MARVIN:
MARtian Vehicular INvestigator
A Proposal for a Long-range Pressurized Rover

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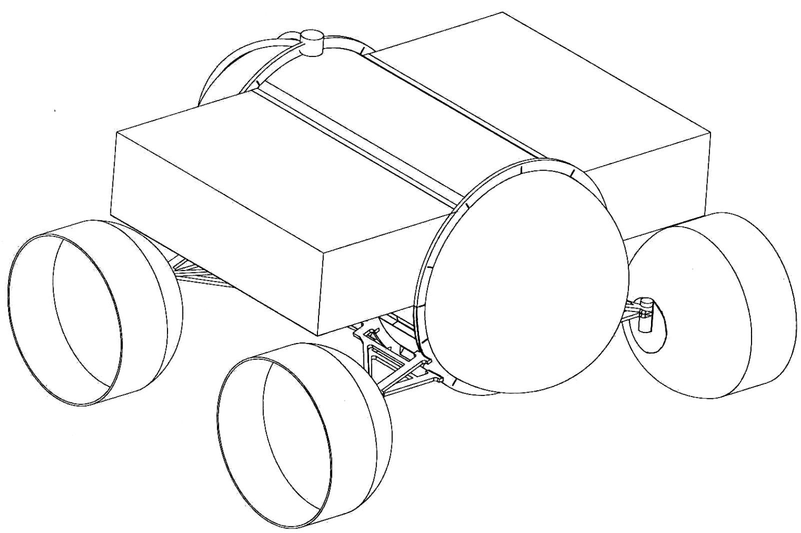


Front Quartering View of MARVIN

Abstract
NASA is planning manned missions to Mars in the near future. In order to fully exploit the available time on the surface for exploration, a roving vehicle is necessary. A nine-member student design team from the Wichita State University Department of Aerospace Engineering developed the MARtian Vehicular INvestigator (MARVIN) a manned, pressurized, long distance rover. In order to meet the unique requirements for successful operation in the harsh Martian environment a four wheeled, rover was designed with a composite pressure vessel six meters long and 2.5 meters in diameter. The rover is powered by twin proton exchange membrane fuel cells which provide electricity to the drive motors and onboard systems The MARVIN concept is expected to have a 1500 km range with a maximum speed of 25 km/hr and a 14-day endurance.

1 Introduction

NASA's reference mission calls for means of exploring Mars's surface. A pressurized rover seems fitted for the task. Therefore, our team of nine students undertook the conceptual design of such a rover, as a requirement for a two-semester design class at Wichita State University. As additional challenges, the team decided to participate in the HEDSUP competition and build a 1/8th-scale model of the rover to use in an outreach program.

1.1 Mission

The MARtian Vehicular INvestigator's (MARVIN's) mission will be twofold. First, as an exploratory vehicle, it will be used to collect, photograph and analyze samples from the Martian surface. Secondly, it will provide the unique opportunity to study human behavior in an unfamiliar and inhospitable environment. This paper deals only with the exploratory aspect of MARVIN's mission. MARVIN will carry a crew of two to three people over 1500 km, during a two-week mission. At an average speed of 15 to 20 km/h, the crew will be driving approximately 6 hours per day.

The design of MARVIN was based on several assumptions. First, fuel was assumed to be readily available on Mars upon arrival of a manned mission. This would be done by producing large amounts of oxygen, hydrogen, water, and other fuels such as methane in situ. The in situ fuel production process will have started several years before the arrival of man on Mars. It was also assumed that the infrastructures necessary to partially assemble the rover would be available on Mars. In addition, no provisions were made for transport to Mars except to assume that the rover could be delivered to the Martian surface in a nearly assembled state.

The MARVIN rover Project was undertaken strictly as a conceptual project. No detailed design or analysis, nor a cost analysis was performed.

1.2 Design Criteria

Most of the design criteria are dictated by the hostile nature of the Martian environment and by the autonomy required in a place millions of kilometers away from home. Hence a Martian rover has to be rugged, lightweight, and have redundant systems. Mars presents several unique design challenges. First, Mars's atmosphere is composed almost entirely of carbon dioxide, which is toxic to humans and renders all surface operations all the more difficult. Also, very fine (≈1micron) surface dust is carried about by surface winds and has the potential to foul electronics, windows, filters, and moving parts. Temperatures on the surface vary widely between day and night and also vary widely over short vertical distances above the surface. These variations have the potential to cause material failures and necessitate careful material selection during design.

Transporting the rover from Earth to Mars also imposes its own constraints on the design. The rover must be both compact and lightweight due to launch cost and volume limitations. To meet the volume constraint, the rover was designed to be partially assembled on Mars. Advanced materials such as composites and titanium were used to satisfy the mass requirements.

In the following sections, our solutions to these unique constraints are presented and explained.

2 Pressure Vessel Structure

2.1 General Dimensions

The rover structure consists of a pressure vessel with a cylindrical mid-section and two semi-spherical end-caps. The cylindrical mid-section has an outside diameter of 2.5 meters, the two semi-spherical end caps have an outside radius of 1.25 meters each, and the overall length of the vessel is 6 meters. The thickness of the walls is approximately 3 cm. The rear end cap will be partitioned for use as an air lock, and the front-end cap will contain the cockpit and controls. In addition to a windshield in front, dome windows on the top of the cylindrical section will aid in natural interior lighting.

2.2 Pressure Vessel Materials and Structure

2.2.1 Composite Vessel Materials

Advanced composite materials are well suited for space structures due to their high strength and stiffness, light weight and low coefficient of thermal expansion (CTE). For a given design application, composites can be tailored to achieve the desired material properties. The composite fibers carry the structural loads in the direction of the fiber, and the composite matrix holds the fibers together, aids in transferring loads and provides environmental protection.

The main structural fibers of the pressure vessel will be carbon. Carbon is chosen due to its high specific strength, high specific modulus, low CTE and high fatigue strength. Aramid Kevlar 49® is an organic fiber that will be used for the outer surface of the pressure vessel. It exhibits a high degree of yielding in compression giving it superior damage tolerance and resistance to impact and other dynamic loading. It also has low weight, good tensile strength and is fire retardant. The fatigue endurance limit for aramid and carbon fiber reinforced epoxies may approach 60% of the ultimate tensile strength

2.2.2 Sandwich Structure

A tape-laying process will be used to construct the vessel in a sandwich structure with a honeycomb core. Filament winding is commonly used for cylindrical shapes such as pressure vessels. An automated fiber placement machine uses a mandrel similar to filament winding, but will allow for a more detailed lay-up in complex areas such as those around the windows and at the bottom cradle attachment area.

The laminate will be symmetric about the mid-plane to avoid bending and twisting due to in-plane loads. Since Kevlar plies will be used on the outside of the structure, the same Kevlar lay-up will also be used on the inside walls. In addition to creating symmetry, the inside Kevlar plies will separate the carbon plies from metal support brackets, which will prevent galvanic corrosion. Composite plies will exist in pairs of opposite orientation to avoid shear distortions due to normal loads. Since Kevlar is non-conductive, fine aluminum filaments will be woven in the outer fabric to dissipate electrostatic energy generated by high winds. These filaments, along with a metallic clear-coat, will also serve to reflect ultraviolet radiation, which contributes to the decomposition of Kevlar. The basic lay-up configuration of the pressure vessel is shown in Figure 2.1.

