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Venus Surface Sample Return: Role of Balloon Technology

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ABSTRACT

The rocks and soils on the surface of Venus record the secrets of why this planet evolved so differently from its sister planet Earth. Both NASA and the European Space Agency are now studying missions for bringing samples from the surface of Venus back to Earth where they can be analyzed with state-of-the-art techniques. Balloon technology will play a key role in such a mission. It will be used for raising samples from the Venus surface when the temperature is 460C and the pressure is 90 bars to the upper atmosphere from where the samples can be launched into orbit around Venus. Three approaches to the implementation of a solid-rocket based Venus Ascent Vehicle (VAV) have been considered in the NASA study carried out at JPL. In the first approach, similar to the ESA concept, the solid rocket is an integral part of the surface sampling system, is carried to the surface of Venus and lifted back to the upper atmosphere on the same balloon. In the second approach, the VAV is deployed in the upper atmosphere and suspended there on a blimp which performs a rendezvous with the balloon carrying the surface sample and effects a sample transfer. In the third approach, the VAV is deployed into the atmosphere on a winged vehicle that performs a rendezvous with the balloon carrying the surface sample and also performs sample transfer. The paper compares the three approaches. It also includes the developments in balloon technology and in materials and devices for use in severe environments.

INTRODUCTION

Thirty years ago, human and robotic missions to the moon, performed the first sample return of extraterrestrial materials. The Apollo astronauts brought back lunar rock, soil and drill core samples in six successful manned missions between 1969 and 1972. The Soviet Union carried out two successful robotic lunar sample return missions in the same period: Luna 16 and Luna 20 that returned drill core samples. A second wave of sample return missions is now under way. On February 7, 1999, NASA launched the STARDUST mission that will fly through the tail of a comet at more than 6km/sec, capture intact particles of comet dust in a low density aerogel collector and bring the samples back to Earth five years later. In January 2001, NASA will launch the GENESIS spacecraft to collect samples of the solar wind in an ultrapure silicon wafer. Then in 2003, NASA in collaboration with CNES (the French Space Agency), will launch the first phase of the Mars Surface Sample Return (MSSR) mission that will collect surface soil, rock core and atmospheric samples from Mars. The samples will be returned to Earth in 2008.

With the launch of the first element of the Mars Surface Sample Return mission only four years away, both NASA and the European Space Agency (ESA) are now turning their attention to sample return from other solar system bodies. Earth's sister planet Venus has high priority for a sample return mission. However, the problems of acquiring and returning samples from Venus are formidable. Venus is comparable in size to Earth and almost 10 times the mass of Mars, but it possesses an inhospitable surface environment with temperatures near 460C, surface pressures of 90 bars and sulfuric acid particles in the upper atmosphere. As discussed in companion papers in this issue, advanced balloon technology can play a key role in carrying out the *in situ* exploration of Venus including close up observations of the surface. Balloon technology also will play a critical role in returning samples of soils and rocks from the surface of Venus.

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ARCHITECTURE OF MARS SURFACE SAMPLE RETURN MISSION

The philosophy underlying the NASA approach to Venus Surface Sample Return (VSSR) is to build on the mission architecture used for the Mars Surface Sample Return (MSSR) mission. In this section, we first give a simplified description of the architecture of the MSSR mission and then describe how a VSSR mission can incorporate key subsystem elements.

In the MSSR, a vehicle is delivered to the Mars surface consisting of sample collection equipment and a three-stage solid-rocket Mars Ascent Vehicle (MAV). Once samples have been placed in a canister in the MAV, the canister is propelled into a low but stable near-circular orbit around Mars. A second spacecraft performs an autonomous rendezvous with the sample canister, captures it and inserts it into a protective aeroshell. The second spacecraft is then injected from Mars orbit on a trans-Earth trajectory. The aeroshell containing the sample is targeted for atmospheric entry and lands at a site in the western United States.

