# MARVIN- Near Surface Methane Detection on Mars

Kshitij Shrotri
Kshitj_Shrotri@ae.gatech.edu
Kavya Manyapu
kavyakamal@gatech.edu

Adeel Khalid
adeel_khalid@ae.gatech.edu
Y. Faik Sumer
faiksumer@yahoo.com

M. Emre Gunduz
gtg128s@mail.gatech.edu
Daniel P. Schrage
daniel.schrage@aerospace.gatech.edu

Georgia Institute of Technology, School of Aerospace Engineering,
270 Ferst Drive, Atlanta, GA, 30332-0150

*Abstract*—An unmanned aerial vehicle (UAV) for a methane detection mission on Mars has been conceptually designed for a science mission in support of the search for life on Mars[1,2]. Methane being one of the indicators of life, it seeks to identify areas of high methane concentration as well as to create a high resolution map of the methane concentration over as large an area as possible. Integrated product and process design methodology (IPPD) has been applied and included the use of a house of quality to rank importance, as well as Pugh and TOPSIS analyses to rank feasible alternatives. The output of the design process is that an airship is most suitable for this mission. The use of an airship allows for long endurance, which is a requirement for mapping a large surface area, as well as a low minimum speed, which allows for a higher resolution map. This design decision led to the preliminary design of an airship and the mission itself. Sizing and Mass Estimation indicates that due to the rare atmosphere and lower than Earth gravity on Mars, the Airship size can be colossal, which poses difficulties. An interplanetary fast transfer trajectory has been chosen for launch atop a Delta II 7925H. The payload will be encased within an aeroshell analogous to the one used on the Mars Exploratory Rovers (MER) mission and an identical Entry, Descent and Landing (EDL) using parachute and airbag landing procedure will be performed. The encasing within the airbag will house a ground station with transceivers and hydrogen gas tanks that can be jettisoned along with Marvin the Airship in a deflated and packed form. Upon initial inflation using hydrogen gas, Marvin shall set off on the methane detection mission within the Elysium Planitia region on Mars. The $H_2$ gas within the envelope will maintain static lift. Refilling through the connection at the airship bottom will be required every 3rd Earth day if altitude is to not decrease below 50 meters from an initial calculated altitude of 78 meters. An innovative pulse jet method using hydrogen gas to propel the Airship has been described. All instrumentation including the spectrometer, anti-collision sensing device and video cameras will be mounted on the gondola attached to the bottom of Marvin by tethers. A tethered anchor for braking, with a miniature actuation motor will be mounted at its bottom. Mission life of two months has been chosen. Mission cost is projected to be US$ 350-430M. The concept is shown in Figure 1.

### TABLE OF CONTENTS

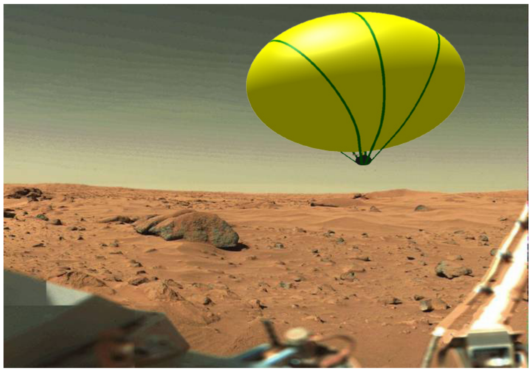


**Figure 1 Marvin – the Methane Detector**

## 1. INTRODUCTION

Advances in space technology have allowed us to seek answers to a question long pondered over, “are we alone?” Scientific missions have indicated possible existence of water on Mars. Another possible sign of life is the presence of methane gas[1]. Methane has been detected remotely using ground based telescopes on Earth by three teams[2] and by European Space Agency’s (ESA) Mars Express orbiter, at a resolution of 10-11 parts in $10^6$ parts (ppm). A mission to Mars that will investigate these areas of higher methane concentration is being investigated. Orbiters (Mars Global Surveyor (MGS), Odyssey etc.) and rovers (Sojourner, Mars Exploratory Rovers (MER) etc.) have successfully performed Mars missions. The disadvantage of the former is that the operation while in orbit does not permit a near-surface mission, while that of the latter is that only a local surface area can be covered. Flight close to the surface of

---

[1] 1-4244-0525-4/07/$20.00 ©2007 IEEE.
[2] IEEEAC paper #1045, Version 3, Updated November 19, 2006

Mars and close to the source of the methane production is required. Hence, it was decided that this mission will use an autonomous unmanned air vehicle (UAV) capable of flying long distances, in order to allow for many high resolution measurements of methane concentration. Higher levels of methane have been detected in three regions: Elysium Planitia and Arabia Terra in the Northern hemisphere and Memnonia in the Southern hemisphere[3]. While the orbital and ground based instrument data match, resolution is low. More precise measurements in parts per billion (ppb) would allow determination of the best place to send a mission to look for evidence of life on Mars. This need forms the basis of this scientific mission. From the maps shown in figures 2 and 3, it can be seen that Elysium Planitia encompasses the largest surface area and the topography surrounding it and the Memnonia appears more favorable. Hence, Elysium Planitia, latitudes of 10° to 30° N and longitudes of -20° to -40° W was chosen as the region of interest.

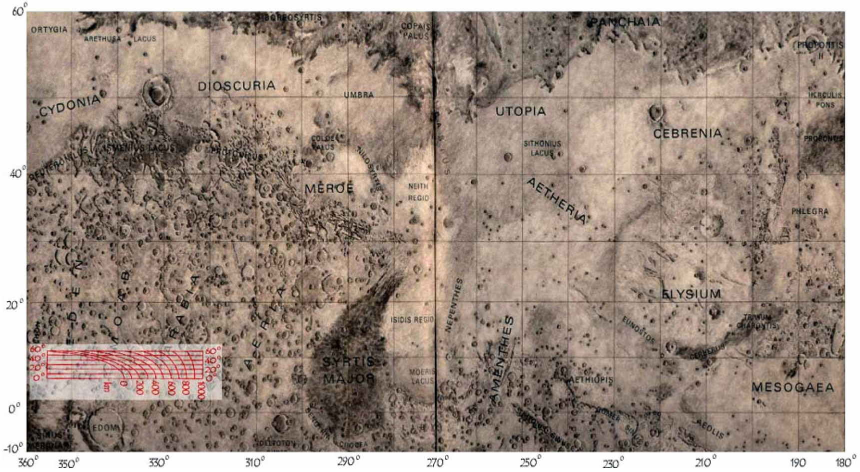


Figure 2 Northern Hemisphere of Mars

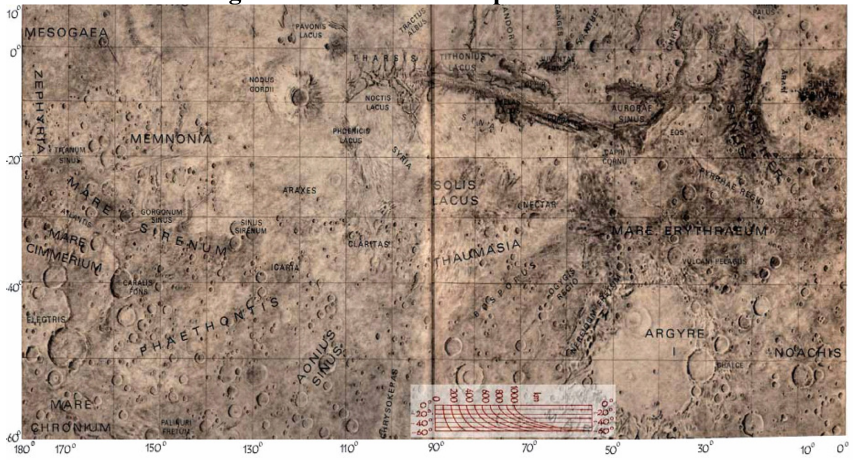


Figure 3 Southern Hemisphere of Mars

## 2. SYSTEMS ENGINEERING DESIGN METHODOLOGY

Integrated Product and Process Design (IPPD) methodology[4] has been used. Customer requirements came from the original NASA[5] future flight vehicle, with specific mission to Mars, 2006 graduate student design competition. Pugh (+/-/same rating with respect to the baseline concept) and TOPSIS (Technique for Order Preference with Similarity to Ideal Solution) analyses, both based on weights calculated on a 1-5 scale using Analytical Hierarchy Process (AHP) during requirement analysis, were used for evaluating feasible concepts. As such a mission has not been performed before, the baseline architectures were chosen from six probable concepts, namely; airship, rotorcraft, three types of powered fixed wing aircrafts and glider. Results of the Pugh Analysis are listed in tables 2 and 3. TOPSIS results are shown in Figure 4 and Figure 5.

