EXPLORING MARS WITH AMBIENT GAS BALLOONS AND INFLATABLE ROVERS. Jack A. Jones and Jiunn Jeng Wu; Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109; Jack.A.Jones @jpl.nasa.gov and Jiunn-Jen.Wu@jpl.nasa.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 [1]. Both systems are currently being tested at JPL; preliminary results show great promise. The balloon technology 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 [2]. 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 Figure 1).

Large tires can greatly increase a rover's versatility, speed, and range. It has been estimated that in the 5% rockiest regions of Mars, rocks of 0.5 m or higher cover approximately 1% of the surface [3]. 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 more than 99% of the Martian surface. To minimize mass and complexity, a three-wheeled vehicle was selected. This vehicle has a wide wheel base to enhance stability in rugged and steep terrain.

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.

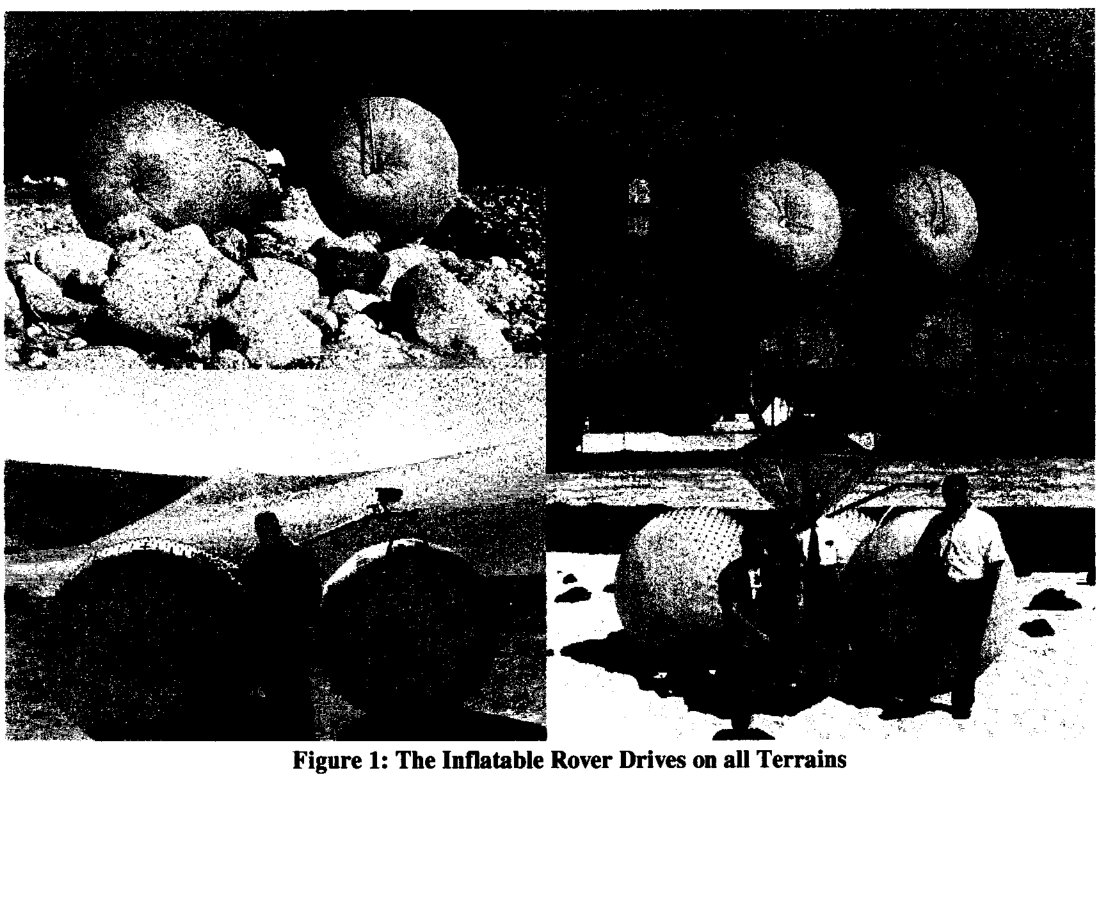

Figure 1: The Inflatable Rover Drives on all Terrains

The current lightweight nylon tires (1.5 kg each) have already accumulated more than 20 km of driving over very rugged rocks, sand dunes, and gravel without a single puncture or failure. However, B. F. Goodrich Aerospace is currently fabricating more durable tires. The more durable tires will be tested later this summer (2000) in volcanic ejecta terrain (Death Valley National Park), in a meteor crater (Meteor Crater Park), and in steep canyons (Grand Canyon National Park). Two sets of tires will be tested: one from super-strength Spectra fiber and the other from Vectran fiber (2 kg each). During test, each tire will have one strong internal-membrane tire (1 kg each); actual flight units may have multiple inner tubes for redundancy. Furthermore, each tire for Mars operation is likely to have its own small pump (electrical or sorption) to allow for initial filling and small leaks.

Balloons: 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). This balloon can also be used 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 [4]. Using solar heat only, Montgolfieres are ideal for landing at the Martian poles during summer or for shorter flights at lower altitudes. 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 that is radio controlled.

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 results are encouraging [5].

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.

Future Inflatable Robotics for Mars: The development of new, strong, impermeable materials for balloons will also likely lead to the use of helium super pressure balloons that will have full global coverage and can last for perhaps several weeks. These balloon systems will likely be heavier, however, since one must bring along helium as well as heavy pressurized tanks. Altitude control systems are currently under development for helium balloons at Mars [1], for helium balloons at Titan and Venus [4], and for ambient gas balloons at Jupiter, Saturn, Uranus, and Neptune [4].

For the inflatable rovers, much larger systems can be developed for transporting heavy equipment, in situ construction material, or astronauts. JPL is, in fact, in the process of designing inflatable tires for a 500-kg Martian astronaut transportation vehicle in development at Johnson Space Center [6].

References: [1] Jack A. Jones et al. (1999) *Acta Astronautica*, Volume 45, Nos. 4–9, 293–300. [2] Jack A. Jones et al. (2000) *Space 2000 Robotics Conference*, February 2000. [3] M. Golombeck and D. Rapp (1997) *Journal of Geophysics Research*, Volume 102, 4114–4129. [4] Jack A. Jones (2000) *IEEE Aerospace Conference*, March 2000. [5] Jack A. Jones (2000) JPL Internal Test Report, June 2000 [6] Jack A. Jones (2000) NASA Surface Systems Quality Review, March 2000.

Figure 2: Montgolfiere in Flight