Multi-Segment Zeppelin-Aided Robotic Rover For Ground-based and Atmospheric Exploration. Tarek El-Gaaly, Brian McMahan and Ali El Qursh, Rutgers University - tgaaly@cs.rutgers.edu, brian.mcmahan@rutgers.edu, elqursh@cs.rutgers.edu

Introduction: Current Mars exploration is limited in range and its capacity for in-situ resource utilization. The rovers currently on Mars have covered a very limited region of the planet. Opportunity, the survivor of the Mars Exploration Rovers [1], has covered a distance of approximately 34km as of November 2011 (~8 years of activity – limited by Martian winters). For this reason, there is a need for an exploratory vehicle that can cover longer distances in shorter time. This will allow the vehicle to transmit valuable information, not just from local vicinities around a landing site, but all across the planet. In addition, a vehicle capable of airborne travel can provide altitude-specific information about the largely unstudied atmosphere/weather systems of Martian summers and winters [5]. In order to do robust and long-lasting exploration, the vehicle must be adapted to the thin atmosphere (*i.e.* aerodynamically unfriendly), harsh and variable climate of Mars. In-situ resource utilization is also key to keep the vehicle active for a long duration.

In this extended abstract we propose a multi-segment zeppelin design (depicted in fig1) for such an exploratory vehicle that is able to lift-off and utilize the wind to move faster and farther. Our design also enables altitude control to sample/study the atmosphere and weather conditions at various altitudes and locations.

System Design:

We propose a multi-segment zeppelin-aided vehicle to explore the red planet. The zeppelin segments (a.k.a blimp) are filled with a gas less dense than the surrounding atmosphere and thus provides lift for the robotic rover.

Mars's atmosphere consists of 95% carbon dioxide and its gravity is 38% that of Earth [2,3]. These two factors encourage our design to utilize oxygen or methane to provide lift. Liquid methanol is also a possibility for solar balloons [6]. A multi-segment zeppelin can carry a large payload on the gravity-deficient Mars allowing the possibility to navigate and explore vast regions of the planet.

Our zeppelin is not a conventional one; it is a multi-segment zeppelin consisting of a column of inflated segments (fig 1). This offers two main advantages over traditional designs. Firstly, a multi-segment zeppelin offers flexibility in deployment and withdrawing as each segment can be made physically foldable and, one by one, drawn in to the hull of the rover (*i.e.* payload vehicle of the zeppelin system) and deflated simultaneously. The foldable segments can then be stowed away in a storage compartment in the rover's hull to be deployed again at a later time when needed. All the segments can be deflated and withdrawn once the rover has touched down on the surface. The rover then becomes a robotic land-based vehicle that can explore without being hindered by the zeppelin segments' lift and wind drag. Secondly, the altitude can be controlled by deploying varying numbers of segments. The more the inflated segments deployed, the higher the rover can soar. This offers many additional advantages, for example, sampling/studying the atmosphere from different altitudes, birds' eye observation at different heights of the terrain below, flying over high Martian mountain ranges, riding different weather systems at different altitudes…etc. When the rover wants to land, or is forced to land in low temperatures during Martian nights, at a certain site it will start withdrawing the gas from the zeppelin segments into a compressed canister in the hull one at a time, slow enough to ensure a soft touchdown. Altitude, wind, pressure and location (relative to any of the satellites currently orbiting Mars) feedback via visual data, altimeters, wind/pressure and location sensors…etc can control this process to allow an accurate take-off, cruise and landing.

We describe the modules required to fulfill the goal of speedy long-distance transportation, in-situ resource utilization and exploration of Mars.

Long-distance/duration Navigation. A multi-segment zeppelin provides the following main contributions:

1. Weather/temperature/pressure adaptability for in-air navigation. Deploying different numbers of segments in-air can provide the right amount of lift under different atmospheric conditions for cruising at different altitudes.
2. Withdrawing the segments prevents wind hindrance on the ground (incase of strong winds and global dust storms that engulf Mars from time to time).

