MERLIN:

Martian Exploratory Rover for Long-range INvestigation

University of Maryland

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Abstract

In the days of the Apollo program, it was recognized that it was necessary to cover as much of the surface of the Moon as possible in order to accurately portray the planet's geology. Due to the time and weight constraints of the program, the first few missions covered the surface on foot, with only the last three using battery-powered, unpressurized rovers.

In the future, when mankind colonizes the other planets, the surface stay will be considerably longer, the weight allowances will be much greater, and the science to be performed will be expanded dramatically. All of these factors will cause serious consideration to be given to the idea of a pressurized rover for extended surface excursions.

The following is one possible design for a pressurized rover for use on Mars. It was designed by University of Maryland, College Park Aerospace Engineering students in the second semester of their senior Space Systems Design class. The class was broken down into six groups in order to spread out the workload. The groups were the following: Avionics; Crew Systems; Mission Analysis; Power, Propulsion, and Thermal; Structures and Loads; and Systems Integration.

1. The Reference Mission

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

2. Design Constraints

At the beginning of the semester, the class was given several design constraints. These include the following requirements. The final outcome of the class should be some type of rover for use on Mars. This rover would need to conform in whatever ways we deemed necessary with the NASA Mars Reference Mission. The rover needed to be manned in some capacity. The rover needed to allow for Extravehicular Activities (EVAs) by its crew. Finally, it would need to be able to cover as much of the Martian surface near Olympus Mons, the Tharsis Montes, Valles Marineris, and Lunae Planum as was possible.

It was this last design consideration which made the Martian Rover for Long-range INvestigation's (MERLIN's) design diverge from the vehicle design in the Reference Mission. The rover in the Reference Mission is also pressurized, but is only meant for excursions that are relatively close to base (within a radius of 500 km). Also, this rover did not include very much in the way of on-board science facilities. Below is the region which MERLIN was to explore. The inner circle is the travel radius of the Reference Mission rover and the outer circle is the travel radius needed to fulfill the exploration design constraint (~3000 km). To give the reader an idea of the scope of the exploration area required of MERLIN, a map of the continental United States has been overlaid on the map of Mars. Obviously, this constraint greatly drove MERLIN's design. Not only would MERLIN need to cover a huge expanse of the surface of Mars, it would need to do so with its own fuel, as gas stations are not readily accessible on the surface of Mars.

