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# SOLAR MONTGOLFIERE BALLOONS FOR MARS

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## ABSTRACT

A novel hot air balloon system, known as a solar "Montgolfiere," appears quite viable for controlled balloon landings at selected martian surface locations. This balloon could soft-land payload packages, such as science instruments or even lightweight surface roving vehicles. Using entirely solar heat, they are ideal for flying at the martian poles during summer or for shorter flights at lower latitudes. Recent tests have already confirmed the ease of high-altitude deployment and filling of these solar hot-air balloons. Furthermore, actual landings and reascents of solar hot-air balloons have been recently demonstrated by JPL, using a novel, lightweight, top air vent that is radio controlled. It may be possible to fly 2 kg imaging gondolas on Mars with a balloon mass of only 4.4 kg if tests this year confirm the viability of new envelope materials.

## BACKGROUND

Until now, the only practical balloon systems proposed to explore the martian atmosphere have been superpressure balloons, which fly at a constant altitude, or short-lived helium balloons, which precariously drag a snake through all types of surface weather, or a day/night combination of the two. A novel atmospheric balloon system, known as a solar "Montgolfiere," now appears quite viable for controlled balloon landings at selected martian surface locations. This balloon could soft-land payload packages, such as science instruments or even lightweight surface roving vehicles.

"Montgolfiere" balloons are named after the 18th-century French brothers Joseph-Michel and Jacques-Etienne Montgolfiere, who first flew hot-air balloons.

Using entirely solar heat, they are ideal for landing at the martian poles during summer or for shorter flights at lower latitudes (Figure 1). Recent tests, which are herein described, have already confirmed the ease of high-altitude deployment and filling of these solar hot-air balloons. Furthermore, actual landings and reascents of solar hot-air balloons have also been recently demonstrated by JPL, using a novel, lightweight, top air vent that is radio controlled.

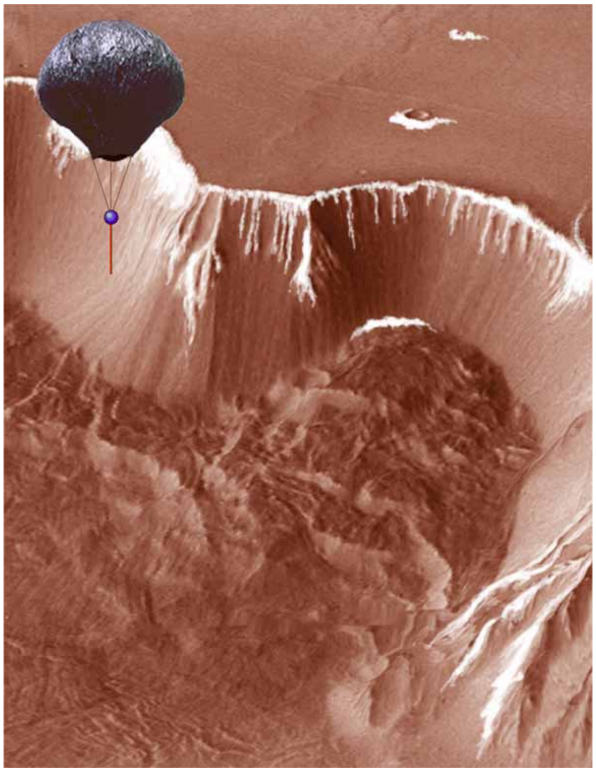

*Figure 1. Mars Solar Hot Air Balloon*

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## COMPARISON TO PRESENT MARS LANDING SYSTEMS

The soft-landing system presently used on all Mars missions involves a standard atmospheric aerobraking entry capsule, followed by a parachute deceleration to about 75 m/s at 6–8 km altitude. This is followed by a retrorocket firing that brings the payload to near zero velocity near the surface (Viking) or at about 50 m altitude above the surface (Pathfinder). In the case of Pathfinder, the payload is dropped from about 50 m altitude, and lands on deployed air bags with a vertical landing speed of about 20 m/s.

