Inflatable Robotics for Planetary Applications

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1 Background

Space Inflatable vehicles have been finding popularity in recent years for applications as varied as spacecraft antennas, space-based telescopes, solar sails, and manned habitats [1]. Another branch of space inflatable technology has also considered developing ambient gas-filled, solar balloons for Mars as well as ambient gas-filled inflatable rovers [2]. More recently, some other intriguing space-inflatable vehicles have been proposed for the gas planets and Pluto, as well as for Saturn's moon, Titan, Neptune's moon, Triton, and Jupiter's moon, Io [3].

2 Inflatable Rovers

The general purpose of designing a large, lightweight, inflatable rover is to allow the rover to travel over rocks instead of around them, as present planetary rovers are required to do. This can greatly increase a rover's versatility, speed, and range. It has been estimated that in the 5% rockiest regions of Mars, approximately 1% of the surface is covered by rocks of 0.5 m or higher [4]. Early tests with scale models of inflatable rovers showed that this type of vehicle could easily scale rocks that were 1/3 the diameter of the wheels. Thus, a wheel size of 1.5-m diameter was chosen to allow the rover to traverse well over 99% of the Martian surface. In order to minimize mass and complexity, a three-wheeled vehicle was chosen with a wide wheelbase to enhance stability in rugged and steep terrain.

The first full-size bench model of the inflatable rover (Figure 1) has two 1.5-m diameter rear-drive wheels

Figure 1: Inflatable Rover

with a forward steering wheel of the same size. It is shown with an inflatable solar array that is sized to produce over 100 W of electrical power on Mars. Thus far, the rover has been successfully tested in a wide range of conditions including on giant sand dunes in the Mojave desert, in very rugged, lava-strewn terrains, and on calm lakes simulating liquid methane seas anticipated to exist on Saturn's moon, Titan. The rover has successfully climbed rocks as high as 0.75 m, and has traversed well with ascents and descents on hills and slopes as high as 30°. JPL has prepared videotapes [5, 6] that demonstrate operation in these various terrains.

2.1 Titan Aerover

JPL has also considered various types of inflatable vehicles for operation at Saturn's largest moon, Titan, which is the only moon in our solar system with a significant atmosphere. The atmosphere is composed primarily of nitrogen and has a surface pressure of about 1.4 bar with a temperature of about 93 K [7]. With a density of about four times that of Earth's surface atmosphere, Titan is ideal for ballooning. A relatively small helium balloon (3-m diameter) can easily lift a 50-kg payload to 10-km altitude. For one balloon mission on Titan, JPL has proposed filling helium into three large spherical tires (2-m diameter) of a 50-kg inflatable rover, such that the rover could be flown as a controllable aerovehicle. Using periodic venting and ballasting, the balloon could land and re-ascend numerous times before ultimately replacing the helium with ambient atmosphere.

More recently, the Titan aerover has evolved into more of a blimp-shape with a large lower wheel to allow operation/floatation on Titan's solid surfaces and liquid methane/ethane seas (Figure 2).

