ALTITUDE CONTROLLED BALLOONS FOR MARS SURFACE LANDINGS

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BACKGROUND

The exploration of the solar system has proceeded in several phases beginning with flyby missions, proceeding to orbiters, then to probes and landers and finally mobile vehicles that operate on the surface and in its atmosphere[1]. For the most accessible planetary bodies, Venus and Mars, we are now entering the phase of mobile exploration of the surface and atmosphere. This paper is concerned with the use of robotically-controlled and autonomous aerovehicles-aerobots-and their use in planetary exploration of Mars.

The earliest solar system exploration missions were flyby missions which made no attempt to orbit or land on the targeted object Typically, flyby missions conduct observations for a few days around closest approach. Later, using more sophisticated technology, orbiter missions were developed which observed the planet for months or years from close range, acquiring detailed maps of the surface and characterizing diurnal and seasonal variations in any atmosphere. To date, orbital missions have been carried out only for the Moon, Mars, Venus, and Jupiter.

In this same time frame, atmospheric probes and surface landers have conducted much closer range observations. Landers have now been placed on the surfaces of the Moon, Mars and Venus and obtained images and geochemical and atmospheric data of the immediate regions of landing sites. In the early 1970s, during the Apollo program, mobile surface exploration began when the U.S.A. deployed rovers to the lunar surface which were used by the astronauts. In the same time period, the Soviet Union carried out unmanned rover missions to the lunar surface. To date, no rover mission has been successfully carried out to any other body than the Moon, and most recently, Mars.

Mobile atmospheric exploration of the planets is in some respects ahead of mobile surface exploration. In 1985, the Soviet Vega mission successfully deployed two balloons into the upper atmosphere of Venus. A Soviet-French-American experiment tracked these balloons for two days on the side of the planet visible from Earth at an altitude of 54 km determining wind velocities and characterizing atmospheric turbulence. A French-Russian team had been recently working on the development of a balloon mission for the 1998 launch opportunity to Mars. This experiment was to be equipped with imaging cameras and meteorological and geochemical sensors. It was designed to operate in the lower atmosphere of Mars and make excursions to the surface during the night, although funding was cut off due the disintegration of the USSR and concerns regarding forced nightly landings during bad weather. This design, with US assistance was changed to a constant-altitude, super-pressure, helium balloon design. with no capability of landing. although again the funding was cut off. At JPL, we are now involved in planning and developing the technology for the next phase of planetary exploration using buoyant vehicles. This phase will draw on the technical experience of earlier missions but will employ telerobotic and autonomy technologies to control motion in all three dimensions. There are significant parallels in these systems to the capabilities needed for mobile surface vehicles. However, there are also significant new challenges in atmospheric exploration which demand distinctly different approaches.

PHASE CHANGE BALLOON CONCEPTS FOR VENUS AND TITAN

In the late 1970's and early 1980's, G.M. Moskalanko of Russia did significant research into various types of controllable balloon systems for exploring the atmosphere of Venus[2-3]. One of the concepts explored was to use an ammonia/water balloon system that would have both the ammonia and water evaporate at Venus' hot surface, thus filling a balloon. At higher altitudes, the water would preferably condense out, thus deflating the balloon and allowing re-descent to the surface. A balloon filled with water at equilibrium would be 100'XO vapor below 42 km and 100% liquid above a 42-km altitude. In fact, since water is buoyant in the Venusian CO_2 atmosphere, the balloon would tend to stabilize at the 42-km altitude point. In 1981, Moskalanko proposed trapping the condensed water in a pressure vessel, thus allowing the balloon system to land for brief periods on the surface of Venus[3]. Opening a valve would allow the fluid to boil, thus re-filling the balloon and allowing re-ascent.

In the 1990's, work by Nishimura et al[5] of Japan also discussed using two phase water balloons in the Venus atmosphere. In these studies, a model experiment is described which measures the phase transition as well as the heat transfer characteristics of a water balloon in a Venus-like atmospheric test bed,

Recently, Jones of JPL[6] has proposed modifications of these concepts that could enable aerobots to perform multiple controlled landings on both Venus and Titan. A series of highly successful flights in the Earth's atmosphere has, in fact, been conducted for a 1994-95 JPL DRDF known as the Altitude Control Experiment, or ALICE[7].

