INVESTIGATION OF THE APPLICATION OF AEROBOT TECHNOLOGY AT VENUS;
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The exploration of the solar system has evolved in several phases, beginning with planetary reconnaissance missions in the form of flybys, remote sensing orbiters, *in situ* vehicles such as landers and entry probes, and recently, mobile vehicles capable of operating on surfaces (rovers) and atmospheres (balloons and aerovehicles)[1]. We are involved in the planning and development of mobile, buoyant vehicles for long-lived missions within planetary atmospheres. To this end, we investigate the new scientific and technological concept of robotic aerovehicles, or aerobots, with specific applications to Venus. An aerobot is distinguished from a conventional balloon by having one or more of the following characteristics: 1) autonomous position, altitude, and velocity determination without intervention from the ground or support spacecraft, 2) altitude control capability, 3) ability to execute a designated flight path within an atmosphere, and 4) the capability of landing at designated surface sites [1]. Aerobots serve as a new and powerful tool that allow us to extend our observations of planetary surfaces and atmospheres both in space and time.

The advantages of aerobots in the exploration of Venus are numerous. Aerobots provide the practical solution of a craft that spends most of its lifetime in the cool upper atmosphere of Venus, making brief excursions to the surface, a concept proposed as the Venus Flyer Robot (VFR) by JPL. A surface temperature of 450°C and pressure of 92 bars limited the lifetime of the Soviet *Venera* landers to a few hours. Long-lived systems could survive at the Venusian surface only with temperature control systems that are costly in both energy and mass. The VFR is capable of remaining aloft with minimal energy consumption utilizing reversible fluids as the means for primary buoyancy. A balloon containing a reversible fluid will ascend at low altitudes, where temperatures are higher and the fluid changes to to a vapor; when the balloon reaches higher, cooler, altitudes, the vapor will condense and cause the balloon to descend. Thus the balloon will oscillate about an equilibrium altitude dependent on the reversible fluid mixture [2]. Trapping the condensed fluid above the equilibrium altitude would allow the balloon to descend to the Venusian surface, remaining there until the fluid was released, converting to vapor at the high surface temperatures, thus forcing the aerobot to ascend [3]. Several types of reversible fluids have been studied at JPL for use on Venus that would allow an aerobot to oscillate around an equilibrium altitude of 40-60 km, corresponding to temperatures of 150°C to -10°C, 3.4 to 0.2 bars, respectively [1,4,5]. Reversible fluids allow the aerobot to utilize the easterly winds on Venus whose speeds vary with altitude, thus lending the aerobot some degree of lateral mobility. As the aerobot ascends and descends in the atmosphere, it can also extract thermal energy from the atmosphere using a generator driven by the relative motion of the vehicle and the atmosphere.

We have performed preliminary investigations into the application of aerobot technology at Venus, in particular defining scientific objectives and payloads for the proposed Venus Flyer Robot (VFR) mission. A primary scientific objective of a VFR mission is to make high-resolution (1-10m) visible to infrared imaging of the surface. These data will complement existing data by helping to determine the surface characteristics responsible for variations in backscatter seen in both Earth-based and orbital SAR imagery. Such high-resolution images will allow study of the geologic processes operating at the "outcrop" scale (≤10m) on Venus, of which we received tantalizing views from the Venera landers. These images can be used to investigate the nature of surface fines associated with radar-dark parabolas, ash deposits, aeolian deposits, and alteration products which contribute to significant differences in the emissivity values seen in the radar data. Infrared data can also be used to monitor areas of enhanced surface heat flow that may be connected to subsurface processes. The lateral mobility and long lifetime of the VFR craft can result in a near-complete and overlapping set of images near the equator, which is the latitude of choice for aerobot insertion and maneuvers in order to cover a maximum amount of surface area. The vertical mobility of the craft will allow repeated imagery of the same areas at various scales.

