

USING WIND ENERGY TO PULL A SURFACE ROVER ON MARS, VENUS, OR TITAN

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ABSTRACT

A balloon high above a surface rover tethered to a dragchute just below has enough energy from the wind to pull a rover on Mars for hundreds of kilometers. All the semi-autonomous rovers sent to Mars planned for the future are restricted by the places they can land, by the terrain they can climb, by the slope of the surface, by the obstacles they may encounter and in the amount of space they can travel in. Yet simply by using the wind to sail across its surface a rover on Mars can go where no rovers could ever go before and much further than can be imagined. Some terrestrial tests on this new device we call the Windsurfer were performed by using several different methods listed below. In the following pages we will describe how this way of tapping into the natural force from the wind on the atmospheric-rich worlds of Mars, Venus and Titan can be done with a minimal amount of resources and cost. We will show how even the wind in the thin Martian atmosphere is dense enough to push a Windsurfer, thereby driving a rover on its surface, for hundreds of kilometers.

INTRODUCTION

The primary goal of this paper is to design a balloon, sail and drag-chute combination to pull a rover over the Martian surface with the help of the wind. On the surface, the rover will gather important data of the surrounding areas and in the air just below the balloon; a camera will gather panoramic views of the surface and scout out places to explore.

We used helium gas as an example only in this paper to fill the balloon envelope to help test the feasibility of a wind driven rover, however different mediums for lift can be used for this to work. By varying its lifting force on the rover from the expansion and contraction of the balloon envelope during the course of a single Martian day, the loss of buoyancy due to the air density change wouldn't affect its elevation. Therefore, a gas-filled zero pressure balloon, would stay above the rover the entire lifetime of its planned mission, The communications link on the Windsurfers after landing will be deployed high above the surface to assure it doesn't get stuck in an inaccessible area so it can phone home in time. The balloon will stay at a fixed elevation above the surface. By capturing the wind at a speed to move the rover over most surfaces on

Mars only 10 percent of the time, at an average rover speed of 5m/s, the rover theoretically can travel over 500 miles, 800 kilometers, in a three week period. Three weeks is the life expectancy of a gas filled zero pressure balloons.

OBJECTIVE

[Image 1] The objective of this paper is to enhance human exploration of Mars by using an age-old remedy, the wind, to explore its wonders. The best way to extract information from Mars is from two vantage points simultaneously, from its surface and a controlled height above its surface. A balloon can do this better than an airplane flying 600 kilometers per hour above the surface with a life expectancy of several hours. Aerial shots alone are always left up to the viewer in trying to decipher what is happening on the ground. It is good to get some pictures and data from above to verify what you found on the surface and to scout out other interesting spots to explore. The surface is where the good raw data is.

[Image 2] Even though the atmospheric density at the Martian datum is thin compared to Earth's, there is plenty of wind energy to help move a rover over the Martian surface. A rover driven by the wind would move freely up gullies, into and out of craters then down into steep canyons. On Earth we have tested a wind-riding rover in one of the most inhospitable places there is; a boulder filled steep hill. It climbed the hill several times by using only the force of the wind on the dragchute and balloon stationed above it to pull the rover over the large boulders up and over the hill. [Image 3]

Summary of Action Needed to Make This Happen

- Design a balloon, sail, drag-chute and or an airfoil type combination around a specific missions and location.
- Choose rover shape, tether material, generator type, solar cell backup, sail, parasail, airfoil, or dragchute combination.
- Design a rover to distribute and cushion the load at impact speeds in excess of 7 m/s, or use one tethered above the surface rover high above a potential impact area.
- Design the complete system to move over the surface of Mars within a percentage of time during a set wind speed.
- Design a winching system on the rover, to raise or lower the balloon and dragchute.
- Design a lightweight dragchute or airfoil, big enough to lift the rover over any obstacle.
- Calculate the aerodynamic loads to estimate its best wind speed performance.
- Choose balloon structures, inflation method, and type of lifting medium for the mission.
- Choose support equipment, solar cells, rover generator, batteries and rover add-ons.

MARTIAN WIND SPEEDS ON THE SURFACE AND PROJECTED ABOVE THE BOUNDARY LAYER

The power generated by the wind is much stronger above its boundary layer. To get the potential 100 % wind speed on Mars, you must go above the boundary layer, which is dependent on the surface coefficient of friction, its thermal boundary layer and other factors. The wind speeds as measured on the surface of Mars at Viking 1 and Pathfinder sites varied over a course of one

day. At these two sites, on the surface the wind varied from below 1 m/s to sometimes over 10 m/s during the Martian day. The Pathfinder's average wind speed was 5 m/s over the course of 20 sols. Viking 1 site was a relatively level area and had the best long-term data. Wind speed data gathered over 200 sols at Viking 1 varied from under 1 m/s to 16.4 m/s. The wind speed was measured from a 1.3 m tall mast; this is fairly close to the surface. The instruments measured wind speeds at least once during the Martian day, at 5 m/s or higher in 182 sol's of the first 200 sol's Viking 1 was on Mars. The first 15 sols at Viking 1 extrapolated out to an average of 6.7 Martian hours per day of wind speeds in excess of 5 m/s with an average of 2.2 hours with wind speeds in excess of 7.5 m/s. Note: at Viking 1 site it was 2-7 m/s (summer), 5-10 m/s (fall).

Above the boundary layer of the Martian surface is where the unhindered wind energy would be the strongest. As verified by the Viking 1 and Pathfinder data, the boundary layers can be modeled after Earth's with some correction factors factored in. However, Mars thin CO₂ atmosphere is different than earth's resulting in a thermal boundary layer that is somewhat different because of the absence of a substantial atmosphere. [1]

On Earth, the maximum wind speed would vary from 300 m above a level area, 400 m above suburbs, to 550 m above an urban area with 200 m tall buildings. [2] In urban areas, a 5m/s wind speed 3 m above the surface would extrapolate out to be over 25m/s at 550 m above to where the boundary layer ends. In a suburb, a 5 m/s surface wind speed would be over 15 m/s at 400 m height. In a level area such as an ocean or flat unobstructed land, a 5 m/s surface wind speed would be over 10 m/s at 300 m height. Note the Pathfinder and the Viking 1 data was taken at the top of their 1.1 to 1.3 m masts. Because of the Martian gravitational field, 0.38 of Earth's, the boundary layer is thought to be proportionally higher on Mars than on Earth and can be scaled universally using dimensionless coefficient [1]. There are some very complicated formulas used to give a more exacting estimate on what the wind speed variation will be with height, under different conditions, terrestrially. [3] However, there isn't enough solid data to predict with certainty what the wind speed would be on Mars at a given elevation. There also is a tradeoff for going above the boundary layer and that is the density of the wind changes. We may elect to install on the balloon's tether-line an instrument that will be able to fish for the right elevation mechanically for the proper wind speed and density for the maximum load on the dragchute and balloon.

