# Wind-Driven Montgolfiere Balloons For Mars


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**Solar Montgolfiere balloons, or solar-heated hot air balloons have been evaluated for use on Mars for about eight years. In the past, JPL has developed thermal models that have been confirmed, as well as developed altitude control systems to allow the balloons to float over the landscape or carry ground sampling instrumentation. Pioneer Astronautics has developed and tested a Montgolfiere landing system, as well as an altitude control system. JPL, together with GSSL, have successfully deployed small Montgolfieres (<15-m diameter) in the earth's stratosphere, where conditions are similar to a Mars deployment. Two larger Montgolfieres failed, however, and a series of larger scale Montgolfiere stratospheric tests is now planned using stronger, more uniform polyethylene bilaminate, combined with stress-reducing ripstitch and reduced parachute deceleration velocities. This program, which is presently under way, is a joint effort between JPL, WFF, and GSSL, and is planned for completion in three years. Hopefully, this program will lead to long-lived polar Montgolfiere missions on Mars, as well as a new means to soft-land payloads on Mars.**


## I. Introduction

Montgolfiere balloons are hot air balloons named after the Montgolfier French brothers who flew the first hot air balloon over two centuries ago. The Montgolfier brothers' balloon, which is now known as a Montgolfiere, was heated by burning wool, while the Montgolfieres herein discussed are heated by the sun to about room temperature (25°C) when in the 220K (-53°C) stratosphere. As shown in Fig. 1, they fill by means of engulfing atmosphere in a lower open hoop as they are descending. They are rapidly heated by the sun, thus providing buoyancy.

Since the 1970s, the French Centre National d'Etudes Spatiales (CNES) have flown over forty Montgolfieres in the Earth's upper stratosphere—which is similar to the Martian atmosphere—for periods of up to 69 days[1]. The Montgolfieres were generally 40-m diameter or larger and were fabricated from 12 micron (0.0005 inch) Mylar and polyethylene. The CNES balloons have been somewhat larger and thicker than the 8 micron, 20-m to 30-m polyethylene balloons proposed herein for Mars.

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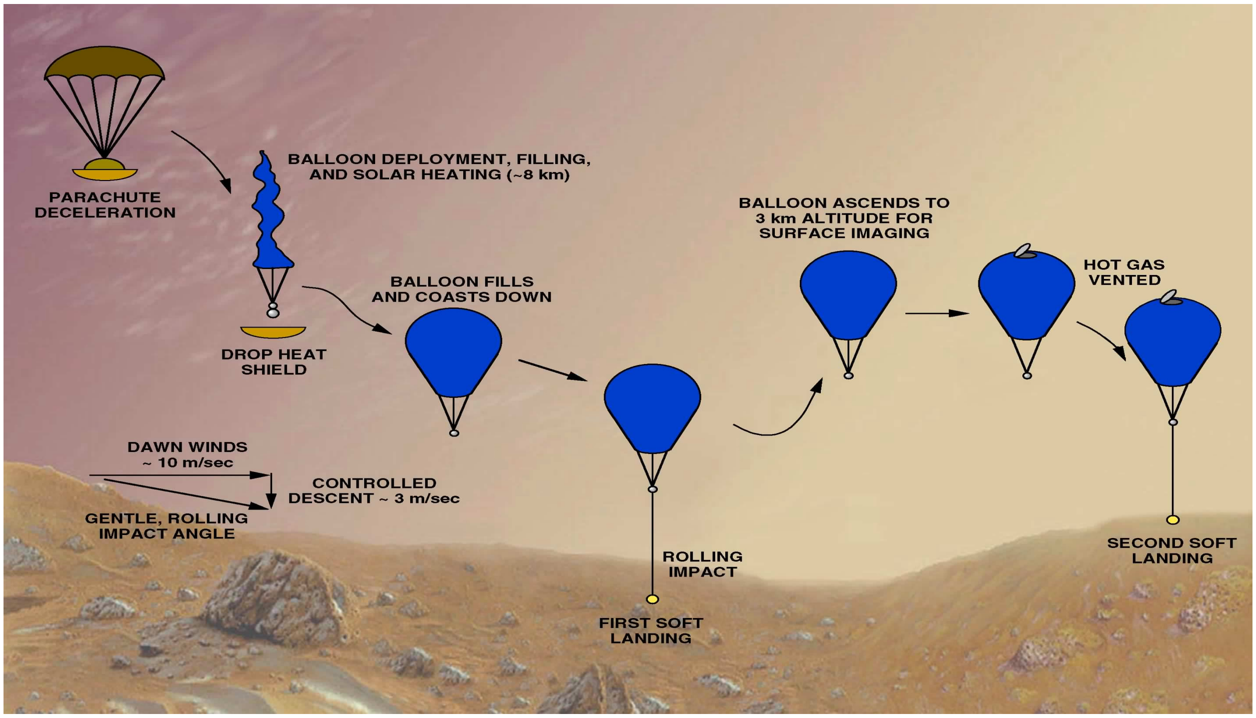


**Figure 1. The Montgolfiere balloon has an open bottom hoop and fills with atmosphere while descending. It is quickly heated by the sun, thus providing buoyancy. It can perform a number of Mars missions, as already demonstrated with Earth tests, such as land payloads, ascend for long duration missions in polar regions, and descend to collect surface soil/ice samples.**

Atmospheric balloon modeling at NASA AMES has shown that a Montgolfiere balloon would encircle the Mars North Pole in sunlight for at least one month, traversing thousands of kilometers, Fig. 2. Similar encircling paths have been made by balloons over Antarctica.