BALLOON CONCEPTS FOR THE OUTER GAS PLANETS

Recent studies[8,9] have shown that the phase change fluid aerobot is far less practical for the outer gas planets than it is for Venus or Titan. The reason for this is that the outer gas planets are at least 80% hydrogen, with the remaining atmosphere being primarily helium In order to "float" a 10 kg payload in the Jovian atmosphere approximately 1000 kg is needed for the hydrogen, balloons, tankage, phaw-change fluids, and entry vehicle mass[9].

An on-going JPL DRDF study has now shown that a very promising, lightweight controllable balloon system using lower planetary radiation heating at night and solar heating during the day appears quite feasible for the outer gas planets, as well as for Venus. The technology is based on a modification of design that was demonstrated by a series of thirty infrared Montgolfiere balloons flown by the French CNES in the Earth's stratosphere in the 1980's10. The balloons' upper surfaces were aluminized to minimize radiant heat loss to space, while the balloon's inside upper surface was blackened to absorb radiation hear from the lower, warmer Earth. The resulting heating of the balloon's internal air allowed missions with 50 kg payloads that lasted up to sixty days and encircled the globe. The French used the name "Montgolfiere" for their hot air balloons, since it was the Montgolfier brothers who flew the world's first hot air balloons (as heated by burning wood) in France during the eighteenth century.

The JPL DRDF study has shown that using the Solar Infrared Montgolfiere Aerobot (SIRMA) approach for Jupiter balloons reduces total system mass for a l (1 kg payload to only about 100 kg, or an order of magnitude improvement over the pure hydrogen balloon system. Deployment tests using a commercial hot air balloon to attain altitude have shown that large hot air balloons (5 m diameter) can easily be stowed into small compact packages (Figure 1) and yet they quickly fill when deployed from even moderate altitudes (Figure 2).

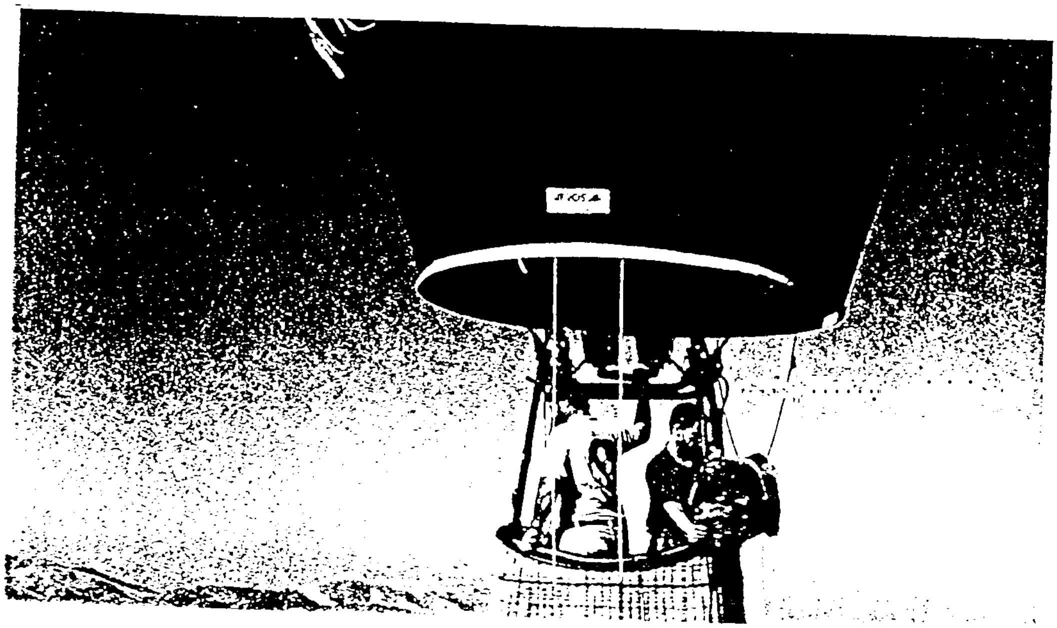

Figure 1. Stowed five meter balloon ready for drop deployment from commercial hot air balloon at altitude