The Viking 1 site would mostly resemble a level ground area, where the wind surface friction is similar to a level ground area on Earth. At the Pathfinder site, the data was gathered in a wind-sheltered area more susceptible to sloping winds, with the Pathfinder lodged at the bottom of a ravine, making it somewhat similar to a suburb area. As a result, at the Viking 1 site if we adjust for the height of the Martian boundary layer we would have a Earth'-like height of 300 m over flat land. During the day the wind speed would be over 10 m/s at an average of 6.7 hours per day. This is most prevalent during seasonal changes. As a result, a balloon and dragchute combination can be raised to a level above the Martian boundary layer by a winch on the rover, or on the tether line, thereby finding the right elevation for the maximum wind speed to power its mission. Theoretically, if the rover moved 1/2 the speed of the 10 m/s wind for an average 6.7 hours per Martian day in a three week period, then the rover would have traveled over the Martian surface more than 1,500 miles, 2400 kilometers, within a three week period.

MARTIAN WIND LOADS AND POWER

The main law governing wind power is that the power from the wind is proportional to the cube of the wind speed. If the wind speed doubles, the power increases by a factor of eight. An increase in wind speed from 9 to 10 MPH will mean a 33 % increase in the power of the wind. [2].

The density of the Martian air at the Datum is $2.0E-5$ slugs/cu ft. at -25 f and is approximately 1 percent of what it is on Earth. Earth's air density is .00237 slugs/cu ft at sea level at 58 f. As a result, the difference between the Martian and Earth's air density and the power produced from the wind is much less on Mars than it is on Earth. Using

$$P = 1/2 C_d pAV^3$$

for the dragchute and the balloon where P = power, C_d = Coefficient of drag, p = density of the air, A = surface area, and V = velocity. [3] For a charted wind speed analysis of the load on different parts of the Windsurfer we can use

$$F = P/V$$

Calculated Loads on the Balloon, Dragchute, and Sail at Different Martian Wind Speeds at the Martian Datum

[Figure 1] Calculations on the dragchute and sail and $C_d = 0.5$ on a spherical balloon from the wind exposed surface area of the balloon only. Actual C_d may be higher depending on the reynolds number. As the reynolds number decreases with altitude, the C_d increases on a spherical object.

A 50 ft diameter dragchute and 50 ft diameter balloon have the same loads even though the balloon was calculated with a 0.5 C_d and only the surface area exposed was used. The dragchute in order to take advantage of a low-speed wind will need to have a continuous canopy opening to maximize the load of the wind on the dragchute. A lightweight plastic ring embedded into the dragchute opening with a minimum bending moment that will deploy upon accent into the lower atmosphere will assure the opening of the dragchute's canopy will maintain a large enough exposed surface area when activated by the force of the wind. The balloon calculations were conservative because the C_d is higher than 0.5 due to deformation by the dynamic wind pressure loads on the balloons and the lower reynolds number. To verify this, we would have to conduct wind tunnel tests with smaller scale models, in a Mars like environment. A dragchute on Mars needs to generate 37 % of the lift that would be required on Earth because of the Martian 0.37 gravitational field as compared to Earth's. This means that it can lift 2.63 more mass on Mars than an equivalent lifting force on Earth because of the difference in the gravitational fields.

The resultant directional vector forces that are acting on the entire system are dependent on how far off of vertical the system gets relative to the rover. Note the lift from the dragchute helps prevent the wind from moving the balloon too far ahead of the rover, closer to the ground.

Can a balloon or Montgolfiere pull a rover on Mars with the help of a lifting device? In order to answer that question, we need to know how much of a load would be generated on the balloon or lifting device from the wind. We extrapolate out the amount of mass that would be needed using the formulas on Table 1 and the resultant load generated on them from the wind (Figure 1), using terrestrial data to come to a conclusion.

MASS OF THE MATERIALS OF THE PARTS SUPPORTED BY THE LIFTING GAS

[Table 1]

By using a 4189 cu m balloon, 20 m diameter balloon if spherical, the gross amount of mass lifted by the helium gas would be 37 Kg, at the Martian datum. Subtracting the resultant load on the balloon and tethered instruments on a 20.0 Kg rover will result in a remainder of 17.1 Kg mass of the rover lifted by the lifting gas. $[37\text{Kg} - (11.5 \text{ KG balloon mass} + 1.0 \text{ Kg solar cell mass} + 1.0 \text{ Kg Camera mass} + 1.5 \text{ Kg antennas mass} + 3.4 \text{ KG dragchute mass} + 1.5 \text{ Kg canopy ring mass})] = 17.1 \text{ Kg}$ remaining lifting force on rover. This would leave the amount of mass needed to go airborne left from the 20.0 Kg rover at 2.9 Kg. Its important to note the further away the balloon and dragchute are from their vertical position, directly above the rover you get the more of a load on the dragchute needed to lift the rovers remaining mass. However, the dynamic pressure of the wind on the balloon at this angle adds more lift. Helium lifting gas, 0.18 Kg/m^3 , has mass and was factored into the formula when calculating the amount of lifting force available. It will be factored in when calculating amount of force needed to move the system.

