

MONTGOLFIERE BALLOON MISSIONS FOR MARS AND TITAN

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ABSTRACT

Montgolfieres, which are balloons that are filled with heated ambient atmospheric gas, appear promising for the exploration of Mars, as well as of Saturn's moon, Titan. Commercial versions of Montgolfieres, also known as "hot air balloons," are typically heated by burning propane, although a number of radiant and solar-heated Montgolfieres have been flown on Earth by the French Centre National d'Etudes Spatiales (CNES). On Mars, Montgolfieres would be heated by the sun, and JPL has initiated stratospheric deployment testing of solar-heated balloons. On Titan, Montgolfieres would be heated by waste heat from a Radioisotope Power Source (RPS). All Montgolfieres are very forgiving to small leaks, since leaking air is rapidly replaced and heated.

1. INTRODUCTION: HISTORY OF MONTGOLFIERES

Montgolfiere balloons are named after the French Montgolfier brothers, who flew their first hot air balloon  two centuries ago. The Montgolfier brothers' balloon, which is now known simply as a Montgolfiere, was heated by burning wool (Fig. 1) Present day commercial Montgolfieres, commonly called hot air balloons, are generally heated by burning propane.

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 fabricated from 12-micron (0.0005-inch) Mylar and polyethylene. Heated by the sun during the

day, they rose to an altitude in the stratosphere corresponding to about 10-mbar pressure. At night, the Montgolfieres were warmed by radiant Earth heat and descended to an elevation with a pressure of about 40 mbar. The CNES balloons have been somewhat larger and thicker than the 8-micron, 30-m polyethylene balloons proposed for Mars.

NASA has also recently become involved in stratospheric testing of solar-heated Montgolfieres for balloon mission applications. The primary focus of NASA's Jet Propulsion Laboratory (JPL) has been on high-altitude deployment of Montgolfieres to simulate atmospheric descent and deployment of a balloon in the



Fig. 1. The Original French Montgolfiere Hot Air Balloon Flown in 1783.

thin atmosphere of Mars. These tests, along with lower altitude control tests, are explained in more detail in the next section.

2. MARS SOLAR MONTGOLFIERES

A typical Mars Montgolfiere mission scenario begins with atmospheric entry, followed by parachute descent, deployment of the Montgolfiere, which is filled by ambient gas flowing in through a hole in the bottom, and rapid heating of the balloon to provide buoyancy. Some options for operation include the soft landing of payloads (Fig. 2) and altitude-controlled sampling of Martian soil and ice (Fig. 3).

Atmospheric modeling at NASA/Ames has shown that a Montgolfiere-type balloon would encircle the Mars North Pole for at least one month [2], traversing thousands of kilometers, given proper sun conditions (Fig. 4). High-altitude balloons have made similar encircling paths over Antarctica.

2.1 Stratospheric Deployment

While the French deployed their Montgolfieres from the ground, 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. Three out of four stratospheric deployments (8-m to 15-m diameter polyethylene Montgolfieres) have been successful, with the only failure due to a configuration/packing error. All thermal and mobility models of the successfully flown balloons have been confirmed. Two large (>20-m diameter) Montgolfiere balloons, however, failed upon stratospheric deployment. Post-flight analysis has shown that stronger balloons and/or lower deployment stress is required to fly the size Montgolfieres that are required for Mars missions.

In a newly commenced 3-year research effort, JPL, NASA's Goddard Space Flight Center (GSFC), and a