Some unique advantages of using Montgolfiere balloons for missions on Mars include the ability to

1) Fly long, near-surface, polar missions of 1-2 months[2] while sampling trace atmospheric constituents from varying altitudes[3].
2) Gather multiple soil and ice samples with altitude control techniques, Fig. 3[4].
3) Soft-land payloads more gently (<5 m/sec) than less-stable parachutes (>30 m/sec) that deflate with Martian wind gusts[5].
4) Montgolfiere balloons also fill with ambient atmosphere, instead of stored gas, and are not impaired by small leaks, since leaking air is rapidly replaced.

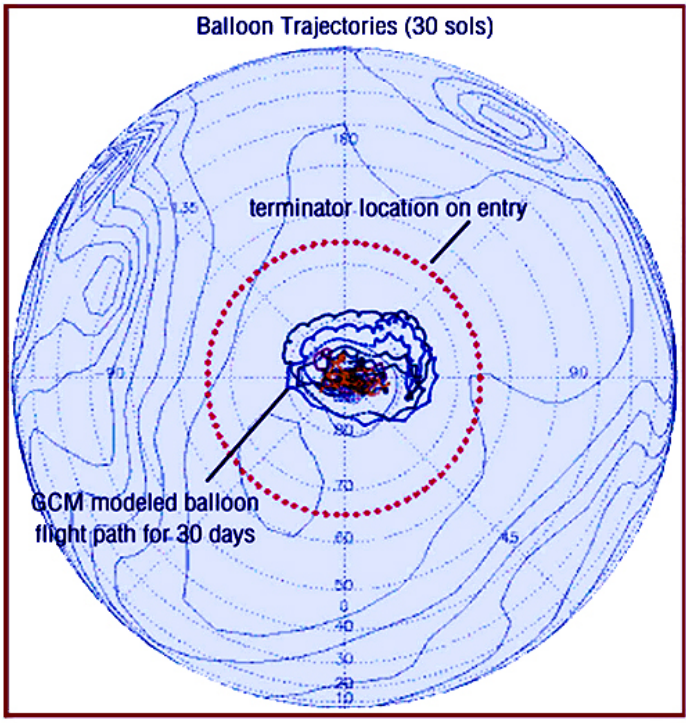


**Figure 2. Balloon trajectories over Mars North.**

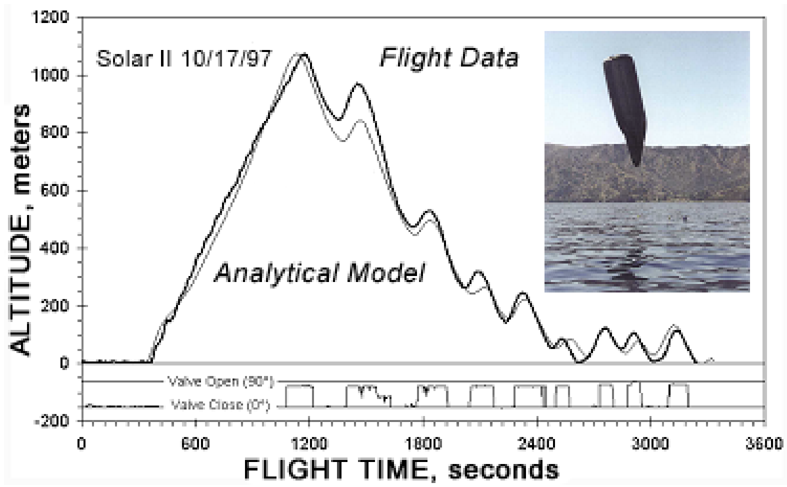


**Figure 3. Altitude control experiments with radio-controlled upper vents on the balloon have shown that Montgolfieres can gently land and take surface samples many times. Other successful altitude tests modulated the volume of the balloon.**

## II. JPL Previous Montgolfiere Development

### A) Stratospheric Deployment

The French deployed their Montgolfieres from the ground, and it has only been since 1997 that JPL has been deploying Montgolfieres at 36 km Earth altitude, where conditions are similar to Mars (0.004 bar, 220K). The packed Montgolfieres are lifted to altitude by a helium tow balloon and then dropped on a parachute for 30 seconds before being released, Fig. 4. Three out of four small polyethylene Montgolfiere stratospheric deployments (8-m to 15-m diameter) have been successful, with the only failure due to a configuration/packing error. All thermal and mobility models of these balloons have been confirmed[5]. Two large Montgolfiere balloons failed, however, upon stratospheric deployment. Post-flight analysis has shown that stronger balloons and/or lower deployment stress is required to fly the larger Montgolfieres (>20-m) that are required for Mars Missions.