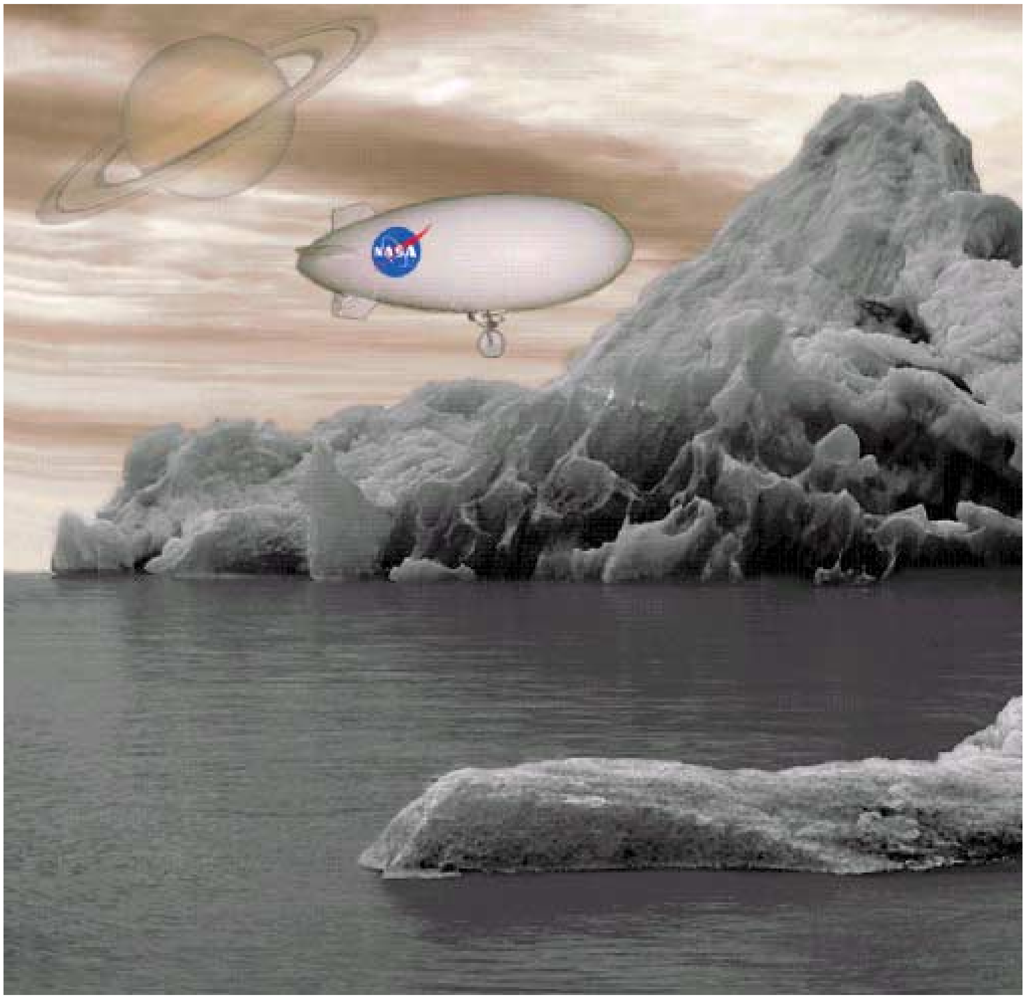

Figure 2: Titan Aerover

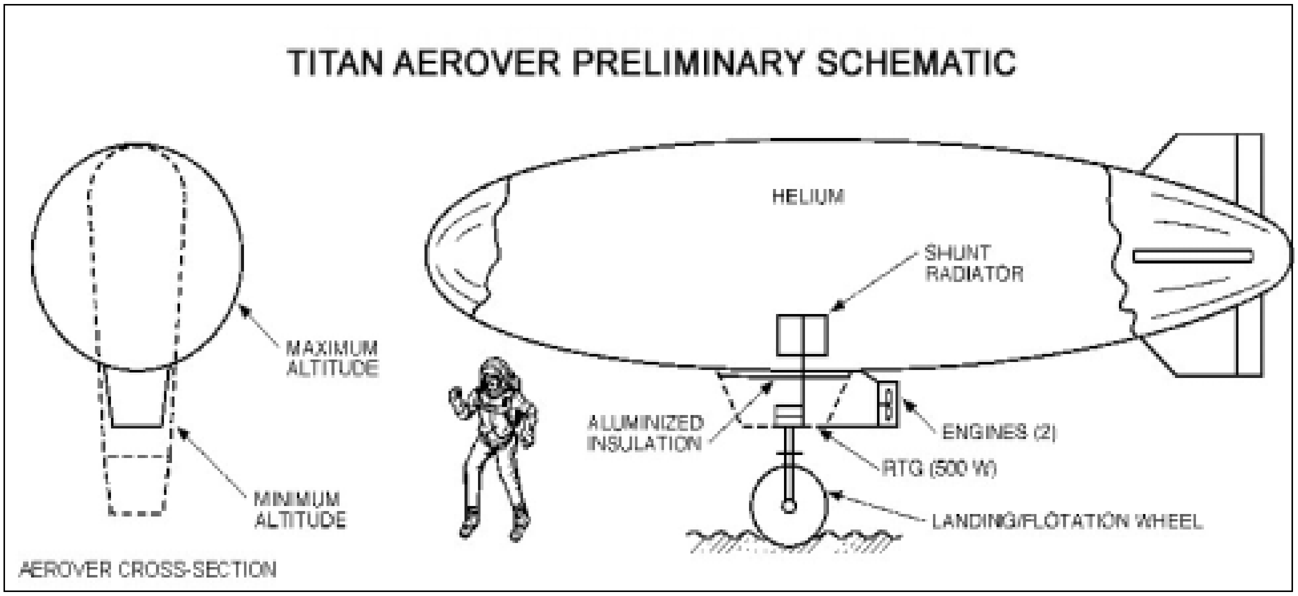

Figure 3: Titan Aerover Schematic

The aerover would have full mobility, including vertical ascent and descent to land in rocky terrain. A preliminary concept being considered is a heat-activated ascent and descent that would have a maximum altitude of about 10 km (Figure 3), where the 100-kg vehicle would be capable of encircling the moon once every one to two weeks and provide surface imaging well below the upper opaque clouds. The maximum surface speed would be about 2 m/sec, which is well above the maximum anticipated surface winds of 1 m/sec. The ten-meter long Aerover would be propelled by two engines of about 20-watts power each.

2.2 Tumbleweed Balls

Another inflatable robotics concept being explored is known as a “tumbleweed ball.” This is a large beach-ball-like device that holds a central payload by means of a series of tension cords. On Mars, a 6-meter diameter ball could be used for descent (replacing the parachute), landing (replacing the airbag) and mobility (wind-driven on surface). The ball could be stopped by partial deflation (Figure 4) and restarted with full inflation during windy periods. On Mars, a 20-kg ball could carry a central 20-kg payload and be propelled at speeds of about up to 10 m/sec during typical afternoon winds of 20 m/sec. The ball could easily climb 20° hills, with moderate winds (20 m/sec) and 45° hills with stronger winds (30 m/sec.)

