# MARV

## Martian Airborne Research Vehicle

## University of Maryland

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## 1.0 Abstract

Current Mars reference missions specify mission lengths that exceed present day limits on long-duration space flight. An increase in the length of on-site times over previous manned missions allows for greater scientific and exploratory flexibility. With this flexibility comes new opportunities for increasing our understanding of the solar system in which we live. To take advantage of these opportunities requires the development of new long-range transportation systems. Such systems must be able to operate in adverse environments with minimal investment in infrastructure while providing a high scientific return on investment.

An aerial research vehicle provides a great deal of mobility in selecting specific sites to explore. Recent developments in the space community have recognized the need to explore beyond the limited scope offered by a stationary base camp or even a land rover. An airborne research vehicle provides the mobility to explore areas of interest that lie at great distances from the base site. Long distance missions requires the crew to have a great deal of discretion in selecting destinations based on information not available before the mission. Airships have the flexibility to travel to sites without prior knowledge of the site's conditions. The selection of an airship as the primary mode of transportation maximizes the crew's ability to act on "local decisions" which in turn increase the mission's scientific return.

## 2.0 Reference Mission

As a starting point, the class was given the NASA Mars Reference Mission. This document is available from the following URL: http://www-sn.jsc.nasa.gov/marsref/contents.html.

## 3.0 Design Constraints

The Mars Reference Mission provided a base set of design criteria from which our other criteria were created. Project requirements for distance and total trip time also played a large part in the determination of the final vehicle configuration. MARV must be capable of safely transporting at least three people and the requisite life support and scientific equipment to virtually any point on Mars within a pre-determined amount of time. The base camp, located in Western Daedalia Planum, will serve as an operational base for all mission sorties and at times as a communications relay for contact with Earth.

## 4.0 Why a Lighter-Than-Air Vehicle?

Several possible designs were originally considered. Three designs were explored in depth, an airplane, a ballistic vehicle, and a lighter-than-air vehicle. From these three a final configuration was selected and developed further.

### 4.1 Airplane

Several variations of the Mars plane configuration were studied, all of which entailed very large wings spans and many structural difficulties. A length of 65m and a wingspan of 155m posed the greatest challenges to the airplane concept. Stowing the vehicle inside the descent lander's 19m long payload shroud requires the wings and the fuselage to fold at multiple points, thus making assembly on Mars difficult and uncertain. Finally through the requirements, the plane has to be capable of landing at unimproved landing sites. With such a large wing span, the possibility of landing at any unimproved sites is very uncertain and difficult at best. The combination of these problems led to the search for a better solution.

### 4.2 Ballistic

Sub-orbital flight was originally considered as a viable option because of the high velocities and short trip times (~1 hour) inherent in ballistic vehicles. Driving the design were the requirements for antipodal range and in-situ resource utilization (ISRU). Carbon Dioxide and Liquid Oxygen were chosen as the vehicle's propellant combination since both $CO_2$ and LOX can be extracted from the Martian Atmosphere. Round trip antipodal flight on Mars requires at least 11.4 km/s $\Delta V$. Using $CO_2$/LOX, with an Isp of 300 sec, the vehicle can only produce a maximum of 6.9 km/s $\Delta V$. Extracting the necessary 622 mt of propellant at a rate of 21 mt/sol requires 829 mt of equipment and 25 MW of power. Manufacturing sufficient quantities of propellant would have necessitated more time, power, and support equipment than were available within the scope of the Mars Reference Mission and the Design Constraints.

### 4.3 Lighter-Than-Air

A lighter-than-air vehicle with a volume of 2.3 million cubic meters would be capable of lifting the required structure and payload. Landing on unimproved terrain can be accomplished, and final approach can be done visually due to the slow speed. The vehicle has the advantage of high definition mapping and exploring any sights of interest while en-route. The proposed non-rigid design can be stored compactly for transportation to Mars. Solar generated electric power could provide for both propulsion needs during flight and equipment power on-site. The power produced and thus the speed varies throughout the day. The system was planned around 12.5 meters per second average velocity.

### 4.4 Conclusion

Of the three configurations evaluated the lighter-than-air vehicle was deemed most viable. Both the airplane and ballistic vehicles suffered logistics problems resulting from structural complexity or resource availability. A lighter-than-air vehicle, while very large, is able to circumvent these obstacles through its inherent simplicity of design, construction, and assembly.

## 5.0 Missions

Sortie mission sites, as well as the base site, have been determined as part of our mission requirements. MARV and the crew are required to land, perform scientific experiments at site, gather scientific samples from site and return to base camp. Western Daedalia Planum, base site, is located at 19°S, 144°W. The site is located at an altitude of 3 km. The terrain is a relatively smooth, flat plain. The required sites are listed in the table below in the order of execution.

| Load Source | Affected Component | Load Quantity |
|---|---|---|
| Gondola and Propulsion | Envelope | 35000 N |
| Tail Fins | Envelope | 4500 N |
| Hydrogen Pressure | Envelope | |
| Thrust | Envelope and Propeller Pylon | 2100 N |
| Aerodynamic Loading - Fins | Envelope and Fins | 4800 N |
| Aerodynamic Bending Moment | Envelope | 157,000 N-m |
| Cabin Pressure | Pressure vessel | 50,000 Pa |
| Payload | Internal Structure of Pressure Vessel | 24000 N |
| Hoop Stress | Pressure vessel | 33 MPa |
| Longitudinal Stress | Pressure vessel | 466000 N |

**Table 1**

All sortie sites are out of line of site with base camp and located at different altitudes, in different terrain and experience varying weather conditions. The vehicle must be able to land at each sortie site within a 1km radius, except for the base site. Since the base site will be improved the vehicle must be able to land within 50 meters of the landing area. In order to visit each site in relatively mild weather with longer hours of daylight, the northern sorties are visited first. In accordance with the "Human Exploration of Mars : The Reference Mission of the NASA Mars Exploration Study Team", expected landing on Mars is July 2014, using the fast-transit mission profile. In July of 2014 Mars will be experienceing a northern summer, southern winter. A travel time table is presented below.