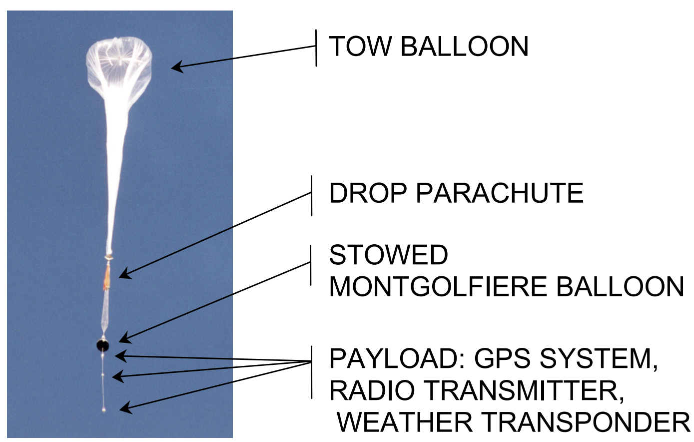


**Figure 4. For stratospheric testing, a helium tow balloon carries a deflated parachute followed by a packed Montgolfiere balloon and a payload/ flight train. When the tow balloon reaches 36 km altitude (0.004 bar, 220 K), the parachute separates from the tow balloon and fills while it descends. The Montgolfiere is below the parachute and then separated to complete filling on its own.**

### B) Thermal Model Verification

The polyethylene material that has been used on all six stratospheric deployment tests thus far has been 8-12 micron (0.32 to 0.48 mil) single–layer extruded polyethylene. The thickness of the balloon envelope is dictated by the need to use very lightweight material in order to float at a reasonable altitude (4 km) above the ground in the very thin atmosphere of Mars (0.006 bar surface pressure). Several of the first polyethylene balloon deployments used black polyethylene (8-12 micron thickness) in order to confirm thermal models of the Montgolfiere, which must operate at about room temperature, 295K (22$^o$C), in the cold stratosphere (200K to 220K). Due to lower solar intensities at Mars, an aluminized coating will be used to maintain a similarly warm balloon for buoyancy in the cold Martian atmosphere (220K). All thermal models have been confirmed with actual earth stratosphere Montgolfiere tests, Fig. 5[4].

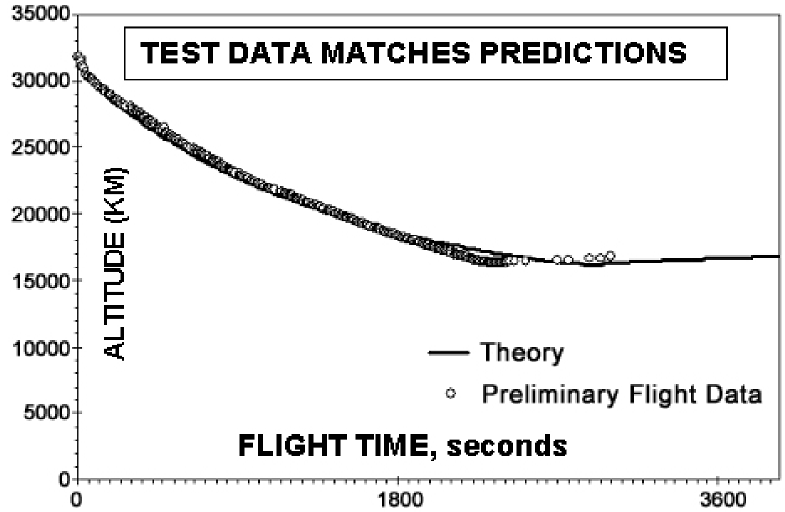


**Figure 5. Thermal and Mobility models have closely matched previous stratospheric deployments for 8-m to 15-m Montgolfiere balloons.**

**C) Altitude Control Tests**

Several altitude-controlled tests have been successfully conducted using black plastic Montgolfiere balloons. In the first field test in California's Mojave Desert in 1998, a radio-controlled vent was placed at the top of the balloon. When the vent was opened, hot air was released and the balloon descended. Conversely, closing the vent caused the balloon to ascend. This initial successful flight of about 15 minutes was followed by a much longer flight over the Pacific Ocean later that year.

During this ocean test, the balloon was allowed to climb to about 1 km altitude, and the vent was periodically opened to allow descent. The balloon payload was actually soft-landed on the ocean several times before the test was terminated. Post-flight thermal analysis very closely agreed with actual balloon behavior during the entire flight, Fig. 3.

The amount of mass that a Montgolfiere can float in an altitude-controlled manner is significantly less than it can land upon first descent. Figure 6 shows markedly the difference for a spherical balloon envelope with an equivalent aerial density of 12 gm/m$^2$. A Montgolfiere balloon can soft-land significant mass at less than 5 m/sec, far slower than less-stable parachutes at Mars. The Montgolfiere can also be used to float smaller payloads many kilometers above the Martian surface for up to two months.