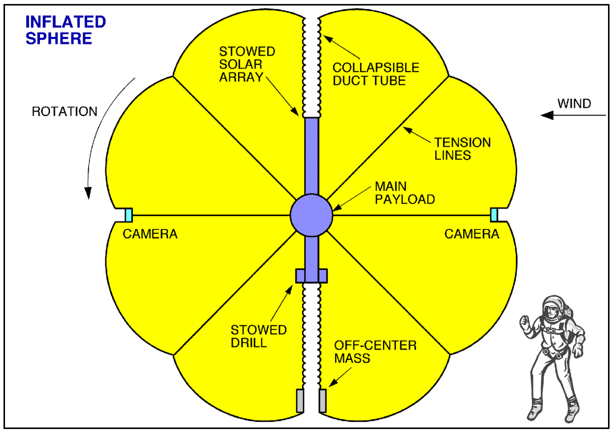

Figure 4: Tumbleweed Ball

Tests using this type of ball as an impacter sphere were successfully conducted in the 1960s at JPL [8]. Impact speeds of as high as 60 m/sec were tested with payload fractions of as high as 75%. By comparison, the nominal tumbleweed ball of Figure 4 would have an impact speed of 30 m/sec with a payload fraction of about 50%.

The use of tumbleweed balls has also been evaluated for the microbar atmospheres of Pluto, Neptune's moon, Triton, and Jupiter's moon, Io [3]. Pluto's 10- to 20-microbar nitrogen atmosphere is anticipated to have very calm winds, thus not conducive to windballs. Triton's 17-microbar nitrogen atmosphere, however, is anticipated to have at least 5–15 m/sec winds [9] with locally higher winds possible. Preliminary calculations have shown that winds of about 20 m/sec may induce motion of Tumbleweed Balls at Triton, and thus this remains a possibility. Io's one-microbar atmosphere is likely to have supersonic winds during frequent volcanic activity, and the resulting wind forces would be more than ample to propel windballs across large areas of the volcanic surface.