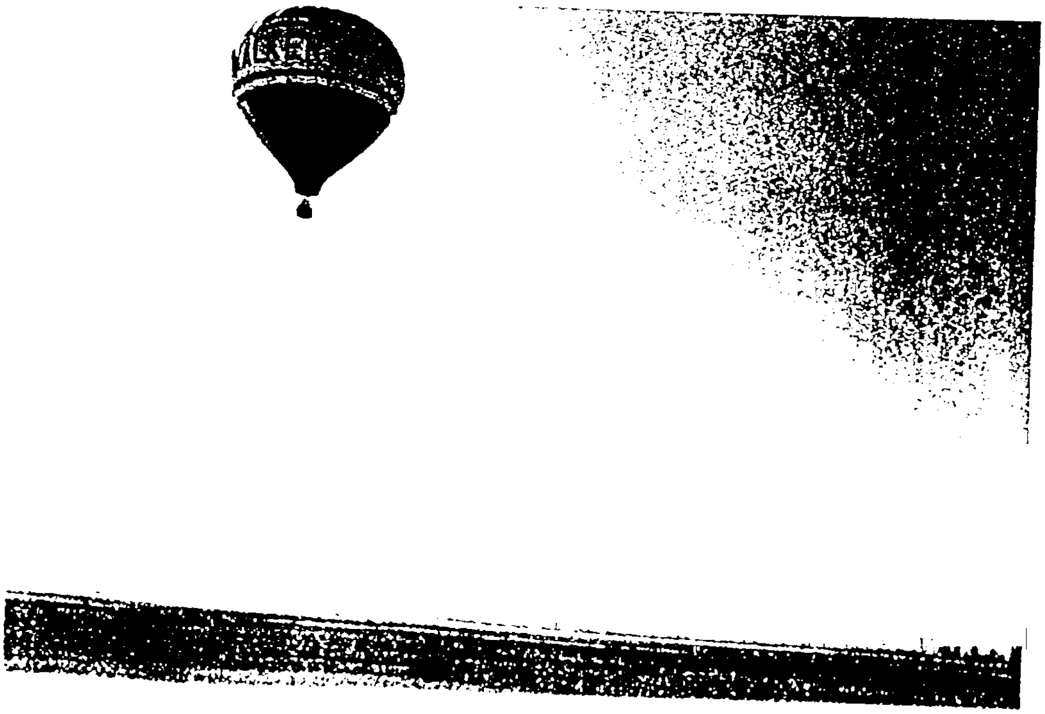

Figure 2. Fully deployed five meter diameter solar hot air balloon shortly after deployment from commercial hot air balloon

ALTITUDE CONTROL CONCEPTS FOR MARS BALLOONS

Unfortunately. neither the phase change balloon concepts (Venus, Earth, Titan) nor the SIRMA concepts (Giant Gas Planets) can apply to Mars due to the extremely thin Martian atmosphere and its very cold nighttime surface temperature.

Up to now, the only practical balloon systems proposed to explore the Martian atmosphere and surface have been super-pressure helium balloons, which fly at a constant altitude, or short-lived zero-pressure balloons which drag a precarious snake through all types of surface weather, or a day/night combination of the two[15].

The following sections describe the first two viable means ever proposed to actually control balloon landings on selected Martian surface locations.

SOLAR HOT AIR BALLOONS

The first method is to use solar-heated balloons at the Martian poles during the summer. The extremely long Martian summer polar days (up to 0.95 Earth years) and high Martian axis inclination (23.6 degrees) makes "solar polar" hot air ballooning ideal for long periods (Figure 3). Tests have already been initiated during an ongoing JPL study entitled "Infrared Montgolfiere Balloon Aerobots for Outer Planet Atmospheres" that have confrrmed ease of altitude deployment and filling of solar-heated hot air balloons (Figures 1 and 2 of previous section), and more tests are in progress to confirm analytical predictions of buoyancy. Altitude control of the hot air balloons appears quite feasible using techniques similar to those used in commercial/recreational hot air ballooning, i.e. hot air can be vented from the top of the balloon, allowing safe descent to the ground, and with the vent closed, the balloon will reheat, allowing re-ascent.

Figure 3. Mars Solar Hot Air Balloon for Summer Polar Landings

Solar heated balloons are nothing new. In fact they are commercially available as novelty items[2,3] and have even been banned in Italy due to interference with commercial aviation[14]. Accurate altitude control of solar balloons, is however new, although it certainly appears feasible by using attitude control techniques used by commercial fuel-powered hot air balloons and by the French CNES[10] on stratospheric hot air balloons. These balloons use vents in the top to allow hot air to escape, thus temporarily reducing lift and allowing descent. Closure of the vent allows re-ascent.