As charted above, a Martian 9 m/s (20 mph)-wind speed on the balloon and dragchute is enough to make the rover go airborne if there is a minimal amount of rover mass to lift. The load on the balloon from a 9 m/s wind would move the 4189 cu m balloon far enough off of its vertical position above the rover to activate the dragchute, which would add more of a lifting and lateral force to the system when activated. Remember by extrapolating the data out, there is at least 6.7 Martian hours a day in the first 15 sol's of winds at the Viking 1 Landers site in excess of 10 m/s that is above the boundary layer. [Figure 2]

We need to do wind tunnel test under a Martian-like environment to confirm this on reduce-size models of the items stated above to correctly verify our model. Lifting more of the rovers mass on the surface will remove most all the frictional forces, so the rover moves more easily as it is pushed by the winds constant pressure on the balloon and dragchute. [Figure 3]The directional vectors changes as the system moves with the wind. As a result, the 20.0 Kg rover pulled by the 4189 cu m balloon listed above should move over most surfaces and obstacles in a Martian 9 m/s wind at the Martian datum if the dragchute is activated. The force of the wind will drive the balloon more off vertical relative to the rover, but as the rover moves freely across the surface the balloon and dragchute tethered line moves back more to its vertical position relative to the rover, as demonstrated in tests. One of the main reasons this all can be possible in such a thin Martian atmosphere is because everything has to be relative. On Mars, the balloon has to be much larger than it is on Earth; therefore, its larger surface area is exposed to more of the dynamic pressure of the wind, resulting in more of a load extracted out of the increased size of the balloon.

Test Results

We used a two-wheeled, self-righting, chariot-style rover in our test. Because of its freedom of movement by having only two wheels the rover can turn any direction without putting much resistance on the system. A 1-meter diameter latex balloon filled full of helium gas with a lifting force of 6 ounces in a 5.1 m/s wind was used to lift a 20-ounce rover over all kinds of obstacles, even straight up and over a 90-degree barrier. The balloon had help lifting the 20-ounce rover over these obstacles from a 1.2-m diameter dragchute that weighs 2-ounce. Because of the curvature of the dragchute, the actual surface area affected by the wind was less than 1 m diameter. As the wind speed opened the dragchute, it provided much more lift to the system, helping the balloon and dragchute to work together to move the rover on the ground over obstacles. The resulting pull on the tethered line from the balloon drag chute combination was 4 ounces on the rover from the lifting gas alone, in a static position. Therefore, the dynamic wind pressure added over 16 ounces of pulling force to the system to lift the rover over these obstacles. We took QuickTime movies of the Windsurfer prototype in action.

In a 5.1 m wind, the actual calculated load on the balloon was 2.66 pounds and on the dragchute was 2.26 pounds. We used the Earth's air density of .00233 slugs/cu ft, the temperature was 55 F at the time of test, at 700 ft above sea level. The balloon first moved relative to the rover by the force of the wind before the rover moved. By doing this, the angle of the tether line relative to the rover increased enough to use the force of the wind to activate the dragchute. Although the balloon movement, because of being spherical, wouldn't change its load factor, the dragchute in our test was only activated when the speed of the wind was strong enough to move the balloon lower towards the surface.

[Image 4]The stronger the wind, the more likely the entire system may momentarily go airborne. As the rover moves airborne in a strong wind, the closer to the speed of the wind it gets, the more the dynamic wind pressure on the balloon and dragchute are reduced, because there is nothing holding the system back from moving. The rover will glide to the ground as it approaches the speed of the wind. When the rover provides resistance to its forward motion by tugging on the balloon and dragchute again, then it will go airborne temporarily, as the wind energy increases from the drag induce force on the dragchute. This Windhopping effect was demonstrated in tests, in gusts and high winds.

The 45-degree angle of the tether line relative to the surface seems to be the equalizing angle in our test so far. The vectored pull and the lifting force on the rover from the Windsurfer is equal at 45 degrees, although the dragchute has less of a full load because it is at an angle relative to the wind direction. When the rover moved freely, the balloon and dragchute moved back to its vertical orientation relative to the rover, which caused the dragchute to close up. Once the rover got close to the speed of the wind the dragchute and balloon was almost directly above the rover as it moved over a flat low friction area deactivating the dragchute.

The first outside test was in a 6m/s wind and was on level ground with some small rocks without the dragchute attached. The rover in the test moved over more ground in 11 seconds than the

Sojourner rover did the whole time on Mars. [Image 5] In the next test we used a Windsurfing sail in a field of grass. It worked well enough to do more tests on, then we tried other ideas.

We later tried it out when there was a low breeze by constructed a rectangular jibe sail out of thin mylar, using it to pull a rover in a 2.1 m/s (5mph) wind. The rover speed was 1 m/s while moving across a flat dirt and gravel surface. The more sail surface area exposed to the wind, the more force was generated on the rover to make it move on the surface. [Image 6] In a low wind speed, this effect would work well to generate enough horizontal force on the rover if we used the maximum lift on the rover from the balloon without making the rover go airborne. The balloon tried to stay vertical above the rover because there was less of a load on the balloon than the jibe sail from the wind; this made the tether line more rigid. Therefore, the lifting load of the balloon will make the balloon more like an anchor in the sky, to help translate most of the lateral load on the tether from the force of the wind on the jibe sail to pull the rover. This works the best when the rectangular sail is 2/3 the distance down the tether line from the balloon.

The jibe sail will help lift the rover up and over obstacles if the total load on the sail from the wind exceeds the total amount of remaining mass not lifted by the balloons lifting medium on the rover. This type of system would work in very minimal wind speeds that wouldn't be strong enough to activate the dragchute. [Image 7] The sail may have remote control setting, like a window shade, that rolls up the jibe sail in high winds and lowers it in low winds. As a result, in a low wind speed, the speed of the rover on the surface would be reduced to about the same speed as a human's brisk walk if we use a jibe sail on Mars.

After testing other types of lifting devices out, with a balloon lifting them into the air, including a light weight helicopter rotary devise, we decided to do the ultimate test of moving the rover up a steep, boulder, covered hill with a dragchute attached. The chariot-style self-correcting rover moved up the hill with the help from the balloon and dragchute combination providing lift. It easily scaled all the rocky barriers in its path. It did this many times.

One of the QuickTime movies, while the rover was climbing the rocky hill revealed something we weren't expecting. This unexpected surprise was that the dragchute opened and closed as it pulled away from us. It looked like an octopus swimming in the sea. It did this because of the resistance and nonresistance of the rover and balloon pulling on it from different directions. When the rover ran into resistance, the dragchute opened to pull the rover over the obstacle; when the rover was moving relative to the balloon and dragchute, the dragchute had little resistance from its forward motion and it closed up from the pull on it from the balloon. [Image 8] To prevent the rover from getting away from us, we had the balloon tethered at the other end to a fishing pole spectra 80-pound test line to reel it back. We learned our lesson earlier when our 8-pound test fishing line broke from the force of a strong wind gust on the dragchute and the whole system momentarily went airborne.