| Sortie | Mission Description | Site Name | First Leg (sols) | Mission Execution Time (sols) | Returning Leg (sol) | Total Length of Sortie (sols) |
|---|---|---|---|---|---|---|
| 1 | *Medium Range Mission* | *Olympus Rupes* | 2.2 | 30.0 | 5.7 | *37.9* |
| 2 | *Polar Mission* | *North Polar Region* | 8.3 | 30.0 | 17.4 | *55.7* |
| 3 | *Triangle Mission* | *Maja Valles (leg 1)* | 7.6 | 13.0 |  | *51.4* |
|  |  | *Connecting (leg 2)* | 9.3 |  |  |  |
|  |  | *Candor (leg 3)* | 0.0 | 13.0 | 8.4 |  |
| 4 | *Short Range Mission* | *Upper Mangala* | 1.1 | 30.0 | 1.1 | *32.2* |
| 5 | *Antipodal Mission* | *Sinus Sabaecus* | 12.8 | 28.0 | 11.5 | *52.4* |

**Table 2**

There was an important wind direction variation found in Martian Atmospheric Profiles. Easterly winds are prominent in the southern hemisphere and westerly winds are prominent in the northern hemisphere. Viking lander missions measured for a wind variation of 3- 7 m/s. Seventy-five percent of the maximum winds sustained during the Viking lander mission was used to generalize the amount of head and tail winds that MARV would experience. Travel time varies due to the expected winds. Travel distance varies from a direct route due to high-elevation terrain features.

# 6.0 Science

## 6.1 Scientific Objectives

The goal of the each sortie is to collect information about Mars that will allow the completion of the following scientific objectives:

- Gain an understanding of the current state of the Martian environment to determine the possibility of human habitation
- Study Martian geology, meteorology, and seismology to determine what the Martian environment may have been like in the past as well as what it may be like in the future
- Search for evidence of extinct or extant life that may aid the understanding of how life began on Earth

## 6.2 Olympus Rupes

This site is on the side of Olympus Mons. The surface is composed of smooth lava flows of basaltic material from three different ages. Geologic and atmospheric equipment will be needed to perform experiments and collect samples from the surface, below the surface and the atmosphere. It does not appear that this site is of biological significance, so no exobiological equipment will be needed on this sortie.

## 6.3 North Polar Region

This site is on layered polar deposits of Amazonian-age materials. It is believed that the layering is due to variations in the ice-dust mixture. This suggests that the climate in this area has been this way for a long time. An important goal is to measure the water and $C0_2$ content of the ice. Seismology, geology and atmospheric sciences will be studied here. Since there is ice present at this site, exobiological experiments will be performed on certain samples.

## 6.4 Maja Valles and Candor

This sortie is knows as "The Triangle Mission" because two sites will be visited and the path from base camp to Maja Valles to Candor and back to base camp makes a triangle. Maja Valles lies in an outflow channel. From this site information about Martian morphology, outflow dynamics, stratigraphy can be collected. Important samples that can be collected are sediments from channels and fan-deltas and lake deposit. Ancient crustal material, crater ejecta, and exposed strata will also be studied at this site. As with most of the other sites, atmospheric samples will be collected and studied. There is also remote chance that ground ice may exist at this site. If so, it will be studied and exobiological experiments will be performed.

The second site on the sortie is Candor. It is believed that Candor was a locus of ground water discharge on Mars. Because of this, there could be microbial minerals precipitated by iron bacteria located at the heads of channels, sapping sites, and in lake sediments. One of the main objectives at this site is to collect samples of iron ore from red and black ground patches to examine the morphology of iron and magnesium oxides that may have been precipitated by ancient iron bacteria.

## 6.5 Upper Mangala Valles

Most of the scientific work done here will include taking samples of Hespian-age and Nochian-age materials. Also, nearby crater ejecta will be collected and studied. Meteorological experiments will also be performed to study the atmosphere. No equipment for studying exobiology will be taken to this site, as this area is not believed to have any significance as far as life is concerned. However, exobiological experiments can still be performed at base-camp on samples that have been collected.

## 6.6 Sinus Sabaeus Northeast

This site is located on a smooth plain known as the Plateau Sequence. Of major interest on this site is a mound known as "White Rock" which is in a crater on the plain. It is believed that this rock made up of playa deposits composed of chemically precipitated evaporite minerals. These types of formations are important to study because they have the potential to for preservation of organisms and biomolecules. Also of interest are channels that flow into the crater, which resemble terrestrial dendritic drainage systems.

## 6.7 Scientific Equipment

In order to satisfy the scientific objectives, EVAs will be performed on a regular basis to collect samples and perform experiments. Most of the samples collected will be in the form of rocks, dust, or samples obtained from the subsurface by drilling. The vehicle's laboratory will be able to perform tests to determine the age and composition of the samples, as well as detect water or any volatiles that may be present in the sample. Meteorological experiments will be performed to determine properties of the air, such as aerosol content, wind speed, pressure, and temperature. Exobiological equipment will be taken on some of the sorties that appear to have biological significance. This equipment will allow for the detection of organic materials and the determination of whether they are of Martian origin or the result of contamination from terrestrial origins. To perform these experiments, the following list of equipment will be needed.