2.3 Ambient Gas Balloons

2.3.1 Montgolfieres

A novel atmosphere-filled 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 long flights at the Martian poles during summer or for shorter flights at lower latitudes (Figure 5). 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 also been recently demonstrated by JPL, using a novel, lightweight, top air vent that is radio controlled.

Figure 5: Montgolfiere Balloon

The soft-landing system presently used on Mars missions involves a standard atmospheric aerobraking entry capsule, followed by a parachute deceleration to about 75 m/sec 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, and lands on deployed air bags with a vertical landing speed of about 20 m/sec.

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 6, 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. With a polyethylene envelope, a 10-kg (18 m diameter) Montgolfiere can be used to land a 40-kg payload at 8 m/sec and then reascend to 4-km altitude with a 2-kg gondola. Summer polar flights would encircle the poles many times over a period of days.

Montgolfiere balloons can also be used at Jupiter and Saturn [11]. Solar Infrared Montgolfiere Aerobots (SIRMAs) use a combination of lower planetary infrared heating during the night and solar heating during the day. A detailed study performed on SIRMA use at Jupiter shows that the balloon floats at about 0.1 bar during the day and descends to about 0.2 bar at night, using isentropic compression heating to help slow the nightly descent rates. The total delivered mass is about ten times lighter than for comparable pure hydrogen balloons systems at Jupiter. A similar SIRMA for Saturn would weigh about 220 kg, although this mass could be cut in half if the Montgolfiere is flown at a Saturn pole during summer.

2.3.2 Stratosphere-Filled Balloons

Although there is not enough solar heat for viable Montgolfiere at Uranus and Neptune, these planets are unique in our solar system in that the upper methane-free stratospheric atmosphere has a significantly lower molecular weight than the atmosphere below the upper methane clouds. This unique feature allows relatively small balloons (15 kg) to fill with upper atmospheric gas and then float 50-kg payloads in the troposphere.