Pugh selection did not yield a definitive answer. To determine a precise answer, TOPSIS was used. As sizing was not addressed at this stage, the total mass could not be estimated. Hence the science instrumentation was common to all alternatives. 1-3-5-9 rating system (1 - lowest and 9 - highest) has been used. The closeness parameter for the best/worst solution is shown in Figure 4. It shows the airship as closest to the ideal solution. This is due to its long endurance, good maneuverability[6], design simplicity and higher reliability. The second best concept is the rotorcraft, followed by the powered fixed wing aircrafts. The former suffered due to complexity and high risk. The latter lack the ability to hover and fly at low speeds, have lesser endurance and are riskier to deploy. The glider does not require unfolding but its mission would depend on wind updrafts. It would not be able to hover or last long. A worse case analysis with the same propulsion system on the airship and the rotorcraft provided further insight. Figure 5 shows that the airship still prevails.

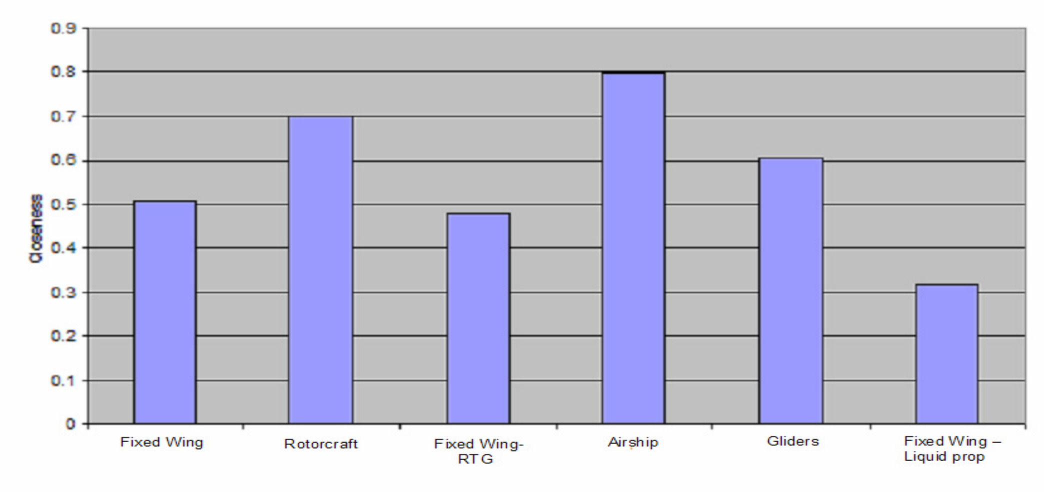


**Figure 4 TOPSIS Closeness Parameters**

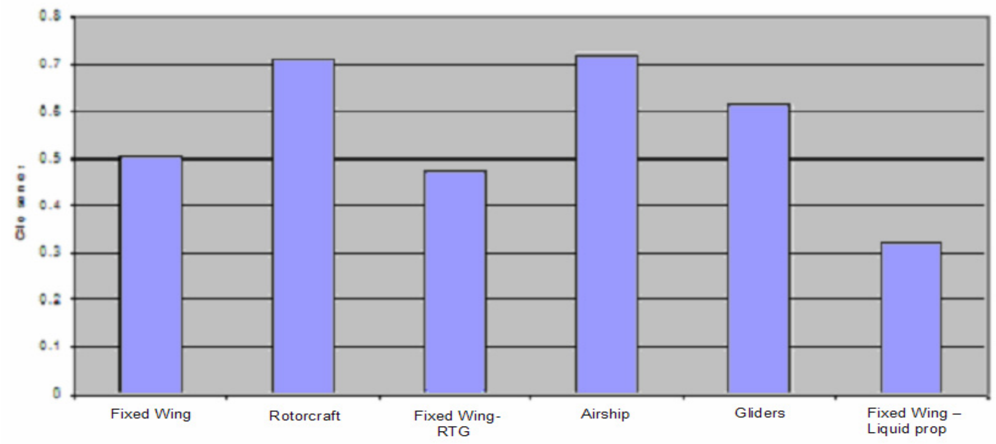


**Figure 5 Worst Case Analyses**

**Table 1 Pugh selection matrix with fixed wing datum**

| **Concept** | Fixed Wing Min. Cost | Rotorcraft | Fixed Wing RTG | Airship | Gliders | Fixed Wing Liquid Prop |
|---|---|---|---|---|---|---|
| Deploy Easily | + | DATUM | - | + | + | - |
| Fly Long Distance | + | DATUM | + | - | - | + |
| Fly Long Durations | - | DATUM | - | + | - | - |
| Fly close to Martian Surface | S | DATUM | S | S | - | S |
| Fly Close to Methane Source | - | DATUM | - | S | - | - |
| Methane Detection Resolution | - | DATUM | - | S | - | - |
| Methane Detection Accuracy | S | DATUM | S | S | S | S |
| Lowest Launch Mass | + | DATUM | - | S | + | S |
| Lowest Vehicle Mass | + | DATUM | - | - | + | - |
| Cost | + | DATUM | - | S | + | - |
| Number + | 5 | 0 | 1 | 2 | 4 | 1 |
| Number - | 3 | 0 | 7 | 2 | 5 | 6 |
| Number S | 2 | 0 | 2 | 6 | 1 | 3 |
|  | **2** | **0** | **-6** | **0** | **-1** | **-5** |

**Table 2 Pugh selection matrix with rotorcraft datum**

| Concept | Fixed Wing Min. Cost | Rotorcraft | Fixed Wing RTG | Airship | Gliders | Fixed Wing Liquid Prop |
|---|---|---|---|---|---|---|
| Deploy Easily | + | + | DATUM | + | S | S |
| Fly Long Distance | S | - | DATUM | S | - | + |
| Fly Long Durations | S | + | DATUM | + | - | - |
| Fly Close to Martian Surface | S | + | DATUM | + | + | S |
| Fly Close to Methane Source | S | + | DATUM | - | - | - |
| Methane Detection Resolution | S | + | DATUM | + | + | - |
| Methane Detection Accuracy | S | S | DATUM | S | S | S |
| Lowest Launch Mass | + | S | DATUM | + | - | S |
| Lowest Vehicle Mass | + | S | DATUM | S | + | - |
| Cost | + | + | DATUM | + | + | + |
| Number + | 4 | 6 | 0 | 6 | 4 | 2 |
| Number - | 0 | 1 | 0 | 1 | 4 | 4 |
| Number S | 6 | 3 | 0 | 3 | 2 | 4 |
|  | **4** | **5** | **0** | **5** | **0** | **-2** |

## 3. MISSION PROFILE

Marvin will be launched atop a Delta II 7925H during the December 2013 to January 2014 time frame from Kennedy Space Center (KSC). A Fast Transfer Injunction (type II trajectory) has been chosen and a Direct Entry to Mars will be performed as shown in Figure 6. Airship Sizing was done so as to permit an Entry, Descent and Landing (EDL) procedure similar to the Mars Exploratory Rovers (MER) procedure. Upon landing, the shell encasing Marvin will be exposed from the airbags. Marvin and the inflating hydrogen gas pumps as well as the ground station antennas will then sequentially deploy. The hydrogen gas will be carried in disposable lightweight cylinders. Three types of antennas, for continuous to ground station and intermittent to Earth as well as existing orbiters, data transfer, will deploy on the ground station. Upon inflation with hydrogen gas at a controlled rate, Marvin will remain attached to the ground station using a makeshift hook anchor till stability is achieved. Upon stabilization and testing of the ground station instrumentation, the anchor will release itself and Marvin will set out on the mission. An anti-collision sensing device to detect obstacles such as mountains or crater galleys, methane detection instrumentation, data transmission sensors, miniature video cameras, a makeshift anchor with a miniature controllable motor and hydrogen propellant tanks will be carried on Marvin. A control algorithm will be used for a combination of pre-defined and adaptive course. In the event of hydrogen loss inside the envelope, a connection to the airship envelope bottom will be used for refilling as discussed ahead.

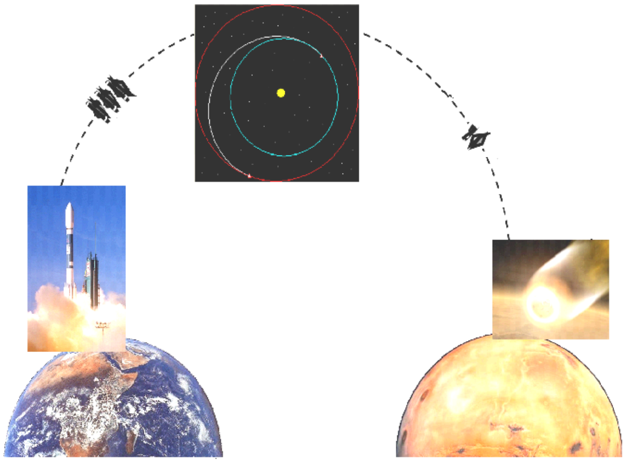


**Figure 6 Marvin Mission Profile**

*Trajectory Analysis*

Deployment after landing on Mars was chosen due to the perceived necessity of a ground station and risk associated with inflating a Tedlar envelope at supersonic speeds, if mid air deployment were chosen instead. Mid air deployment has never been done on Mars before while airbag landing procedure has. Low-energy, Type II Mars trajectory lasting for 214 days shall be used as shown in Figure 7. The upper stage of the expendable launch vehicle will provide necessary propulsion for Earth escape and interplanetary transit. While the spacecraft journeys toward Mars for 214 days, a cruise stage will provide power, communications and propulsion. It includes a $\Delta V$ of 125 m/s (with margin) for 5-6 trajectory correction maneuvers (TCM). Optimization of trajectory has been performed using the Jaqar Swing by Calculator[9] and the trajectory and launch window have been selected which result in favorable Mars entry conditions. The chosen trajectory allows for a launch window from December 13th 2013 through January 12th 2014. Earth escape requires departure energy C3 of 9.92 $km^2/s^2$, as shown in Figure 7. It will be provided by the launch vehicle. On the arrival date, the incoming C3 as shown in Figure 8 will be 30.45 $km^2/s^2$.