**The use of a simple, solar Montgolfiere balloon can eliminate the need for a heavy, expensive retro-rocket landing system, while decreasing system mass and landing speeds.** A full day of solar balloon imaging is then an additional bonus. As shown in Figure 2, after initial parachute deceleration, in the martian atmosphere the solar balloon is deployed, and rapidly fills by way of an open lower loop that scoops in atmosphere as the system falls. Within two minutes, the balloon attains significant buoyancy and its downward velocity is slowed to typically about 5–10 m/sec. After deploying a primary payload on the martian surface, the balloon rises and performs near surface imaging for the remainder of the day.

Calculations have been performed to determine how the solar Montgolfiere compares with a double parachute system for small payloads, i.e., using a secondary, light-density parachute instead of a retro-rocket landing system. This latter approach has been avoided on previous Mars landings due to the required high packing volume of a secondary parachute for heavy payloads.

From Figure 3, the solar Montgolfiere landing system is generally three times less massive than the use of a secondary parachute. Furthermore, the secondary parachute system becomes unstable below about 20 m/sec descent velocity, whereas the Montgolfiere approach is fully stable down to 0 m/sec.

### Balloon Envelope Density Comparisons

The aerial density of the solar Montgolfiere envelopes in these mass comparisions is assumed to be 13 gm/m$^2$, or similar to those balloons which have

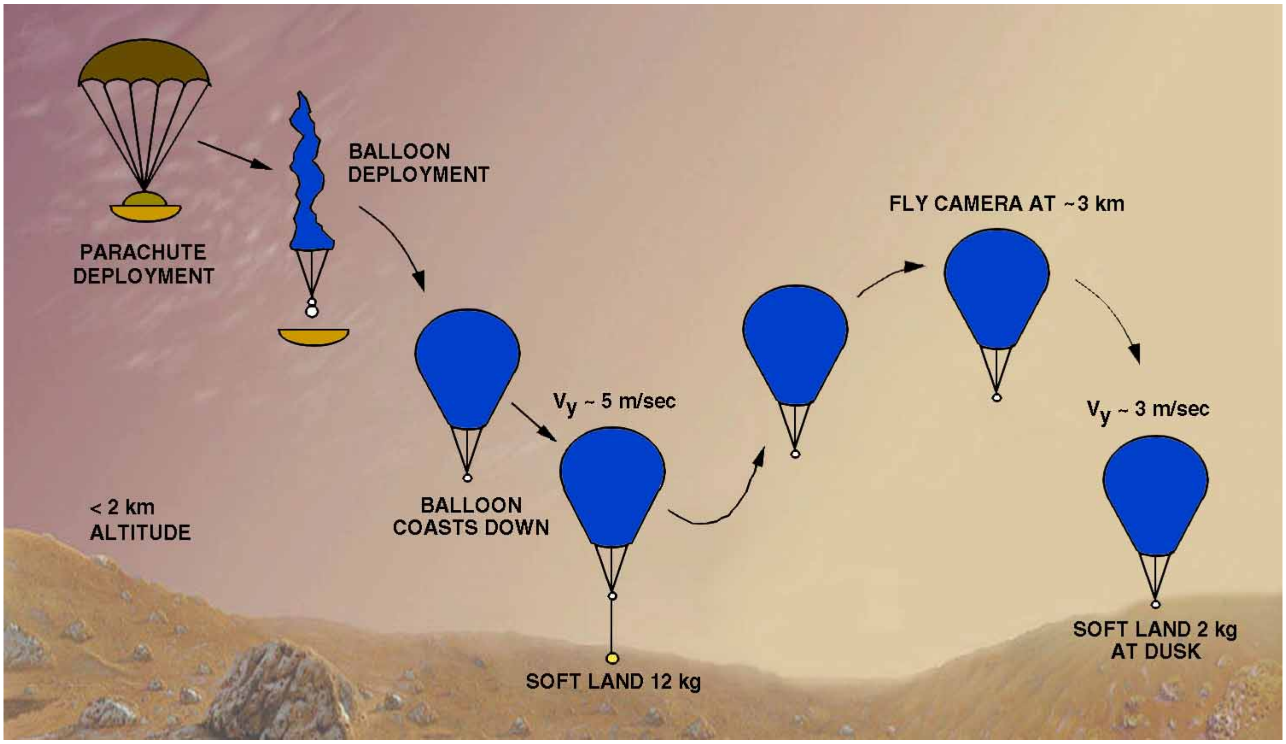

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*Figure 2. Mars Solar Balloon Mission Scenario*