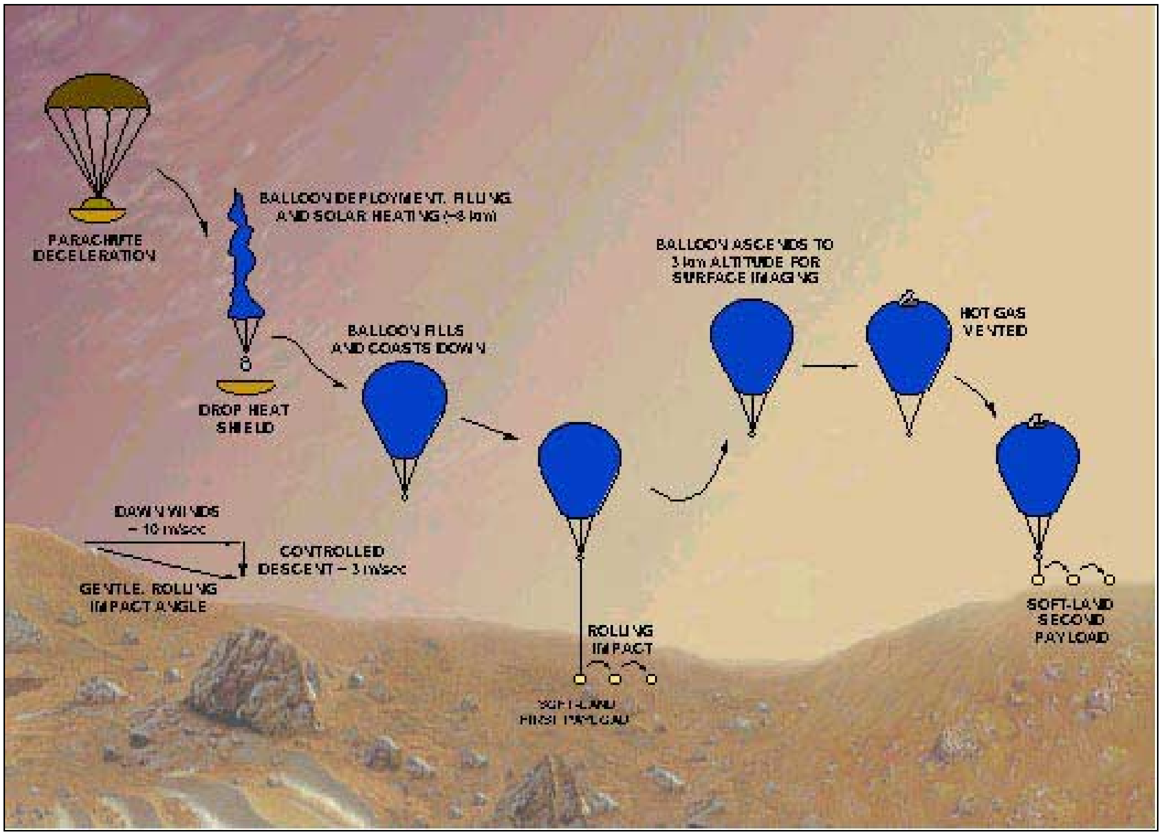

Figure 6: Solar Balloon Deployment

2.3.3 Parachute Balloons

Although there is not atmosphere or enough solar heat to float Montgolfieres at Triton or Pluto, simple parachute balloons appears quite viable to land payloads there.

For both these bodies, a 15-kg parachute balloon could land a 50-kg payload with an impact velocity of about 60 m/sec. Airbags or impact limiters (previously discussed) could then be used to soften the impact. These types of parachute balloons, which fill in about 2 minutes, are typically many times lighter than comparable parachutes, since paraballoons can use much lighter materials than the shock-deployed parachutes.

3 Summary and Conclusions

The use of inflatable space vehicles can provide a number of unique and compelling missions to many bodies in our solar system. Inflatable rovers appear to be the ideal means to transport payloads quickly across large distances on Mars, while inflatable aerovers can be used to navigate the skies, as well as the liquid and solid surfaces on Titan. Inflatable, wind-blown tumbleweed balls can be used for descent, landing, and mobility on Mars and may even be viable for mobility on the surfaces of Triton and Io.

Ambient gas-filled balloons appear quite viable on Mars, Jupiter and Saturn as solar-heated Montgolfieres. The unheated version, or paraballoons, can be used to softland payload on Mars, Triton or Pluto. Finally, Uranus and Neptune provide unique opportunities for light mass balloons that can be filled with upper, lighter stratospheric gas and then float much larger payloads in the lower troposphere.

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References

[1] D. Cadogen et al., Int'l Astron Cong. 1998.

[2] Jack Jones et al, "Balloons for Controlled Roving/Landing on Mars", Acta Astronautica, Vol 45, No. 4-9, Pp 393-400, 1999.

[3] J. A. Jones and J. J. Wu, “Inflatable Vehicles for In-Situ Exploration of Titan, Triton, Uranus and Neptune,” Forum on Innovative Approaches to Outer Planetary Exploration, Lunar and Planetary Institute, Houston, Texas, Feb 21–22, 2001.

[4] M. Golombeck and Don Rapp, “Size-Frequency Distribution of Rocks on Mars and Earth Analog Sites: Implications for Future Landed Missions,” Journal of Geophysical Research, Vol. 102, pp. 4117–4129, February 25, 1997.

[5] J. A. Jones, “Inflatable Rover Demonstration,” JPL Photolab Video #9905-10B (3 minutes), May, 1999.

[6] J. A. Jones, “Inflatable Rover Tests at Death Valley National Park,” JPL Photolab Video (3 minutes), October, 2000.

[7] Ralph Lorenz, University of Arizona, Personal Communication, 2000.

[8] R.G. Ross Jr. and W.E. Layman, “The Design and Testing of an Inflated Sphere Impact Limiter”, JPL Technical Report No. 32-1037.

[9] Andrew Ingersoll, “Nature,” 344, 315–317, 1990.

[10] J. A. Jones and Jiunn-Jeng Wu, “Solar Montgolfiere Balloons for Mars,” AIAA, Paper No. 99-3852, 1999.

[11] J. A. Jones and M. K. Heun, “Montgolfiere Balloon Aerobots for Planetary Atmospheres,” AIAA, Paper No. 97-1445, 1997.