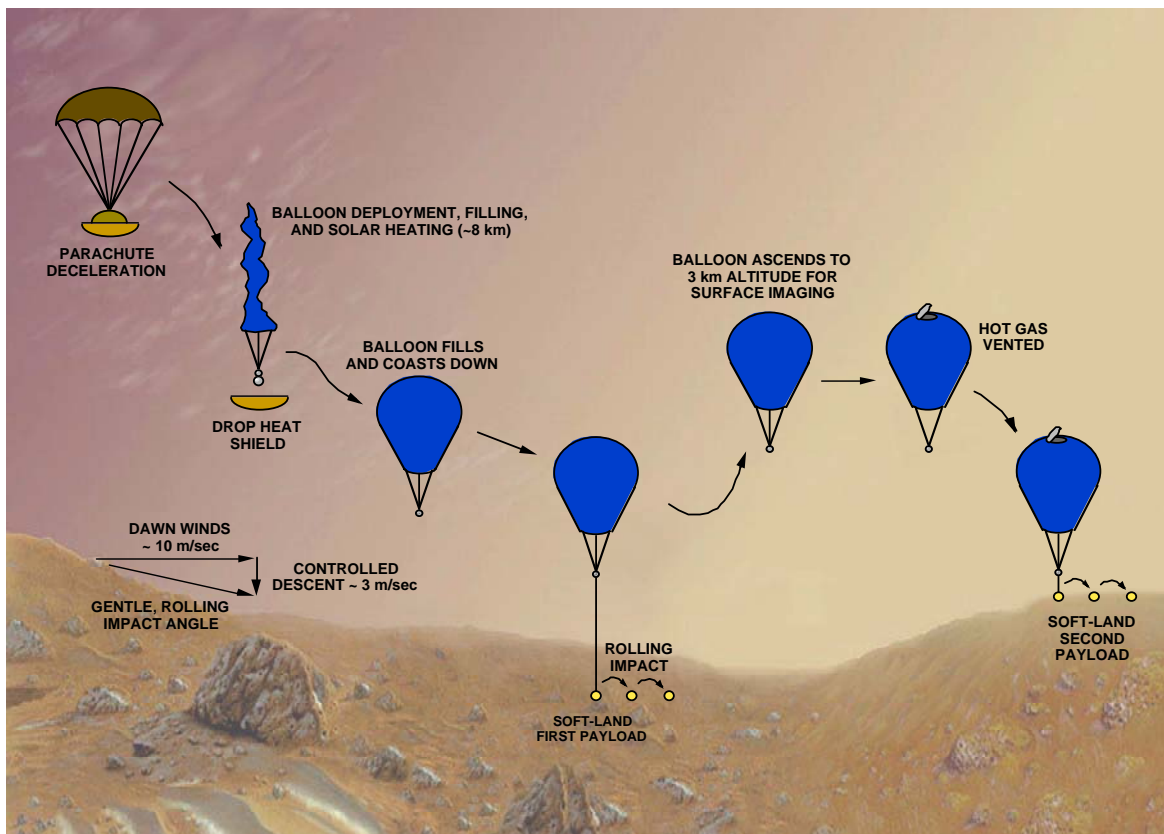


Fig. 2. The Montgolfiere balloon has an open bottom hoop and fills with atmosphere while descending. It is quickly heated by the sun, thus providing buoyancy. It can perform a number of Mars missions, as already demonstrated with earth tests, such as land payloads, ascend for long duration missions in polar regions, and descend to collect surface soil/ice samples.



Fig. 3. 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

private company, GSSL Inc. will deploy 3 additional large Montgolfieres (20-m, 25-m, and 30-m) in the Earth's stratosphere. This effort will focus on stronger, more uniform materials (co-extruded polyethylene), reducing parachute descent rates, and employing a low-stress deployment method using ripstitch inside the Montgolfiere as it extends to its full length.

2.2 Altitude Control Tests

Several altitude-controlled tests have been successfully conducted using black plastic Montgolfieres. In the first field test, in California's Mojave Desert in 1998, a radio-controlled vent was placed at the top of the

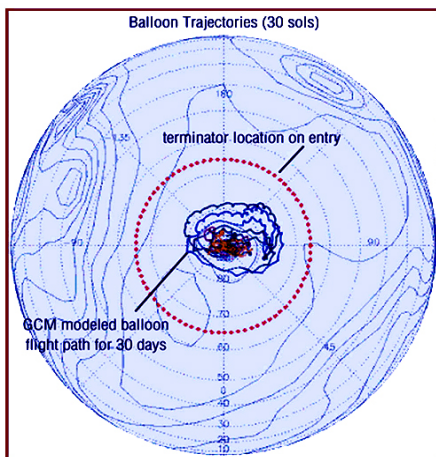


Fig. 4. One-month wind-driven balloon trajectories over the Mars North Pole.

balloon. When the vent was opened, hot air was released and the balloon descended; conversely, closing it 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 [3].

During this test over the Pacific Ocean, the balloon was allowed to climb to about 1-km altitude, and the vent was periodically opened to allow descent. The Montgolfiere's 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. 5).