A rudder and panels on either side of the rover provide directional control along 3 out of 6 degrees of freedom: yaw, pitch and roll. The panels are simultaneously solar panels, wind-catchers and ailerons. They can be rotated about the rover's horizontal axis to act like ailerons or rotated about their own axis to act like wind-catchers when the system is airborne) - refer to figure 1 and 2. These instruments of motion control provide a method of navigation by controlling the motion of the rover hull depending on the wind speed/direction. A wind sensor can provide feedback control for this. As wind-catchers, the panels can turn against or with the wind – each side being the opposite of the other to provide more yaw control and hence navigation (fig 2). Figure 1 provides an overall architecture diagram. The lift is provided by the zeppelin segments which also, in addition to the ailerons/wind-catchers, act like sails providing forward thrust by means of the wind.

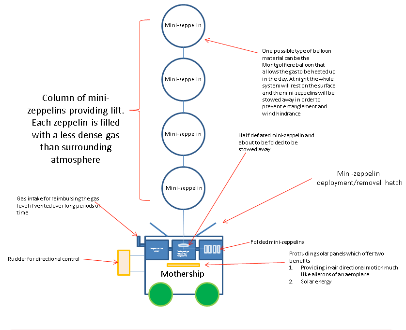

Figure 1: A simple architectural diagram of the system (zoom for details). The mothership here is the rover which can deploy smaller bots

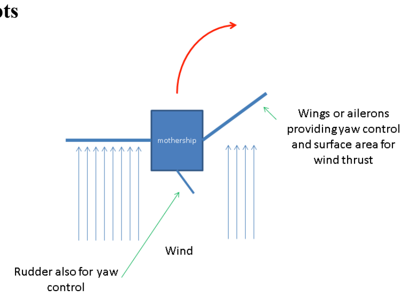

Figure 2: Aileron/solar panels and rudder flight control. The mothership here is the robotic rover that can deploy smaller bots to explore the environment

Zeppelin System Design. There are two possible designs:

- Long-duration Balloons [7]
- Montgolfier Balloons or Solar Bags [6,8]

For buoyancy control, in-situ resource utilization can occur by using methane (available in certain pockets on Mars), surrounding carbon dioxide (gas in the environment which can be heated up by solar energy) to provide lift. Methane can be caught by an intake valve shown in figure 1. Some chemical filteration method can obtain the methane and use it to fill the segments.

Oxygen is a less dense gas than carbon dioxide and possible options for generating oxygen can be: synthetic photosynthesis process, catalytic converter system (chemical process) or biological-systems (*e.g.* plants and bacteria in a self-sustainable bio-dome). More extensive research is needed in order to tackle the problem of producing large quantities of gas over a long duration (*e.g.* 15+ years which is comparable to the expected lifetime of the Plutonium core in Curiosity [3]).

Replacement segments can be attached to the main chord/tether that attaches the column of segments (also supplies gas to the segments) to the hull. This provides maintenance in case a segment ruptures (due to wear and tear). Long life is an important issue for zeppelins or balloons so this must be addressed to create a long lasting exploratory system.

Future Possibilities*:*

A possibility of this design is to perform a high altitude climb to rendezvous with an orbiting craft which can then send small capsules containing a small quantities of soil/rocks back to Earth. The capsules can use ion thrusters [4] with directional control, an aeroshell and parachute for entry and safe landing on Earth. Ion thrusters have their advantages over conventional chemical rockets which make them suitable for this task. Samples have never been sent back to Earth before and thus this will provide invaluable material for science.

Other possibilities consist of the rover dispersing a swarm of pollen bots that have sharp hooks for latching on to rocks and primitively sampling surfaces or analyzing atmospheric patterns and transmitting back information. This process would be done mid-air to ensure a whide dispersal of the bots. On the ground, a hatch in the hull can deploy smaller driller bots that can explore beneath the surface for a limited time before having to return to recharge their batteries.

References:

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