The selection of the launch vehicle is based on the Earth-escape energy provided and the payload mass carrying ability of the vehicle for the mission. For C3 departure of 9.92 $km^2/s^2$, Delta II 7925H[11] allows a maximum payload of 1200 kg; Atlas V 500 series allows a payload range of 2250 to 5500 kg and the Delta IV Heavy Launch Vehicle (HLV) allows up to 8000 kg. It was decided to attempt this mission within the next 5 to 10 years, should the Technology Readiness Level (TRL) permit. The entire payload mass would need to be within 1200 kg if the MER aeroshell is to be used. The MER Rovers have a mass of 180 kg each. This restricts the mass of the airship and the equipments required to inflate it, if the ballistic coefficient (ratio of mass delivered to product of aeroshell area and hypersonic drag coefficient) is to be equal to or less than that of the MER mission, considering that the same EDL sequence parameter values (entry angle, disk-gap-band parachute diameter, sequence timings etc.) have been chosen for this mission. While the ground station would be the same shell in which it would be encased, the transceiver mass on the ground station would need to be included too. While the Delta II has a smaller fairing diameter of 2.65 m, it is also economical in comparison to the Atlas V, which has good reliability and 100% launch success.

### *Inflation for Flight Reconfiguration*

Two concepts were looked into. $CO_2$ gas was considered as a lifting gas due to its natural abundance on Mars. Elementary calculations show that a pump of capacity of 618 $ft^3$/min (cfm) would be required to inflate the Airship in 24 Earth hours. The pump can be discarded upon first use. Heating of the $CO_2$ gas to maintain static lift would have to be done by excess heat from a power source such as a Radioisotope Thermoelectric Generator (RTG) or Sterling Radioisotope Generator (SRG) Plutonium battery. The standard mass of an RTG battery is 34 kg and the cost of one is roughly US $10 M. While this is a good source of energy for as long as a decade, its usage results in an Airship size of colossal proportions, making initial inflation difficult and jeopardizing mission life due to winds. Hydrogen gas, an alternative, is not only light but can be compressed to high pressure. This will aid in rapid airship inflation and production of static lift, eliminating the need for a pump. It will also be used as a pulse propellant for thrust, as explained in the Propulsion section. Rapid inflation also eliminates the hazards posed due to extreme temperature diurnal cycles on Mars, which can cause mechanical pump failure.

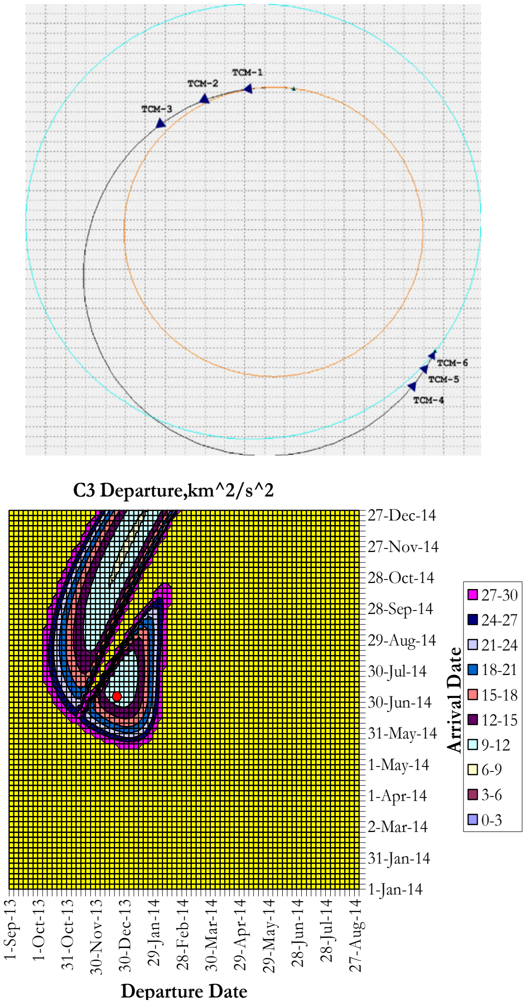


**Figure 7 Marvin Trajectory to Mars and Departure C3 Energies**

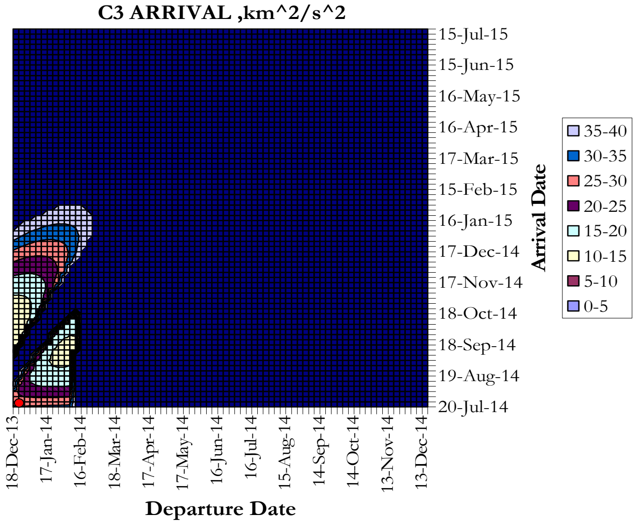


**Figure 8 Arrival C3 Energies**

*Data transmission*[12,13]

A ground station would be used to locate the high gain antenna. An omni-directional low gain antenna can be used to provide data transfer between Marvin and the ground station. A low gain antenna does not have to be pointed at the station. No system to change its position is needed and its signal is simultaneously sent out in all directions, thus reducing the airship payload. Low gain antennas weighing only *0.5 kg* are available. An extra antenna can be carried as a backup without significantly increasing the payload. This will be a direct transmission path where Marvin will transmit the data to the ground station using the low gain antenna at *2 kbps* and the high gain antenna X-band will transmit this data in a narrow beam to the Deep Space Network (DSN)[14] stations at locations on Earth at California, Spain and Australia. These dish antennas are distributed over a wide region on Earth so that as it rotates, at least one part of the network will have Mars in its view at all times. The diameter of the high gain antenna is *0.28 m* and it can transmit data at around *1850 bps*. This path is depicted as path 1 in Figure 9. A second path can be used as backup path in case the high gain antenna fails or if *faster communication* with Earth is needed. In this path, data transmission is completed in three steps. This increases the chances of losing data. An Ultra High Frequency (UHF) antenna must be used to communicate with existing Mars orbiters (Odyssey, Mars Global Surveyor (MGS), Mars Express and Mars Reconnaissance Orbiter (MRO))[15]. They have UHF and high gain antennas, which will allow the ground station to communicate with them using a UHF band. This data obtained by the orbiters will be transmitted to Earth. These orbiters have to be in the line of sight of the ground station for communication. This means that there are only specific time windows during the Martian sol when the ground station can transmit data to these orbiters. MGS and Odyssey pass over the station twice a day, 12 hours apart, allowing only 10 minutes a sol for the station to uplink the data. The orbiters have more power and bigger high gain antennas than the ground station. On successful up linking, they can transmit the data at rates of 110 Kbps. This is referred to as the indirect path and is shown as path 2 in Figure 9. A receiver will be needed that can operate in the frequency band of the low gain antennas to receive data. Antenna specifications[16] are listed in Tables 3 and 4. Direct to Earth, which is not preferred, is shown as path 3.