| Name | Description | Mass (kg) | Power (kw) | Volume ($m^3$) | Use |
|---|---|---|---|---|---|
| Mars Geophysics Package | Determines local magnetic and gravitational fields and detects water and volatiles | 25 | .01 | .02 | Field |
| Marsnet | Seismological stations that measure long-term seismic activity | 25 | .01 | .02 | Field |
| Geological Field Package | Hand tools for use on EVA, sample containers, and documentaion tools | 335 | .2 | .55 | Field |
| Differential Scanning Calorimeter | Identifies minerals and volatiles | 20 | .04 | .03 | Field |
| 10-meter Drill Rig | Used for obtaining samples below the surface | 260 | 5.5 | 10 | Field |
| Thermal/Evolved Gas Analyzer | Analyzes gasses released from the soil | 2 | .014 | .0014 | Lab |
| Multispectral Imager | Close range imaging | 35 | .024 | .16 | Field |
| Binocular Microscope | Preliminary sample examination and evaluation | 5 | .02 | .01 | Lab |
| Petrographic Microscope | More intensive petrographic analysis of samples | 20 | .04 | .04 | Lab |
| X-ray Fluorescence Spectrometer | Mineralogical analysis | 3 | .01 | .02 | Lab |
| X-ray Diffractometer | Elemental anaylsis | 5 | .015 | .015 | Lab |
| Mossbauer Spectrometer | Analyzes iron oxides and dust particles containing iron. | 3 | .01 | .01 | Lab |
| Mass Spectrometer | Determines absolute ages of rocks | 50 | .1 | 1 | Lab |

**Table 3 Geological Equipment**

| Name | Description | Mass (kg) | Power (kw) | Volume ($m^3$) | Use |
|---|---|---|---|---|---|
| Surface Atmospheric Package | Measures temperature, pressure, wind velocity, and aerosol content | 5 | .05 | .02 | Field |
| Aerosol Volatile Sniffer | Collects aerosol particles in order to analyze volatiles | 15 | .05 | .1 | Field |
| Ionospheric Sounder | Measures the ion compostion of the upper atmosphere | 50 | .14 | .3 | Field |
| Meteorological Balloons | Determines wind speed, cloud height, pressure, temperature and humidity | 50 | .05 | .1 | Field |
| Aerosol Laser Ranger | Measures the height and content of clouds | 40 | .3 | .1 | Lab |

**Table 4 Meteorological Equipment**

| Name | Description | Mass (kg) | Power (kw) | Volume ($m^3$) | Use |
|---|---|---|---|---|---|
| Incubator | Used for incubating petri dishes for exobiologcial experiments | 3 | .03 | .01 | Lab |
| Neutron Spectrometer | Anaylsis and detection of organics | 6 | .006 | .00015 | Lab |
| Specific Electrode Analyzer | Analysis of solutes that may be of biological significance | 1 | .002 | .008 | Lab |
| Soil Oxidant Survey | Equipment used to analyze the oxidants in the Martian soil | 1 | .005 | .003 | Lab |
| IR Laser Spectrometer | Study trace gasses in the atmosphere and soil which may contain biological activity | 5 | .01 | .03 | Lab |
| Optical Microscope | High resolution optical microscope | 3 | .02 | .002 | Lab |
| Biological Apparatus | Petri dishes, glass spreaders, and other biological equipment | 30 | 0 | .08 | Lab |

**Table 5 Exobiological Equipment**

## 7.0 Vehicle Description

The non-rigid airship will have an overall length of 344 meters and a height of 114 meters. The Kevlar/Mylar envelope will have a total gas volume of 2.3 million cubic meters and a surface area of 122,000 square meters. All lift will be generated by filling the envelope with hydrogen gas. Varying the volume of

Martian atmosphere in each of the ballonets will provide trim control for both altitude and pitch. The ballonets will also be used to maintain an envelope gage pressure between 45 Pa and 200 Pa.

Primary yaw, pitch, and roll control will be provided by the rear mounted fins. The fins will be composed of non-rigid cylinders filled with hydrogen gas for compact storage and increased buoyancy. The neutrally buoyant fins will eliminate the extra weight of conventional rigid fins. As with the envelope, all inflatable structures will be computer monitored for leaks and pressure loss.

| Section | Mass (kg) | Power (kW) |
|---|---|---|
| Communications, Navigation, and Electronics | 150 | 7.5 |
| Flight Propulsion System | 1350 | 50 |
| Science Equipment | 1500 | 7 |
| Life Support and Personnel | 2200 | 2.5 |
| Power Generation System | 11200 | 60 |
| Vehicle Structure | 120000 | <1 |

**Table 6**

# 8.0 Structures

## 8.1 Structural Requirements

All structural components must have non-negative margins of safety, and be able to accommodate touchdown velocities of 1 m/s lateral and 1 m/s vertical. In addition, all safety-critical mechanisms shall have redundant sensing and actuation.

The following factors of safety must be incorporated

- Secondary structure: 1.5
- Primary structure: 2.0
- Pressurized tanks: 3.0
- Pressure lines: 4.0

## 8.2 Load Sources and Quantities

The major loads on the vehicle are generated from the lifting gas. The internal pressure of the gas creates the greatest amount of stress, which is in the hoop direction. The longitudinal stress of 17 MPa is about half the amount of the stress in the hoop direction. The lifting gas imparts a bending moment of 976,000 N-m. This moment is a result of the super-pressure created, which causes the ends of the envelope to bend downward thereby, creating stress on the top of the envelope. All other loads are listed below.

| Load Source | Affected Component | Load Quantity |
|---|---|---|
| Gondola and Propulsion | Envelope | 35000 N |
| Tail Fins | Envelope | 4500 N |
| Hydrogen Pressure | Envelope | 200 Pa |
| Thrust | Envelope and Propeller Pylon | 2100 N |
| Aerodynamic Loading - Fins | Envelope and Fins | 4800 N |
| Aerodynamic Bending Moment | Envelope | 157,000 N-m |
| Cabin Pressure | Pressure vessel | 50,000 Pa |
| Payload | Internal Structure of Pressure Vessel | 24000 N |
| Hoop Stress | Envelope | 33 MPa |
| Longitudinal Stress | Envelope | 466000 N |

**Table 7**

## 8.3 Envelope Design

The 0.07mm thick Kevlar outer hull will provide the strength necessary to withstand the maximum hoop stress of 33.6 MPa. Kevlar was chosen because it is twice as strong as Nylon-66 and 50% stronger than E-glass. Kevlar also has a high tear resistance. The inner hull will consist of 0.012mm thick Mylar, which will be used to contain the lifting gas. Mylar was chosen because of its low permeability to hydrogen. Ballonets constructed of Mylar will occupy the lower half of the envelope and provide trim control.