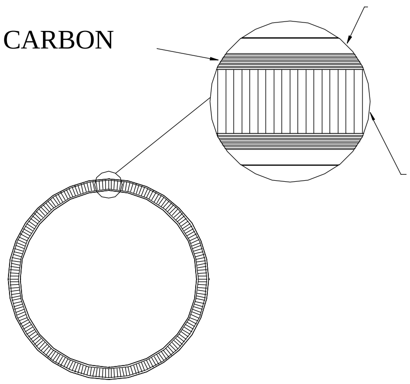


Figure 2.1: Lay-up Configuration

Between the carbon layers, a fiberglass reinforced phenolic honeycomb will be bonded to the carbon with film adhesive. This material has excellent thermal stability and has been used from -423°F up to 400°F. The honeycomb increases the structure's rigidity, its ability to withstand bending and shear loads, and has good strength to weight and stiffness to weight ratios. It provides acoustic absorption, radio frequency shielding, and it is an extremely effective mechanical energy absorber. The faces of a sandwich panel act similarly to the flanges of an I-beam by taking the bending loads. The core corresponds to the web, resisting the shear loads and increasing the stiffness of the structure. Unlike the I-beam's web, it gives continuous support to the facings. The adhesive joins the components and allows them to act as one unit with high torsional rigidity.

The honeycomb at the lower portion of the vessel will be filled with potting compound to distribute localized loads. This type of compound has a typical density of 0.189 g/in^3 and a compressive strength of 17 ksi. Since the average surface temperature on the Martian surface is -65°C, the remainder of the honeycomb will be filled as necessary to aid in internal thermal equilibrium to maintain a "shirt sleeve" environment. Polyethylene is chosen to fill the core since it also provides radiation protection. It also will aid in core stabilization, stiffening and core crush reinforcement.

2.3 Lay-up Configuration

The pressure vessel will need to be able to contain the pressure differential and to withstand the stresses due to the internal loads. The ply-stacking configuration will be designed to allow fibers orientated in the axial and hoop directions, as well as off axis layers to provide some circumferential and torsional stiffness and to hold the load carrying layers together.

The critical stress resultant can be calculated using a form of Hooke's Law:

$$N_{xx} = E_{xx} \cdot \varepsilon_{xx} \cdot n \cdot t_p$$

where N_{xx}= the critical stress resultant
E_{xx}= the longitudinal modulus of the material
ε_{xx}= the allowable strain
n = the number of plies
t_p = the thickness of each ply

Using a maximum strain allowable of 0.003 and a carbon unitape with a longitudinal tensile modulus of 18 Msi, 2.5 plies with fibers in the hoop direction are necessary to withstand the hoop stress due to the pressure loads.

As a starting point, a factor of safety of 5 is applied. As a result there are 12 plies with fibers in the hoop direction, 6 plies in the axial direction, and 4 plies are added off-axis to provide torsional stiffness. The plies are arranged symmetrically without grouping the same oriented plies. When plies of the same orientation are grouped together, there are higher interlaminar stresses. Eight Kevlar plies are added for impact resistance. Table 2.1 shows the initial lay-up configuration.

Table 2.1: Composite Layup

	Number of Plies	Thickness per Ply (cm)	Orientation Sequence
Kevlar	4	0.0254	0/+45/-45/90
Carbon	11	0.0127	0/90/0/+45/0/90/0/-45/0/90/0
Honeycomb	1	2.5	1 layer
Carbon	11	0.0127	0/90/0/-45/0/90/0/+45/0/90/0
Kevlar	4	0.0254	90/-45/+45/0

The configuration was put in a classical lamination program with the pressure loads applied. Using the Tsai-Wu failure criteria, all plies have a factor of safety of 7.4 to 11.5.

2.4 Mass Calculations

Using the dimensions of the pressure vessel and ply thicknesses of 0.0254 cm for the Kevlar, 0.0127 for carbon unitape, and a honey comb thickness of 2.5 cm, the following mass table was generated.

Table 2.2: Mass Calculations

Material	Outer Radius (cm)	Inner Radius (cm)	Panel Thickness (cm)	Volume (cm^3)	Density (g/cm^3)	Mass (kg)
Kevlar	125.00	124.90	0.102	47850	1.33	63.64
Carbon	124.90	124.76	0.140	65700	1.54	101.20
Honeycomb	124.76	122.26	2.500	1158000	0.048	55.60
Carbon	122.26	122.12	0.140	63750	1.54	98.17
Kevlar	122.12	122.02	0.102	46300	1.33	61.58
Total	--	--	--	--	--	380.19

2.5 Radiation Shielding for MARVIN

Studies have shown that in order to achieve necessary radiation shielding for a maximum exposure of 20 mSv/year , 0.15cm of aluminum or 0.3-cm protection of Polyethylene is needed. Polyethylene is used to fill the honeycomb core and therefore provide a good thermal insulator as well as a significant radiation protection.

3 Cradle Structure

3.1 Material Selection

The cradle structure will be made of titanium. Specifically, Ti-6Al-4V alloy. This alloy can withstand large temperature gradients, has an low CTE, and 3 times the strength to weight ratio of aluminum. A suitable paint/coating will further enhance the corrosive properties of Ti-6Al-4V and increase the structure's ability to resist the damaging effects of the Martian environment.

3.2 Results of Stress Analysis

MARVIN has five (5) longerons and five (5) frames. The longerons were given a T shape to reduce critical stresses. The frames were designed to resist torsion as much as possible, and an “r” shape was used for them., and the whole assembly minus the ears is shown in Figure 3.1.

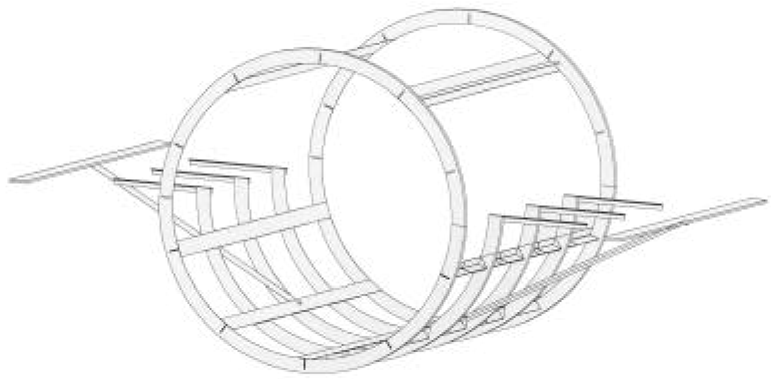


Figure 3.1: Structure with Ear Attachments

3.3 External Storage System

The rover's power production and storage systems are stored outside the pressure vessel in two rectangular containers or "ears". The fuel cell dimensions dominated the overall geometry of the ears. The rectangular structure runs the length of the cylindrical part of the pressure vessel and is 1.5 meters in width and 0.75 meters high. MARVIN has two identical ears, one on each side of the pressure vessel. The ears extend inboard to the contour of the pressure vessel and the extra volume is used for water storage tanks. Figure 3.2 shows the general geometry and inside arrangement of the ears.