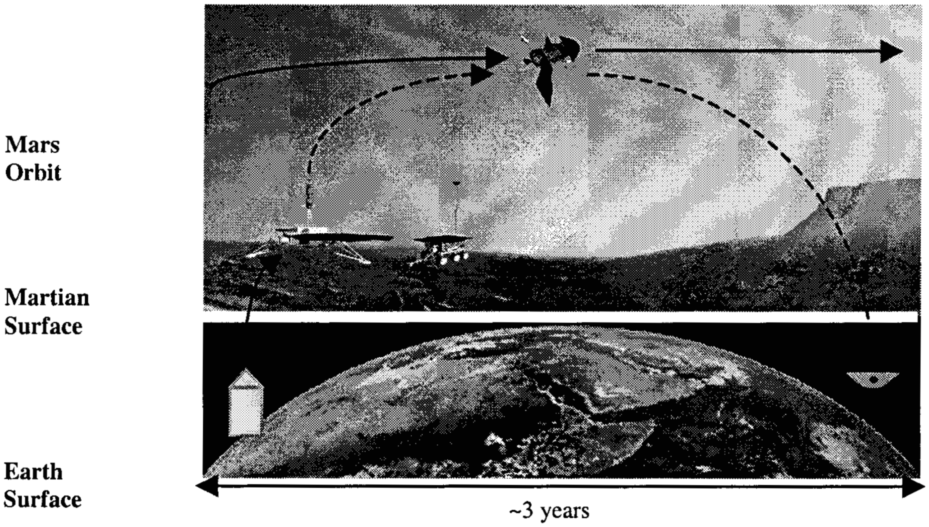

Fig 1: Architecture of the Mars Surface Sample Return Mission

The overall architecture of the MSSR mission is not new - it bears a strong resemblance to the architecture of the manned lunar Apollo mission. The prime difference is that the MSSR mission is completely robotic and depends on a sophisticated acquisition system for the orbiter to locate and capture the sample return capsule in Mars orbit. The MAV, on the other hand, is a small and comparatively simple vehicle using solid rockets and minimal overhead in guidance and control systems such that it can lift a sample from the surface and delivering it to a stable although not precisely defined orbit.

VENUS SURFACE SAMPLE RETURN

The philosophy of the recent JPL study of VSSR was to apply as much as possible of the architecture, technology and, where possible, specific hardware of the MSSR to sample return from Venus. However, there are significant differences in the operating enviornment (Table 1) that require significant modification to the MSSR architecture.

Table 1: Comparison of Surface Environments of Venus, Mars and Earth

Planet	Venus	Mars	Earth
Surface gravity (m sec$^{-2)}$	8.87	3.71	9.80
Velocity to orbit			
Surface Pressure (bars)	90	.006	1.0
Surface Atmospheric density (kg m^{-3})	65	.015	1.2
Surface temp(max,equator,K)	730	270	315
Surface temp(min,equator,K)	730	190	270
Sulfuric acid concentration	High	Neglig	Neglig

The Mars Ascent Vehicle is much smaller than a comparable launch vehicle for raising a sample from the surface of the Earth to orbit. This is because the Martian gravitational acceleration is almost a factor of three smaller than that of Earth and the Martian atmospheric density is less than 1% of that near the Earth's surface. A Venus ascent vehicle, on the other hand has to lift the sample out of a gravitational well comparable to that of the Earth. Moreover, the atmospheric density on the surface of Venus is 50 times greater than that at the surface of the Earth and 10,000 times greater than that at Mars. At the same the Venus Ascent Vehicle (VAV) and Sample Acquisition Vehicle (SAV), have to be designed to tolerate an external pressure of 90 bars and a temperature of 460C.

Two different approaches to Venus Surface Sample Return, have been devised and both of them make extensive uses of balloon technology. Lighter than air vehicles are the only practical means of raising samples from the surface of Venus to where the atmosphere is thin enough for rocket injection into space. The rocket itself may also be deployed from a balloon or blimp depending on the specifics of the approach.

Combined Atmospheric Vehicle – In this architecture, the VAV and SAV are combined into a single vehicle. This vehicle descends to the surface where sample acquisition occurs, a balloon is deployed and the combined vehicle ascends to an altitude where the atmospheric pressure is sufficiently low for an efficient launch of the ascent vehicle.

Dual Atmospheric Vehicles: In this architecture there are two separated vehicles entering the Venus atmosphere. The SAV descends to the surface, acquires samples and deploys a balloon that causes it to ascend to an altitude from which a launch to orbit is feasible. The VAV enters the atmosphere, performs a rendezvous with the SAV, transfers the sample and then launches the sample to orbit. Two options for deployment of the VAV and rendezvous with the SAV have been considered: a blimp and an airplane.