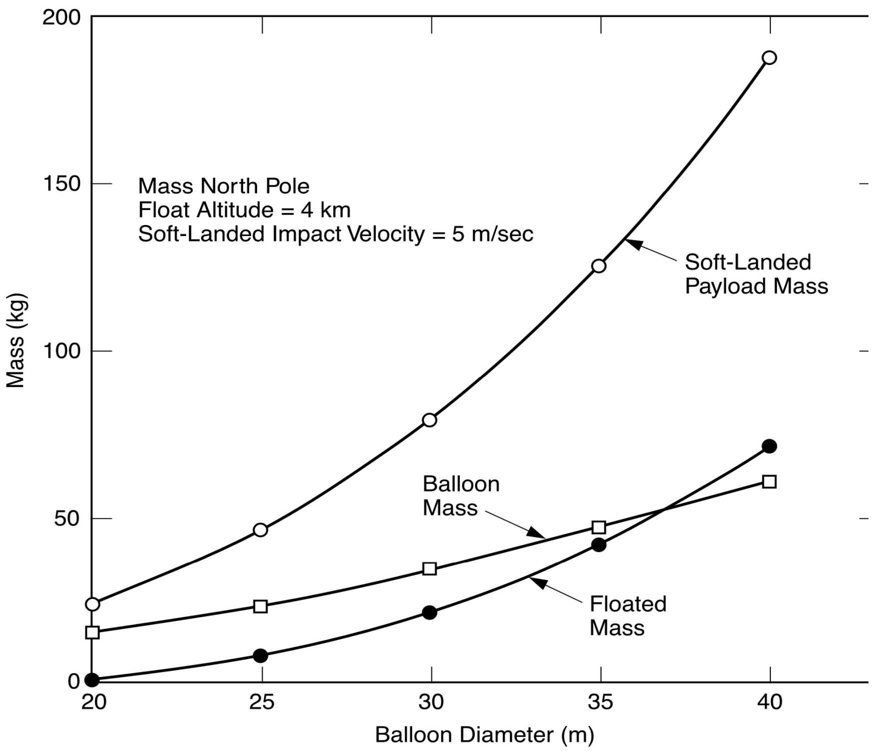


**Figure 6. A Montgolfiere balloon can soft-land significant mass at less than 5 m/sec, far slower than less-stable parachutes at Mars. The Montgolfiere can also be used to float smaller payloads many kilometers above the Martian surface for up to two months.**

## III. Present Montgolfiere Development at JPL, WFF, and GSSL and Pioneer Astronautics

### A) Balloon Materials

In a newly commenced three-year research effort, JPL and GSFC will utilize and test recently developed balloon materials to significantly increase the strength of the balloon. The standard specification thickness for 8-micron (0.32 mil) single-layer polyethylene allows thickness variation from 5 microns (0.20 mil) to 10 microns (0.40 mil). Thus, there were likely numerous sections of balloon that were significantly thinner, and therefore weaker, than the average balloon specifications. The use of recently-developed co-extruded polyethylene, wherein two layers of polyethylene are extruded through a single process, allows much more precise thickness control to 8 micron +/- 1 micron. WFF has led the development of this technology for use in balloon materials for the large, high altitude, ultra long duration balloons (ULDBs).

### B) Reduce Deployment Stress with Ripstitch and Slower Parachute Descent Rates

GSSL will assist JPL in reducing deployment stress by a factor of at least five by reducing deployment descent rate from 50 m/sec to 30 m/sec and by using ripstitch deceleration bands, which absorb energy by ripping increasingly strong bands of stitched materials, Fig. 7. We will thus provide an order of magnitude strength-to-stress improvement for Montgolfiere deployments.

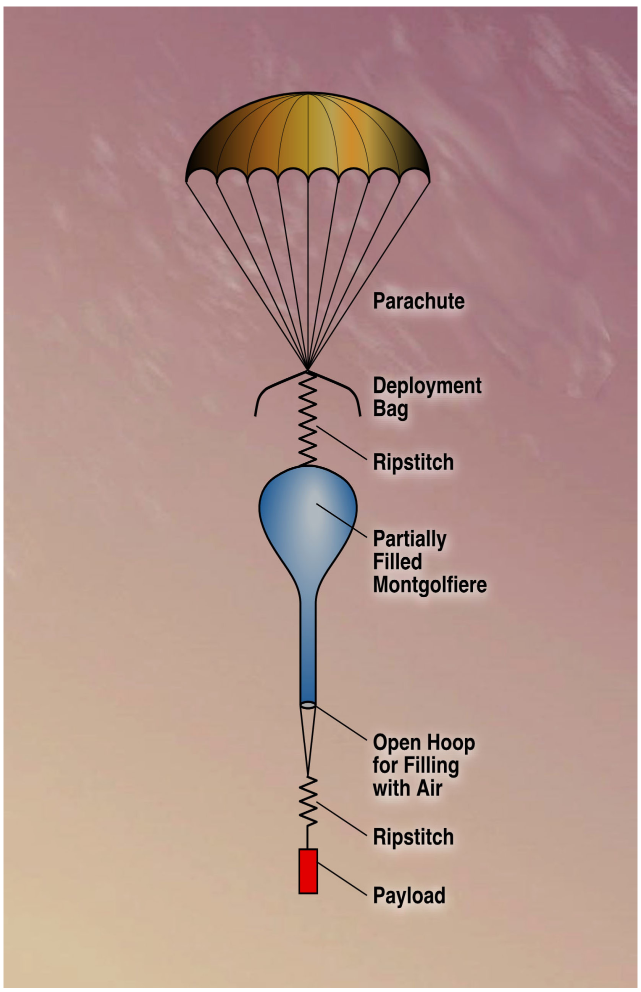


**Figure 7. Ripstitch, which absorbs energy by ripping calibrated strength stitches in a cloth ribbon, will separate the major components above and below the Montgolfiere, thus reducing stress to the Montgolfiere during deployment.**