Calculations have been performed that show for a 15 kg payload, which could include imaging, atmosphere and ground sampling equipment. and a subsurface, water-seeking radar, total system mass is only about 60 kg using already developed hot air balloon materials, while for a much smaller payload of 2.5 kg, total system mass may be as little as 7.5 kg (Table 1). Transient heating up response time to achieve positive buoyancy while falling has been calculated to be less than one minute at Mars and less than two minutes at lower, more dense altitudes on Earth. Typical solar surface coatings of titanium (solar absorptivity/emissivity = 0.8/0,2) and germanium[17] (0.6/0.05) result in balloon temperatures of over 300 K, thus providing high buoyancy in the cold Martian polar air (-160 K).

It should also be mentioned that the solar balloon approach looks quite attractive for Venus, as well as for Mars, and thus there could be significant synergy with any future potential Venus solar hot air balloon programs. Very lightweight solar hot air balloons (<3 kg) appear viable to carry payloads of 25 kg at Venus for periods of up to 100 hours of sunlight in the fast-moving upper Venus clouds (-60 km altitude, 0.23 bar, -10°C). Similar hot air venting altitude control techniques could be used to descend to altitudes as low as about 10 km (47 bar, 380°C) before re-ascending to the cooler Venusian cloud tops. Teflon balloons, which were used by the Russian/French/US Vega mission to Venus, can be used for this solar balloon mission, since Teflon is impervious to the sulfuric acid clouds of Venus.

VARIABLE EMISSIVITY BALLOONS

Further evaluations at JPL have shown that an alternate design, known as variable emissivity balloons, may also be capable of allowing controlled landings on Mars. These landings could be at the lower, non-polar latitudes, which cannot be reached by the polar hot air balloons. The variable emissivity balloons would be gold-coated, super pressure helium balloons during both night and day. They could land at prescribed targets by exposing a section of upper white balloon surface to the radiant cooling of deep space, thus reducing the pressure/density in the balloon to create negative buoyancy (Figure 4), and causing descent. Replacement of the gold cover top causes re-ascent.

For a 15 kg payload, total floating system mass is about 93 kg for the helium, variable emissivity balloon (Table 2). Super pressure during the day is about 120 Pa (0.02 psi) and during the night it is about 20 Pa (0.003 psi). The nighttime overpressure is similar to that predicted for the recent JPL MABS Mars balloon design[16], but the daytime over-pressure is only about one half that of MABS, due to the new model's higher convective/lower radiative tie to the Mars ambient, The design is sized for a constant 6.5 km altitude. although this can be varied to lower altitudes (less mass) or higher altitudes (more mass). Ambient pressures for the solar balloon (Table 1) are higher, since they are assumed to float near the surface. While the solar hot air balloon can land during the day, the variable emissivity helium balloon has the landing option available only at night until dawn. Present night vision amplification optics can be used for imaging during the nighttime, and conventional imaging can be used at each dawn as the balloon re-ascends.