**Table 3 High Gain Antenna (HGA[17]-Unidirectional) and Low Gain Antenna (LGA-Omni-directional)**

| High Gain Antenna | | Low Gain Antenna | |
|---|---|---|---|
| Diameter | 0.28m | Length | 0.76m |
| Speed | 1850 b/s | Speed | Direct to earth 40 bps* |
| Transmit-Receive | X Band (8-12 GHz) | Transmit-Receive | S Band (2-4 GHz) |
| Gain | 24 dBic on beam | Gain | 8 dBic on zenith |
| Mass | 5 kg | Mass | 0.5 kg |
| Power | 40 Watts | ** shorter distance up to 2kbps* | |

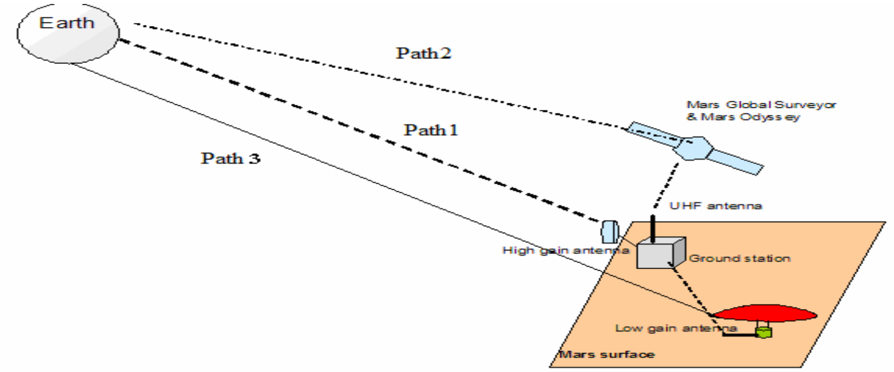


**Figure 9 Data Transmission paths from Mars to Earth**

**Table 4 Ultra High Frequency Antenna (UHF)**

| | |
|---|---|
| Transmit-Receive Band | UHF band (0.3-3GHz) |
| Mass | 0.5kg |
| Power | 12W (used by satellite) |

## 4. METHANE DETECTION

The science instrumentation aboard Marvin will include a spectrometer to detect methane, an anti-collision sensing device and a digital video camera. The primary performance metrics of interest are resolution in parts per billion (ppb) and the mass of the instrument. The instrument recommended for this mission, after conducting literature survey, is the *Quantum Cascade Laser*

*Spectrometer*[23,24]*(QCLS)*. It works on the principle of Laser Cascade Spectroscopy and has been designed by Webster et al for in-situ methane detection on celestial bodies such as Mars, Venus and Titan. It is a miniature tunable mid-infrared (MIR) laser spectrometer. The unique feature of this instrument is that its mass is ***less than 1 kilogram***. Additionally, as reported in *Trace Gas Detection*[25]*,* such an instrument will also have a resolution of 1 ppb. This makes it ideal for the current mission. The operation principle of QCLS is as follows. Each electron creates N photons in the process of traversing an N stage cascade structure as shown below in Figure 10 and Figure 11. This instrument has a high reliability and low failure rate. It uses high power lasers that provide the amount of energy for photon creation. The wavelength range is 3.4-17 µm. Due to the increased number of "*steps'* in stages, very high power is generated. In addition to carbon compounds, this instrument is sensitive to other compounds such as nitrous oxide (NO), $N_2O$ and ammonia ($NH_3$), water ($H_2O$), sulphur dioxide ($SO_2$) and hydrogen sulphide ($H_2S$).

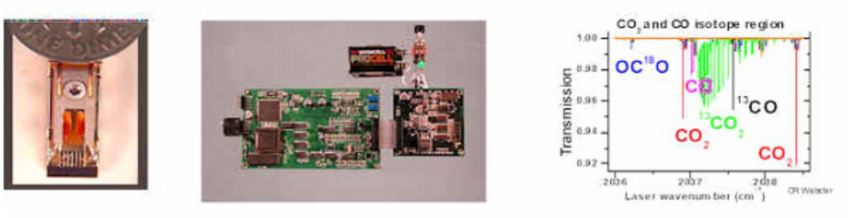


**Figure 10 Quantum Cascade Laser Spectrometer**

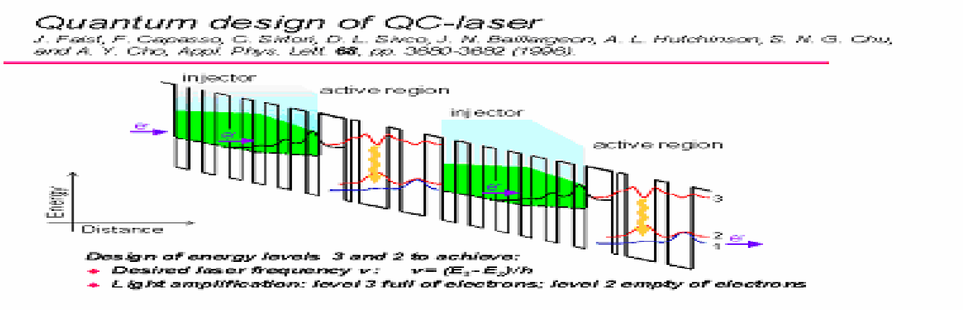


**Figure 11 Quantum Cascade Laser Spectroscopy**

## 5. POWER SOURCE AND PROPULSION

Amongst the two options that were considered for inflation of the airship was the usage of $CO_2$ gas. Propulsion was first considered to be enabled by a propeller, powered by either an RTG or SRG[29]. Calculations revealed that the propeller diameter would be roughly 1 m and would need to rotate at Mach 0.75 on Mars. A duct in the airship would be useful for the purpose of refilling with atmospheric $CO_2$ gas should there be a pressure drop inside. This would mean added weight of the propeller and more moving mechanical parts. The electrical power generated by an RTG has to be converted to thrust by means of an electric motor, transmission elements and a propeller. Although the airship is assumed to be flying close to the surface and does not climb higher than 100 meters unless required, wind speeds can reach 30 m/s during a dust storm. An airship with a relatively big flat plate area would require higher power, i.e. more RTG's to generate enough power to withstand those winds. This means it would be heavier, hence bigger, thus having an even larger flat plate area and can be blown away by winds. A second detrimental effect of dust storms would be on the transmission and other mechanical components. Dust particles inside rotating machinery can shorten the life of the system significantly, if not cause complete failure. Though this concept is relatively feasible, the problems posed during inflation and heating with the RTG batteries in addition to the resulting Airship colossal size resulted in this idea being rejected. This gave way to the proposed novel propulsion method as being described.

Two hydrogen cylinders of low weight would be carried on the airship that would propel it by ejecting hydrogen gas out in the form of pulses, when propulsion or maneuvering is required. The amount of hydrogen that would be carried was bounded by an upper limit due to the mass limitation of 180 kg coming from the MER aeroshell and EDL concept. The mass of hydrogen was as a result restricted following calculations, to not more than 80 kg. Sizing considerations for the Airship diameter resulted in the total hydrogen propellant mass to be 50 kg. Hydrogen can be compressed to 700 atmospheres pressure[30] for use in cars running on hydrogen. Assuming it to be at 700 atmospheres implies that it contains practically usable potential energy. Care must be taken that the drop in temperature during cruise to Mars does not liquefy the gas and cause much leakage. Through the use of a control valve at the nozzle of the $H_2$ tank, it may be possible to generate thrust simply by producing controlled hydrogen bursts to push the vehicle just enough so that it gains speed and does not tip over because of moment around its center of gravity. The direction of thrust can be adjusted by rotating the protruding tail of the vertical nozzle, as shown in Figure 12. The tail can also be swiveled about the vertical and horizontal planes in order to change the thrust vector and gain altitude if desired. The proposed solution for "*dust devils*" is having a small electric motor-controlled low weight "*anchor*" attached to the airship. Lowering it will decelerate the ship by dragging onto the surface. The hydrogen leak rate from the Tedlar skin is typically 51.8 cc per 100 $in^2$ of surface area of the envelope in 24 Earth hours[31]. Calculated loss of mass is 0.0034 kg of hydrogen in 1 Earth day resulting in a loss of lift equaling $1.92 \times 10^{-6}$ N which implies a maximum acceleration downward of $1.7424 \times 10^{-8}$ $m/s^2$. Assuming a constant acceleration implies, from Newton's law and equations of motion, that 1 m altitude loss occurs in 2.9 Earth hours or 8 meters in 1 Earth day. The actual mass of hydrogen required to generate lift equaling the total weight is roughly 24.9 kg. With only the additional 0.1 kg of the total 25 kg hydrogen for inflation (separate from propellant 50 kg), calculations reveal that the airship would rise to an altitude of roughly 77.6 meters in 1 Earth hour, after including the loss rate, if controlled properly. This release of extra hydrogen can be suited as per need at the beginning of the mission. Hence, if the altitude is to be maintained to not lower than 25 meters, refilling would be necessary every third Earth day. While the total mass of propellant gas is 50 kg, usage of only 1 kg for this purpose is sufficient as the loss per Earth day is only 0.0034 kg of hydrogen. Thus, without any refilling, if Marvin were to be at 78 meters, the mission would last for only 9 Earth days. But with refilling, the mission life can be significantly extended. As a redundancy for this and other exigencies, the propulsive $H_2$ container nozzle will be connected to the bottom of Marvin and controlled by a dual valve for refilling and propulsive purposes. With leakage not being a concern now, the mission can last much longer. However, keeping dust devils, stability, temperature effects and the unknown in mind, a conservative mission life of 2 months was chosen. The relative speed with respect to the ground has been kept at 7 m/s as a solution to the sizing equations could not be found for winds above 7 m/s. Beyond this, the anchor would need to be lowered. Altitude can be gained by refilling $H_2$ more than required. Descent can be controlled by inverting the $H_2$ pulse vector, shown in Figure 12

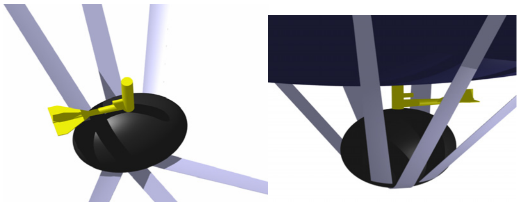


**Figure 12 Gondola Hydrogen Pulse Jet Nozzle**

### *Battery for Marvin*

The major battery requirements for this mission are long endurance and lightweight. Battery capacity is usually better with lower drain currents[32]. The drain rate greatly determines the life of the battery. Alkaline batteries are designed to provide large amounts of power, while others are designed to last a longer duration for products like smoke detectors and watch batteries. Figure 13 shows that low demand of current at the same voltage can significantly increase the life of the battery. A comparison of Nickel Cadmium (Ni-Cd), Nickel Metal Hydride (Ni-MH), and Lithium Polymer (Li-Poly) batteries is shown in Table 5.