A previous balloon proposal by the Jacques Blamont of the French Space Agency (CNES) proposed using a solar heated balloon in 1987, or Montgolfiere, to be flown on Mars with a snake like extension on it. He suggested the snake like rope to move from the air in the daytime to the surface at night, because of the change in the temperature of the balloon, therefore maintaining the Montgolfiere buoyancy. (7)

Another idea on using a balloon, gondola with a airfoil to direct the path of the balloon was proposed by Global Aerospace Corporation, November 5th of 2002 while we were in the testing phase of the Windsurfer. (8)

The Windsurfer is different than the above-proposed ideas in several different ways. The advantages of having a robotic rover on the surface to explore simultaneously with a balloon in the air above will keep the balloon close to the surface. In one of the Windsurfer modes, it will move over unforeseen barriers by having a tethered attached dragchute or airfoil, to help provide lift on the rover to get it over the obstacles. The rover on the surface will direct the Windsurfer movements in the direction of the wind to a desired location. There are several other methods we mention later on including wind hopping, windsailing, electrical generation and the yo-yo affect by jumping from one place to another, that wasn't covered by these cited proposals.

Future Tests

After doing some initial tests' with the rover in different situations, we would like to turn this loose in an environment on the Earth more closely resembling the Martian terrain. Our next project is to go above the tree line on one of our local mountains in the Pacific Northwest or in a sand dune area in the Arizona desert and let it loose. A valve will meter out the lifting gas from the balloon. By doing this, it will deflate the balloon within a set time so we can retrieve it after it travels more than a mile. A more robust test with a larger balloon and rover planned for the future, depending on funding, is planned to take place in the arctic, where there are no trees or brush. We would use a larger polyethylene balloon with a more robust rover and instruments as charted above, including a GPS guidance equipment attached that would help maneuver it and let it go for tens of miles.

A more adventuresome trial may incorporate using a hot air balloon or a helium balloon large enough to lift a passenger, by having a person riding in the gondola tethered to a surface rover moving below them. The person in the gondola would drive the rover remotely from his perch above, whereas they can conduct other test while suspended in the air. One of those tests may be to release a dragchute to help pull the rover over obstacles over the Martian-like surface while the pressure from the force of the wind pushes the Montgolfiere. A jibe sail and a windsurfing sail can later be tested for the best method to extract the most energy out of the wind. Note the rover, by providing resistance on the surface to the movement of the Montgolfiere to travel the same speed as the wind, will reduce its speed enough to insure a sufficient wind speed for an airfoil, dragchute or sail to provide lift when needed.

Titan

[Image 9] This would work especially well on Titan, even in a 3m/s wind, because of its thick cold dense atmosphere, about two to four times the density of Earth's. At 2 atm a 14 cu m, 3 m diameter if spherical, balloon on Titan would have about the same lifting force as a 4100 cu m, 20 m if spherical, balloon on Mars. Because solar cells wouldn't work on Titan, the movement of the rover wheels over its surface can generate electricity, like a bike generator does to a bicycle by the radial movement of the wheels over the surface. However, there will be a lot of times the

rover will be in the air because of the weak gravitational field on Titan. In this case, for Titan, the rover can have much more mass to lifting ratio than would be needed on Mars. The dragchute can be smaller and pull a much heavier load. As shown in the test above, on Titan, the rover could weigh 5 times more than the resultant lifting force on it from the balloon, a similar ratio to our terrestrial test. If the dragchute was scaled to 6.2 m diameter, to compensate for the extra load it needs to pull, then it is conceivable to have a 14 cu m balloon pull a 100 Kg rover in a 5m/s wind on Titan with the help from the dragchute.

Two other methods may be employed on Titan to generate electricity. One of those methods is to drag a turbine through the ocean of methane if one is found there to generate electricity. Imagine how much power can be generated by using high temperature superconductors on the generator that is naturally cooled by the ocean of methane. However, the liquid hydrocarbons may be too dense to do this.

Another method of generating electricity on Titan is to use two counter rotating Darrieus eggbeater type vertical axis wind chargers on the tether line with superconductors, cooled naturally by the extreme cold, to generate electricity. [Image 10] The generator would be in between the two counter-rotating wind-chargers blades. With two 5.5 m diameter counter-rotating Darrieus type wind-chargers, if they can be made to fold out using light weight material and the wind speeds are sufficient, each would generate an average of 16 kW of electricity for a total of 32 kW. With the more mass you add to the tether line, the larger volume of gas you will need. That much power on Titan would light up a very large area and provide extra electrical needs for drilling and other research goals.

There needs to be artificial lighting to see more of the surface of Titan because its distance from the sun, Solar Cells are out of the question. The electric generators would provide the power for most if not all the lighting. As a result, the backup power supplied by the wind or turbine driven generator will assure an alternate energy supply to augment the RTG's while help charging the batteries. By using extra electrical generating techniques we will gain a much better view of Titans geological wonders if we illuminate the surface.

Venus

Imagine moving freely over the surface of Venus and removing all the guesswork of trying to see through its thick atmosphere. On Venus you would need a different approach than Mars and Titan. The approach that seems the most logical is for the balloon and dragchute to be made out of a rigid structure made out of titanium or another heat resistance material to make it buoyant, to take the 462°C, 864°F Temperature, and 96 atm's. The rigid, submersible-like balloon may first descend opened to the atmosphere and as it gets close to the ground, it closes. This would create less pressure inside of the vessel than outside making it buoyant. A pressurizing generator and exhaust valves may be attached to regulate the inside pressure to keep it buoyant. A cooling system may be employed.

There have been two launches of balloons in the upper atmosphere of Venus in the nineteen-eighties that were successfully launched from the Vega spacecraft. Its success story was the brainchild of Jacques Blamont of France and culminated by the international team of the French,

former Soviet Union, and American scientists. Although this was the first insertion of a balloon into another planet's atmosphere, there have been many launched into Earth's upper atmosphere at the start of the American and former Soviet Union's space race. Echo 1 and Echo 2, launched by NASA, were the first balloons that were successfully placed in orbit around the Earth in the early nineteen-sixties.