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As the bulk of the lifetime of a Venus aerobot will be spent in the atmosphere, several of the remaining questions concerning atmospheric composition and dynamics can be addressed with such a mission. The measurement of atmospheric composition at various altitudes, especially the lower ≈ 20 km of the atmosphere about which little is known, can be accomplished by the VFR with a gas chromatograph, mass spectrometer, and/or infrared spectrometer, where variations can be tracked over time and in three dimensions. Of particular importance is the distribution of sulphur and carbon species, which are the most abundant species in the atmosphere. Knowledge of the CO to CO_2 ratio, for example, will help constrain the oxidation state of the atmosphere. Also of considerable interest and debate is the abundance of atmospheric water on Venus - the result of both volcanic and atmospheric evolution and an indicator of mantle water abundances [6]. An increasing number of atomic and molecular species are being called upon to explain low emissivity highland areas on Venus that are hypothesized to result from atmosphere-surface interactions, a form of chemical weathering [7, 8]; analyses of these species can be prioritized and undertaken.

The chemical composition of the atmosphere can be measured at all stages of an aerobot mission, also true of measurements of wind speeds and direction. The *Vega*, *Venera*, and *Pioneer Venus* probes yielded some information on the variation of wind speed with altitude [9], but almost nothing is known about variations of wind speed and direction over time. Winds can be measured by tracking the craft relative to the surface of Venus, data that will augment our understanding of Venus atmospheric circulation and help us address questions such as whether the the wind streaks seen on Venus correspond to near-surface winds.

Perhaps the most powerful and unique feature of an aerobot for Venus study is its ability to descend to the surface of the planet where it can perform geochemical measurements of surface rocks at multiple sites. We suggest that an omnidirectional X-ray fluorescence (XRF) spectrometer (analysis of major elements) be mounted on a flexible snake that is attached to the balloon gondola. We have identified four types of terrain of highest scientific priority for surface sampling that have the benefits of being great in areal extent, abundant near the equator, and existing at altitudes several kilometers above mean planetary radius, they are: 1) tessera terrain, 2) candidates for high silica lavas in the tessera [10], 3) volcanic highlands, and 4) the high dielectric, low emissivity materials that typically occur above 6053 km.

The question of whether tessera terrain is composed of basalt or a more evolved composition like granite, is one of the most fundamental on Venus and has far-reaching implications for models of Venus geologic evolution. It is also a question that simply cannot be answered unequivocally without geochemical analysis. The geochemical measurement of tessera terrain is therefore the highest priority surface mission of the VFR. Similar doubts exist about the variations in composition of volcanic flows on Venus, both for silicate lavas and carbonate-sulfate lavas which are theorized to be more abundant on Venus than on Earth [11]. Such direct measurements of the composition of surface materials can be coupled with near-surface atmosphere measurements in order to constrain atmospheric-surface interactions responsible for rocks that have anomalous electrochemical properties.

Planetary aerobots can perform long duration, detailed studies of planetary surfaces and atmospheres in three dimensions. These autonomous systems will be very powerful tools to carry out imaging and compositional measurements of Mars and Titan in addition to Venus in the near future and the investigation of the atmospheres of the four outer planets as technologies continue to develop. Aerobot technology will certainly pave the way for planetary exploration in the next millennium.

References. [1] Cutts J. A. *et al.* (1996) Planetary Exploration by Robotic Aerovehicles, submitted to *J. Autonomous Robots*. [2] Rougeron M. (1969) CNES Article 329/DET/TO/BA/EE. [3] Moskalenko G. M. (1981) "Dirizhabl" dlya Venery (Dirigibles for Venus), *Nauka i Zhizn*, 85. [4] Jones J. A. (1995) *Proc. 11th Lighter-than-Air Syst. Tech. Conf.* AIAA-95-1621. [5] DiCicco A. *et al.* (1995) *Proc. 11th Lighter-than-Air Syst. Tech. Conf.* AIAA-95-1623. [6] Namiki N. and Solomon S. C. (1995) *LPSC XXVI*, 1029. [7] Arvidson R. E. *et al.* (1994) *Icarus 112*, 171. [8] Fegley Jr. B. *et al.* (1992) *PLPSC 22*, 3. [9] Schubert G. (1983) in: *Venus*, U. of AZ Press, 681. [10] Head J. W. and Hess P. C. this volume. [11] Kargel J. S. *et al.*, (1994) *Icarus 112*, 219.