EXPLORING MARS WITH BALLOONS AND INFLATABLE ROVERS. Jack A. Jones, James A. Cutts, Viktor V. Kerzhanovich, Andre Yavrouian, Jeffery L. Hall: Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena CA 91109; Steven Raque and Debbie A. Fairbrother: Goddard Space Flight Center, Greenbelt MD 20771. E-mail: Jack.A.Jones@jpl.nasa.gov, James.A.Cutts@jpl.nasa.gov, Viktor.V.Kerzhanovich@jpl.nasa.gov, Andre.Yavrouian@jpl.nasa.gov, Jeffery.L.Hall@jpl.nasa.gov, Steven.M.Raque.1@gsfc.nasa.gov, dafairbr@pop800.gsfc.gov

Introduction: Until now, the exploration of Mars has taken place with global coverage of the planet by satellites in orbit or with landers providing very detailed coverage of extremely limited local areas. New developments in inflatable technology, however, now offer the possibility of in situ surface and atmospheric global studies of Mars using very lightweight rovers and balloons that can travel hundreds or even thousands of kilometers relatively quickly and safely. Both systems are currently being tested at JPL; preliminary results show great promise. One of the balloon technologies offers the additional bonus of being able to land payloads on Mars much more gently than parachutes, yet with considerably less mass.

Inflatable Rovers: The inflatable rover being developed at JPL uses novel, large, inflatable wheels to climb over rocks, instead of traveling around them. This enables the rover to traverse over the vast majority of the Martian surface. Preliminary tests using commercial nylon balloons as tires, a rigid metal chassis, and a simple joystick control have shown great promise [1]. Tests have been successfully conducted in rugged rocky canyons, on giant sand dunes, and on calm lakes, simulating the liquid methane lakes anticipated on Saturn's moon Titan (see Fig. 1).

The first full-size bench model of the Inflatable Rover (Figure 1) has two 1.5-meter diameter rear-drive wheels with a forward steering wheel of the same size. The 20-kg prototype rover has two Micro Mo coreless motors with planetary-reduction gears. The two motors propel the rover at 2.0 km/hr, using only 18 W of power on level terrain. Considering Mars' reduced gravity of 0.38 kg, this same 18 W of power could propel the vehicle at approximately 5 km/hr in level terrain.

Figure 1: The Inflatable Rover Drives on all Terrains

Balloons: Different well-known types of balloons provide flight duration from about ten hours to several weeks and eventually months. Solar-heated hot air balloons can fly for about ten hours of daylight, although much longer at the martian poles during summer. Conventional zero-pressure ballooons can fly 1.5-2 days with ballasting, overpressure balloons with a guiderope (the Russian-French Mars Aerostat project) can fly up to 7 days, and constant volume superpressure balloons can fly up to several months at a nearly constant altitude. With average martian winds of ~15 m/sec, the flight path of aerobots would vary from 500 km for solar-heated balloons to tens of thousands of kilometers for super-pressure balloons. Balloon altitude control systems are currently under development for Mars, as well as for Venus, Titan, and the giant gas planets [2]

Solar Montgolfieres: A lightweight, solar heated, hot air balloon, known as a Montgofiere, has been in test at JPL for more than two years. This balloon shows great promise for exploring vast areas of the Martian atmosphere (see Figure 2), as well as for soft landing payloads on Mars much more gently and for less mass than parachutes. Montgofieres are named after the 18th-century French brothers Joseph-Michel and Jacques-Etienne Mongolfiere who first flew hot air balloons. Recent tests have already confirmed the ease of altitude deployment and filling of these solar hot air balloons. Furthermore, JPL has recently demonstrated actual landings and re-ascents of solar hot air balloons using a novel, lightweight top air vent [2].

The Montgolfieres are deployed with relative ease by dropping a packed balloon that has a hole in the bottom with a payload (gondola) hanging beneath the balloon. The payload pulls the Montgolfiere down, with the hole acting as a ramjet to fill the balloon, typically in 1 to 2 minutes; solar heat then provides buoyancy in approximately one additional minute. A number of high-altitude (32 km to 34 km) deployment tests have already taken place at JPL.

The development of an ultra-lightweight composite film—weighing only 7 gm/m^2—allows for very lightweight Montgolfieres to fly at Mars. The film consists of 14-gauge (3.5 micron) mylar film with rimstop scrim material bonded to it. A 4-kg, 13 meter diameter Montgolfiere with a metallic film coating can fly at 4-km altitude while carrying a 1-kg imaging and science gondola. This same Montgolfiere can be used to soft land Mars payloads varying from 5 kg (1m/sec impact velocity) to 40 kg (15 m/sec impact velocity). After landing the payload, the Montgolfiere can ascend for a full day of imaging and science while traveling many hundreds of kms. If landing in a summer polar region, the same Montgolfiere could travel many thousands of kms over a period of many days. It should be noted that small leaks do not effect a Montgolfiere's endurance because leaking air is quickly replaced.

Helium Aerobots: Helium superpressure balloons are balloons that have an internal pressure somewhat higher than ambient pressure. With a constant volume, they fly at a nearly constant altitude wherein the mass of atmosphere displaced is equal to the total mass of the balloon, payload and contained helium [3]. Although the anticipated flight duration is much longer than that for Solar Montgolfieres, the helium superpressure balloons are somewhat heavier and involve more risk, since one must bring along a pressurized supply of helium (as opposed to filling with ambient air) and one must be assured of a fully impermeable balloon membrane.

Extensive work is presently underway at NASA to help confirm the use of helium superpressure balloons for long-term missions at Mars. A comprehensive test program (MABVAP – Mars Balloon Validation Program) designed to address the most important issues was initiated in JPL in late 1997. The program includes development and tests of materials, balloon and inflation system prototypes, packaging and deployment methods, laboratory, vacuum chamber tests and flight tests at low altitude and in the stratosphere. Four NASA Centers (JPL, Langley, Dryden, and Glenn) as well as several industrial partners are involved in this program. Development of new modeling and simulation tools by JPL and GSFC/Wallops Flight Center is part of the program.

References: [1] Jack A. Jones et al. (2000) *Space 2000 Robotics Conference*, February 2000. [2] Jack A. Jones, (2000) *IEEE Aerospace Conference*, March 2000. [3] James Cutts and Viktor Kerzhanovich, The Planetary Report, 1999.

Figure 2: Montgolfiere in Flight