MARS AERIAL AND SUBSURFACE EXPLORATION USING THE 'LArK' (LIGHTER THAN AIR KITE) CONCEPT. Lionel Ernest Edwin[1], Davy Hausser[2], Parth Shah[3] and Pradeep Kumar[4], [1,3,4]North Carolina State University, Department of Mechanical & Aerospace Engineering, Engineering Bldg 3, Campus Box 7910, 911 Oval Drive, Raleigh, NC 27695-7910, [1]ledwin@ncsu.edu, [3]pvshah@ncsu.edu, [4]pkumar3@ncsu.edu [2]Embry-Riddle Aeronautical University, 600 S. Clyde Morris Boulevard, Daytona Beach, FL 32114-3900, [2]hausserd@erau.edu.

Introduction: With the overwhelming success of the twin rovers and now the successful launch of MSL, the red planet Mars has been the focus of planetary exploration for quite a while. The number of unanswered questions about it forces us to develop innovative concepts to explore the planet more efficiently. It is clear that aerial exploration platforms have unparalleled advantages over ground exploration platforms in terms of range, mobility and terrain insensitivity, and it is for this reason that aerial exploration platforms have received a lot of attention recently. There are a variety of proposed aerial exploration configurations in the literature, fixed wing [1], rotorcraft, bio-inspired [2], hoppers and Lighter than air vehicles [3]. The ones that have gotten the notable attention are the ARES [1] and the Entomopter concept [2].

The LArK (lighter than air kite) concept like the acronym suggests is a hybrid between a lighter than air balloon and a kite that can harvest airborne wind energy at higher altitudes on Mars. Although the Martian atmosphere is not ideal for a lighter than air (LTA) vehicle, research suggests that it is possible to have enough buoyancy to carry a scientific payload if the balloon is beyond a minimum size [4]. This large size of LTA concepts for mars is an inherent disadvantage that disqualifies most of them. A novel idea in LArK however turns this disadvantage of size into an advantage by using its large surface area as a kite and thus harvesting a great deal of airborne wind energy for operations.

Driving Science goals: The driving science goals for the design were chosen from the MEPAG goals document [5], specifically goal I that focuses on characterizing the present and past habitability in order to determine if life ever arose on Mars. Research [6] has pointed scientist time and again to lava-tubes as being of prime interest in terms of habitability. Thus the LArK concept is a unique attempt to design an aerial exploration platform that can explore Martian lava-tubes through accessible skylights.

Conceptual vehicle overview: Figure 1 shows the main parts of the *LArK*. The balloon itself is approximately 7000m^3 in volume and is filled with helium. It can keep afloat a mass of about 35kg after subtracting off the volume enclosing fabric which is proposed to be made of 'Turtle-skin fabric' (Vectran+Mylar). The appendages on the sides that look like wings are actually just drag elements whose leading and trailing edges are inflated compartments of pressurized atmospheric CO_2 for structural strength and in between is a single layer of fabric that does not enclose any volume. The angle of attack of the kite is controlled by tethers attached to a bridle or a kite control platform much like a Peter-Lynn type Kite.

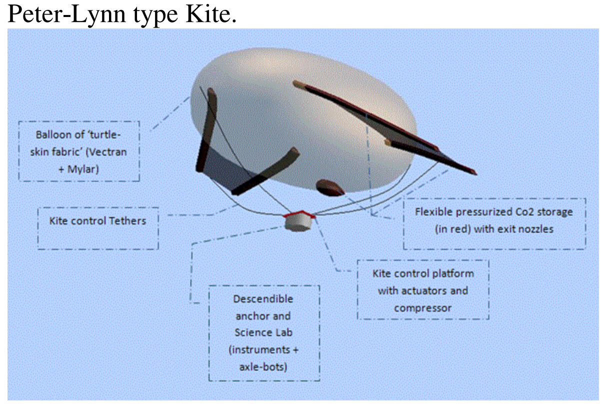

Figure: 1 – 'LArK' high level overview

Attached to the Kite control platform is a descendible module called the science lab that is designed to explore lava tubes by descending into a skylight and deploying axle-bots. The thrust for the vehicle is provided by electrically compressing atmospheric CO_2 and expanding it through nozzles located at different locations on the craft. The storage for this pressurized CO_2 is in a flexible compartment also shown in figure 1.

Concept of operations:

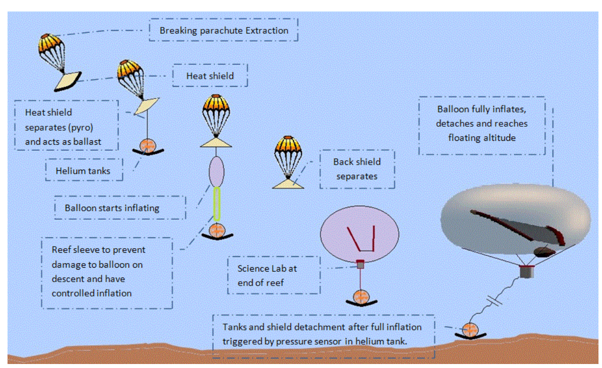

Figure 2: Entry descent and deployment

Entry, Descent and Deployment (EDD): Figure 2 shows the different stages in EDD in the Martian atmosphere. The Tharsis region is chosen as the landing site because of its history of volcanic activity and consequently there being a high probability of the presence of skylights. This region is at average about 5Km above the Martian sea level and current EDL technologies do not allow landing at such high altitudes. Thus EDD technologies were appropriately projected to make it possible to land in this area.