COMBINED ATMOSPHERIC VEHICLE:

The combined atmospheric vehicle concept for this mission is illustrated in Fig 2. The phases of the mission carried out in the Venus atmosphere are as follows:

- ***Descent and landing (1 hour):*** – This can be executed quite rapidly although the density of the Venus atmosphere impedes rapid descent and the nature of the integrated VAV/SAV vehicle makes it difficult to achieve a highly streamlined shape.
- ***Land and drill for samples(1.5 hour):*** The acquisition of core samples in rock as opposed to loose soil or regolith, are critical to a useful science experiment. An ultrasonic drill appears to be the most effective approach to drilling high temperature rock.
- ***Stow sample and ascend to launch altitude(3-5 hours):*** After completing sample acquisition, the balloon is rapidly inflated. The sample canister is detached from the drilling mechanism and the VAV/Sample canister ascends to an altitude from which the VAV can be efficiently launched.
- ***Launch and ascent to orbiter altitude:*** The VAV is launched from beneath the balloon and injects the sample canister into Venus orbit where it can be retrieved.

The concept developed by JPL for a Venus Sample Return mission is similar in many respects to the concept developed by ESA (Ref. 1) Some of the differences between the concepts are summarized in Fig 2 and elaborated on below.

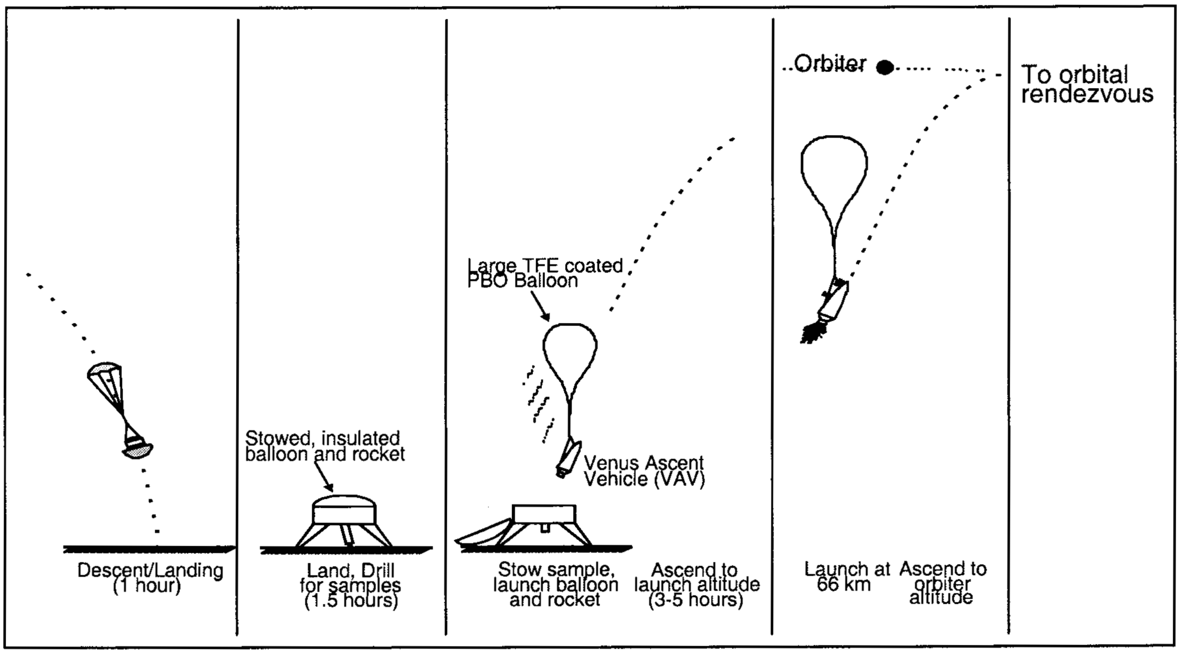

Fig 2: Combined Atmospheric Vehicle Approach to Venus Surface Sample Return

Subsystem or Function	ESA Study June 1998	NASA-JPL Study January 1999	Comments / Rationale
Sample Container mass (kg)	10	2	Minimize launch mass and all other key Transportation systems including balloon and Venus Ascent Vehicle
Balloon deployment and inflation	*Aerial*	*Surface*	Venus Environment permits both approaches. However, surface inflation requires lower mass and reduces exposure of balloon to high temperatures
Thermal control for rocket cocoon	Multilayer insulation blanket with helium heat exchanger. Dumb excess heat to helium	Multilayer insulation and fibergalss blanket. Dump heat to propellant and helium tanks. Nitrogen inner layer is option	Nitrogen maintains lower temperature and prevents CO2 condensation