### C) Paraballoon Design

Parachute balloon combinations, known as "paraballoons" were extensively tested by the US Air Force in the 1960's as a means to allow parachutes to descend much more slowly and with more stability[6]. These types of balloons were basically a parachute on top and a balloon on the bottom, Fig. 8. They were used as a means of slow descent of payloads to earth, as well as a means of holding torch-lit Montgolfieres above battlefields before the advent of night vision equipment.

The inflatable "burble fence" shown at the top of the paraballoon was a means of breaking up the boundary layer and providing a more stable descent for high velocity deployments.

### D) Balloon Drop Tests at WFF and GSSL

We will demonstrate these technologies with a series of 1-m balloon drop tests at WFF and 10-m balloon drop tests at the GSSL hangar in Tillamook, Oregon. Deployment experiments with small 1-m model balloons have already been initiated at WFF. The experiments will help determine time prior to inflation, time for inflation, altitude of inflation, stability of balloon during and following inflation, and the shapes the balloon takes as it inflates. They will also be used to determine if certain balloon designs inflate more efficiently than others. Various parameters are being examined during this period of experimentation. Balloon type (paraballoon, Montgolfiere, or a para-Mongolfiere mix), payload weight, and the effect of a "burble fence" briefly outline the parameters. The behavior of the low altitude, small model balloons will assist in understanding the behavior of large, stratospheric balloons. Ultimately, the more known about the large, stratospheric balloons, the easier it will be to predict the behavior of inflating balloons on Mars.

Several one-meter (3.3 ft) balloons will be deployed from a tethered aerostat using ram air inflation. The balloon will be deployed between 91.44 m (300 ft) and 304.8 m (1000 ft). However, optimal deployment altitude is 213.4 m (700 ft). A small payload carrying an up-looking camera will be attached to the balloon. The gathered information from the experiment will eventually be used to perform computational fluid dynamics (CFD) on the system.

The balloons are initially contained within a bag to prevent inflation upon ascent and to allow for an initial velocity to be applied to the system before the balloon begins inflating. Photographs of the "before" drop packed Montgolfiere and "after" drop inflated Montgolfiere are shown in Figs. 9 and 10. To simulate scaled stratospheric conditions, the package freefalls 4.57 m (15 ft) to reach and estimated velocity of 6.8 m/s (22.31 ft/s). At this point, the line attached to the top of the bag and the aerostat stops the containment bag, releasing the balloon. Fifteen successful deployments and inflations in this configuration have been completed to date (October 18, 2004).

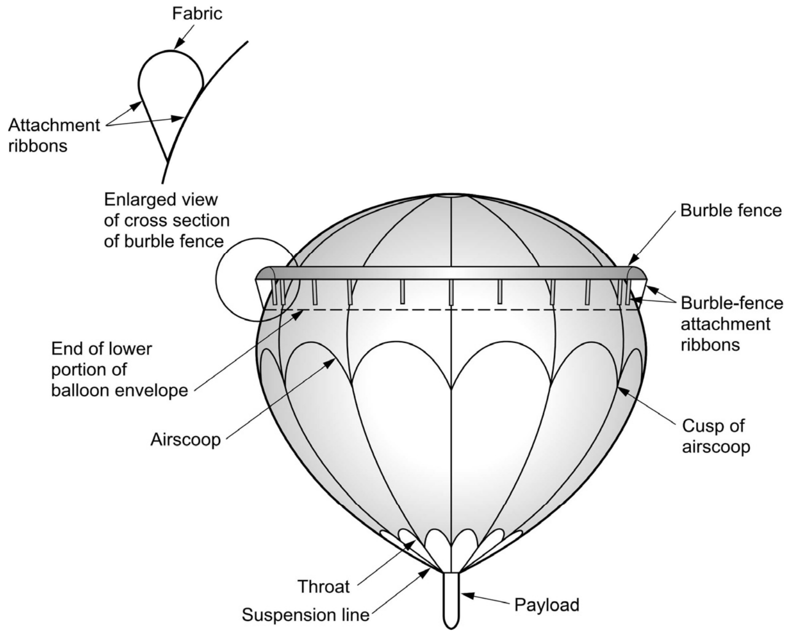


**Figure 8. A paraballoon is a combination parachute and balloon. During descent, gas opens and fills the balloon through the mid-section cusps. After full inflation, the cusps then seal shut.**

Two 10-m Montgolfieres will be used in at least four hangar drop tests at the GSSL hangar facility in Tillamook, Oregon. Deployment stresses will be measured in the entire flight train above and below the Montgolfiere, as shown in Fig. 7. In order to reduce the shock to the Montgolfiere when it falls away from the parachute while still attached, it will be necessary to apply calibrated strength cloth stitches, also known as "ripstitch," between the Montgolfiere and the upper parachute, as well as between the Montgolfiere and the lower payload. Ripping of the stitches absorbs energy and has been fully tested and analyzed by JPL for applications such as this.