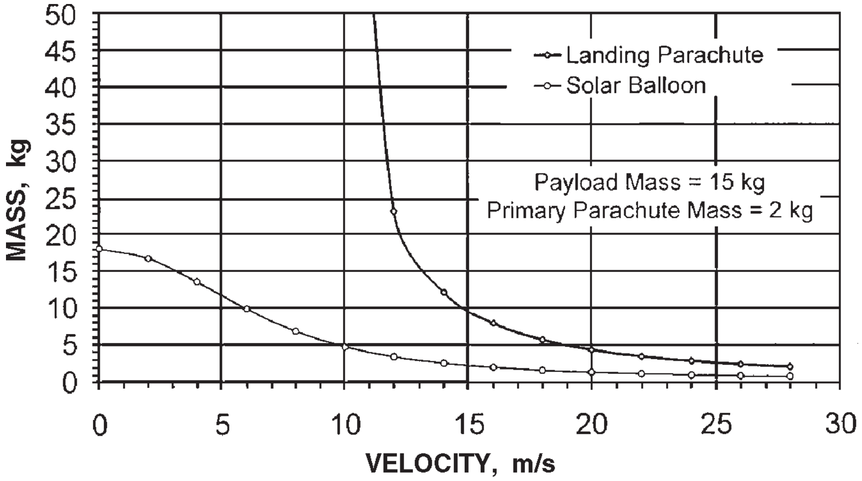

*Figure 3. Mars Descent Mass Comparison*

*Table 1. Mars Solar Montgolfiere Comparison*

| | Envelope Density $g/m^2$ | |
|---|---|---|
| | 9.0 | 13.0 |
| 2 kg Gondola Mass | | |
| Balloon Dia. (m) | 12.46 | 15.05 |
| Balloon Mass (kg) | 4.39 | 9.25 |
| 10 kg Gondola Mass | | |
| Balloon Dia. (m) | 17.96 | 19.97 |
| Balloon Mass (kg) | 9.12 | 16.29 |
| Assumptions: | Pressure at 3 km = 0.00457 bar, Atmospheric Temperature = 200K Solar Absorptivity = 0.6, Emissivity = 0.03, Solar Flux = 500 $w/m^2$ | |

recently been tested. Using a lower aerial density of 9 $gm/m^2$ results in significantly lighter and smaller balloons. Balloons are presently being fabricated from this lighter material (3.5 micron mylar with 55 denier kevlar mesh, plus attachment tapes) and will be tested later in 1999. A summary of mass comparisons of the lighter and heavier materials is shown in Table 1 for a 2 kg and a 10 kg gondola. For the germanium/aluminum coating that has been assumed, all balloon temperatures are approximately 415 K (142°C).

## CONTROLLED ALTITUDE LANDINGS

As reported in Reference 1, a radio-controlled vent was installed in the top of a black polyethylene solar Montgolfiere. When the vent was closed, hot air was trapped and the balloon rose. When the vent was opened, hot air escaped and the balloon descended. A second solar balloon was designed to be very similar to the first, although it was slightly larger and it was tested offshore at Santa Catalina Island. A series of vent opening and closing signals was sent until ultimately the balloon's ballast was soft-landed on the ocean briefly, followed by reascent. The soft-landing maneuver was repeated several times until the balloon dipped too low and eventually got slightly wet, ending the tests. Thermal analyses of the mission coincided very closely with actual test results when the upper air vent openings and closing were taken into account (Figure 4). A description of the thermal analysis approach is described in Reference 2.