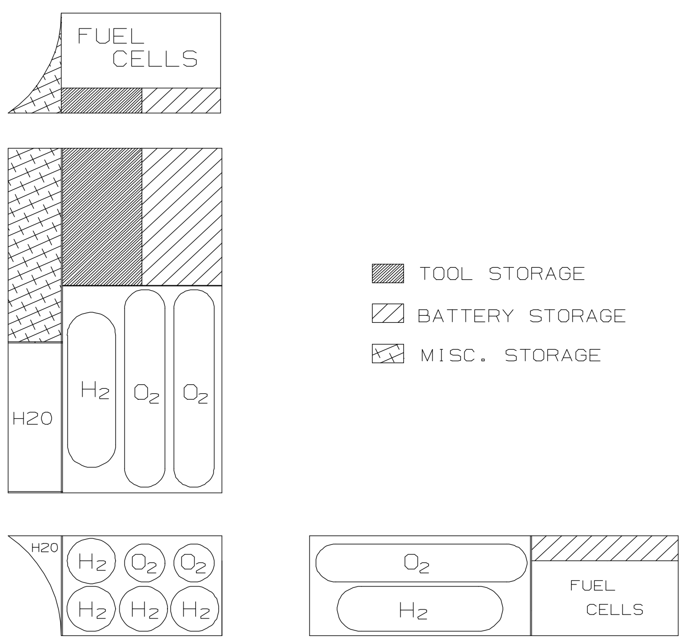


Figure 3.2: Internal Configuration of the Ears

4 Powerplant

4.1 Power Requirements

4.1.1 Mission Definition

The energy requirements for three reference missions were calculated. The first mission represents a 750 km-drive on flat terrain. The second mission has 500 km long climbing and descending portions at an angle of 25 degrees and a 500-km long flat portion. The third reference mission has 750 km long climbing and descending portions at an angle of 10 degrees. Figure 4.1 is an illustration of these three reference missions.

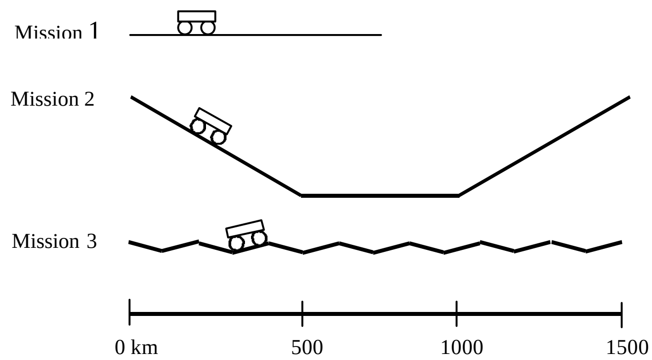


Figure 4.1: Reference Missions Profiles

4.1.2 Energy and Power Requirements

The following simplified equation was used to calculate the energy requirement for each mission:

$$dE = Fdx$$

Where *dE* is the total energy required to overcome the resistive force *F* over a distance *dx*. The resistive force is approximated as follows:

$$F = mg_M\left(m + \sin q\right)$$

Where *m* is the Rover's mass, g_M is Mars'gravity, *m* is the surface's friction coefficient and *q* is the terrain's slope. Aerodynamic drag was voluntarily omitted from this equation. Drag's contribution to the resistive force is about 2kN in a 300 km/hr Martian storm, which is negligible. The total mass of the rover is 4000 kg and *m* was approximated at 0.5, which gives the following energy requirements:

Table 4.1: Energy and Power Requirements

Mission	Energy Requirement (MJ)	Power Requirement (kW)
1	5592	37
2	11184	37
3	11184	37
Max Slope @ Max Speed		69 (Max power required)

Therefore, the powerplant's power output has to be about 40 kW continuous and 70 kW peak. Note that these power requirements are only for the drivetrain. Hence they do not include the powering of MARVIN's internal systems and external tools and accessories.

4.2 Power Generation

4.2.1 Powerplant Selection

In order to satisfy to mission requirements, a fuel cell was chosen to power our rover. The low-temperature fuel cells (alkaline and Proton Exchange Membrane (PEM)) are favored. The alkaline fuel cell, however, is CO_2-intolerant, which makes it a poor choice for Mars's CO_2 atmosphere. As the following table illustrates, the logical choice is the PEM fuel cell, because it operates at low temperatures, is CO_2-tolerant and has a high energy density.

Table 4.2: Fuel Cell Comparison

Fuel Cell Type	Operating Temp. (°C)	Power Density (kW/liter)	Power Density (kW/kg)	CO_2 tolerant	CO tolerant
Solid Oxide	1000	1-4	1-8	Yes	Good
Molten Carbonate	600	-	-	Yes	Good
Phosphoric Acid	150-205	0.16	0.12	Yes	Fair
Alkaline	65-220	0.1-1.5	0.1-1.5	No	Poor
PEM	25-120	0.1-1.5	0.1-1.5	Yes	Poor

4.2.2 Operating Principle of a PEM Fuel Cell

In any kind of fuel cell, the combination of hydrogen and oxygen creates electricity and water. The reaction at the anode is:

$$H_2 \Rightarrow 2H^+ + 2e^-$$

The electrons travel to the cathode through an external circuit where they perform work. The protons travel through the proton exchange membrane to the cathode. There, the protons and the electrons combine with the oxygen to form water, according to the following reaction:

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \Rightarrow H_2O$$

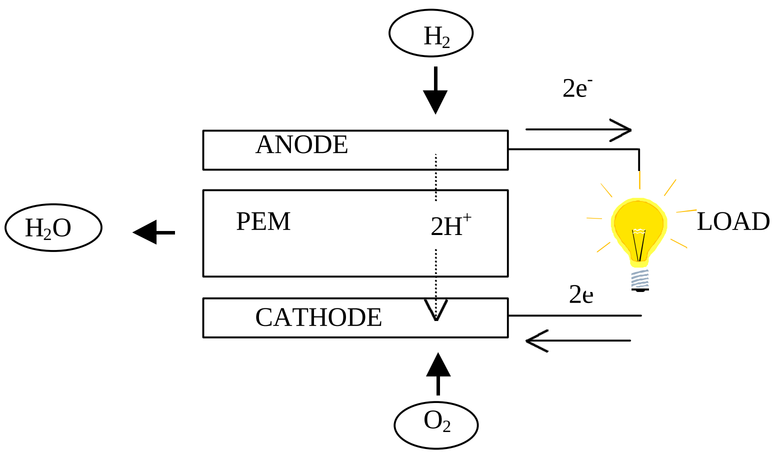


Figure 4.2: Working Principle of a PEM Fuel Cell

4.3 Specifications of a PEM Fuel Cell Powerplant for MARVIN

4.3.1 Weight and Dimensions

The best laboratory PEM fuel cells currently have power densities of 1.5 kW/kg and 1.5 kW/liter. The observed efficiency for a PEM fuel cell ranges from 50 to 90% . Therefore, assuming a fuel cell efficiency of 80 % and a drivetrain efficiency of 80 %, the system's nominal power has to be: 62.5kW, and a maximum power of 110 kW

Allowing for the rover's internal and external systems, the total power requirement is 83 kW. Therefore, a PEM fuel cell with $P_n = 85$ kW and $P_{max} = 150$ kW was selected. Such a fuel cell would weigh 150 kg and occupy a volume of 0.15 m^3.

4.3.2 Fuel Requirement

The fuel requirement calculations are based on the "Ballard Fuel Cell Powered ZEV Bus". In that design, a 120 kW PEM fuel cells powers a city bus with a range of 160 km on 12 kg of hydrogen and oxygen in 2:1 stoechiometric proportion. The hydrogen needed to achieve a range of 1500 km can be estimated at 120 kg. The volume of H_2 can therefore be calculated to be 1700 liters. In order to satisfy the chemical reaction's proportions, the volume of oxygen is 750 liters with a mass of 960 kg.