The Russian Venera Landers, after landing on Venus, recorded relatively calm wind speeds close to the surface below at 1 m/s. However, they showed how some fine grain regolith was disturbed after landing and was removed by the currents within the eight hours of transmission. There are some very high winds above the boundary layer on Venus. Even in these calm winds by the surface, the atmosphere is more fluid, more like ocean currents, and there is a lot of force in the wind movement. In this case the entire system would have to be close to the surface. This may be where the rover on wheels may be able to move freely over the surface without the help of a dragchute, just by the way the rover and buoyant device is designed. The buoyant device may have vertical and horizontal stabilizers to provide lift to direct the rover's movement on the surface. Venera Landers instruments recorded sunlight penetrating to the surface on Venus as similar to a cloudy day on Earth, making robust solar cells possible.

Entry into the Martian Atmosphere

[Image 11] Entry into the Martian atmosphere can be accomplished several different ways. One way is to use a Russian designed inflatable re-entry vehicle, the IRDT, to help slow the payload down on descent. After it is through the upper atmosphere, the remainder of the IRDT inflates and the main parachute then opens. After slowing the system down more while descending, the main parachute is ejected when the speed of descent has been reduced enough to allow the Windsurfer drag chute to open. On top of the dragchute is the balloon and the medium used to inflate it, which now rapidly inflates as it descends through the Martian lower atmosphere. Once the IRDT inflatable hits the ground as illustrated, the rover is ejected out of it and starts its mission on the Martian surface. We illustrated using this method as one of the best means to streamline the cost of the mission [Image 12] We may use the main drag chute until the balloon is fully inflated, then eject it before the rover hits the surface. Because of the reduced mass in a micro ballooning method needed to land on Mars, one spacecraft may send three or more wind-riding rovers to the Martian surface. Its important to note that NASA is developing simple lightweight inflation and deployment methods for some of their space missions. [9]

Another way to ensure a successful mission, but will end up costing more, is by doing the pathfinder bounce on airbags when it hits the surface This method would allow a more timely inflation of the balloon after it lands.

In places like the bottom of Hellas Planitia, the air density is twice that of the Martian Datum and the wind energy is so strong on potential descending probes to prevent NASA from considering sending a space probe to the bottom of the 1500-mile diameter crater. The floor of Hellas is more than 5 miles below the top of the cratered plains and over three miles below the Martian datum. [4] The last Martian global dust storm started at Hellas. This would be the best place to send the first balloon, dragchute and rover to explore.

The Many Different Benefits of a Balloon, Tethered Rover Configuration on Mars

- The rover can let out the tether line to the balloon and dragchute, allowing it to ascend to a higher elevation above the wind-sheltered areas to catch the wind. If the Windsurfer needs to get out of the high-speed wind and do some exploring, it can reel the line in to bring the balloon and dragchute down to a lower level in a wind-sheltered area while tugging the balloon and dragchute along with it.
- The balloon can be made to detach from the rover with some of the instruments on the rover to freely float above the surface to conduct high altitude experiments with the help of tethered solar panels. It can do this by securing the rover in its proper exploration location, or if the rover is disabled on the surface.
- If targeted for a landing area down wind of an exploration site, it could use the wind to get to this site by using the rover, like a rudder on a boat to guide it to its destination upwind. [Image 13]
- A large balloon of 50 m diameter or larger with a dragchute combination attached can insert on Mars a sample return mission that will return Martian samples back to earth. With this combination, a relatively heavy payload can be successfully installed on the surface. A heavier mass return vehicle can take advantage of adding Pathfinder type airbags to cushion its fall if more mass and fuel is needed for the return trip back to Earth. This will allow more of a larger Martian sample to be returned back to Earth. The cost would be drastically lower for a sample return using a balloon, dragchute, and bounce method than from other means to do this. A small 1/2 the mass Sojourner type rover can collect and install the sample and place it into the returning capsules payload bay for the trip back home.
- Having a sensor remotely raising or lowering the sails or opening or closing the dragchute while exploring Mars will enhance the mission. Anemometers can be place on the tether-line at different heights. An added benefit of having Anemometers on the tether-line is that data can be transmitted back to Earth for modeling the Martian boundary layers and other atmospheric disturbances for future explorers. You get a better idea of the atmospheric conditions from placing sensors farther up into the atmosphere than just 1.1 meters on top of the mast of a Lander stuck at the bottom of a ravine, like the height of Pathfinder's mast.
- The rover can be programmed to steer the Windsurfer like a rudder on a boat in the direction of the wind. A rover can generate hundreds of watts of power from the work its wheels do on the surface resisting its forward movement, if the wind is strong enough and the surface mass is increased more from the example above. Larger designed system would extract more energy out of the system resulting in larger electrical output. [Image 14]
- In larger systems, some smaller rovers and probes can be stored inside the crash protected self-righting surface-rover or be stored high up the tether away from a potential crash site of the surface rover. When the surface rover finds a place to explore, the smaller rovers and probes from high above the rover would be tethered down to the surface below as needed.