## DEPLOYMENT TESTS

### Low Altitude Deployment Tests

At least thirty low altitude deployments of solar Montgolfieres have taken place in the last two years by means of dropping stowed solar Montgolfieres from a commercial hot air balloon flying at altitudes up to 500 m above the ground. In all cases in which there was some type of lower hoop opening device, the balloons successfully filled and heated. The opening devices tested were metal hoops, plastic hoops, spring-loaded hoops, and inner tube hoops. Conversely, for all cases in which there was no lower hoop opening devices, the balloons always failed to fill before hitting the ground.

The most significant test in this deployment series, however, was the demonstration of how a black polyethylene balloon of 5 m diameter could be deployed from only 400 m, and yet fill and attain positive buoyancy before reaching 100 m altitude (Figure 5). This balloon contained an upper vent and was later cycled in altitude. It should be mentioned that although the available sunlight on Mars is about half as much as on Earth, actual heat up times on Mars are faster due to the much lower mass (density) of gas contained in the balloon.

## High Altitude Deployment Tests

Since the late 1970s, the French CNES has ground-launched over forty stratospheric solar Montgolfieres (Reference 4). These balloons have all been launched from the ground using helium as an initial lift gas. The helium is then gradually displaced by air that is heated by the Sun during the day or by radiation to the Earth at night.

For Mars deployment, however, it is greatly preferred to deploy the balloons during initial entry from above, assuming initial deployment stresses are not too high. On July 24–25, 1998, two additional deployment tests took place at high altitude. In the first test, a black polyethylene balloon (12 micron thickness, 6 meter diameter) was deployed at 10 km,and it quickly reached its planned stabilization altitude of 20 km. In the second test, an