## 8.4 Pressure Vessel Design

### 8.4.1 Assumptions

The analysis for the minimum wall thickness was based on the hoop stress of a cylinder with hemispherical endcaps. A variety of materials, internal pressures, and radii were initially studied. The internal volume and pressure were later determined by Life Support and Human Factors to be 100 $m^3$ and 50 kPa, respectively. A factor of safety of 3 was used in accordance with the structural requirements.

### 8.4.2 Results

The dimensions will be as shown in Figure 1, with an internal cylinder radius of 1.8m. The material will be Kevlar-90, and the wall thickness will be 3mm except for the rear endcaps which will be 5mm. All loads will be transmitted to the internal structure, not to the pressure vessel walls. The resulting minimum margin of safety is 3.25

## 8.5 Pressure Vessel Internal Structure Design

The internal structure will consist of a main support beam with hanging rings. All internal loads will be transmitted by simply-supported beams that connect to the rings. All doors and windows will be framed so that all loads can transmit to the rings. The Kevlar-90 pressure vessel will be attached to the outside of the rings.

## 8.6 Airlock Design

The airlock will be attached to the back of the pressure vessel. The rear cap and cylindrical section of the airlock are the same dimensions as the pressure vessel itself. The airlock will accommodate at least two astronauts with substantial scientific loads. The door between the pressure vessel and the airlock will open towards the pressure vessel so that pressure assisted sealing is achieved when the airlock is depressurized. The door to the outside must be pulled inward before it will open outward so that it achieves pressure assisted sealing when the airlock is pressurized. The door to the outside will act as a staircase to provide access to the surface, but the design is still TBD.

## 8.7 Cockpit Windshield Design

The window will have a field of view of 60 x 90 degrees (vertical by horizontal), and will be constructed of Polycarbonate plastic. The stress was calculated by assuming a 1.8 m sphere of polycarbonate plastic subjected to the internal pressure of the cabin. The resulting thickness was 6 mm, which yields a margin of safety of 7. The reason for the high margin of safety was the concern over the approximations made during analysis.

## 8.8 Figures

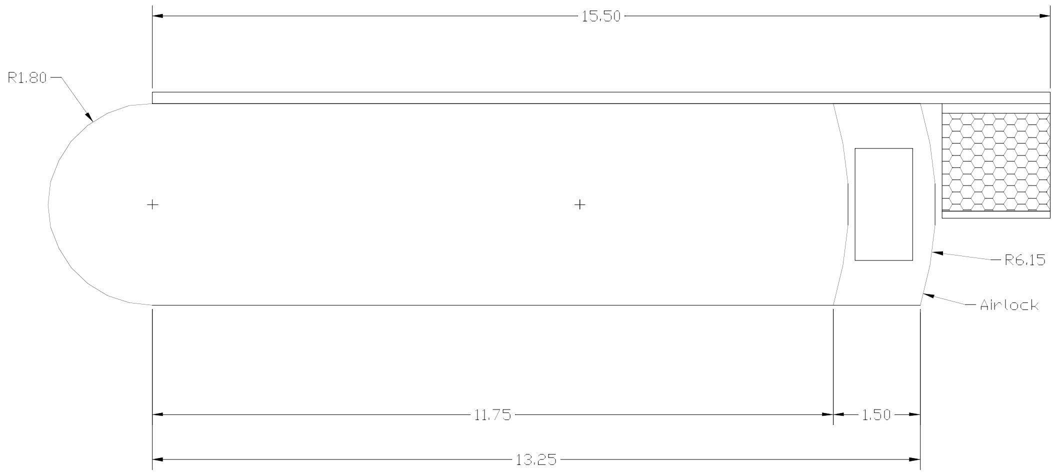

**Figure 1 Pressure Vessel External Dimensions**

**All dimensions in meters**

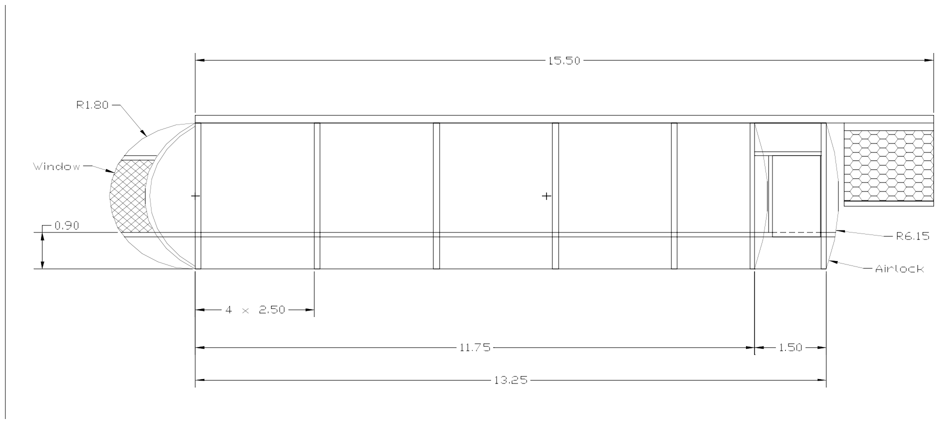

**Figure 2 Pressure Vessel Structural Diagram**

**All Dimensions in meters**

# 9.0 Power, Propulsion, and Thermal

## 9.1 Power

The power subsystem can be broken down into several parts, which include a primary power source, power distribution mechanisms, power regulation and control, and energy storage. The two main sections are those of primary power and energy storage, for which a solar array system and battery configuration, respectively, were chosen.

Power system trade studies were based primarily on weight and volume considerations. Photovoltaic arrays proved to be the most economical and efficient method of power generation. Energy storage needs will be provided by nickel-hydrogen batteries.