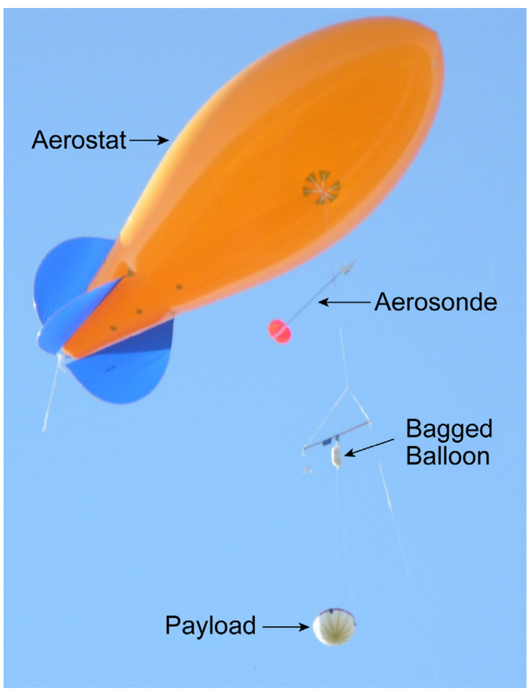


**Figure 9. During tests at WFF, a 1-m paraballoon and payload were suspended below a helium-filled aerostat.**

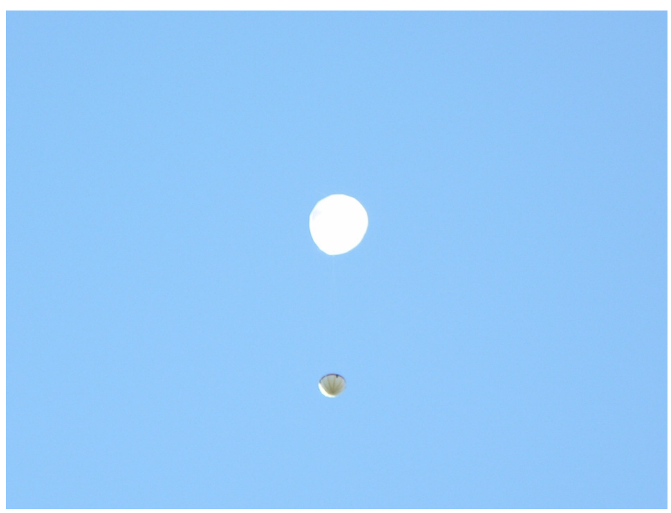

**Figure 10. The 1-m paraballoon quickly filled and descended to the ground with the payload below contained in a reinforced package.**

## E) Stratospheric Deployments

Both standard and paraballoon Montgolfieres will be used on the 1-m drop tests at WFF and the 10-m drop tests at GSSL. After all drop tests are performed, and stresses analyzed and calculated, a decision will be made as to which Montgolfiere design to use. As used on previous tests, a standard payload (GPS, temperature, pressure, and upward live video) will be added below a 20-m, 25-m, and 30-m diameter Montgolfiere. The packed Montgolfieres will be lifted to 36 km altitude (0.004 bar pressure, 220 K) by means of a helium tow balloon as shown in Fig. 4. The uninflated parachute is below the tow balloon and is followed by the packed Montgolfiere and the payload flight train. As used on previous tests, a standard payload (GPS, temperature, pressure, and upward live video) will be added below the Montgolfieres.

## F) Pioneer Astronautics System Development

The Mars Solar Balloon Lander (MSBL) is a system, which uses a solar balloon, with or without a lighter-than-$CO_2$ float fluid, as a system for landing payloads on the surface of Mars. This technology has been developed for JPL by Pioneer Astronautics as part of a 2004 SBIR Program (Reference 7). Once the payload is delivered, the balloon can detach for an independent remote sensing flight mission, deployment of additional payloads elsewhere, or remain attached to the lander to provide such useful functions as local aerial survey, communications, or towing.

Under this SBIR contract, rapid progress was made towards implementation of practical Mars Solar Balloon Lander (MSBL) technology. A fully functional MSBL prototype was designed, built, and tested under manual radio control, achieving a soft landing with an impact velocity of about 2 m/s. in addition a new type of Mars surface mobility system called the two-wheeled chariot (TWC) for use in conjunction with the MSBL was developed and successfully field tested in high winds on both steep dunes and rocky terrain that would be impassible by conventional surface rovers, Figs. 11 and 12.

The combined MSBL/TWC system is attractive for soft landing large payloads on Mars, as well as conducting high-speed long distance surface missions that combine surface sampling and imaging with very high resolution imaging and remote sensing from altitudes of tens to hundreds of meters. This system is also attractive for distributing networks of small surface stations on Mars for meteorology, seismology, or other purposes. Mission analysis was done showing that the MSBL can softly land more than double the payload to the ground than parachute/airbag system for a given landing system mass, and at a much lower landing velocity as well. Furthermore, should the landing site prove unsatisfactory, the MSBL can fly the payload to an alternative landing site. The MSBL is capable of safely landing payloads on the side of steep slopes that would be fatal to other landing systems.