Table 2: Comparison of ESA and NASA-Baseline Approaches to Sample Return

Sample Container Mass: A major difference between the two concepts is sample container mass. The ESA study adopted a sample container mass of 10 kg. In the NASA study a much smaller sample container is used. Since the sample container mass drives the mass of all other parts of the payload, reducing the sample container mass makes it possible to reduce the launch mass and all other key transportation elements including the balloon and the VAV.

Balloon Deployment and Inflation: In the ESA concept, aerial deployment of the balloon is used whereas in the NASA/JPL study a surface launched balloon is baselined. The Venus environment of low surface winds and a dense atmosphere near the surface permit both approaches. In the ESA study, aerial deployment was required in order to facilitate thermal control of the solid rocket. Helium was injected into the cocoon surrounding the solid rocket in order to slow the heating of the solid propellant.

In the NASA/JPL concept, this approach to cooling was not used. Moreover, to enable the use of a mature material technology for the balloon envelope it was desirable to limit the duration of exposure of the balloon envelope to the high temperature gases in the Venus lower atmosphere. This was most effectively accomplished with a surface deployment and inflation of the balloon timed to occur shortly before launch.

Thermal Control for the Rocket Cocoon: In both NASA and ESA concepts the solid rocket equilibrates with the Venus pressure and a insulation blanket is used to maintain the solid rocket below its ignition temperature. In the ESA concept, the balloon is inflated during the last phases of descent and helium is passed through the insulation blanket through the balloon to enhance the effectiveness of the insulation. In the NASA concept, there are two layers of fiberglass insulation. The outer layer is filled with atmospheric CO_2; the innter layer with nitrogen or helium from the balloon inflation system. The nitrogen that prevents possible liquid action of CO_2 on the cold pressure vessel surfaces.

Venus Ascent Vehicle(VAV) Launch Conditions: In the NASA concept, the launch altitude for the VAV is 66 km – 12 km higher than for the ESA concept. The six-fold reduction in atmospheric density reduces the atmospheric drag losses on the solid rocket substantially. Although the balloon has to be somewhat more massive to reach this altitude, the overall system mass is optimized.

DUAL ATMOSPHERIC VEHICLE:

Two approaches of this type were considered; one uses a balloon and the other an airplane

Blimp Options:. A schematic of the blimp option appears in Fig 3. The first three phases of the mission bear a close resemblance to the baseline option. However, the VAV is not carried to the surface with the SAV but is deployed separately on a blimp at an altitude of 65 km. After the sample is acquired with the SAV, a balloon is deployed and the SAV rises to 65 km where the blimp performs a rendezvous and transfers the sample. Following sample transfer, the VAV is launched and injects the sample canister into orbit. The orbiter then carries out the rendezvous and sample transfer in identical