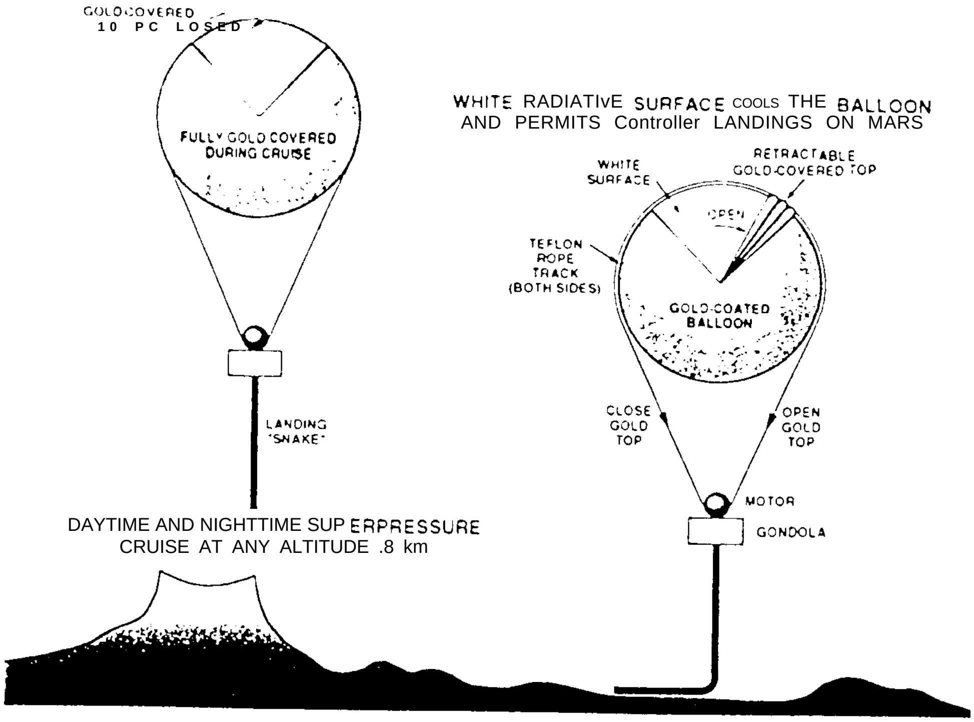

Figure 4. Mars Variable Emissivity Balloon for Landings at Lower Latitudes.

SUMMARY AND CONCLUSIONS

Up to now, the only practical balloon systems proposed to explore the Martian atmosphere and surface have been super-pressure helium balloons, which fly at a constant altitude, or short-lived zero-pressure helium balloons, which precariously drag a snake through all types of surface weather, or a day/night combination of the two. Controlled ascent/descent balloon aerobots have, however, been proposed for all the other significantly atmosphereed bodies in our solar system by using either phase-change buoyancy fluids (Venus, Earth, Titan) or solar day/infrared night buoyancy ssytems (gas giant planets). Unfortunate>, neither of these techniques can be used in the extremely thin Martian atmosphere with its very cold nighttime surface temperatures.

For the first time, two systems now appear quite viable for actually *controlling* balloon **landings** on **selectd Martian** surface locations. The first system would employ solar hot air balloons for landing at the Martian poles during summer. The extremely long Martian summer polar days (up to 0.95 Earth years) and high Martian axis inclination (23.6 degrees) makes “solar polar” hot air ballooning ideal for long periods. Altitude control of the hot air balloons appears quite feasible using techniques similar to those used in conm]ercial/recreational hot air ballooning, i.e. hot air can be vented from the top of the balloon, allowing safe descent to the ground.

The second method is to use variable emissivity superpressure helium balloons for landing at any Martian latitude. The variable emissivity balloons would be gold-coated, super pressure helium balloons during both night and day. They could land at prescribed targets by exposing a section of upper white balloon surface to the radiat cooling of deep space during the night. This reduces the temperature and pressure in the balloon to create negative buoyancy, thus causing descent, while replacement of the gold cover top causes re-ascent. Landings could be made at any Martian latitude with this system, and specific areas could be targeted by using atmospheric currents at various altitudes, similar to techniques used by Earth balloon enthusiasts.

Calculations for both the solar polar hot air balloon system, and for the variable emissivity balloon system look very promising thus far. For a 15 kg payload, total floating system mass is about 93 kg for the helium super pressure, variable emissivity balloon. For the solar polar hot air balloon, total system mass is about 60 kg for the same 15 kg payload, and only about 7.5 kg for a smaller 2.5 kg payload.

TABLE 1. SOLAR HOT AIR MARTIAN BALLOON PARAMETERS

	15 kg Payload	2.5 kg Payload
Balloon Diam(m)	27.2	11.5
Envelope (gm/m^2)	15.0[1]	9.0[2]
Ambient Pressure (bar)	0.005	0.006
Ambient Temperature (K)	160	160
Component Mass:		
Payload Mass	15.0	2.5
Balloon Mass	34.9	3.7
Landing Snake	5.0	0.7
Thermal Control Vent	2.0	0.3
Miscellaneous	2.7	0.3
TOTAL MASS (kg)	59.6	7.5

1. Present developed hot air balloon envelope density
2. Envelope density for JPL "Mars Balloon Technology Experiment"

TABLE 2. VARIABLE EMISSIVITY MARTIAN BALLOON PARAMETERS

Balloon Diam (m)	27.2
Envelope (Gm/m^2)	20.0’
Ambient Pressure (bar)	0.00335
Ambient Temperature (K)	200
Component Mass:	
Payload Mass	15.0
Balloon Mass	46.5
Larding Snake	5.0
Thermal Control Top Cover	12.0
Miscellaneous	7.0
Helium	9.4
TOTAL MASS (kg)	92.9

1. Envelope density for Mars MABS study

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