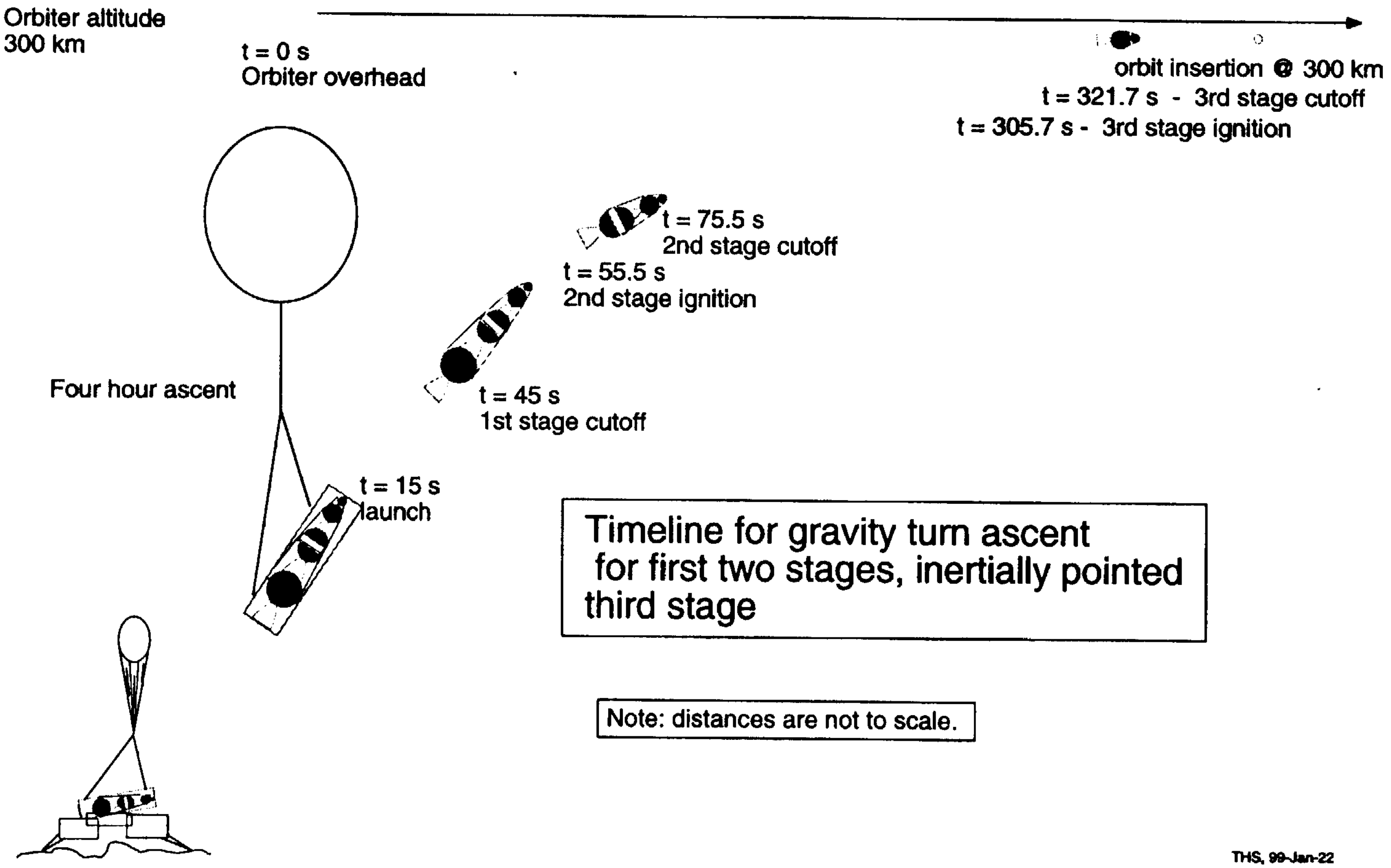
Venus Sample Return Mission Baseline and Trades

Mission Trade	Baseline	Alternatives	Reason
Launch	single	multiple	cost
Transfer to Venus	chemical ballistic	SEP, solar sail	cost, simplicity
Capture at Venus	ballute	conic aeroshell, biconic aeroshell, propulsive	mass
Initial Venus orbit	ellipse	circular	delta-V, mass
Lander entry orbit	circular equatorial	ellipse, direct entry	site selection
Entry technology	ballute	conic aeroshell, biconic aeroshell	mass
Sampler element	full lander	tether from floating platform, freeflyer from platform	risk, simplicity
VAV* handling	take to surface	hold at floating platform	risk, simplicity
Sample selection	random	selected, rover	cost, simplicity
VAV configuration	"thin" cylinder	toroidal	cost
VAV avionics	IMU on second stage	radio beacon, horizon sensors, sun sensor, star tracker,gyros	mass, simplicity
VAV control	3-axis 1st & 2nd stages, spin 3rd stage	multiple possible combinations	cost, simplicity
Rendezvous tech.	radio beacon+visual	visual only	risk
Rendezvous prop.	chemical	SEP	risk, simplicity
Transfer to Earth	SEP	chemical ballistic, solar sail	mass
Earth entry	capsule aeroshell	ballute	risk, cost

* VAV = Venus Ascent Vehicle

Venus Sample Return Mission – Venus Ascent Profile



Orbiter altitude
300 km

t = 0 s
Orbiter overhead

orbit insertion @ 300 km
t = 321.7 s - 3rd stage cutoff
t = 305.7 s - 3rd stage ignition

t = 75.5 s
2nd stage cutoff

t = 55.5 s
2nd stage ignition

Four hour ascent

t = 45 s
1st stage cutoff

t = 15 s
launch

Timeline for gravity turn ascent for first two stages, inertially pointed third stage

Note: distances are not to scale.

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