- By having a dragchute attached to the tether, anytime there is a problem in a free fall state such as when the rover goes over a cliff, the dragchute would be activated to help break its fall. Having a maximum speed at which the rover would fall by the constant pull on the rover by the balloon and dragchute would help the rover transverse most places on Mars without fear of damaging the instruments. The dragchute acting like a parachute in a free fall state will stop the acceleration downward movement of the rover so it would maintain a constant speed. The surface rover's protective shell will be made to take impact speeds 10 m/s or more. [Image 15]
- Use other types of mechanical lifting forces, such as an attached rotary type device with the axis parallel to the tether line. It will use the energy from the solar cells for the rotor's electrical needs to lift the rover up in place of the dragchute. [Figure 4] Another method may be to use a long, lightweight airfoil tethered below the balloon to provide lift in lieu of a dragchute. Use a light mass inverted sail similar to a racing cup sails inverted and autonomously controlled extended from a cylindrical balloon, making it look like an upside down sail boat.
- Future Windsurfers may use the low coefficient of drag of a cylindrical or dirigible shaped object made to slice through the wind. A large inverted lightweight windsurfing sail gyroscopically controlled may be able to steer the system by tacking into the wind if the coefficient of drag is sufficiently low enough on the balloon, therefore moving freely in any direction. By having the added luxury of tacking into the wind, the Windsurfer would have more control.
- It's important to note that by having the shape of the canopy of the dragchute permanently opened, with a flexible ring around the opening it will provide lift vertically by the wind blowing over its surface area, similar to a Frisbee. Another choice may be a kite shaped airfoil that may be tethered to the balloon below, as a way to provide added lift.
- Since there is more lifting force from the lifting gas than there is mass on the rover in the example above, a quick tug, either spring loaded, counter balanced, or electrically generated on the tether, will pull the rover skywards. This can happen by using the impulse momentum of the mass on the tether line from its upward accelerating motion when letting out the tether-line. Terrestrially speaking, when a balloon is first released, it accelerates to its terminal velocity in 5 seconds, with an average rate of ascent of 3.6 m/s for the first 1000 m [3]. It will suddenly stop and rewind its tether-line a maximum amount causing the rover to fly skywards. The rover would then float back down to the surface after winding in the maximum tether line then release the tether line and do it all over again. An added benefit is that the dragchute will be activated the higher up the rover jump which gives it more resistance to the downward pull from the rover. In effect the rover can use this yo-yo effect to hop from place to place if there isn't enough wind to move the rover. [Figure 6] The Yo-yo effect would be most beneficial in heavier mass ratios from the lifting medium to rover mass, larger balloons with more mass on the tether line from instruments such as ULD's, of which is made out of heavier and stronger material.

- Humans may someday explore Mars by riding above the surface rover under the balloon in a lightweight, shock-absorbing, gondola-like pod high above the surface rover. In the pod, the human explorers will steer the surface rover to the destination they wanted to go. By using one of these methods mentioned above with a much larger volume balloon, the human explorers aren't confined to explore only easy-to reach regions of Mars. [Image 16] In the example shown in the rendered picture, after they trim the sail and stop the rover, the explorers would lower the pod down to attach to the top of the surface rover. The rover would drive them, the pod, the balloon, and the lifting device to their final destination. The surface rover will pick up Martian rocks, ballast, prior to the explorers leaving the pod. With the added ballast in the rover after they drop anchor, a surface penetrating device, the explorers are free to leave the pod and walk on the surface to conduct their research without fear of seeing their transportation sailing away from them.

IN CONCLUSION

As shown in the previous pages, there is enough force from the wind that can be used as a mechanism to move a rover on the surface of Mars, Titan or Venus. There have been some other good ideas using other mediums beside helium and hydrogen-lifting gas that can be used to do this. [6] Robert Zubrin and Pioneering Aeronautics proposed one of these new ideas. [4] The Montgolfiere hot air balloon method would work on Mars by using solar energy to heat the medium in the balloon envelope.

Balloons are relatively inexpensive and the journey to Mars will cost much less if one of these cited mediums were used to reduce the traveling mass to Mars. As a result the Windsurfer isn't restricted to use only lifting gas as the medium of choice for the balloon.

Another method involves using a combination ULD balloon with a solar heated balloon, the smaller sized ULD balloon would keep the solar heated balloon material suspended in the air at night, the solar balloon gets refilled with warm air during the day, to help add lift to the system. By using a combination ballooning system with a ULD balloon as an anchor would help guarantee a longer exploration time and reduce the risk of having to inflate a supper sized ULD balloon on descent.

By tethering a rover to the balloon we increase our data gathering twofold. It would help remove the guesswork from just exploring the Martian surface from above, while providing more robust data collection from the surface below. It will assure that the balloon will be at a specified distance above the Martian terrain, not in an uncontrolled, altitude-changing, chaotic movement above the Martian landscape. The rover would move over the Martian surface with the help of the balloon and dragchute tethered above capturing the wind, or by hopping from place to place.

By the time humans' land on Mars in the next couple of decades, a new inexpensive tool for them to use to explore it with will already have helped pick the best landing spot. This new method of exploring Mars will utilize an age-old natural resource, the wind, to help the pioneer's journey beyond their campsite. This new approach is much like what our forefathers and mothers used so long ago when they depended on the wind to sail across the ocean of space to a New World.

**"Greatness is not in where we stand, but in what direction we are moving. We must sail sometimes with the wind and sometimes against it, but sail we must, and not lie at anchor."
Oliver Wendell Holmes**

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Tables, Figures and Images

Part	Mass Kg	Terrestrial Weight lb.	Material
65,450 cu m Balloon, 50 m diameter, if spherical.	500.0	1102.5	ULD balloon material < 60g/m ² mass
65,450 cu m Balloon, 50 m diameter, if spherical.	68.8	151.7	0.2 mil Polyethylene glued to 0.1mil mylar < 8g/m ² mass with Spectra netting
4189 cu m Balloon, 20 m diameter, if spherical.	11.5	25.4	0.2 mil Polyethylene glued to 0.1mil mylar < 8g/m ² mass with Spectra netting
15.38 m (50ft) exposed canopy of dragchute	3.4	7.6	0.2 mil Polyethylene glued to 0.1mil mylar < 8g/m ² mass with Spectra netting
15.38 m (50ft) plastic ring around canopy	1.5	3.3	Plastic ring with minimum bending moment to maintain a 15.38 m opening of dragchute
30.77 m (100ft) exposed canopy of dragchute	12.2	26.8	0.2 mil Polyethylene glued to 0.1mil mylar < 8g/m ² mass with Spectra netting
18.46 X 30.77 m rectangular Sail	4.6	10.1	0.2 mil Polyethylene glued to 0.1mil mylar < 8g/m ² mass with Spectra netting
Solar cells	1.0	2.2	Sojourner solar cell 3 X .340 KG @16.5 Watts = 49.5 watts peek (1.1 m ² area)
Camera	1.0	2.2	Used on tether line from above for scouting and surveying.
Instruments	1.5	3.3	High gain and low gain antennas (If it can be miniaturized with this low mass)

Table 1

Table 1 is estimates only of the many different types of material and instruments that are available for Martian balloons. There are parachutes made today with a maximum canopy of 154-ft diameter used for balloon, payload retrieval. The gondola mass is calculated from the honeycomb reinforced Solar-cell material and has been added into the mass of the Solar-cells. The zero-pressure balloons are calculated to be pear shaped and the ULD balloon is close approximation of a pumpkin shape balloon. Actual mass will vary depending on the shape, therefore this is the minimum mass that will be used. The boom and mask wasn't included in the projected mass of the sail; a mask may not be necessary because the tether line acts as a rigid part of the system the more the lifting force from the balloon is acting on it. A strong Spectra line may replace the mast. Spectra tether line mass is added to the rover mass and its mass is very minimal unless the intention of the mission is to have the balloon deployed hundreds of meters into the air.