2.3 Montgolfieres Used as Parachutes

As shown in Fig. 1, Montgolfieres can be used on Mars to soft-land relatively large payloads (up to 150 kg and possibly larger). Montgolfieres are far more stable than parachutes at Mars, and can soft-land payloads at under 3-m/sec total impact velocity. By contrast, parachuted payloads on Mars must be landed much faster in order for the parachutes to remain stable (30 m/sec vertical impact velocity). An additional approximately 20-m/sec horizontal residual entry velocity, which cannot be damped out by the fast moving parachute in the thin Martian atmosphere, must also be taken into account, plus whatever ambient winds may exist [4]. With typical local winds of about 10 m/sec (lower at dawn and higher planet-wide during the southern summer), a typical Montgolfiere could land payloads on Mars at a total impact velocity of 10.4 m/sec, with at least 90% of the V^2 energy convertible to rolling impact energy. A typical parachute-landed payload, however, would land payloads on Mars with a total impact velocity of about 42.4 m/sec, and only half the V^2 energy can be converted to rolling energy (Fig. 6). Thus, the vertical impact energy is about 100 times higher for parachuted payloads compared to Montgolfiere-landed payloads. This is why missions such as Pathfinder and Mars Exploration Rover have used rockets to slow down prior to surface impact, even with air bags.

3. TITAN RPS MONTGOLFIERES

Various aerial vehicle missions to Saturn's moon, Titan, have been envisioned which take advantage of Titan's thick nitrogen atmosphere (1.46-bar, 93K over four times more dense than the atmosphere on Earth). One of the simplest altitude-controlled atmospheric missions for Titan is that of a Radioisotope Power Source (RPS)-heated Montgolfiere. For this mission, the RPS would be held inside the lower portion of the balloon, thus allowing nearly all of the waste heat to warm the

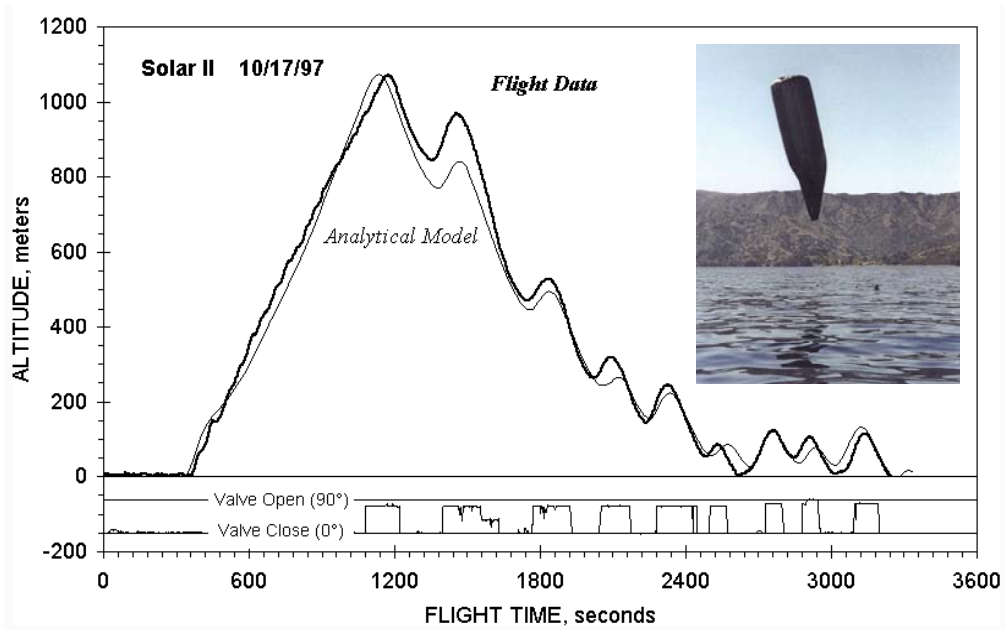


Fig. 5. Altitude control experiments with radio-controlled upper vents on the balloon have shown that Montgolfieres can gently land and take surface samples many times. Other successful altitude tests modulated the volume of the balloon.