4.3.3 Powerplant Specifications

The following table summarizes the specifications of MARVIN's PEM fuel cell powerplant:

Table 4.3: Fuel Cell Powerplant Specifications

Stack Weight	150 kg
Stack Volume	0.15 m^3
Hydrogen Mass/Volume	120 kg / 1.7 m^3
Hydrogen Storage Temperature/Pressure	20 K / 0.1 MPa
Hydrogen Delivery Pressure	0.3 MPa
Oxygen Mass/Volume	960 kg / 0.75 m^3
Oxygen Storage Temperature/Pressure	60 K / 0.1 MPa
Oxygen Delivery Pressure	0.3 MPa
Continuous Power Output (kW)	85
Maximum Power Output (kW)	150
Output Voltage (Vdc)	160 – 280
Stack Efficiency	0.8
Drivetrain Efficiency	0.8

4.4 Powerplant Subsystems

The following figure represents the power plant and most of its associated subsystems:

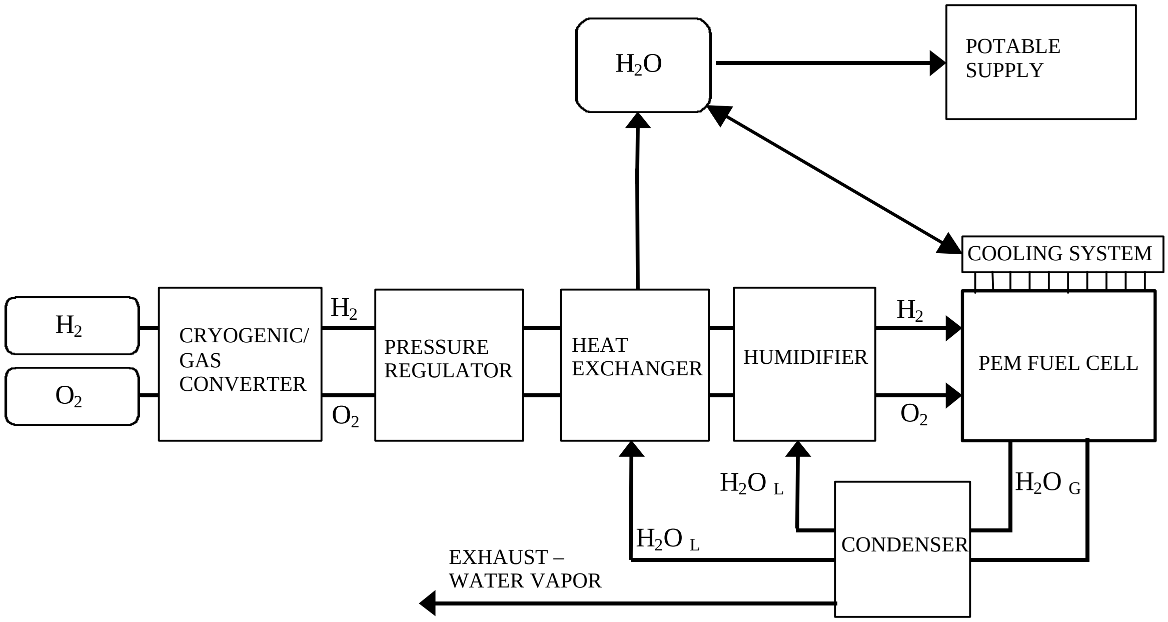


Figure 4.3: PEM Fuel Cell Powerplant and Associated Subsystems

4.4.1 Electrical Subsystem/Battery

A 400-kg Al/Air battery would provide the rover with 2kW of continuous power for 48 hours and provide starting power to the fuel cell

4.4.2 Water Management System

An 80 % efficient fuel cell produces approximately 7.3 kg of water for each kg of hydrogen it uses. Therefore, during the 14-day mission, the fuel cell will produce around 900 kg of water. About half of it will be used as potable supply. Some of it will be exhausted as water vapor in the Martian atmosphere and the rest, in liquid form, will be used as a coolant. Some of the vapor is released into the atmosphere and the rest goes through a condenser. The resulting warm liquid water is used in a heat exchanger that regulates hydrogen and oxygen temperatures and in the humidifier. The cold liquid water is then distributed between an electrolysis tank, the potable supply and the fuel cell cooling system. Water is produced by the fuel cell only as the rover is running. Therefore, there will need to be an initial amount of water in MARVIN's tank upon departure for a new mission.

5 Suspension and Traction System

5.1 Terrain Features

Photographs from the recent NASA Pathfinder mission clearly show the harsh terrain that surrounds the Pathfinder landing site. The surface is covered by a mixture of fine sandy soil and small pebbles, and strewn with stones ranging from gravel to boulder. The terrain shown in Figure 5.1 is likely the terrain that could be encountered by MARVIN during its missions

Figure 5.1 Pathfinder Photo of Martian Surface

5.2 Wheels

The wheels need to be reliable and easily maintainable by astronauts in EVA suits. Also, the selected wheel design must be able to provide sufficient traction to successfully move the rover over the terrain. In light of the mission design criteria composite cone type wheels were chosen.

5.2.1 Design and Material Selection

The cone type wheel geometry offers several benefits. The wheels can be closely stacked onto each other and fitted over one end of the pressure vessel during interplanetary transport thus conserving payload volume. The cone type wheel can also be constructed in a very lightweight manner.

Kevlar could be used to construct the entire wheel or just the outer layers for abrasion and impact resistance. Honeycomb and fiberglass are perfect materials for strengthening and stiffening while still keeping mass low.

In order to maintain the wheel shape, stiffening protrusions are added inside the tread surface. The flat, hub portion of the wheel is to be used for motor mounting and as such will require much stiffness in order to make motor mounting feasible. Honeycomb and fiberglass can also be used in this area to maintain bending strength. The proposed wheel cross-section is shown in Figure 5.2.

Wheel traction can be aided by attaching protrusions onto the tread surface that can be tailored exclusively to the type of terrain expected to be encountered during a mission. Similar to specialized snow or mud tires used on Earth-based terrain vehicles.

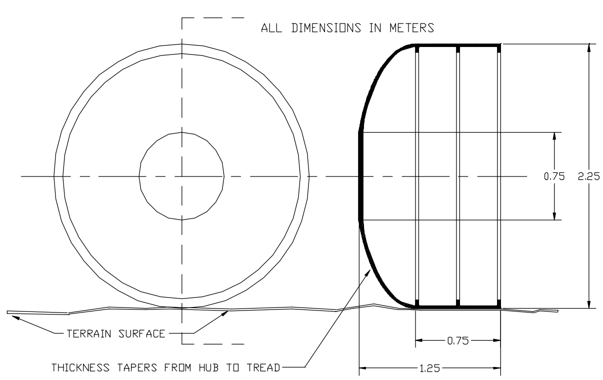


Figure 5.2: Wheel Cross-Section

A limiting factor in the wheel sizing is the physical space the wheel has in which to operate. A minimum ground clearance of one meter is expected and the wheel must not interfere with the ear structures that contain the rover's power generation and fuel storage facilities. When these constraints are balanced with the desire for high suspension travel the acceptable range of wheel diameters becomes clear. MARVIN's wheel diameter of 2.25 meters balances all these needs and falls in the middle of the acceptable values for wheel diameter.

The two types of terrain vehicle clearance failure modes are hang-up failure (HUF) and nose-in failure (NIF). Hang up failure occurs when the terrain contour changes suddenly and the middle of the vehicle between the wheels interferes with the terrain. Nose-in failure occurs when the front (or rear) of the vehicle interferes with the terrain during a sudden contour change

To avoid these failure modes the wheels should be of sufficient diameter and near enough to the ends of the vehicle to prevent terrain vehicle interference. MARVIN's wheelbase and wheel diameter are both sufficient to provide adequate protection against these failure modes during average terrain encounters. Terrain that could cause these types of failure modes in MARVIN is also high risk terrain for causing rollover failure.