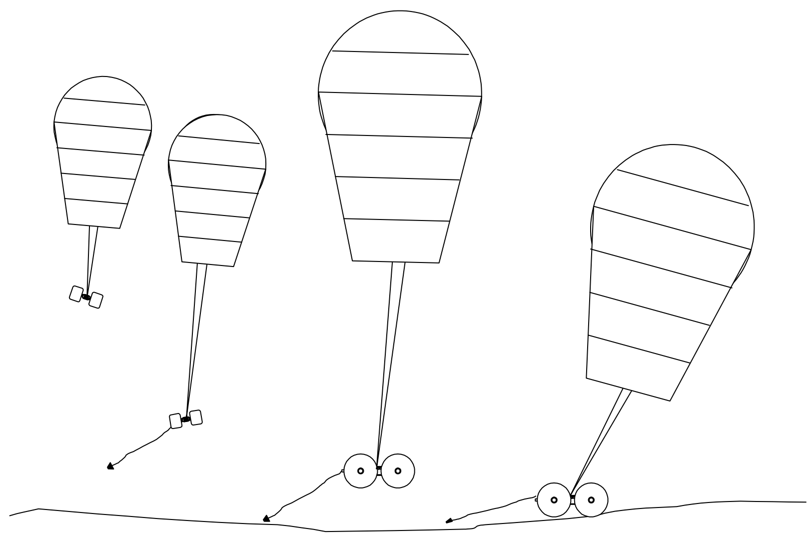

**Figure 11. MSBL/TRS Landing Sequence. After landing the balloon can be released for independent flight operations or retained for local recon and towing.**

Tests were also conducted with a 5-m diameter black polyethylene balloon that had been outfitted with a radio-controlled vent in the top of the balloon. The balloon was elevated to an altitude of about 370 meters with the vent closed. The vent was then partially opened, thus allowing the balloon to descend slowly, Figs. 13 and 14). The actual landing speed was about 2.2 m/sec, and was similar to previous altitude control tests shown in Fig. 5. Analysis has shown that this type of controlled altitude descent is quite feasible on Mars and represents an alternative soft landing system for payloads on Mars.

**Figure 12. Actual testing of the MSBL in rugged terrain.**

**Figure 13. MSBL soft-landing of 2.2 m/sec was demonstrated with a radio-controlled vent in the top of the Montgolfiere.**

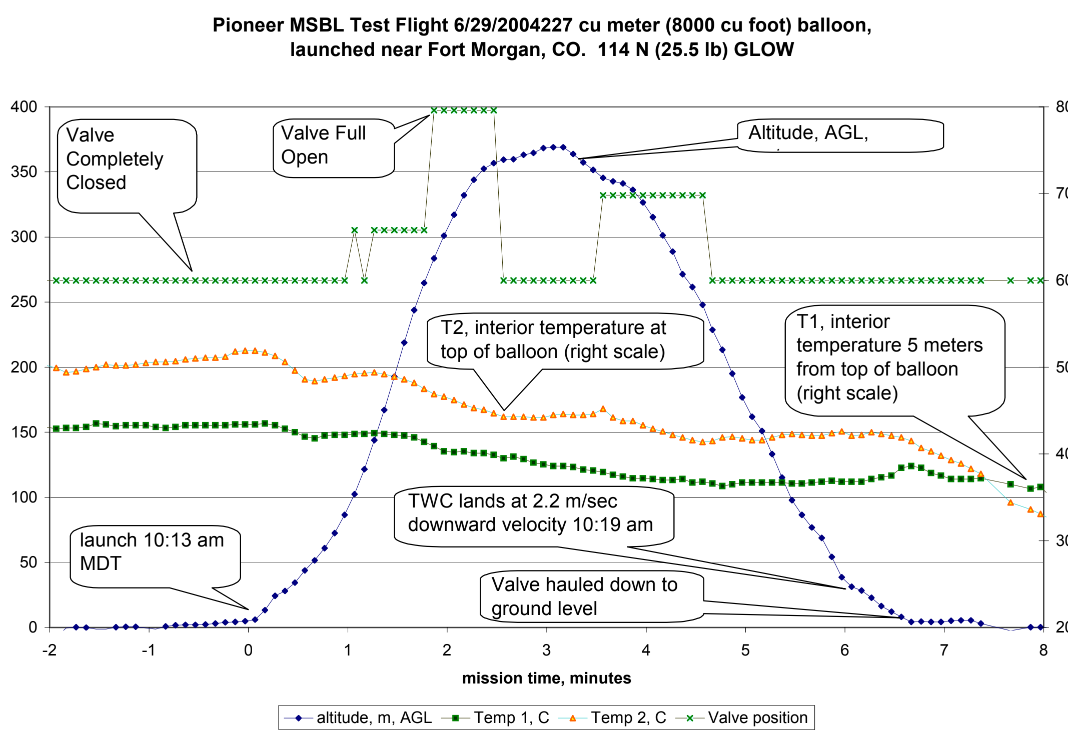


**Figure 14. Parameters for Pioneer Astronautics Montgolfiere altitude control test with soft landing.**

In ground tests of the MSBL in conjunction with the TWC, it was found that the system had great ability to free itself from surface traps, as the aerodynamic lift provided by relative surface wind allowed a net heavier-than-air MSBL/TWC system to hop out and over any obstacle that could stop its forward roll.