The primary power generation and power storage systems were sized according to the power needs of the vehicle. These included 60 kW required inflight during daylight hours, 18 kW required for onsite daylight operations, 8 kW required over 10.6 hours for night operation, which amounts to storage capabilities of 84.9 kW-hours, and a 10% contingency plan, which amounted to an additional 6.8 kW.

The primary power generation system, consisting of photovoltaic arrays, will be mounted on the vehicle's outer structure in order to take advantage of the envelope area. Thus, it will be a non-tracking system. Blocking diodes can be used to prevent battery discharging in cases where sections are shadowed at a given time. The design was limited by the following parameters:

| | Ultra Flex Arrays |
|---|---|
| Efficiency, % | 22 |
| Degradation, %/yr | 3.75 |
| Density, kg/m$^2$ | 1.75 |
| Power Output Density, W/m$^2$ | 66.8 |
| Lifetime, yrs | 5 |
| Peol, W/m$^2$ | 55.2 |
| Power Output, kW | 66.8 |
| Area, m$^2$ | 1210 |

**Table 8**

This assumption was based on the premise that further development over the next 15 years will lead to higher efficiency solar cells. Furthermore, this is also taking into consideration the factor that the operating temperature on Mars is much lower than that of an Earth-based satellite. The Ultra Flex Array Design was chosen as the anticipated array design because it provides the type of flexibility that will be needed to mount the solar array on the blimp's envelope. The solar flux is approximately 22% of that received in Earth orbit because of atmospheric losses and Mars' greater distance from the Sun. Furthermore, dust storm conditions characteristic of the Martian environment drop this percentage to roughly 6.5%, or approximately 86.9 W/m$^2$. Power at the beginning of life, Pbol, is a function of cell efficiency and solar flux. Power required by the solar array, Psa, is a function of the power necessary to conduct day and night operations. Power required at the end of life, Peol, is a function of lifetime degradation and Pbol. Lifetime of the solar array system was estimated at one year for the primary purpose of attempting to reduce the overall mass of the system.

The power storage system will consist of nickel-hydrogen ($NiH_2$) batteries. The required 84.9 kW-hours of energy will be stored in batteries consisting of 17 cells rated at an 81 A-h capacity. Battery lifetime was assumed to be five years. A short battery life was chosen with the expectation that they will be replaced as they wear out. Furthermore, because depth of discharge (DoD) is a function of cycle life, as lifetimes increased, DoD decreases significantly. Thus, a shorter lifetime is more efficient.

| $NiH_2$ Battery | Operating Conditions |
|---|---|
| Daylight Duration, hrs | 14 |
| Eclipse Duration, hrs | 10.6 |
| Bus Current, A | 100 |
| Charging Power, kW | 6.8 |
| Depth of Discharge, V | 0.7 |
| Discharge Voltage, V | 1.25 |
| Charge Voltage, V | 1.4 |
| Rating, A-h | 81 |

**Table 9**

# 10.0 Crew Systems

## 10.1 Cabin Conditions

Pressure of the crew cabin will be maintained at 50 kPa for the duration of the mission in order to have zero pre-breathe time for EVAs. The percentage of oxygen maintained in the cabin is 45 %, this value allows the cabin to operate at equivalent sea level conditions. The cabin conditions are given in Table 10.

| Atmosphere Parameter | Cabin Value |
|---|---|
| Total Pressure | 50 kPa |
| ppOxygen | 22 kPa |
| ppNitrogen | 27.5 kPa |
| ppCarbon Dioxide | 0.4 kPa |
| Temperature | 18.3 - 26.7 C |
| Relative Humidity | 25 - 70 % |

**Table 10**

This pressure is governed by the requirement for daily EVAs on the mission. A cabin pressure of 50 kPa allows for daily EVAs without decompression or pre-breathing . The suit pressure is kept at 30 kPa to allow for mobility and dexterity.

## 10.2 Air Revitilization

Air in the crew cabin must be monitored and maintained to ensure crew survival. For this design, particles such as dust and micro-organisms are removed from the air using High Efficiency Particulate Arrestance (HEPA) filters. Carbon dioxide is then removed using Solid Amine Water Desorption. The carbon dioxide collected from the cabin air is reduced using both the Sabatier process and carbon dioxide electrolysis. Carbon dioxide electrolysis will be used to generate oxygen for the mission. Additional carbon dioixde can be obtained from the Martian atmosphere in order to produce more oxygen.

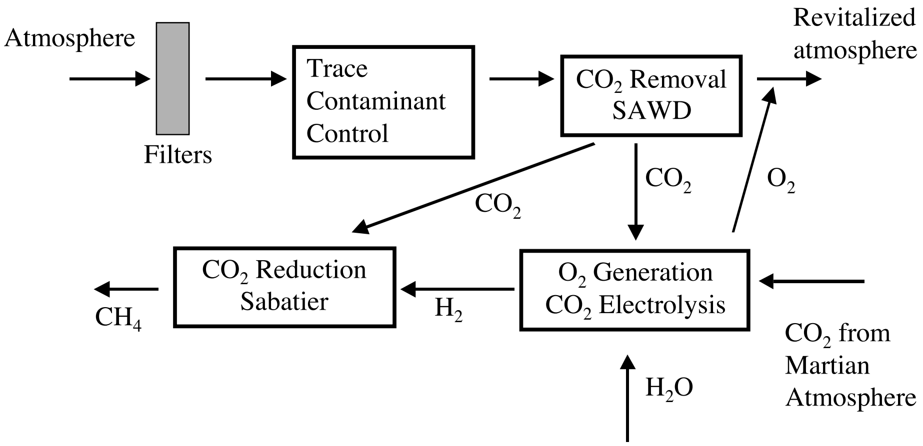

**Figure 3**

## 10.3 Air Maintenance

Air quality must be maintained closely in a small environment such as a crew cabin. Contaminants, temperature, humidity and components of the air must be carefully monitored. Particulate levels will be monitored using a "non-dispersive infrared" (NDIR) technique with a Gas Chromatograph/Mass Spectrometer (GC/MS). As mentioned before, High Efficiency Particulate Arrestance (HEPA) filters will be used to remove dust and micro-organisms. A Temperature and Humidity Controller (THC), which is a condensing heat exchanger, is used to maintain comfortable temperature levels in the cabin. Partial pressures of oxygen, carbon dioxide, carbon monoxide, nitrogen, and water vapor will be monitored and maintained on an “as needed” basis. Ionization fire detection devices will be placed in air ducts with the ability to detect smoke particles 0.3 microns or larger in less than 5 seconds. In larger spaces flame detectors will be used to monitor flicker rate in the UV and infrared bands.