5.2.2 Ground Pressure Analysis

The soil sinkage analysis is very simplistic and considers the static loading case. The equation in Figure 5.3 describes rover sinkage in terms of ground pressure and two soil constants, the Bernstein's modulus of soil deformation and the exponent of soil deformation. These constants are obtained through testing of the soil. The approximate values used are 0.50 for the soil deformation exponent and 39,000 N/m^3 for the Bernstein's modulus of soil deformation. Based on the curve, the rover is expected to sink between two and seven centimeters into the Martian soil when static. These values are quite acceptable and validate the wheel sizing.

Assumptions about wheel slippage were also made in order to calculate MARVIN's turning radius. Essentially, the wheels were assumed to have no slip in turns. Some slip is expected to occur, thus the turning radius calculated for the rover is a best-case turning radius.

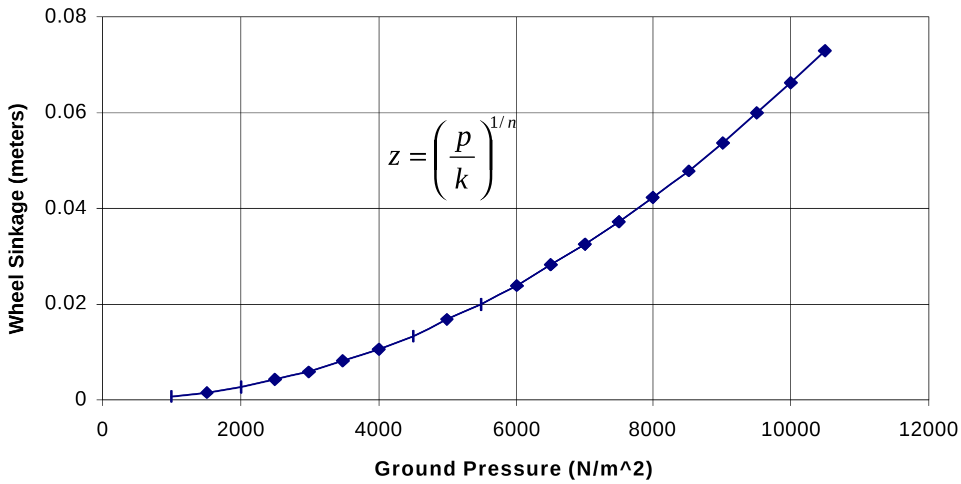


Figure 5.3: Estimated Rover Sinkage versus Ground Pressure

5.3 Suspension and Steering

5.3.1 Four-Wheel Steering

Ride quality will affect the astronauts both physically and psychologically. Turn radius calculations were simplified by assuming zero wheel slip in turns and by using a simple two-dimensional geometrical model to derive the turn radius equation. Since wheel slippage and lateral wheel separations were not considered, the results obtained can only be considered as 'best case' values.

For the rover's maximum expected steering angle of approximately 35 degrees, the rover has a three-meter turning radius or approximately half the vehicle's length. This is exceptional when compared to most four-wheel Earth based terrain vehicles, which generally have a turn radius larger than the vehicle length. This low turn radius was achieved with four wheel steering.

5.3.2 Dual A-Arm Suspension

Dual A-arm suspensions offer many benefits over other terrain vehicle suspension methods. The dual A-arm offers independent motion to each wheel. Thus, each wheel's vertical position over the terrain can be optimized without consideration to the other wheels' positions. In essence, the rover has more freedom to adapt to the varying terrain it is sure to encounter. Also, the 4 wheel independent suspension is very conducive to control by an active damping and wheel actuation system.

One advantage of wheel actuators is the ability to manipulate the pressure vessel's position relative to the ground. When stopping the rover for EVA traverses the vehicle could be positioned so that the rear ladder assembly could easily reach the ground. Also the rover could be leveled for extended parking such as an overnight site stay.

Expected suspension travel is on the order of 0.3meters up or down. The main limitations on suspension travel are the position of the ear assemblies directly above the wheels and the need to keep the pressure vessel relatively close to the ground to minimize potential rollover hazards.

5.4 Drive Motors

5.4.1 Mounting

The mounting concept we have chosen requires no flexible driveline and maintains the simplicity, ruggedness, and compactness that was required of the drive system. The motor housings are fixed to the wheel hub and rotate with the wheels when driving. The output shaft of the drive system is fixed to the A-arm assembly and serves as the axle for the wheel. This mounting concept is illustrated Figure 5.4.

By placing the motors inside the wheels, a large amount of the rover's weight is placed near the ground and far from the rover's centerline. This increases both the lateral and longitudinal rollover margins by lowering the rover's center of gravity.

5.4.2 Gearing

At MARVIN's top speed of 25 km/h, each of the wheels will be turning nearly 60 rpm. Electrical motors typically operate best at much higher rotational speeds. Thus, some type of gearbox is necessary to translate the motor's high rpm rotation into the much lower rotation speed needed for the wheels.

Planetary gears seem to be the most obvious choice, given our unique mounting situation and the need to retain the axially centered shaft position. A planetary gearbox could be placed between the motor and the wheel hub as shown in Figure 5.4. In this configuration, the gearbox also serves as the means of mounting the motor to the wheel hub.

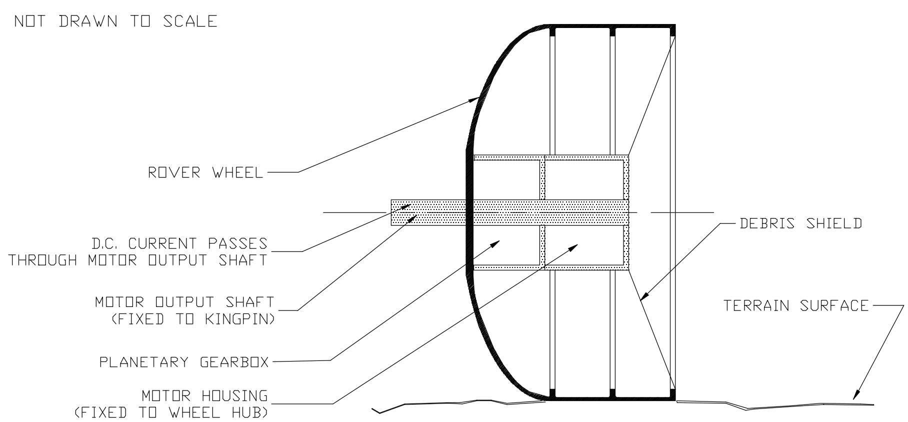


Figure 5.4: Drive Motor and Gearbox Mounting Schematic

6 Cockpit Design

This study was to look at the communication and navigation requirements and determine the basic flight instrument weights. An Integrated Modular Avionics (IMA) system is recognized as providing an answer to the requirements and constraints of modern spacecraft. According to the IMA concept, a system implementation is built up from hardware modules and software components with standardized interfaces. In comparison with the previous generation of federated avionics architectures, the benefits provided by IMA systems will include improved fault-tolerant operation, leading to improved operational and mission performance, as well as a greater openness to growth and innovation, and a reduction of life cycle costs.

The cockpit will be a drive-by-wire system. The design of MARVIN's glass cockpit was based on that of the new space shuttle and Boeing 777. In these cockpits, dual Honeywell aircraft information management system (AIMS) contains the processing equipment required to collect, format and distribute onboard avionics information, including the fight management system (FMS), engine thrust control, digital communications management, operation of cockpit displays and monitoring of MARVIN's condition. Both pilots and ground engineers can assess the condition of all onboard avionics systems.