**Table 5 Comparison of batteries**

| | **Lithium Polymer** | **Nickel Cadmium** | **Nickel Metal Hydride** |
|---|---|---|---|
| Nominal Capacity | 1400mAh | 1300mAh | 1350mAh |
| Nominal Voltage | 3.7V | 1.2V | 1.2V |
| Weight | 31g | 35g | 26g |

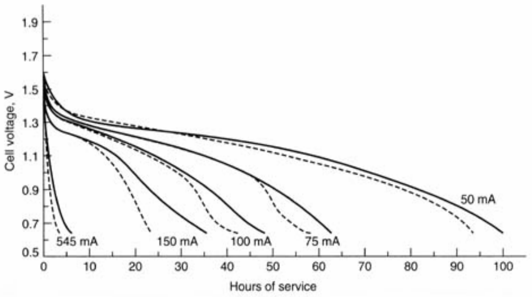


**Figure 13 Life of the battery is directly proportional to the drain rate**

One major disadvantage with onboard power is weight. Lithium Polymer batteries reduce weight without compromising on power. These batteries provide more energy per gram than other commonly available batteries. In some cases they provide up to 4 times the specific energy (Watt hour per kg) than many others. These batteries can also be linked together if necessary[33]. There are several different types of Lithium Polymer batteries available. Depending on the amount of power required, an appropriate battery can be chosen. Table 6 lists a variety of Li-Poly batteries[33].

## 6. GUIDANCE, NAVIGATION AND CONTROL (GNC) [34]

### *Grid based Methane Search*

Grid search is an exhaustive search method that can be used to detect the location of the highest concentration of methane in an area. It allows for an easy to program search algorithm in which grid lines are placed on the entire region of interest. Marvin can be programmed to follow the grid lines in a pre-defined structured manner. Grid line resolution is variable. In areas of high $CH_4$ concentration, fine grid can identify exact location.

**Table 6 Types of Li-Poly Batteries available**

| Voltage (V) | Current (A) | Weight (gm) | Dimensions | Power (mA-h) |
|---|---|---|---|---|
| 3.7 | 0.5 typical | 4 (0.13 oz) | 1.2" x 0.8" x 0.14" | 145 |
| 3.7 | 1.4 typical | 8.7 (0.31 oz) | 2.36" x 0.79" x 0.16" | 400 |
| 3.7 | 2.5 typical | 14 (0.5 oz) | 1.9" x 1.17 x 0.19" | 650 |
| 3.7 | 4.0 typical | 17.6(0.62 oz) | 1.89" x 1.18" x 0.25" | 800 |
| 3.7 | 3.0 typical | 19.5(0.69 oz) | 1.9"x 1.3" x 0.24" | 900 |
| 3.7 | 3.5 typical | 24 (0.85 oz) | 1.9"x 1.3"x 0.3" | 1200 |
| 3.7 | 5.0 typical | 34 (1.2 oz) | 2.35" x 1.3" x 0.33" | 1700 |
| 3.7 | 7.0 typical | 45 (1.65 oz) | 2.44" x 2.75" x 0.22" | 2200 |

This method is commonly used for forced search of the optima in a non-uniform, multidimensional, and multi-modal hyperspace. It is a zeroth order method. Gradient calculations are not required on the mass scale, which minimizes error. Grid search is a robust method and it finds not only the area of the highest concentration of methane but also identifies other possible locations where methane exists. A schematic is shown in Figure 14. However this method may be inefficient for large areas and may take long time for completion. To expedite search, a first order gradient-based method can be used in conjunction with grid search.

*Fletcher Reeves search method*

Fletcher Reeves (F-R) also known as conjugate gradient method is a popular gradient based search method used for search direction. It uses information from the previous step and the local gradient to decide where to go next. Motion of Marvin is governed by the following equations.

$$\overline{X} = \overline{X_o} + \alpha \cdot \hat{S} \tag{1}$$

$$\overline{S^q} = -\nabla F \cdot (\overline{X^{q-1}}) + \beta \cdot \overline{S^{q-1}} \tag{2}$$

where,

$$\beta^q = \frac{\left|\nabla F(\overline{X^q})\right|^2}{\left|\nabla F(\overline{X^{q-1}})\right|^2} \tag{3}$$

Equation 1 shows how the new step is updated based on the previous step, the direction and the step size. The direction of movement is obtained from Equation 2 where a gradient of the objective function, which in this case is the concentration of methane, is calculated based on the previous step. While performing a grid search, when Marvin detects methane, it will alter course and use the Fletcher Reeves method to reach the sources, traveling the shortest path. From that point on, it will resume its search based on the grid search method. This combination of grid search and F-R method is very efficient because it will continue even when there is no methane detection and the gradient is zero and will converge to the source quickly as soon as methane is detected. This search method can continue for long durations till Marvin exhausts the search area.

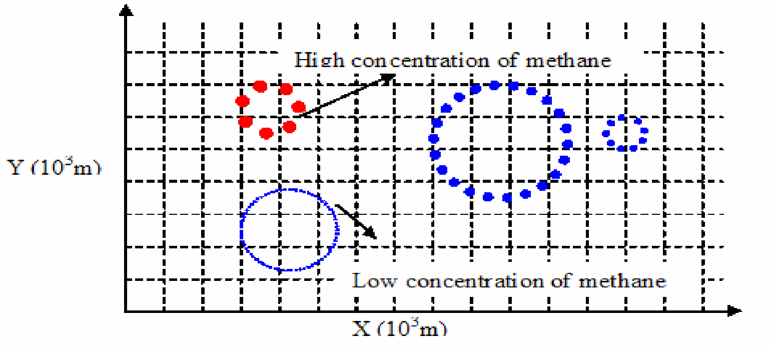


**Figure 14 Grid based search for Methane concentration**

*Control Algorithm*

A control algorithm is devised to steer the airship through the desired trajectory. By conjugate gradient (Fletcher-Reeves) methodology the airship can advance toward the target in the steepest gradient direction at every step. In order to avoid overshooting the target (location of maximum methane in a local grid), the size of the step taken toward the target is adjusted. From equation 1, the step size α is defined as the product of the velocity of the airship and time delay between detections. This gives the airship deflection from the previous location. The modified equation is:

$$\overline{X} = \overline{X_o} + \hat{S}\bar{V}\Delta T_{\det ection} \quad (4)$$

$\hat{S}$ is a 3*3 matrix that has the information of methane variation in every step for all three dimensions. It has sign information as positive or negative in its diagonal and off-diagonal terms are zero. $\bar{V}$ *and* $\bar{X}$ are 3*1 vectors. If methane concentration is higher than the previous detection, it keeps the airship going in the same direction, otherwise the sign changes and the airship traverses in the opposite direction. Figure 15 represents the flow diagram of the methane detection algorithm. For example, if it is assumed that Marvin is on the top left corner of the map in Figure 14, it has to move diagonally in the southeast direction to the next spot and at the same time gain altitude in the z direction. This will be the initial direction. The top left corner will be the landing point and center of the inertial frame. After the first detection is complete and methane percentage is measured, adjustments will be made for the next move depending on the concentration of methane detected. If no methane is detected, Marvin keeps moving along the diagonal path to the next checkpoint as in Figure 15. If methane is detected and is higher in concentration than the previous step, the speed of the airship is decreased in order to take smaller steps toward the source of methane, and to not overshoot it. If methane concentration is not higher than the previous step, Marvin turns in another direction depending on the gradient information of methane variation ($\hat{S}$). Frequency of direction changes is important. The time between the detections can be shorter than the actual time it takes the airship to reach its desired position and velocity after activating the change direction algorithm. This must be handled carefully in the analytical expression in equation 4. For the beginning case of each checkpoint, if methane is not found, the airship will travel all the way diagonally to the next checkpoint. Direction change algorithm is shown in Figure 16. Upon inflation, Marvin will communicate with a Mars orbiter to identify surface location coordinates. Inertial navigation system (INS) is used to keep track of the position, velocity and attitude of the airship. Information from the previous update is used to calculate the new direction based on the methane variation. The next step is to calculate the necessary control actions to maneuver the airship to its new position. Actuators will then be activated to operate the control valves to release required amount of pressurized hydrogen gas. At the end of the maneuver, the new position information will be stored. Error of the INS increases with time. For rectifications, periodic communication with orbiter is necessary..