## 10.4 Airlock and EVA Operation

The airlock on the vehicle is able to accommodate two fully suited crew members and EVA equipment. The airlock is capable of supporting both crew members with oxygen, power and water during EVA suit donning and checkout. The airlock can also function as a hyperbaric chamber in order to treat decompression sickness. The EVA suit pressure is maintained at 29.6 kPa with 100 % oxygen. The EVA suits should be self carrying, with a Personal Life Support System (PLSS) to monitor health, life support and power system status. EVAs will require no pre-breathe time due to the lowered cabin pressure. Each EVA has the capacity to last for 6 hours with 15 minutes for donning, 15 minutes for checkout and 30 minutes of reserves.

## 10.5 Water

The human body requires approximately 2.5 kg/man-day of consumed water in order to survive. The water design loads provided for this mission are 3.0 kg/man-sol potable water and 6.0 kg/man-sol hygiene water. These will be provided to the crew through a closed water loop consisting of a Multifiltration process for potable water recovery and Vapor Compression Distillation System (VCDS) for hygiene and urine water recovery. Potable water will be recovered from the humidity control system condensate and water transfer from the hygiene water reservoir. Hygiene water will be supplied from recovered hygiene water and urine water.

## 10.6 Food

The crew will be provided with approximately 0.62 kg/man-sol (dry weight) of food. Food packaging weighs approximately 0.45 kg/man-sol. Dry beverage powder mixes, freeze dried, irradiated, rehydratable, and thermostabalized foods will be provided to the crew during their mission. Three meals will be allowed per sol with repeat of meals after 6 sols.

## 10.7 Radiation Protection

The established radiation exposure limits for low Earth orbit are defined in the table below. These limits are used since there have been no well defined limits for a Martian mission. Also required is an exposure limit of 3 REM body dose exposure limit in a maximum length mission including a Class IV solar flare in the worst case mission location. From this table, it can be seen that the blood forming organs (BFO) have the most stringent exposure limits.

| Exposure Duration | BFO (cSv) | Eye (cSv) | Skin (cSv) |
|---|---|---|---|
| Daily | 0.2 | 0.3 | 600 |
| 30 days | 25 | 100 | 150 |
| 90 days | 35 | 52 | 105 |
| Annual | 50 | 200 | 300 |
| Career | 100 - 400 | 400 | 600 |

**Table 11**

The protection provided by the Martian atmosphere is summarized in the table below. Atmospheric protection on the surface of Mars varies directly with the surface pressure. Therefore, the amount of protection varies with altitude and also as the atmosphere density changes seasonally.

| Altitude (km) | Protection, g/cm$^2$ CO$_3$ | |
|---|---|---|
| | Low-density Model | High-density Model |
| 0 | 16 | 23 |
| 4 | 11 | 16 |
| 8 | 7 | 11 |
| 12 | 3 | 8 |

**Table 12 Simonsen, L.C., Nealy, J.E., 1993**

The equivalent doses to the blood forming organs (BFO) as a function of altitude for both galactic cosmic rays and solar flare events are summarized in the graphs below. From these graphs, it is concluded that sufficient radiation protection is provided by the Martian atmosphere alone.

# 11.0 Avionics

## 11.1 Navigation System

The primary vehicle navigation system will be inertial based navigation, with position and velocity updates provided by a terrain contour navigation (TCN) system and a sun tracking system. An air data system is also present to provide dissimilar redundancy.

The TCN system provides positional resets by comparing the terrain profile, as measured by laser altimeters, against the terrain profile as stored in a database in the vicinity of the estimated position provided by the inertial system. The TCN system can provide positional accuracy of up to 50 m with present technology. These position estimates may also be differentiated to provide velocity estimates.

The sun tracking system provides attitude information based on the measured location of the sun in the sky and its known position based on location and time estimates.

A breakdown of the navigational sensor system is given below.

| Component | Accuracy | Mass (kg) | Power (W) | Volume (cc) | MTBF (hrs) | Levels |
|---|---|---|---|---|---|---|
| Inertial Sensor | - | 1.4 | 30 | 1600 | 50,000 | 2 |
| - Gyros | 0.01 °/hr | - | - | - | - | - |
| - Accelerometers | 50 μg | - | - | - | - | - |
| Laser Altimeter | 15 cm | 2.0 | 50 | 6000 | 25,000 | 3 |
| Sun Sensor | .008° | 2.5 | 15 | 1200 | 40,000 | 2 |
| Air Data System | - | 5.5 | 20 | 8000 | 12,000 | 2 |
| - Pitot Probe | 0.1 m/s | - | - | - | - | - |
| - Barometric Alt. | 6 m | - | - | - | - | - |
| - Temp. Probe | 1 K | - | - | - | - | - |
| **Totals** | - | 24.8 | 280 | 39600 | - | - |

**Table 13 Navigational Sensors**

In order to meet the requirement of landing within 1 km of an unimproved landing site with these sensors, a positional reset rate of 0.752/hour is required, and the overall system reliability is 99%.

Below is a schematic representation of the navigation system. It shows how the strap down inertial navigation system works with the position and attitude updates. These updates are optimally combined with the inertial estimates in order to produce an overall position estimate.