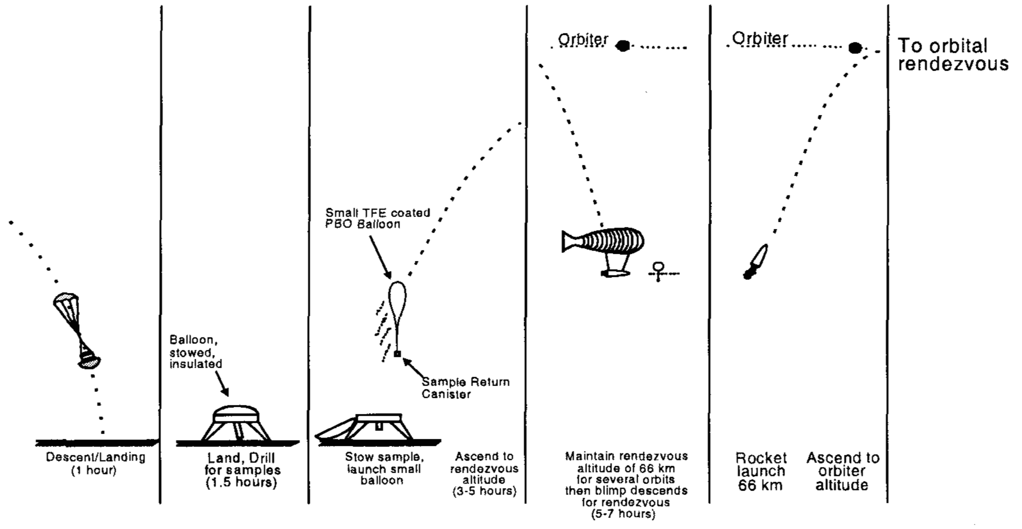

Fig 3: Schematc of the Blimp Option for Venus Surface Sample Return

fashion to the baseline VSSR option and to the Mars Surface Sample Return.

In this approach there is no need to design the solid rocket and its control systems to tolerate the high temperature and pressures environment experienced near the Venus surface. However, from an architectural point of view, the mission is more complex and requires an atmospheric rendezvous.

Required Control Authority: A fundamental issue with the blimp approach is the control authority required to achieve rendezvous of SAV and VAV in the atmosphere:

- The upper atmosphere winds at the altitude at which the VAV must be deployed are of the order of 100m/sec. However, the north south component of winds is modest and the wind turbulence is believed to a few meters per second with a time constant of 30 seconds
- In order to avoid having to carry out the rendezvous on the night side of the planet, it is necessary to carry out the rendezvous of VAV and SAV, sample transfer and launch of the VAV within about 20 hours after the SAV leaves the surface of Venus.
- We estimate that the latitude and longitude of deployment of the blimp can be controlled to within about 10 km of the location of the SAV balloon when it has risen to the altitude of rendezvous.

A simple simulation of the approach and rendezvous of balloon and blimp appears in Fig 4 below. Even though the blimp velocity is only 4 m/sec, the approach phase lasts less than 1 hour and the two vehicles close steadily on one another with minor perturbations due to atmospheric fluctuations. The actual approach with this level of control authority may be even faster because in this model there was no attempt to exploit the pronounced vertical shear of the zonal winds or expected vertical variations in the direction and magnitude of the meridianal component to leverage the use of propulsion.

Blimp Design: The principal features of a blimp design capable of supporting the VAV and of providing 4m/sec control authority is shown in Fig 5 and in Table 3. The total system mass of the VAV, blimp and propulsion system is 816 kg. The blimp uses a Lutz and Wagner Region II shape, has a total volume of 4,800 m_3 and an aspect ratio of 3.17. The shaft power at 50% efficiency needed to overcome the estimated drag on the blimp of 10N is just over 80 watts. This is easily provided by a solar voltaic power system for operation at these altitudes.

Airplane Option:

In an earlier study of a Venus Sample return, Nock and Jones (Ref 2) considered an option with three atmospheric vehicles – one balloon to lift the SAV to altitude, a second balloon to support the VAV at altitude and an airplane to transfer samples from the SAV to the VAV. In our view, this architecture is not only complex but is unnecessarily complex. Our last option, avoided the use of an aircraft by replacing one of the balloons with a blimp. An alternative might be to replace the blimp with an aircraft carrying the VAV accurately deployed to rendezvous with the SAV. The details will be published separately.