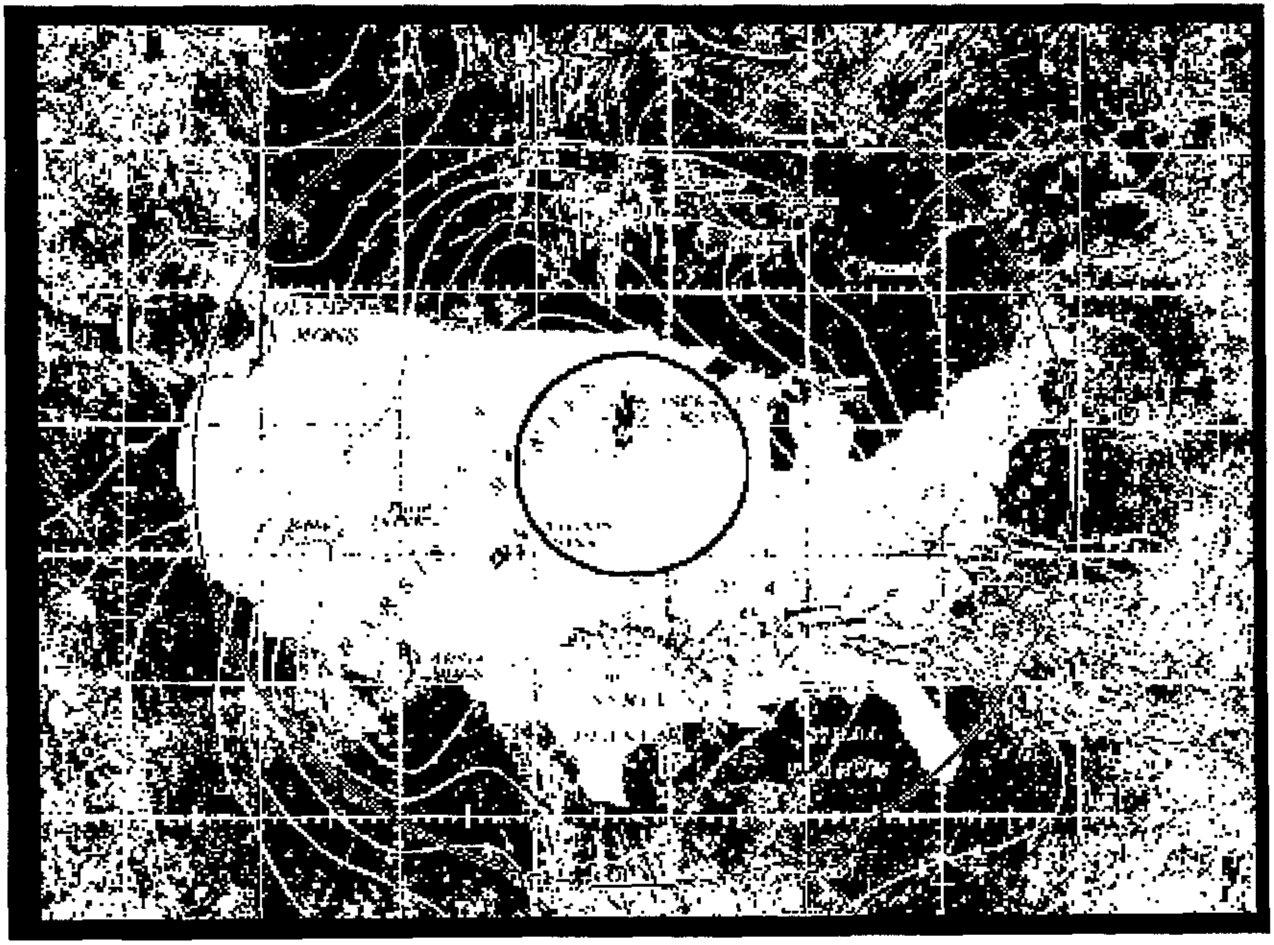

Fig. 2.1. Respective Ranges of MERLIN and Reference Mission Rover.

3. Why a Pressurized Rover?

At the beginning of the semester, many possible designs for a rover were discussed. These included: an airplane, a dirigible, a land-based rover, and a sub-orbital hopper.

3.1. By Air

The possibility of a Martian airplane has been discussed numerous times in scientific literature. The main design constraint on a Martian airplane is the extremely low atmospheric pressure of Mars (which averages 800 Pa or 0.12 psi). In order to carry the mass of the required scientific equipment, a planform area of over 15,000 m^2 (almost 4 acres) is necessary. Another major disadvantage of an airplane is that it requires landing strips everywhere it wants to stop. As this mission is the first exploration of the Martian surface, landing strips are not readily available.

Another air-based possibility is a dirigible. This, however, requires a volume of over 900,000 m^3 due to the low atmospheric density in order to lift the required scientific equipment. Both of these possibilities do have some major advantages over the other possibilities to be mentioned later. These designs are not limited by terrain (except in launch and landing), as a land-based rover would be. They also have the ability to see the "big picture," geologically speaking, but since they are limited in their landing sites, they are not flexible enough to be able to stop at an interesting site that had just been discovered.

3.2. By Land

Land-based rovers are probably the best understood of all of the options, as they have been designed and built successfully in the past. The main disadvantage of a rover is that terrain does play a major factor in the time it takes to get to each site. While it might take an air-based design a few hours to get to a distant location, it would take a land-based design days or even weeks to get to the same place. A land-based rover would not be able to see the "big picture," but it would have the flexibility to stop at any point and examine an interesting site. A land-based design would be limited severely by its power, propulsion, and life support systems. If unpressurized, the life support system would consist mainly of the astronaut's EVA suits. If pressurized, however, a rover would be able to go farther and would be a safer environment for the crew due to its on-board life support systems.