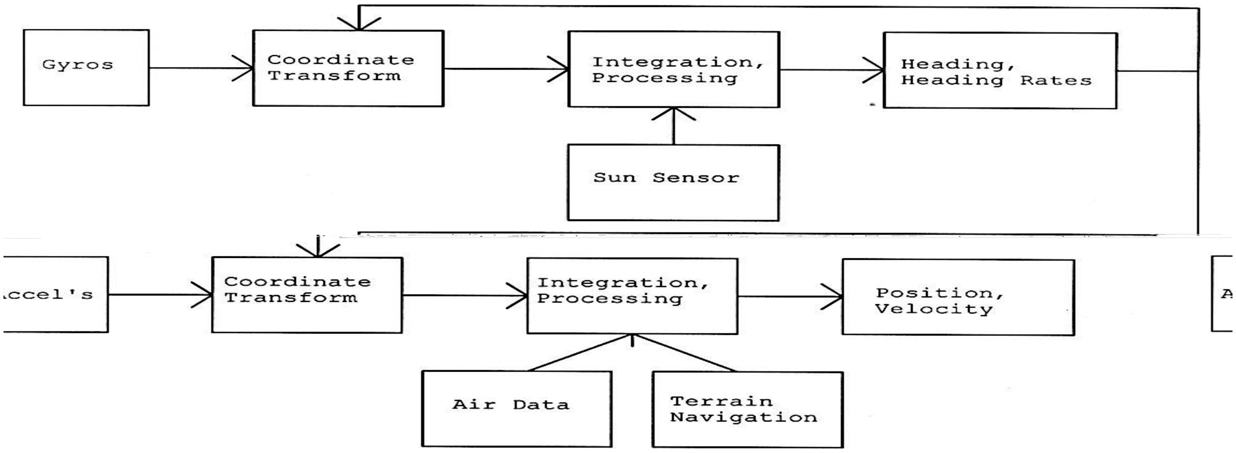

**Figure 4 Navigation System Diagram**

## 11.2 Flight Control System

The vehicle is controlled in flight by a Fly-by-Light system. This type of control system is similar in structure to a more conventional Fly-by-Wire system, but replaces electrical wires by fiber optic cables, thereby saving weight and increasing reliability.

Present fiber optic technology has proven a typical MTBF of 30,000 hours. In order to meet the reliability requirement of 99%, 5 levels of redundancy in flight control is needed. This gives an overall power requirement of 50 W and a mass of 85 kg.

In flight attitude control is achieved primarily by use of aerodynamic control surfaces, whose movements are commanded by the flight control system. Secondary sources of attitude control are provided by differential power output from the engines and differential inflation of the fore and aft ballonet, for yaw and pitch control, respectively. Active roll control is not required, because there is no need to rotate the craft about its roll axis, but in the event of perturbing forces the aerodynamic control surfaces combined with the overall system stability may be used to damp out the resulting motions.

Reaction control while on station performing the scientific mission, or while anchored for night is primarily passive in nature. Here the vehicle is simply allowed to turn into the wind, as would a weathervane. In a more violent dust storm situation, it may be required to use some combination of aerodynamic controls and the secondary controls as previously discussed, for which there is some reserve power.

A diagram of the flight control system is given below.

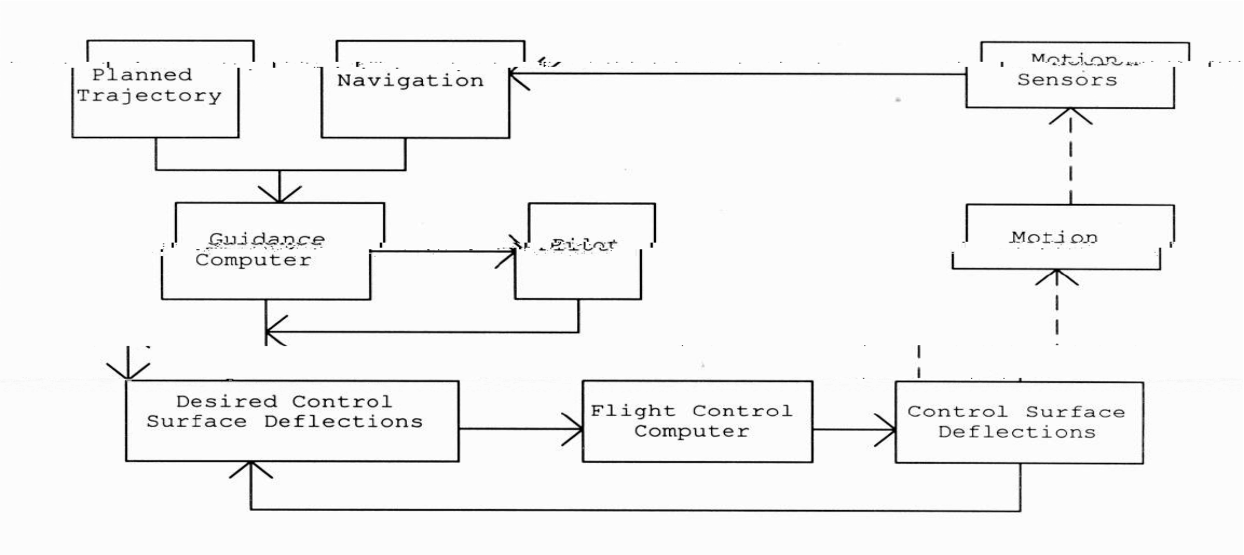

**Figure 5 Flight Control System Diagram**

In the event of any deviation from the planned trajectory, as determined by the navigation system, the guidance computer determines the necessary course corrections to bring the craft back onto its nominal path. The flight control computer then implements these corrections by issuing commands to the control units. The resulting motions are then detected by the navigation system thereby repeating the process until the craft is back on its planned track. As required, it is also possible for the craft to be capable of active human control to modify its trajectory.