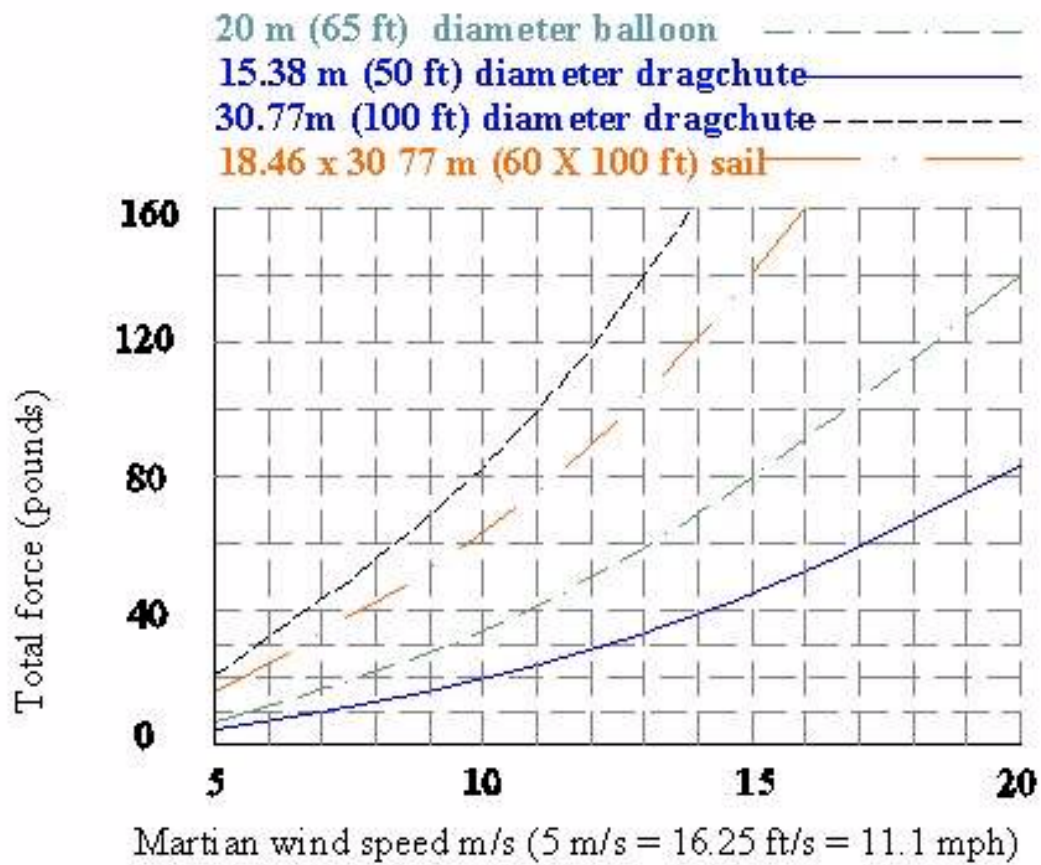


Figure 1

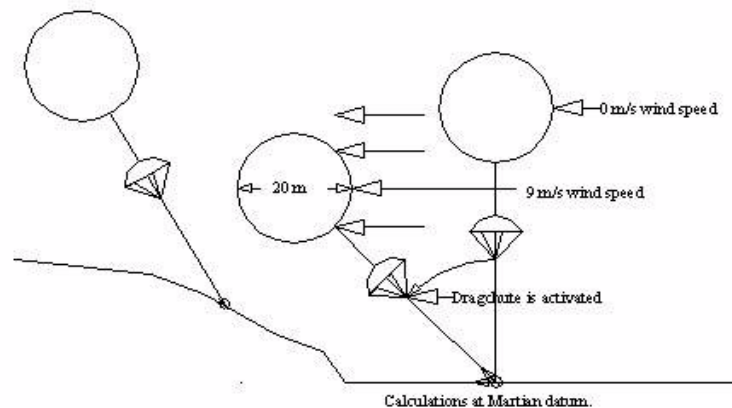


Figure 2

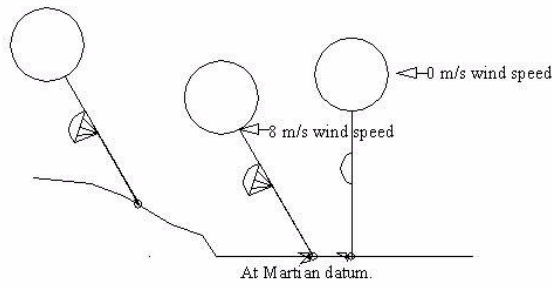
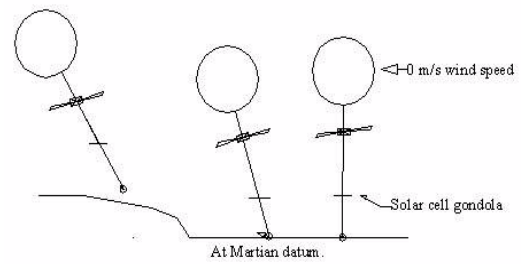