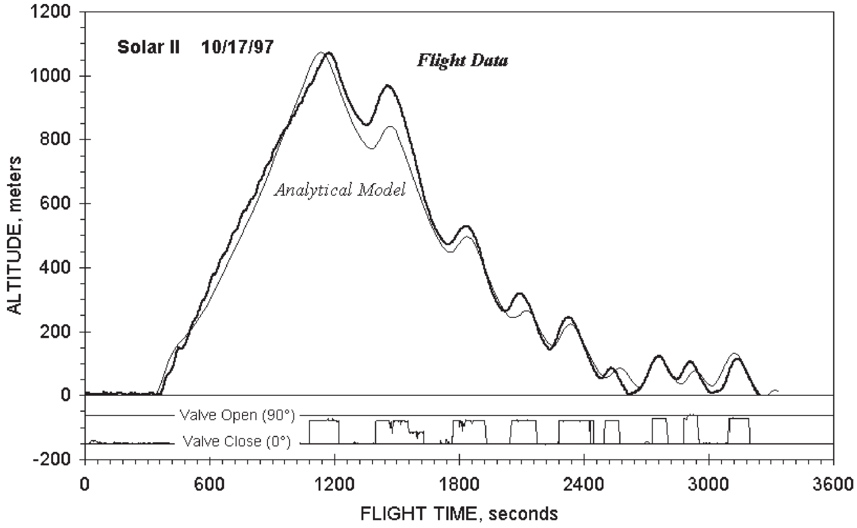

*Figure 4. Solar Montgolfier II Altitude vs. Time*

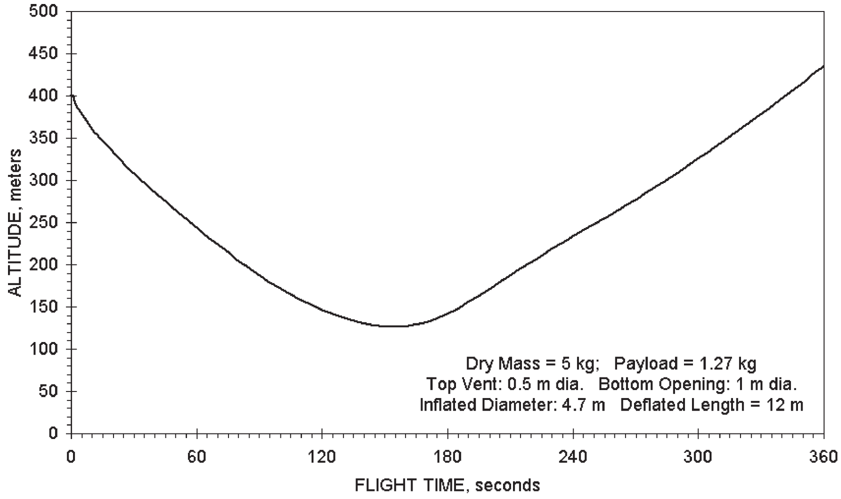

*Figure 5. Transient Heating of a Solar Montgolfiere*

aluminized Mylar balloon with Kevlar scrim (6 micron thickness, 8 meter diameter) was deployed at 32 km (0.010 bar), and then descended at about 10 m/s to reach its predicted stabilization altitude of 17 km. Both balloons were perforated with a small diameter hypodermic needle in thousands of places in order to assure adequate outgassing during ascent.

Plots of the altitude vs. time and velocity vs. time for this second flight are shown in Figures 6 and 7, respectively. The test data very closely matches analytical predictions for the entire 1-1/2 hours of data taken. It should be noted that the balloon attained velocities below 10 m/sec in only about four minutes.

These two small balloons (6 m and 8 m diameter) have thus demonstrated high altitude deployment with lower altitude floatations, but high altitude floatations ($P < 0.010$ bar) require balloons of about 15 m diameter. One such balloon (12 micron black polyethylene, 15 m diameter) was tested in October 1998, and is shown prior to deployment in Figure 8. Unfortunately, this balloon became tangled in its own lines, and failed prior to full deployment.