The Multifunction Electronic Display System (MEDS) is comprised of ten Multifunction Display Units, Integrated Display Processor (IDP), Mass Storage, and Honeywell analog-to-digital (A/D) converters.

Mars is a little more than half the diameter of the Earth, so the horizon is correspondingly closer. If the terrain on Mars were as flat as Kansas, the horizon would only be about 40 kilometers away. So, if the excursion team wants to go anywhere on Mars, they're definitely going over the horizon, which rules out line-of-sight radio transmissions. Communication satellites, on the other hand, cost money, and are subject to failure.

One alternative is ham radio. Mars has an ionosphere, a layer of charged particles in the high upper reaches of its atmosphere, that can be used to reflect radio signals, enabling global surface-to-surface communication in the short-wave radio bands, just as on Earth. According to previous data gathered on Mars's ionosphere, such a radio would operate at about 4 MHz during the day and 700 kHz at night. The latter figure is too low to transmit images or engage in other kinds of high data rate transmission, but it is more than adequate for engineering telemetry or voice communication.

In addition to maintaining communication with the home base, Mars's explorers will also need to navigate. While good maps of Mars are available from orbital imaging, the essential problem for a Mars rover crew will be determining their own location. A radio beacon at the base could help a crew find its way home, but its range would reach at most only to the nearby horizon (just 40 kilometers away). Upon approaching the limits of the base beacon's range, a departing rover crew could station a second beacon on a hilltop, and then another, and another, and another, to mark a return path. Such techniques are, however, quite limiting, and as in the story about the bread-crumb trail being eaten by birds, are subject to catastrophic failure if one of the beacons composing the trail should cease functioning. Inertial navigation and the use of navigation satellites are two other options

The table shows the total weight for the different instruments and the seats in the cockpit.

Table 6.1: Total Weight for Instruments and Seats

System	**Quantity**	**Total Mass (kg)**
SKN-2443 High-Accuracy Inertial Navigation System	2	30
Albus-1553-8 Bus Monitor Data Handling	3	21
Mil-Std-1553B Data Buses	3	21
Multi-Purpose Color Display for F-15C & F-15E	4	48
Wiring and Cooling Fans and Pipes	1	50
Seats	2	100
Total		**270**

The power required for the cockpit is 2kW, plus 4 kW for the exterior lighting and 1 kW for the external cameras, which add up to 7kW.

7 Interior Living Quarters

7.1 MIS Units

Adequate supplies must be carried on MARVIN while leaving storage space for scientific equipment. Since MARVIN’s mission objectives will vary, cargo storage with modularity, accessibility and functionality is ideal. MIS (Multipurpose Interior Storage) Units have been developed to accommodate each of MARVIN’s missions. The MIS Units are capable of storing all the necessary perishable and expendable items such as water, food, clothing as well as the food preparation equipment. Additionally, there is plenty of storage space available to carry scientific equipment.

The MIS units are located on both sides of the fuselage in the living quarters. (See Figure 7.1) The right MIS unit is 2.97 meters long and runs from the back of the cockpit to the front of the waste management system. The left (not shown) MIS Unit is identical to the right MIS Unit except that it extends the full length of the living quarters, 2.97 meters, from the cockpit to the airlock pressure bulkhead because of the absence of the Waste Management System (See Figure 7.1). Note the person standing inside is 1.83 m, or six feet tall.

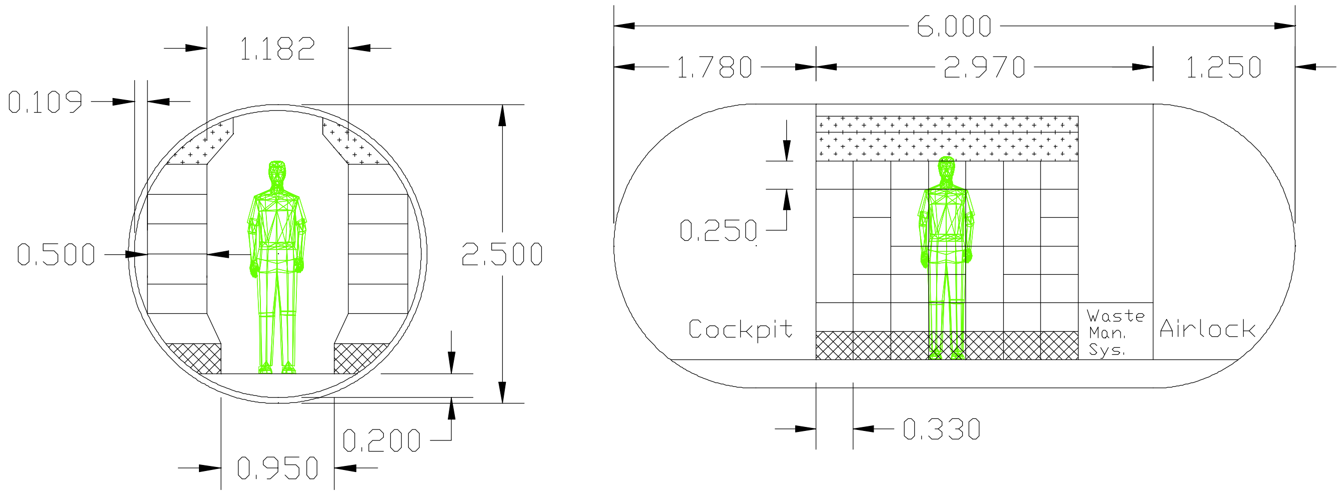


Figure 7.1: Front and Right Side Cross-section View of MARVIN

7.1.1 Potable and Waste Water Storage

The fuel cells that power MARVIN will produce approximately 900 kg of water on the two-week mission. The 3-person crew will use approximately 420 kg of this water, based on a 10 kg per person per day. At any one time, enough potable water will be stored in MARVIN to safely bring the crew back to base should a problem arise. Upon return to the base, the majority of the water stored in the MIS Units would be wastewater. This water can then transferred to the base for reclamation of potable water.

7.1.2 Fire Suppression and Lighting

The top portion of the MIS Units is where the Fire Extinguishing (FE) and Interior Lighting (IL) Systems are located.. A HALON® or a FE-241(chlorotetrafluoroethane) FE system will be employed on MARVIN.

The IL system will be used to light MARVIN in low light conditions such as a sandstorm or at dusk. Additionally, the IL system will be capable of supporting MARVIN during nighttime missions by illuminating the cabin with red light. It is estimated that this system will require about .25 kW of peak continuous power and .10 kW of power at normal operating conditions.

7.1.3 Modular Storage Capabilities

The MIS units are designed to be very modular since MARVIN's mission will be likely different on each excursion. Both the left and the right MIS units are six drawers high, minus the bottom layer for water storage, with the inner four layers being completely interchangeable. Because of MARVIN's geometry, the top and bottom drawer layers are not interchangeable and are used for more permanent equipment such as food preparation equipment, the crew's personal items, etc…. A variety of drawer combinations can be used within these four inner layers. Each inner drawer is .330 meters wide, .250 meters high and .500 meters deep. This gives each inner drawer approximately .041m^3 of storage space. Currently each drawer is fabricated in the same manner as the ones used on the Space Shuttle which employ a Kevlar-Epoxy sandwich structure. The resultant empty mass each drawer on MARVIN is approximately 2 kg.

However, it is conceivable that different missions will require different size equipment and so one(1) double high drawer can replace two(2) single high drawers or one(1) triple high drawer can replace three(3) single high drawers and so on. Electrical connections are provided behind each of the MIS Units for providing power to the scientific, hygiene and food preparation equipment.