Figure 3



Electrically driven rotary device

Figure 4

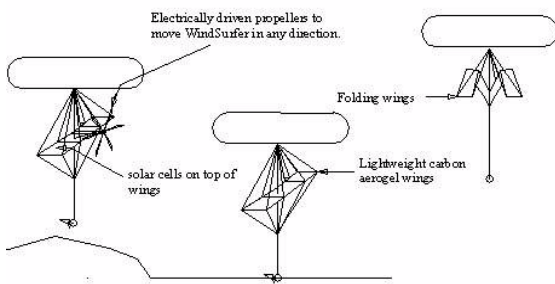


Figure 5

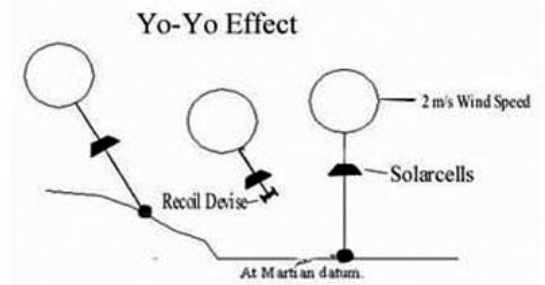
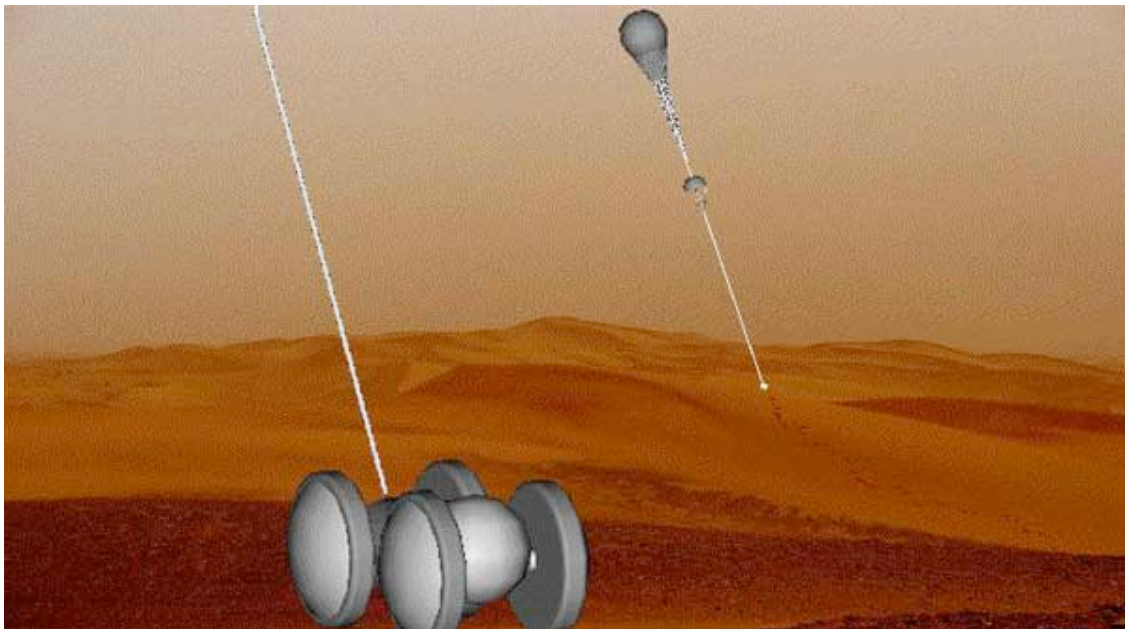


Figure 6

Images



Top of front page



Image 1



Image 2



Image 3



Image 4



Image 5



Image 6



Image 7



Image 8



Image 9

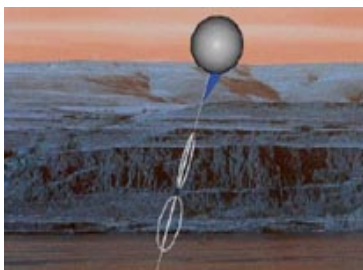


Image 10

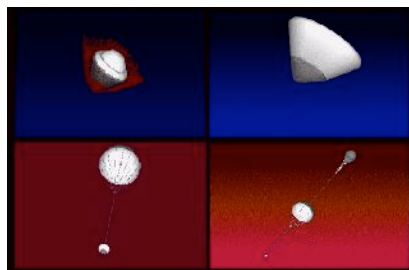


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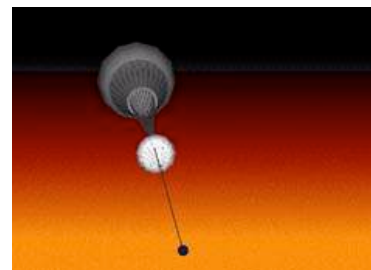


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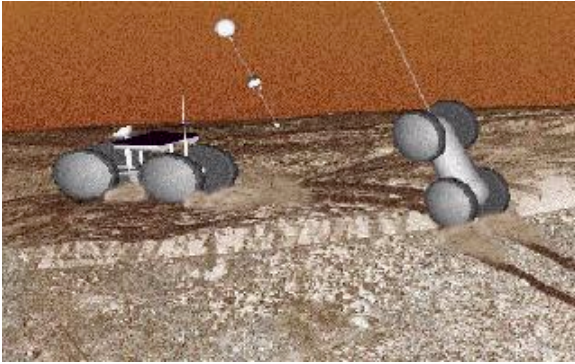


Image 13

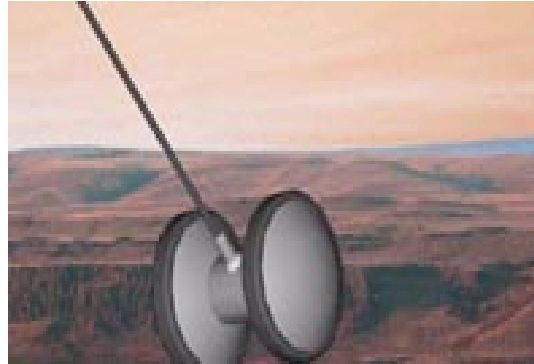


Image 14

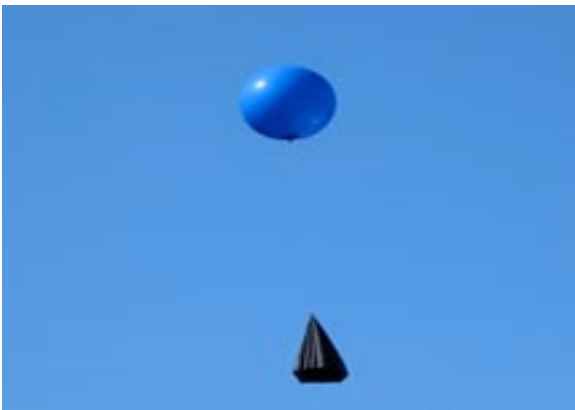


Image 15



Image 16

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