## 7. AIRSHIP DESIGN

*Material Selection*

Low-density high tear strength materials have been chosen for the Airship. Typically, Kapton is used in space applications. While its density, 1.42 g/cc is slightly higher than that of Mylar (1.36 g/cc), it is a strong and light material. Mylar films too are lightweight and are available in thicknesses ranging in mils (1 mil = 0.001 inch). Tedlar too has similar properties. The airship dimensions and the low weight payload requirements mandated the choice of these light materials. Sizing has been done for a thickness range of 1-10 mils using Tedlar[35]. Structural analysis to justify that the gondola carrying the instruments attached to the bottom of the Airship by tethers would not cause tear or wrinkle, has not been included in this paper.

*Sizing and Mass Estimation*

For $H_2$, the amount of gas required would be tremendous as compared to airships on earth. This is because the Martian atmospheric density is only 0.015 kg/$m^3$, which is 1.2 % of that on Earth[37]. Hence, $H_2$ will have to be compressed in special containers, which take up a high percentage of the total weight resulting in heavier structures, more fuel and higher cost. Using $CO_2$ results in an unwieldy airship size. It was assumed that all of the $CO_2$ inside the airship's envelope is heated evenly to 500 Kelvin, and the outside atmospheric temperature is -140C° (130K°), which is also the lowest surface[38] temperature. Even with this optimistic assumption, the final size of the airship was calculated to be as big as a football field. The empty weight is about 100 kg of mass, and the envelope is assumed to be a prolate spheroid with the slenderness ratio (total length to maximum cross-section diameter) of 4. Even when the shape is reduced to a perfect sphere to minimize surface area, its diameter exceeds 60 meters. This implies it would require thousands of cubic meters of hot gas. It would be impossible to heat that much $CO_2$ at 210K° in the environment[38] up to 500K° using any conventional methods. Even continuous pumping of the gas into the envelope would take weeks. Using $H_2$ makes the airship size more manageable, and the gas does not need to be heated. Since it will be compressed and carried in tanks, the task of filling up the envelope can be performed better by a controlled depressurization of a tank into the envelope. Using $H_2$ in airships poses a serious risk of fire on Earth, but this should not be a problem on Mars, since the amount of $O_2$ in the atmosphere is only 0.13%[38]. Simplified sizing and maximum weight capacity calculations were done for $H_2$ gas as the lifting gas.

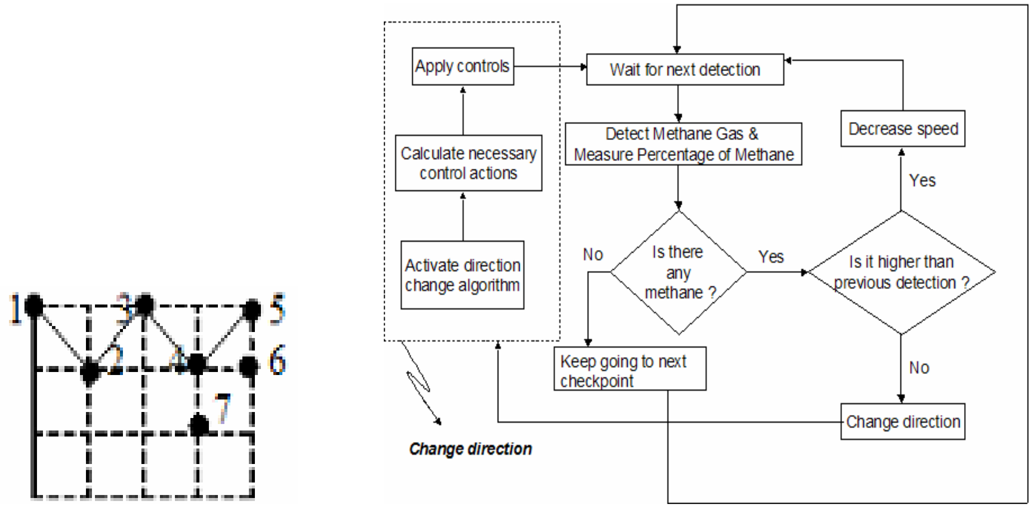
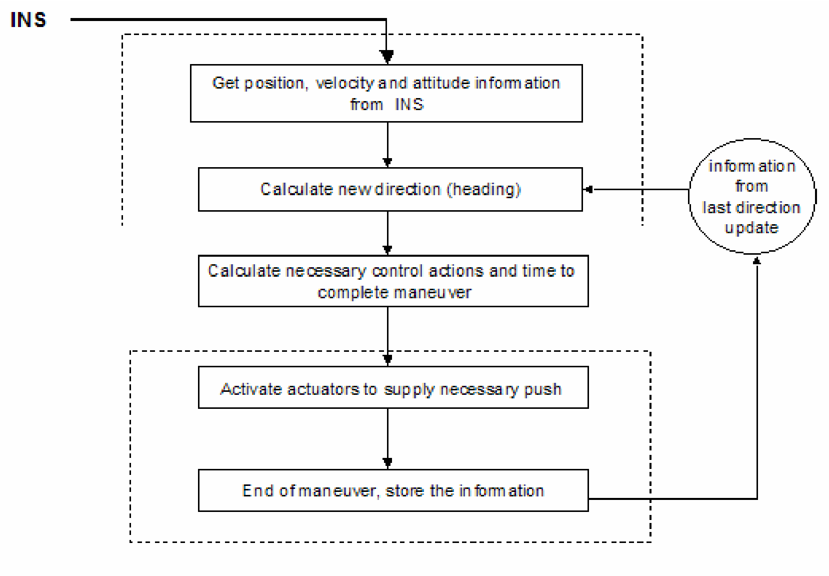


Figure 15 Methane detection algorithm



INS : Inertial Navigation System

Figure 16 Direction Change Algorithm

*Sizing methodology*[39]

The same formulas were utilized for calculation of lift using both $CO_2$ and $H_2$. The airship is assumed to be flying at an altitude less than 100 m above the surface. The envelope is filled with lifting gas only, and it does not have any ballonets. Since a $CO_2$ airship on Mars is similar to a hot air balloon on Earth, this approach was deemed adequate. Using the same method for $H_2$ enables direct comparison of the results from both designs. The geometry of the airship envelope is schematically shown in Figure 17. The volume and surface areas of the prolate spheroid (an ellipse revolved around its major axis) are given as per Equation 5. Equation 5 is used to calculate the required gas volume, and surface area S in equation 6 is used to calculate the envelope weight. Using the density of Tedlar and its minimum commercially available thickness of 1 mil (≈ 25 microns), the envelope weight $W_{env}$ is obtained as per Equation 6. Other weights components are presented in Table 7. Major axes lengths were calculated to be a = 13.33m and b = 20m. Thus, Marvin has a *26 m diameter* and *40 m length* with a slenderness ratio of 1.5.

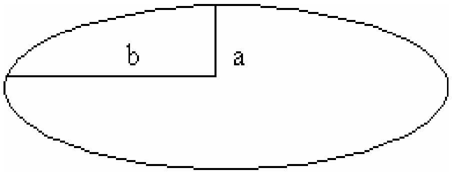


Figure 17 Elliptical Cross-Section of a Prolate Spheroid

$$V = \frac{4\pi ab^2}{3} \tag{5}$$

$$S = 2\pi b\left(b + \frac{a\arcsin(e)}{e}\right),$$

$$where\ \ e = \sqrt{1 - \frac{b^2}{a^2}}$$

$$W_{env} = S\rho_{Tedlar}t \tag{6}$$

Hydrogen required for lifting is found as follows. The airship is assumed to fly at a constant altitude. Therefore it is assumed that the lifting force required is equal to total weight W of the airship. For gases lighter than atmosphere, Equation 7 is valid.

$$L = V_{req}g(\rho_{atm} - \rho_{gas}) \tag{7}$$

$V_{req}$ is the required lifting gas volume, g is gravity on Mars (3.73 $m/s^2$) and the remaining terms are densities of the atmosphere and the lifting gas, respectively. Density of Hydrogen was calculated using the ideal gas law (p=ρ*R*T), where pressure p is atmospheric pressure on the Martian surface (600Pa), R is the gas constant for Hydrogen (4124.2) and T is the ambient temperature (about 210°K). Excel sheets were developed using the formulas and values above to calculate the minor axis "a" of the envelope. Iterations began with an initial guess for "a". Then the geometric envelope volume V, weight W and $V_{req}$ were iteratively calculated. Using the MS Excel Solver, the value of "a" was iteratively updated until V - $V_{req} \approx 0$ was achieved. Envelope thickness was kept constant during the above calculations. Minimum required thickness depends more on the weight of the envelope than the pressure exerted by the lifting gas, since the pressure inside the envelope is approximately equal to ambient pressure. The highest stresses are expected to occur on the centerline in Figure 18. The lifting gas carries upper half of the envelope weight. The lower half weight is entirely carried by the elliptic cross-section at the centerline level. The minimum thickness is calculated using Equation 8 below.

$$t = \frac{W_{env}/2}{\sigma p_{cross}} \tag{8}$$

σ is the tensile strength of the material, and $p_{cross}$ is the perimeter of the cross-section being cut.