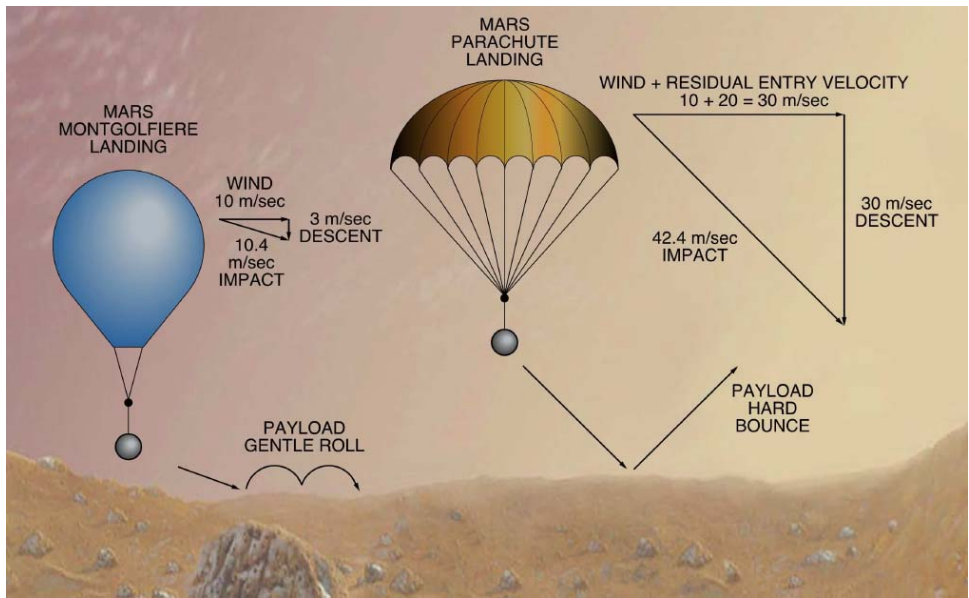


Fig. 6. Montgolfieres can land payloads on Mars with less than 1% of the vertical energy compared to parachutes.

internal ambient nitrogen atmosphere (Fig. 7). Altitude control could be maintained by opening and closing a vent at the top of the balloon.

Analytical predictions show that a 10-m diameter balloon can carry a 125-kg payload at 8-km altitude (0.96-bar, 85K) with only 2000 watts of RPS waste heat. By controlling the vent, the altitude can be held

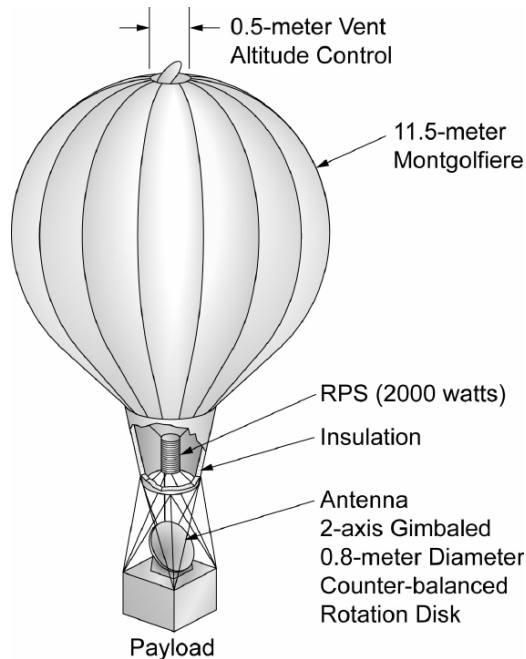


Fig. 7. RPS-heated Montgolfiere for Titan.

within +/- 15-m of a 100-m altitude above Titan's surface (Fig. 8). The vent control algorithm involves both the offset altitude and the ascent/descent velocity.

One unusual point to be noticed is that Montgolfieres on Earth typically require about 200,000 watts to float a 400-kg payload beneath a 17-m diameter balloon, while

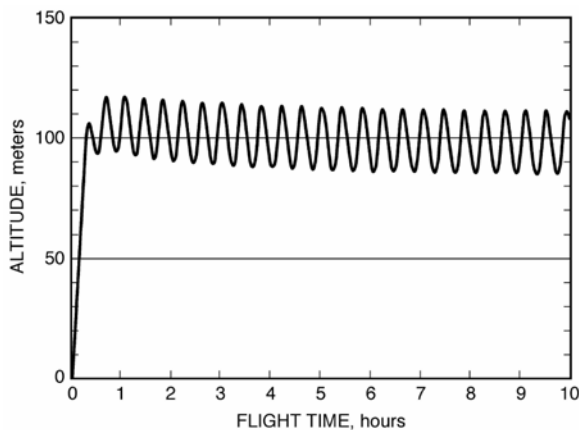


Fig. 8. Titan RPS-Heated Balloon with Upper Vent Altitude Control.

Montgolfieres on Titan could float the same payload, under the same balloon, for only about 2000 watts—a factor of 100 less power than is required on Earth. One

reason for this is that the sum of radiant and convective heat transfer coefficients on Titan is nine times less than on Earth. Furthermore, since buoyancy is inversely proportional to square of the absolute temperature, this adds an additional factor of about 11, making the total required heat load on Titan about 100 times less than on Earth.

JPL presently has plans to develop advanced materials for a Titan aerobot, as either an RPS Montgolfiere or a propeller-driven blimp. JPL also plans to provide further high fidelity thermal modeling of the RPS Montgolfiere system, as well as system costing analyses. If the thermal modeling and costing of RPS Montgolfieres show that this system is advantageous for Titan aerial missions, then further design and prototype testing may be developed.

3. REFERENCES

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