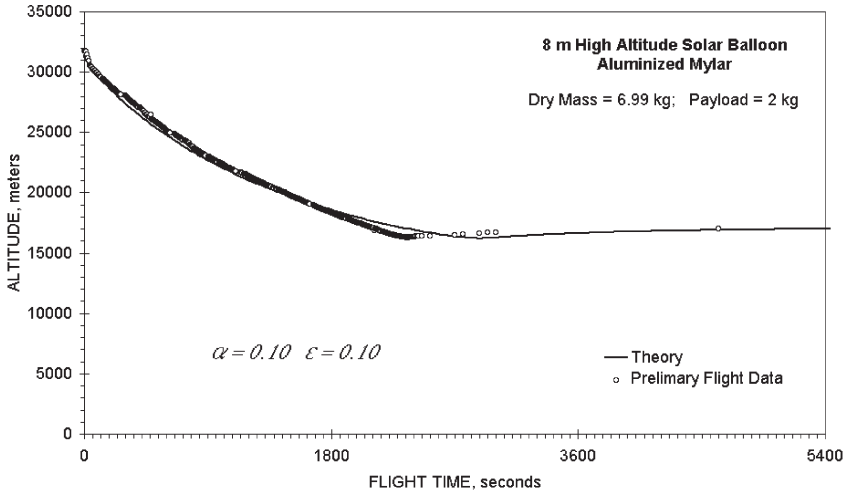

*Figure 6. Montgolfiere Altitude vs. Time*

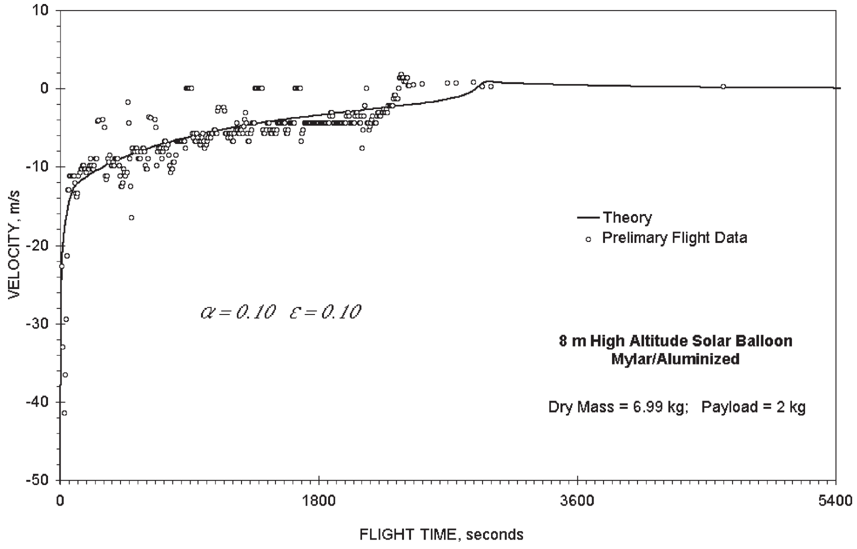

*Figure 7. Montgolfiere Velocity vs. Time*

*Figure 8. Full-Size, Stowed Balloon*

## Future Tests

Three full sized balloons (15 m diameter) have recently been fabricated by GSSL for JPL and will be deployed at high altitude (>32 km) during 1999. One balloon is a natural shape black polyethylene (12 micron thickness) and the other two are natural shape aluminized Mylar (6 micron thickness) with a Mylar scrim. All three balloons will use a lightweight rip-stitch connected to the parachute for the first five seconds of deployment to ensure that the initial air infusion reaches the top of the balloon. Preliminary rip-stitch tests in the tall GSSL hangar have thus far been successful.

Another future test will involve using a conventional Mars rover to launch a solar Montgolfiere. The rover will search a rocky canyon for a relatively clear area and then deploy the balloon on the ground in a down-wind direction. The rover will then move up-wind and will remotely activate a brief, partial helium fill of the balloon. After the balloon lifts off the ground, the helium is eventually replaced by ambient air which is quickly solar-heated. It should be noted that a strictly helium balloon has been deemed impractical for a Mars ground launch due to the fact that in the thin martian atmosphere, a helium balloon must form a “pumpkin” of at least 8 m diameter before it can lift off the ground. Contact with 50 $m^2$ of martian surface is likely to cause some minor hole damage, even in a clearing. Although helium balloons are adversely affected by small holes, solar balloons are not, since leaking air can be quickly replaced.

## APPLICATIONS TO OTHER PLANETS

Solar Montgolfieres look especially attractive for short (<50 hr) flights above the clouds at Venus, as well as for long duration flights above the clouds on Jupiter and Saturn (Reference 3). For Jupiter and Saturn, the short nights (~5 hours) allow the balloon to drift downward while isentropically heating, thus slowing the downward descent rate. The balloons then re-ascend at dawn.

Solar Montgolfieres on Uranus and Neptune, however, appear impractical due to their far distance from the sun. A novel balloon system that also uses ambient gas has been proposed for these planets (Reference 5). A falling balloon would fill in the upper, methane-free, low molecular weight atmosphere. When the balloon is then sealed off, it can easily float at various desired altitudes below the methane clouds where the atmospheric molecular weight is significantly higher. Unfortunately, this concept will not work at Jupiter and Saturn, since their atmospheres are too warm to condense the relatively abundant methane.

## SUMMARY AND CONCLUSIONS

A series of low altitude and high altitude tests with balloons =8 m diameter has confirmed the use and deployment of solar Montgolfieres as a simple, lightweight balloon system that can float by means of solar heating of ambient-collected air. To confirm useful applications on Mars, a series of high altitude deployment test are planned in 1999 for 15 m diameter balloons. This size balloon could potentially deliver small payloads (~15 kg) to Mars and eliminate the need for heavy, expensive retrorocket landing systems.

When compared to the use of a second parachute as a landing system for small payloads, the solar balloon system is about three times less massive and may become even lighter if new materials tests are successful later this year. Furthermore, solar Montgolfieres have the capability of landing payloads with much lower impact velocities (20 m/sec vs. <5 m/sec). The solar Montgolfiere has a unique advantage in that after landing a primary payload, it can re-ascend to provide low altitude imaging for the remainder of the martian day. The solar Montgolfiere thus potentially represents a significantly "faster, better, cheaper" landing system for payloads on Mars.

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