## 11.3 Communications

The communications system is required to provide two-way communications incorporating high-rate telemetry, voice, and high-definition video simultaneously to three EVA suits, the EVA Rover Vehicle, Earth Deep Space Network (DSN) Stations, and Base Camp whenever possible. In addition to this, the vehicle must also be capable of receiving, storing, and forwarding data to a Low Mars Orbiting (LMO) satellite for non-real-time communications to base camp.

To satisfy these requirements, there are three antenna systems required. The first is an off-the-shelf dipole system that will provide the ability to communicate with the three EVA suits as well as with the rover vehicle to relay the high-definition video, voice, and telemetry required. The second antenna system is a five-meter parabolic dish that is used for communications back to Earth, when in view. This system makes use of the DSN's k-band capabilities while also including an encoding scheme of Reed-Solomon and 1/4 convolution to improve the data integrity during transmission. The third system is a two-meter parabolic dish that is used to communicate to base camp when in line of sight or to the LMO satellite for non-real-time communications.

| | Earth | LMO Satellite/Base |
|---|---|---|
| Receive/Transmit Frequency (GHz) | 25.8 / 23.7 | 4.6 / 5.1 |
| Receive Data Rate (Mbps) | 127.5 | 108.1 |
| Transmit Data Rate (Mbps) | 138.5 | 100.0 |
| Bit Error Rate (bps) | $10^{-3}$ | $10^{-9}$ |
| Power Required (W) | 5000 | 50 |

**Table 14**

In addition to these nominal operating systems for communications, there is an Omni antenna for emergency transmissions from the vehicle to the LMO satellite or to base camp when in a line of sight.

The total power required for the communications system is 7kW when all the available links are being utilized simultaneously. During emergency transmissions, only 200 W is required. The total mass of the entire system is 80 kg.

## 12.0 Cost Analysis

MARV's cost breakdown was based on the Spacecraft/Vehicle Level Cost Model (SVLCM) developed by NASA's Johnson Space Flight Center. The SVLCM is a simplified cost model that provides cost estimates for the development and production of spacecraft, launch vehicle stages, engines and scientific instruments. SVLCM is a top-level implementation of the NASA/Air Force Cost Model (NAFCOMM). (http://www.jsc.nasa.gov/bu2/guidelines.html)

The input for the SLVCM requires the user to know what type of spacecraft (manned, launch vehicle, etc.), dry weight of the spacecraft, quantity that your going to produce, and the learning curve percentage. As a rough approximation, MARV's dry weight is 30mt, the quantity is two, and we assumed a learning curve percentage of eighty-five percent.

MARV's largest cost was that of the Development phase accounting for 82% of the total project with an estimated cost of 5.2 billion ($FY99). The Production phase second, accounting for fourteen percent at an estimated cost of 890 million ($FY99). Including Mission Operations, which was calculated by the Mission Operations Cost Model (MOCM), was four percent of MARV's cost budget, 276 million ($FY99). The total program cost approximates to 6.1 billion ($FY99).
(Figure 9)

| **Spacecraft/Vehicle Level Cost Model** | |
|---|---|
| **Vehicle Dry Weight (kg)** | 30000 |
| **Quantity** | 2 |
| **Learning Curve (%)** | 85 |
| **Validity range (kg)** | 231 - 69638 |
| **Number of Data Points** | 8 |

**Table 15**

| **SVLCM Results** | |
|---|---|
| **Development ($BFY99** | 5.2 |
| **Production($BFY99)** | 0.89 |
| **Total($BFY99)** | 6.0 |

**Table 16**

| **Mission Operations Cost Model** | |
|---|---|
| **Investment ($BFY99)** | 6.0 |
| **Mission Type:** | Manned |
| **Average Annual MODA ($MFY99)** | 276 |
| **Total MODA ($BFY99)** | 2.2 |

**Table 17**

Every aerospace program includes in their cost analysis an allocated yearly cost through the duration of their program. Annual cost allocation is based on two parameters: cost fraction, and the peakedness factor. The cost fraction represents the total cost spent when fifty percent of the project time is complete. For MARV, it was estimated to be 0.5. The second parameter is the peakedness factor, which helps determine the maximum annual cost. For MARV, the peakedness factor was 1.0 which assumes that the development activity rises rapidly, peaks, and then falls rapidly. The project timeline for MARV is eight years, starting in 1999 and ending in 2007. (Figure 10) The projected cost throughout the program takes on a chevron form with small cost required to begin the project, large costs in the middle and small costs towards the end of the program. (Figure 10)

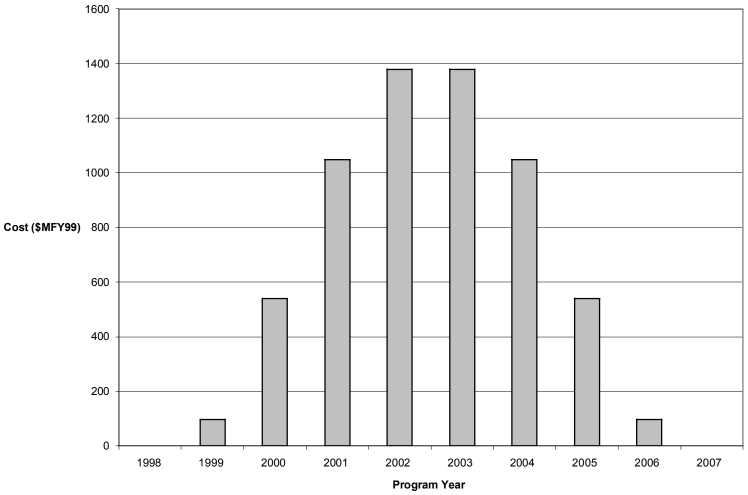

**Figure 6 Cost Allocation**

## 13.0 Conclusions/Recommendations

Analysis of the Lighter-Than-Air concept indicates that it is both practical and feasible It should , however be noted that further, more detailed, studies are required before this design can be brought to implementation. Areas needing additional consideration include storage and deployment, maneuverability, solar array technology, envelope maintenance, ground handling, and Martian weather forecasting systems.