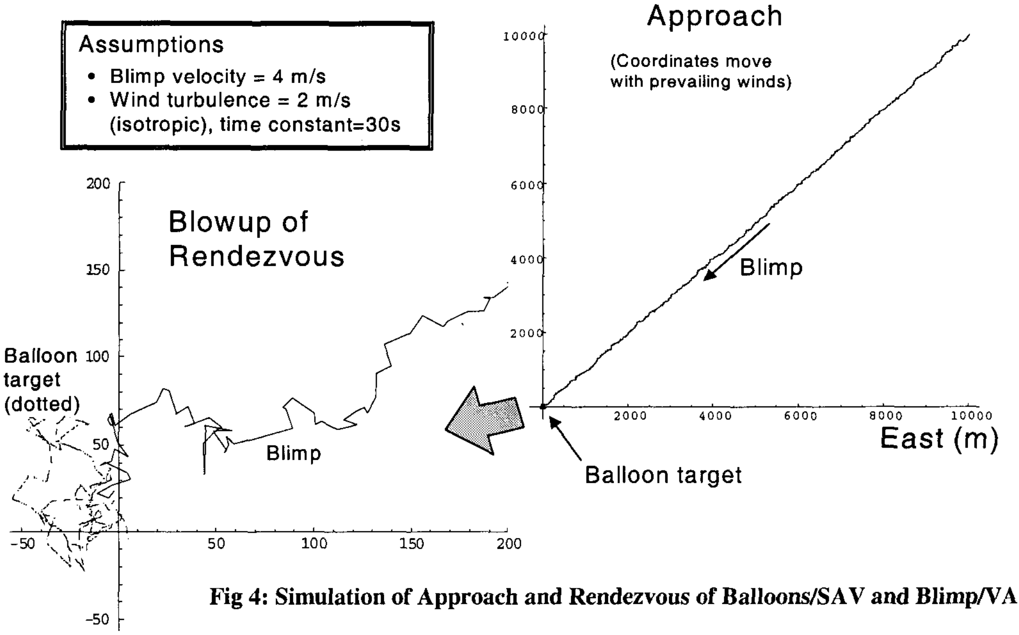

Fig 4: Simulation of Approach and Rendezvous of Balloons/SAV and Blimp/VAV

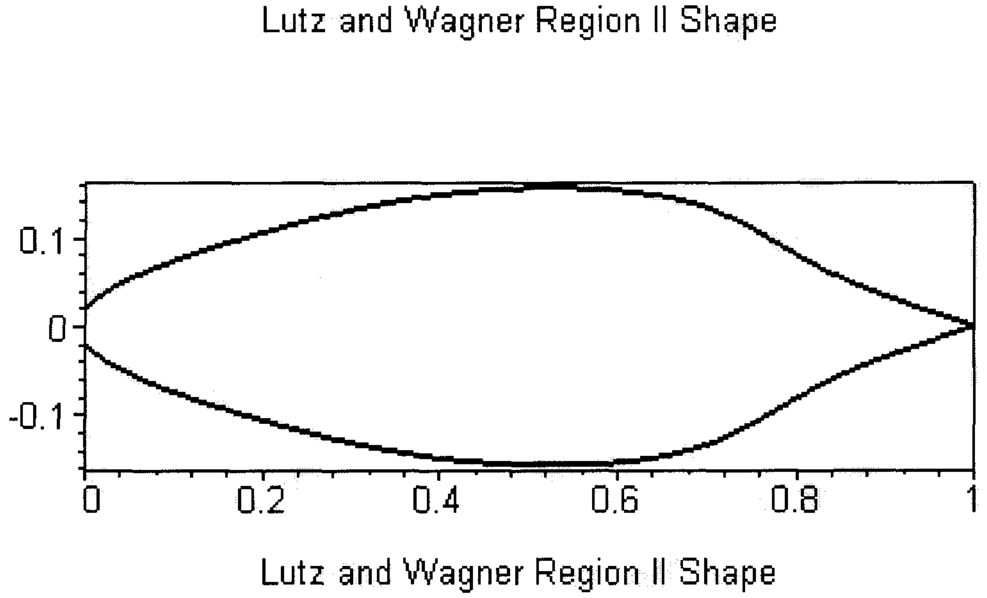

Fig 5: Venus Surface Sample Return – Design of Blimp for VAV Deployment

COMPARISON OF VENUS SURFACE SAMPLE RETURN OPTIONS

The three VSSR options described above are now compared with respect to the mass allocations and the technology readiness.

Mass Comparison: A mass comparison for the three options appears in Table 3 below:

Payload: The payload in each case is assumed to be the same. It consists of a sample canister, Venus Ascent Vehicle and drilling equipment and instrumentation.