The TWC can also generate power through the rotation of its wheels at levels considerably in excess of what is practical with solar energy on a small Mars lander, and can do so (if a positive lift gas is used in the balloon) at night or under dusty atmospheric conditions where photovoltaic panels would fail to produce an acceptable yield.

The ability of the MSBL/TWC to travel rapidly over rocks, dunes, dust deposits, ice, and snow, to generate power, and to perform simultaneous surface contact science in close coordination with low altitude remote sensing makes it extremely attractive for many Mars exploration missions, for example a long distance rover mission to cross the Martian pole.

## IV. Summary and Conclusions

A significant amount of work has been done for developing solar-heated Montgolfieres for use on Mars. In the past, JPL has developed thermal models that have been confirmed, as well as developed altitude control systems to allow the balloons to float over the landscape or carry ground sampling instrumentation, Fig. 15. JPL, with balloon fabrication and launch assistance from GSSL, has successfully deployed three out of four small Montgolfieres in the earth's stratosphere, where conditions are similar to a Mars deployment. Two larger Montgolfieres failed, however, and a series of larger scale Montgolfieres is now planned using stronger, more uniform polyethylene bilaminate, combined with stress-reducing ripstitch and reduced parachute deceleration velocities. This program, which is a joint effort between JPL, WFF, and GSSL, will be completed in three years. This program will hopefully lead to the use of Montgolfieres as alternative, lightweight, low-speed landing systems. The Montgolfieres can also potentially be used to fly instruments aloft for up to two months during Mars polar summers, while routinely dropping in altitude to the Martian surface to perform science and in-situ sample analysis. A comparison of Montgolfiere performance with other Mars robotic means in shown in Table 1.

**Figure 15. The Montgolfiere can be used to perform science from various altitudes, to soft-land payloads, or to take surface samples for analysis by on-board instruments.**

**Table 1. Comparison of Montgolfiere Balloons with other Mars Mobility Systems**

| Mobility | Duration | Range (km) | Comments |
|---|---|---|---|
| Orbiter | >1 year | ~$10^8$ | Wide coverage at high altitude. No in-situ data. |
| Rover | 1-3 mos | ~$10^1$ | Excellent in-situ data, but very localized. |
| Glider | <1 hr | ~$10^2$ | Short, simple descent. |
| Plane | 1 hr – 2 hr | ~$10^3$ | Short, powered flight. |
| Helium | 1 wk – 1 yr | ~$10^4$ - $10^6$ | Flies at constant altitude at any latitude.<br>Potential helium leakage problems.<br>Requires strong material for superpressure, but high buoyancy (smaller diameter) |
| Montgolfiere* | 1-2 mos at Mars poles.<br>10 hrs at low latitude. | ~$10^5$ | Requires sunlight for buoyancy (6 months sunlight at Mars poles).<br>Can soft-land small payloads day or night.<br>Controllable altitude to sample soil/ice over large range.<br>Uses ambient atmosphere, without heavy compressed gas tanks.<br>Tolerant to leaks, since atmosphere is quickly replaced.<br>Internal pressure=external pressure, thus low material stress<br>Three successful small-scale deployments (8-m, 10-m and 15-m), thus high success likely for larger balloons. |

* Balloons travel slowly with the wind at about 40-100 km/hr.


## Acknowledgements

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## References and Citations


[1]P. Maleterre, "Long Duration Balloon Flights in the Middle Stratosphere", Adv. Space Res., Vol. 13, No. 2, pp. (2)107-(2)114, 1993

[2]Paul Mahaffy – PI (GSFC), "Mars Polar Region Balloon Scout Mission", Mars Scout Proposal, August, 2002.

[3]Jack Jones, Paul Mahaffy, and William Farrell, "Sampling of Trace Atmospheric Constituents Above the Surface of Mars from a Montgolfiere Balloon," Mars Atmospheric and Chemistry Astrobiology (MACA) Workshop, Caltech, Dec. 2001.

[4]Jack A. Jones, Steve Saunders, Jacques Blamont, and Andre Yavrouian, "Balloons for Controlled Roving/Landing on Mars," IAA International Conference on Low-Cost Planetary Missions, California Institute of Technology, Pasadena, CA April 1998, and Acta Astronautica, Vol. 45, No. 4-9, pp. 293-300, 1999.

[5]J. Jones and M. Heun, "Montgolfiere Balloon Aerobots for Planetary Atmosphere" AIAA Lighter Than Air Systems Technology Conference, San Francisco, (AIAA Paper No. 97-1445), June 3-5, 1997.

[6]Sanger M. Burk, Jr, "Low Speed Deployment, Inflation, and Steady-Descent Characteristics of Ram-Air-Inflated Balloon Recovery Systems with Peripheral Airscoops", NASA TN D-5186, June 1969.

[7]Robert Zubrin, "Mars Solar Balloon Lander", SBIR #NNG04CA92C, Phase I Final Report, July 10, 2004.