After the braking parachute extraction the heat shield separates and acts as ballast during the rest of the descent. The balloon is packed in a reef sleeve[3] to protect it during descent and achieve controlled inflation. It begins inflating using the helium tanks attached to the back of the heat shield and reaches 90% inflation by the time the heat shield touches the ground, so that at this time it is quite buoyant. Then the rest of inflation takes place with the heat shield on the ground. After full inflation the LArK and heat shield detach, and the LArK rises to reach its floating altitude.

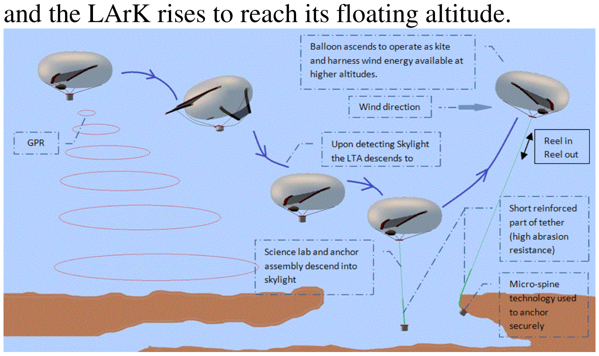

Figure 3: Searching, anchoring and harvesting energy from airborne wind energy.

Searching and Exploring: Once EDD is successfully complete the LArK can operates in two distinct modes: 1) searching mode and 2) exploring mode. These are shown in figures 3 and 4.

In the searching mode, the balloon rises up to its highest floating altitude and uses ground penetrating radar (GPR) and vision systems to look for underground cavities and skylights. Navigating along the underground cavities detected by GPR may lead us towards an accessible skylight. Once an accessible skylight is discovered the LArK descends in altitude and performs an anchoring maneuver. This involves the science lab descending on Carbon Nano-tube (CNT) tethers and an anchor based on micro-spine technology [7] attaching itself to the wall of the skylight. Once this is securely accomplished the LArK ascends back to a higher altitude but this time being tethered to the skylight. Now it can be used as a kite to harness airborne wind energy using David Lang's 'reel-in–reel-out' [8] concept.

In the mean time the science lab descends from the anchoring system onto the floor of the lava-tube and deploys two axle bots, each carrying context cameras, pressure gauges and thermocouples to characterize the atmosphere inside the lava tube. Each bot also has a micro scraper system which allows small samples from deep inside the lava-tube to be brought back to the LIBS (laser induced breakdown spectroscopy) module on the science lab for an analysis of constituent elements. The wheels of the bots also have micro spines [7] which enable climbing vertical walls.

Since every subsystem is retrievable the LArK can perform multiple skylight investigations over its lifetime.

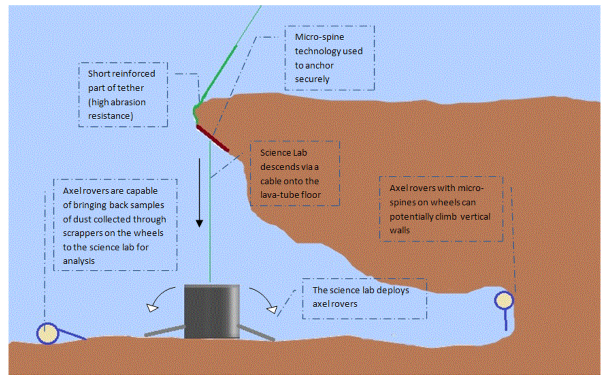

Figure 4: Lava-tube investigation via Axle rovers

Mission duration: The minimum mission duration was set to be 90 sols. Inspired however, by longevity of the twin rovers spirit and opportunity, the LArK design aimed for maximum mission endurance. This is made possible by the inherent design of the LArK as there is no reliance on exhaustible fuel for lift or thrust. Lift for an LTA is by buoyancy which requires no fuel and thrust in the LArK is achieved by electrically compressing atmospheric CO_2 to high pressure and expanding it through a nozzle. This compression and all other operations which run off of electricity are not exhaustible since this energy is harvested and stored from airborne wind energy. This yields an aerial exploration platform that could stay operational in the Martian atmosphere for much longer than the designed mission.

Technological challenges: Projections on enabling technologies were made in the description of the operation of the LArK. These technologies include EDD techniques in high altitudes, CNT technology, Skylight locating technology, anchoring technology [7], wind harnessing technology and LTA fabric technology.

References:

[1] J. S. Levine (2003) AIAA 2003-6576 [2] A. Colozza (2002) NAS5-98051 [3] I. S. Smith (97) AIAA A97-31332 [4] A. Colozza (2004) NASA/CR-2004-213345 [5] J. R. Johnson (2010) MEPAG 2010 [6] P. J. Boston NIAC CP 99-03, Phase 1-#07600-045 [7] A. Parness (2011) IEEE - ICRA [8] M. R. Blouin Jr. (2007) Project#:DJO - 0107