- The payload is 2 kg in each case and contains approximately 500 gm of sample. Since the surface of Venus is sterile, the demanding Planetary Protection requirements needed for Mars Surface Sample Return are not needed and the canister is somewhat lighter than the corresponding equipment for MSSR.
- The Venus Ascent Vehicle is identical in each case and weight 443 kg. Thermal and pressure protection needed for the baseline option is book-kept separately.
- Drilling equipment and instrumentation amounts to 16 kg an estimate based on a detailed analysis of what will be required to drill and package samples under these demanding temperature and pressure conditions

Descent Landing and Aerial Systems: These are the systems that provide the mobility needed to first reach the surface and to perform rendezvous operations where required. The principal discriminators between the options are

- Balloon envelope: The mass of the balloon envelope is much greater for the baseline option than for the other two. In the baseline option, the balloon lifts the sample canister, VAV and its thermal protection system. In the other two options, it lifts only the sample canister and a beacon system to permit acquisition of the payload.
- Thermal Protection System: The baseline system requires a thermal and pressure protection system. The estimate for the mass of this – less than 10% of the mass of the vehicle-requires that a radical new technology can be made to work successfully. It may be optimistic.
- Atmospheric transportation system: The differences between the approaches to deployment of the VAV account for these differences. The mass of the airplane has least supporting background.

	Single Atmospheric Vehicle	Dual Atmospheric Vehicle	
		Ballute	Airplane
Sample Acquisition Vehicle	**18**	**18**	**18**
Sample Canister	2	2	2
Drilling Equipment & Instrum	16	16	16
Venus Ascent Vehicle	**443**	**443**	**443**
Descent, Landing & Aerial Systems	**777**	**850**	**568**
Support Systems	277	251	40
Balloon	86	5	5
Thermal Protection System	45	1	1
Blimp	NA	110	NA
Airplane	NA	NA	300
Inflation System	159	133	6
Container, Parachute & Depl	9	110	100
Inflation gas	78	74	1
Contingency	124	166	114
Aeroassist and In Space Systems	**2712**	**2712**	**2712**
EDL Ballute or aeroshell	117	117	117
Venus Orbiter	2044	2044	2044
Orbiter Ballute	551	551	551
Total System Mass	**3950**	**4023**	**3741**

Table 3: Comparison of System Mass Allocation for Three VSSR Options

Aeroassist and in Space Elements: The mass estimated for all three approaches assumes the successful development of a ballute – a new type of hypervelocity aerobraking device that is used to facilitate the braking needed to enter Venus orbit and for entry into the atmosphere. In view of the small differences in the nominal mass of other parts of the system, the nominal mass for these parts are assumed to be identical.

Technology Readiness: In Table 4, a comparison of the baseline and the two options appears. The system mass for the baseline is 3950 kg. The two options are 5.4% and 1.3% heavier – amounts which are much smaller than the uncertainties in the estimates. In these circumstances, differences in the technology readiness of the three approaches become most critical.

For the baseline option, thermal and pressure protection is a critical technology and the readiness of the lightweight thermal and protection system needed to protect the MAV is immature. The other two approaches involve delivering identical sampling systems to the surface. Existing technology is adequate because the thermal protection system has a minor impact on overall system mass.

Venus Sample Return Atmospheric Segment Option	**Baseline**	**Atmospheric Sample Rendezvous & Sample Transfer**		**Comments**
Vehicles Used	Balloon Only	Balloon/Blimp	Balloon/Airplane	
System Mass	3950	4174 (+5.6%)	3866 (-2.1%	Differences not significant given state of technology readiness
Technology Readiness				
Thermal & Pressure Production	Low	High	High	
Atmospheric Rendezvous	N/A	Moderate	Moderate	
Atmospheric Sample Transfer	N/A	Moderate	Low	
Orbital Rendezvous	Moderate	Moderate	Moderate	
Orbital Sample Transfer	Moderate	Moderate	Moderate	

Table 4: Comparison of Technology Readiness for Three VSSR Options

SUMMARY:

Interest in Venus surface sample return in the space science community has been stimulated by the realization that a mission may be feasible within the 2005 – 2012 period. Balloon technology will play a vital role in any conceivable architecture for returning samples. The approaches investigated in this paper will continue to be pursued in the coming year and will be the basis for defining areas of emphasis in NASA's technology program.

ACKNOWLEDGEMENT:

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ACRONYMS:

MAV -	Mars Ascent Vehicle
MSSR	Mars Surface Sample Return
SAV -	Sample Acquisition Vehicle
VAV -	Venus Ascent Vehicle
VSSR-	Venus Surface Sample Return