The overall storage capacity, minus water storage, of the left MIS Unit is ~2.16 m^3 while the right MIS Unit is ~1.68 m^3 and is slightly smaller because of the presence of the Waste Management System. This gives MARVIN a total internal storage capacity of ~3.84 m^3.

7.2 Life Support and Environmental Equipment

The Cabin Air Conditioning (CAC) system and the Pressure Regulation (PR) system are necessary to keep MARVIN's cabin air clean, cool and semi-humid as well as pressurized. Below the main floor is where the CAC and PR systems are located. Raising panels located in the floor can access these systems.

The CAC controls the environment inside MARVIN to approximately 20 °C with 25 to 50% relative humidity. Lithium Hydroxide filters in the CAC clean the air of deadly carbon dioxide and other airborne contaniments while fans and ducting circulate the air through MARVIN.

7.3 Sleeping Arrangements

The shape of MARVIN was predetermined before serious work and research began on the interior of MARVIN. Sleeping arrangements had to be ultimately developed without compromising the MIS Units and the limited space left inside MARVIN. This was accomplished by using a conventional bed system that could be broken down and stored during the daytime when not in use. Figure 7.2 shows a cross section of the Sleeping Bunks (SB) in place for a three-person crew.

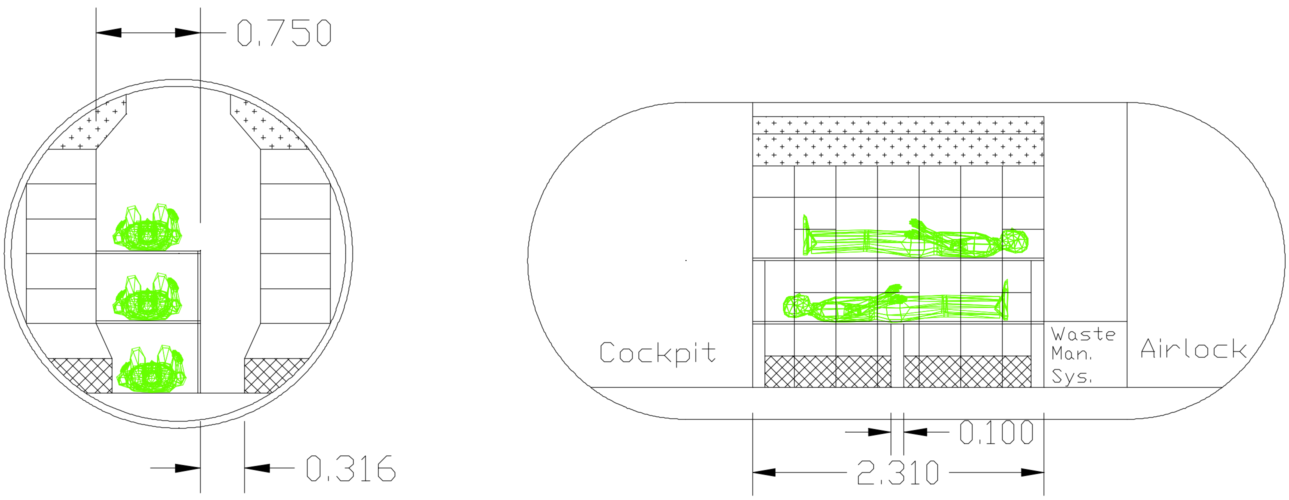


Figure 7.2: Front and Right-side View of the Sleeping Bunks for a Three-person Crew.

Cushioning and bedding are stored in the MIS Units during the daytime. This arrangement allows for approximately 0.316 meters of clearance on the side so the crew can still walk by without too much restriction. It also gives the top two crewmembers a sleeping area of ~1.75 m^2 and the bottom crew member ~1.41 m^2 of sleeping area. Figure 7.2 shows the side view of the SB in place along the right side of MARVIN.

In the daytime the SB can be broken down and stored on the floor. The bottom space between the bottom of the MIS Units is 0.95 meters wide. Each of the supports for the SB is 0.10 meters wide (See Figure 7.2) and each bed itself are 0.75 meters wide. This allows for the SB to be stacked on the floor between the MIS Units.

Access to the Life Support and Environmental Systems is accomplished by removing the bed to gain access to the floor panels. An estimated weight for this bedding arrangement is approximately 25 kg.

7.4 Interior Systems Summary

Table 7.1 Summary of the Interior Systems Located in the Living Quarters.

Equipment	Mass(kg)	Volume(m^3)	Power Required (kW)
MIS Units(2 total)	200	3.84	N/A
Water Storage	425	0.43	N/A
Fire Extinguishing(FE)	~25	0.11	N/A
Interior Lighting	~25	0.11	0.25 peak /0.10 Continuous
Scientific Equipment	650	1.5	2.8
Crew's Personal Gear and Hygiene Equipment	50	0.50	0.10 peak
Food and Preparation Equipment	100	0.50	0.10
Misc. Equipment	300	1.0	1.5
Cabin Air Conditioning(CAC)	~100	0.10	1.5
Pressure Regulation (PR)	~100	0.10	1.5
Beds and Bedding	~25	0.01	N/A
Total	**2000**	**8.20**	**7.75**

8 Airlock

8.1 Airlock General

The airlock's main purpose is to allow its occupants the ability to enter and exit the pressure vessel without depressurizing the entire rover. The airlock is located inside the last 1.25 meters of the pressure vessel. It has two semi-spherical-like, 1.25 m diameter interior and exterior hatch opening doors. The interior door will separate the living quarters from the airlock and the exterior hatch door will allow the occupants to leave the pressure vessel. The airlock hatch doors have dual pressure seals to maintain pressure integrity. The airlock is also used to store two spacesuits and a retractable ladder system that will be use to exit onto Martian soil. The spacesuits are kept at approximately 4-6 psi of pressure. This pressure is the same as that inside the entire rover, which eliminates pre-breathing exercises.

8.2 Airlock Design

The airlock is modeled after the space shuttle airlock. The airlock has five major components: an exterior hatch door, the airlock section of the pressure vessel, steps to reach the exterior hatch door, a pressure bulkhead and the interior hatch door. A layout of each component and a fully assembled configuration, excluding the spacesuits, can be found in Figures 8.1. The bulkhead functions like the end cap of the rover when the airlock is depressurized. Due to the major dust problem in the Mars atmosphere, a dust removal system needs to be designed to remove excess dust from space suits.