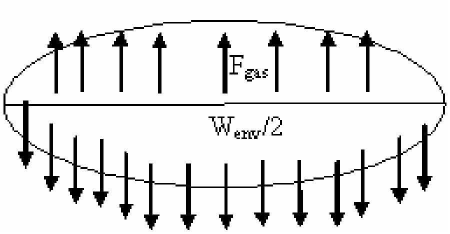


**Figure 18 Forces on Envelope Skin**

*Structures*

Structures in the gondola are composed of solid hollow tubes acting like a skeleton to carry all the electronic equipment, hydrogen tanks, batteries, anchor system and outer skin. The tubular structure is entirely inside the gondola, and has no connection to the envelope. Three wide Tedlar belts wrapping around both the envelope and gondola facilitate structural connection between the gondola and envelope. The belts are wide enough to make sure envelope skin is not deformed or torn by the local stresses generated by the weight of the gondola. Attaching of the belts to the airship is done by means of stitching to the envelope. For the gondola, they are bolted to the tubular structure towards the bottom. The hydrogen tubes between the gondola and the envelope do not carry structural loads.

**Table 7 Marvin Component Mass Breakdown**

| **Component** | **Mass (kg)** | **Comments** |
|---|---|---|
| Envelope weight | 98.51 | Calculated using above formula |
| Payload | 2.00 | Methane detection instruments |
| Structural members and empty gondola | 41.03 | Assumed to be quarter of other elements' weight[40] |
| Other instruments | 11.90 | Assumed constant according to [40] |
| Video camera x 4 | 0.004 | |
| Propulsive hydrogen | 50.00 | Used only for generating thrust and replacing lost gas in envelope, not for filling the envelope. Includes tank weight. |
| Battery | 0.50 | Lithium Polymer |
| Anchor system | 5.00 | A rough assumption |
| Total | 110.44 + 50=160.44 | Total airship Mass + $H_2$ for inflation ***with*** disposable tanks.<br>+ 19.56 kg Margin as compared to the MER rovers. |

## 8. OPTICAL SENSOR FOR MARVIN

The secondary mission for Marvin is to observe the Martian surface using an optical sensor. In addition to low mass and power requirements, a high-resolution sensor is required with the ability to see the complete range of light levels, from sunlight at noon to overcast starlight. Davis et al[42] compared to a variety of optical sensors for a Micro Air Vehicle (MAV) concept. The size and mass of this application is similar to Marvin, since low payload, volume and power are required. The optical sensors being developed at Lincoln Laboratory at MIT have high resolution of 1000 x 1000 pixels at the mission altitude of 100 m. Movement of the aircraft, which may cause the image to blur, and relatively large temperature variations drive other operational requirements. To meet these requirements, Lincoln Laboratory has investigated visible and infrared sensors. Davis et al compare three different CCD cameras and a CMOS camera based on engineering characteristics such as resolution, pixel size, quantum efficiency, read noise, packet size, dark current, shutter, frame store, noiseless binning, voltage levels and signal output. A CCD camera with 1000 x 1000 pixel array is chosen because it provides image resolution equivalent to a high definition television. The photograph is digitized to form an image representative of number of pixels (in the horizontal dimension) and a 4-bit gray scale envisioned for the CCD sensor. The resulting image provides sufficient detail to recognize the presence of vehicles and personnel on earth from an altitude of 100 m. An update rate of 0.5 frames per second for flight speeds of 10 to 15 m/sec is chosen, which would require a communication link capability of 2 Mbps (assuming no image compression). Frame rates could be increased with a more capable communication system. Table 8 lists important camera properties. Figure 19 shows the simulated visible light camera image of an advanced silicon CCD technology that permits the packaging of a 1000 x 1000 pixel imager and associated output electronics in a single chip, resulting in a camera size of 1 $cm^3$, weighing less than 1 gram. Four cameras will be used.

**Table 8 Life Cycle Cost**

| Activity | Cost (FY 2006) |
|---|---|
| Delta II 7925H Launch | $126 million |
| Instrumentation | $ 10-20 million |
| Materials | $ 10 -50 million |
| Hydrogen | $200,000 |
| Development and DOC | $ 200 million |
| Operations | $ 30 million |
| **Total LCC** | **$ 350 – 430 M** |

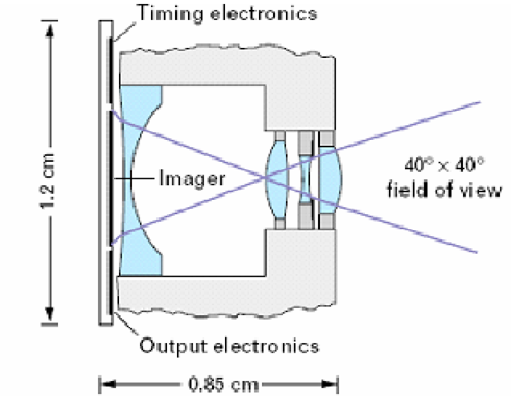


**Figure 19 Advanced Silicon Technology**

**Table 9 Optical sensors technical details**

| | |
|---|---|
| Aperture | 0.26 cm |
| Angular resolution | 0.7 mrad (7 cm at 100 m range) |
| Pixel count | 1000 x 1000 |
| Frame rate | 0.5 frames / sec |
| Mass | < 1g |
| Power | < 25mW |
| Field of View | $40^o$ x $40^o$ |
| Communication range | 5 km |
| Navigation method | Ground Station tracking (line of sight) |
| Mission altitude | 100 m |

## 9. LIFE CYCLE COST (LCC)

As of FY 2006, the launch price for a Delta II 7925H, as advised by Dr. Robert Braun of Georgia Institute of Technology, is US $126 million. For direct operating costs (DOC), 100 to 200 Research Engineers working on this project cumulatively for four years has been assumed as per Dr. Braun's advice. The development cost thus assumed is roughly $ 200 million. The cost of Tedlar was approximated on a linear scale. A 100 liter bag costs $41[43]. Propulsive Hydrogen to be utilized was set to be 50 kg, including the tank. Hydrogen required for filling the envelope was calculated to be approximately 25 kg without a tank. There are new kinds of Hydrogen tanks made of composites under development[44]. Assuming a future technology of 50 % weight-ratio Hydrogen tank, total Hydrogen weight with tanks will be 100 kg. Cost of Hydrogen is assumed to be $2000 per kilogram, including the tank. The instrumentation cost, development of QCLS and other related costs have been estimated based on advice from Dr. Braun. LCC estimate is shown in Table 9.

## 10. CONCLUSION

The primary cause of concern has been the difficulty in accomplishing low speed flight on Mars. This is the main reason for the rejection of the fixed wing aircraft concepts. While a rotorcraft would be ideal for hovering, and landing during severe weather, low weight and less complex technology for power generation are strongly desirable. Stability of the rotorcraft is a key concern. The airship is indeed the better choice as it accomplishes low speed flight more efficiently and under relatively more stable conditions. The sizing of the airship played a key role in this design. The rare atmosphere of Mars makes it difficult to accomplish flight while the lifting gas constraints dictate the sizing of the airship. If safe and reliable means of using atmospheric $CO_2$ that can be efficiently and quickly heated can be designed, mission life extending the chosen 2 months, and altitude maneuverability, can be designed for. The natural abundance of $CO_2$ would no longer necessitate the usage of $H_2$ gas. This would bring down the risk level associated with leakage of hydrogen gas. However, efficient and rapid means of pumping and heating $CO_2$ gas would be needed. The Quantum Cascade Laser Spectrometer (QCLS) does not categorize as TRL of 9, though it is a good prospect. Considering its low mass, multiple such spectrometers can be carried on the mission, to add redundancy, without significantly affecting mass. Should this instrument be not economically available, a mass spectrometer of 4-5 kg will be used. Launch windows are flexible. Provision of multiple data transmission paths adds redundancy to the design, thus reducing the data loss risk. A direct UHF link from Marvin to the Orbiters was not exploited as storing data on the ground station would be less risky. Should the mission have to be aborted, loss of data would be prevented. With the existing technology and resources, Marvin the airship with hydrogen as the lifting gas as well as impulse propellant is recommended for this mission.

## ACKNOWLEDGEMENTS

We wish to thank Dr. Elizabeth Ward at NASA Langley Research Center (LaRC) for the opportunity to work on this project. We also wish to extend special thanks and gratitude to Dr. Robert Braun, Mr. John Christian and Mr. Bob Thompson, all from Georgia Institute of Technology School of Aerospace Engineering, for their valuable advise.

## REFERENCES

1. Oliwenstein L, "*Work Bolsters Life on Mars Theories*" Newsroom, 1 Nov. 2005
2. Zubrin R, "*Methane Detection Points to Life on Mars*", www.marssociety.org
3. Mars Express, "*Water and methane maps overlap on Mars: a new clue?*" 20 Sept. 2004
4. Schrage D, "*MSEA Overview*", Georgia Institute of Technology, Atlanta, Aug 2005
5. Student Competition and Education Information, 7 Dec. 2005, NASA Langley Research Center, 9 Sept. 2005 http://avst.larc.nasa.gov
6. Elfes A, Bueno S, Bergerman M, DePaiva E, Ramos G, "*Robotic Airships for Exploration of Planetary Bodies with an Atmosphere: Autonomy Challenge*s", Autonomous Robots 14, 147-164, 2003
7. Grinsell C., Thompson B, O'Brien P, Senga M, Schrage D "*GTMARS Air Vehicle Submission*" 17th Annual American Helicopter Society Student Design Competition Graduate Entry, June 2000
8. ARES Mars Scout Mission. 14 Dec 2005 http://marsairplane.larc.nasa.gov/science.html
9. www.Jaqar.com/
10. Desai P and Knocke P, "*Mars Exploration Rovers Entry, Descent, and Landing Trajectory Analysis*", NASA Langley and JPL
11. http://www.boeing.com/, Atlas and Delta -Payload Planner's Guide, BOEING Launch Services
12. www.machinedesign.com
13. Home W, Hastrup R and Cesarone R, Telecommunications for Mars Rovers and Robotic Missions, Stanford Telecommunications Inc., JPL, California Institute of Technology
14. www.deepspace.jpl.nasa.gov
15. www.mars.jpl.nasa.gov
16. Kayton M and Fried W R, Avionics Navigation Systems, 1997
17. www.space.com/scienceastronomy/solarsystem/odyssey_update_020207.html
18. http://www.chemguide.co.uk/analysis/masspec/howitworks.html
19. Chasteen Thomas, http://www.shsu.edu/~chemistry/primers/gcms.html
20. Tillman K, Maier R J, Reid D and McNaghten E, *"Mid-infrared Absorption Spectroscopy of Methane using a Broadband Femtosecond Optical Parametric Oscillator based on aperiodically poled lithium niobate",* Journal of Optics: Pure and Applied Optics 7, (2005), S408-S414
21. Uehara K and Tai H, "*Remote Detection of Methane with a 1.66 μm Diode Laser*"
22. Liang G, Liu H, Kung A, Mohacsi A, Miklos A and Hess P, "Photoacoustic Trace Detection of *Methane using Compact Solid-State Lasers*", Journal of Phys. Chem. A 2000 104, 10179-10183
23. Webster C, Flesch G, Scott D, Swanson J, May R, Woodward S, Gmachl C, Capasso F, Sivco D, Baillargeon J, Hutchinson A and Cho A, *"Quantum-cascade laser measurements of stratospheric methane (CH4) and nitrous oxide (N2O)",* , accepted for Applied Optics, 2000

24. Bell Laboratories, http://www1.bell-labs.com/org/physicalsciences/psr/qc/sld019.htm
25. Prasad T, http://nanonet.rice.edu/personal/Tushar/PPTs/elec568.ppt
26. Sausa R, Alfano A and Miziolek A, *"Efficient ArF Laser production and detection of carbon atoms from simple hydrocarbons"*
27. Fawcett B, Parkes A, Shallcross D and Orr-Ewing A, *"Trace Detection of Methane using Continuous Wave Cavity Ring-Down Spectroscopy at 1.65 $\mu m$"*, PCCP, November 2002
28. Muller F, Popp A, Kuhnemann F and Schiller S, "*A continuous-wave optical parametric oscillator for mid infrared photoacoustic trace gas detection*",
29. New Frontiers AO Radioisotope Power Systems (RPS) Information Summary October 2003
30. Preliminary Hydrogen Opportunities Report, Manitoba Energy Development Initiative, April 2003
31. www.dupont.com
32. http://www.batterysavers.com/Compare-Batteries.html
33. http://www.sanyo.com/batteries/specs.cfm
34. Vanderplaats G, *Numerical Optimization Techniques for Engineering Design,* Vanderplaats Research and Development Inc. 3rd Edition 2001
35. www2.dupont.com/
36. http://ase.tufts.edu/cosmos/view_chapter.asp?id=8&page=3
37. http://www.grc.nasa.gov/WWW/K-12/airplane/atmosi.html
38. http://hypertextbook.com/facts/2001/AlbertEydelman.shtml
39. Khoury G, Gillet, J.D., Airship Technology, Cambridge University Press, 1999
40. Colozza A, *Airships for Planetary Exploration*, NASA/CR—2004-213345
41. http://lasp.colorado.edu/~than/academics/project5810/onset.html
42. Davis W, Kosicki B, Boroson D, Kostishack D, "*Micro Air Vehicles for Optical Surveillance*", The Lincoln Laboratory Journal, Volume 9, Number 2, 1996, pp 197-214.
43. http://www.cleanair.com/Equipment/Express/Container-yellow-page.htm
44. Doty D, *A Realistic Look at Hydrogen Price Projections*, Doty Scientific, Inc. Columbia, SC, Mar. 11, 2004 (updated Sept 21, 2004)

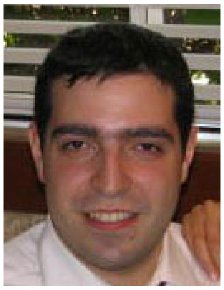
## BIOGRAPHY

***Kshitij Shrotri****, alias Badger, is a graduate research assistant at Georgia Institute of Technology, School of Aerospace Engineering, majoring in Structures. His research area is Structural Design and Analysis. He obtained a Masters degree in Aeronautics and Astronautics Engineering from Purdue University in Dec' 2003 where he worked on Mechanics of Composites. He obtained his Bachelors degree in Mechanical Engineering from the University of Pune in India in Aug'2000.*

***Mustafa Emre Gündüz*** *is a doctoral student at Georgia Institute of Technology, School of Aerospace Engineering, working in Design and Performance of Rotorcrafts. He obtained his Master's degree in Mechanical Engineering from the University of Michigan at Ann Arbor in May 2003 and his Bachelor's degree in Mechanical Engineering from Istanbul Technical University (ITU) in Turkey in June 2001. His research is focused on Structural Design and Optimization of rotorcraft systems for the ITU helicopter.*

***Adeel Khalid*** *is a doctoral candidate in the School of Aerospace Engineering at Georgia Institute of Technology. He obtained his Bachelor of Science degree in Mechanical Engineering (2000) from GIK Institute in Pakistan and finished his Masters degree in Mechanical Engineering (2001) from Michigan State University. He also got a Masters degree Aerospace Engineering (2004); and a Masters degree in Industrial Engineering (2005) both from Georgia Tech. His Ph.D. research includes system level design optimization and its integration with Collaborative Optimization applied to rotorcraft design.*

***Kavya K. Manyapu*** *is an Undergraduate Senior in the School of Aerospace Engineering at Georgia Institute of Technology. She is conducting research in Aerocapture of planetary at Space Systems Design Laboratory. Her primary interests are in Mars Entry, Descent and Landing Systems and Space Systems Design. She has interned at Boeing Integrated Defense Systems on the International Space Station, Ground Based Midcourse Defense and PAC-3 missiles. Presently she is working on a Mars Human Precursor Mission.*



***Yalcin Faik Sumer*** *obtained a Masters degree in Aerospace Engineering from Georgia Institute of Technology in 2004. His area of specialization is in Controls. Currently he is in the Turkish armed forces.*

***Dr. Daniel Schrage*** *is a Professor in the School of Aerospace Engineering at Georgia Tech and also serves as the Director of the US Army Center of Excellence in Rotorcraft Technology (CERT) and Flight Simulation Laboratory (FLIGHT SIM). He is also Co-Director of the Georgia Tech Aerospace Systems Design Laboratory (ASDL). He teaches graduate and undergraduate courses and supervises research in Concurrent Engineering, Integrated Product/Process Development (IPPD) and Aerospace Systems Design, as well as other aerospace engineering disciplines. He has numerous published articles and several book chapters in these areas. He has served as a government senior executive involved in the design and development of Army aviation systems and has served as a consultant to a broad cross-section of the aerospace industry. He has served on several AIAA Technical Committees such as Aircraft Design, V/STOL Aircraft and MDO, and national advisory boards, such as the Army Science Board, Air Force Studies Board, and NASA's Aeronautics Research and Technology Subcommittee (ARTS) for Materials and Structures. He serves as the Director of the Atlanta Chapter of the American Helicopter Society. He is also a member of the MIT team addressing Lean Aircraft Initiatives for the US Air Force and Aerospace industry.*