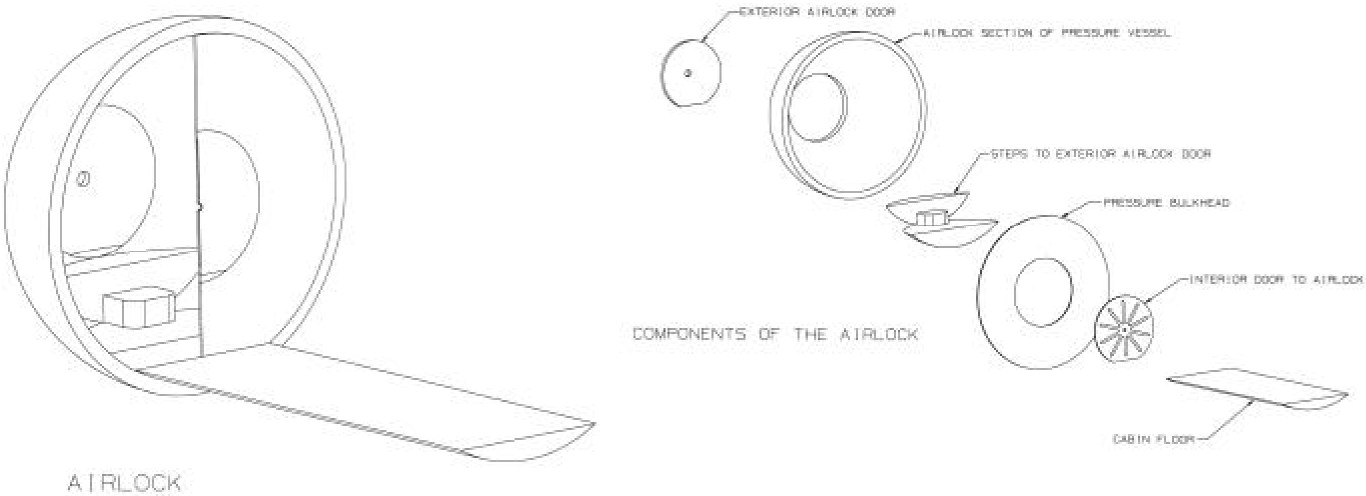


Figure 8.1: Layout of All Structural Components of the Airlock

8.3 Airlock Structure and Dimensions

The airlock section has a thickness of .10 m, an outer diameter of 2.5 m and inner diameter of 2.3 m. The two spherical hatch doors have a diameter of 1.25 m. The doors are constructed out of titanium. Titanium was chosen because of its high strength to weight ratio and its lightweight. Each airlock hatch door has a dual pressure seal to prevent depressurizing the entire pressure vessel. One seal is attached to the airlock hatch door and the other on the airlock structure. A leak check quick disconnect verifies pressure integrity. The interior hatch door has a thickness of .02 m and is located on the pressure bulkhead. The exterior hatch door is .10 m thick and is attached to the end cap of the pressure vessel. There is a circular view window with a diameter of 0.2032 m located in the center of the exterior hatch door.

The pressure bulkhead is located between the living quarters and the airlock structure. The circular bulkhead has a 2.3m diameter and is made from the same composite structure as the entire pressure vessel. The bulkhead is .20 m thick. The bulkhead serves as a substitute end cap for the pressure vessel when the rover is depressurized to allow the occupants to leave for exploration. The interior hatch door is located in the center of the bulkhead.

8.4 Extra Vehicular Activity

Attached to the backside of the spacesuits is an Extra-Vehicular Mobility Unit (EMU). The life-support system which is located inside the EMU help control and maintain temperature and air pressure of the suit while supplying sufficient amount of oxygen to the occupants. Temperatures are maintained by circulating water from a cooling system throughout the interior of the suits.

These suits are made to eliminate carbon dioxide with a hydroxide lithium cartidrige. These are also equipped with special back-up oxygen supply unit in case the main sysytem fails. Electrical power is also supplied from the EMU to run cameras and flashlights.

In order to go on an EVA mission, the astronauts must go through numerous steps to prepare for it. Among these, they must: go through pre-breathing exercises. Pre-breathing exercises are meant to reduce the chances of the astronauts becoming ill in low-pressure atmosphere. Moving rapidly from a high-pressure area to a low-pressure area can cause nitrogen bubbles to form in the bloodstream. Therefore, astronauts would inhale 100 percent oxygen to remove all traces of nitrogen from the body, which can take up to six hours. Keeping MARVIN pressurized at approximately 4-6 psi will eliminate the pre-breathing exercises.

8.5 Rotating Ladder System

Once embarked on a mission, the crew will need to get in and out of the rover and reach the storage compartments on the ears. A rotating ladder was designed to perform these two tasks. The rotating ladder system consists of a platform and a ladder that rotate around the vertical axis of the spherical endcap, as shown in Figure 8.2.

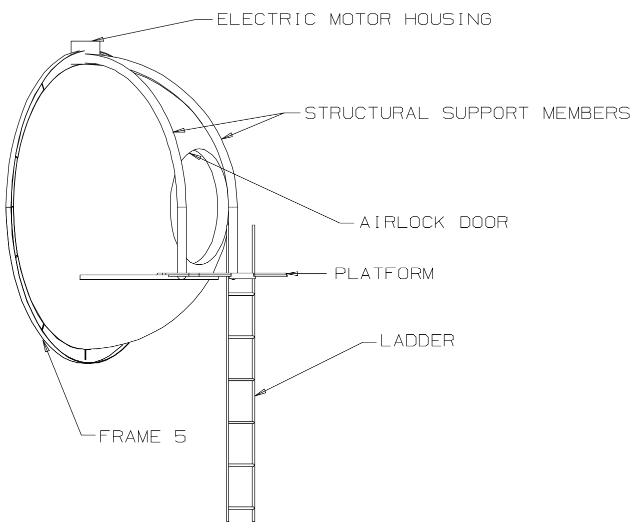
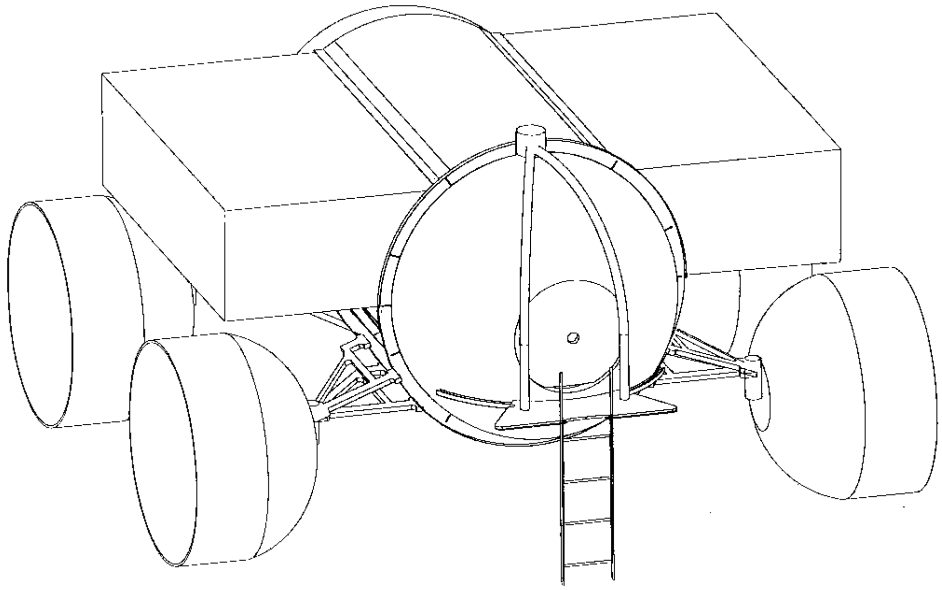


Figure 8.2: Ladder System Layout

9 Conclusions/Recommendations

As stated earlier, MARVIN is a purely conceptual study. Therefore, it lacks the in-depth analysis required for a direct application to a manned mission to Mars. However, the team did its best to present innovative design solutions and gained valuable experience and knowledge from this endeavor. Hopefully, some of these ideas may prove useful or stimulating for future mission plans to Mars.

In an effort to inform young potential engineers about the real possibility of someone landing on Mars in their lifetime, the MARVIN team voluntarily spoke to numerous schools in all grade levels. This was an opportunity to help inform them of the issues an engineer deals with when designing a rover for Mars and answer questions they might have. The main goal of the outreach program was to get the students to think about Mars and hopefully generate new and interesting ideas and concepts. We spoke to groups at three high schools, roughly 290 students, and one elementary school, which had approximately 90 students attend our presentation. To reach a more broad audience, we displayed our project at the University Open House as well as Engineering Open House at WSU. Approximately 500 people from the Wichita community saw our project during these events.



Quartering Rear View of MARVIN

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