3.3. By Space

Another method for transportation on Mars could be a sub-orbital, ballistic hopper. This would need a specified "landing site," but this site would not need to be a landing strip, merely a flat, boulderless spot near the exploration site. This option would minimize the travel time for the crew, maximizing their safety. It would, however, get the worst of both worlds in terms of seeing the "big picture" or the details, as the choice of landing sites would not be flexible enough to land anytime an interesting site was found, and there would also be a rocket engine where the window would need to be in order to see the scenery. Also, unless one added some type of land-based rover to this design (similar to the lunar rover), the exploration would be limited to the maximum walking distance allowed of the crew once they reached their destination.

3.4. Conclusions

The real question in this decision was the level of detail we wished to see on the surface. If one was going from Maryland to California, would they see more of the country by flying, or by hopping in the family Winebago and driving? With this and all of the other advantages and disadvantages in mind, a pressurized, land-based rover was chosen.

4. Science

There are three major science requirements for this mission. These are:

- To understand the history as well as the current state of the planet Mars
- To determine the existence of past or present life on Mars
- To determine the suitability of Mars for long-term human settlement

In order to fulfill these requirements, scientifically interesting sites would need to be chosen. At the selected sites, astronauts will perform EVAs to set up data collection equipment, select samples, and conduct geological and exobiological studies. At some sites, the astronauts will be required to conduct drilling to collect core samples. They will also need to conduct some simple indoor experiments on samples in order to determine which type of samples are worth returning to base camp for further study and which sites warrant further investigation. The sites chosen will also determine what equipment needs to be brought along on each excursion.

4.2. *Areas to be Explored*

As stipulated earlier, the area which was to be explored as fully as possible was the region which included Olympus Mons, the Tharsis Montes, Valles Marineris, and Lunae Planum. The reasons for exploring these areas, and which sites would be explored in each area will be explained below.

4.2.1. Olympus Mons

The first of these sites is Olympus Mons, the tallest known mountain in the solar system. This young shield volcano stands 25 km (15 mi.) high and is around 800 km wide at the base. It also contains an encircling basal scarp which ranges from 2–10 km in height. The immense height of this formation indicates long-term crustal stability of the planet. Of special interest at this site are the basaltic lava flows which are characteristic of shield volcanoes, the aureole deposits, and other surface deposits at the base of the volcano. Basaltic rocks are defined to contain 45–54% silica and often have higher percentages of iron, calcium, and magnesium than other igneous rocks. Aureole deposits, the origins of which are unknown, are lobes of ridged, fractured material surrounding the base of the mountain. Studies of fractured terrain could give clues to seismic activity and the differences in degradation and burial of rocks surrounding the base will suggest the sequence of volcanic activity. Aging of the volcanic material will also aid in determining the age of other surface features. Due to the isolation of this volcano, crater density will be a crucial factor in determining relative age. As part of the determination of planet habitability and search for life, it will also be necessary to determine the distribution of elements and compounds as well as conduct atmospheric studies.

4.2.2. Tharsis Montes

A second region of exploration is the Tharsis Region. This region is characterized by its ridged terrain and three large shield volcanoes. The three volcanoes are Ascraeus, Arsia, and Pavonis Mons. They are only slightly older than Olympus Mons. These volcanoes which range from 9 km to 22 km in height, are smaller than Olympus Mons, but are larger than any terrestrial shield volcano. The scientific interests here are the same as those at Olympus Mons, with the addition of a set of radiating surface fractures. Determination of the origin of these surface fractures will be important in determining the history of the planet and its seismic activity. Studies here will include: atmospheric studies, seismic studies, types and relative ages of rocks, studies on aureole deposits, other surface deposits and lava flows, and the distribution of elements and compounds.

4.2.3. Valles Marineris

The third major region of exploration is the Valles Marineris region. Valles Marineris is a large, complex canyon system which runs along the Martian equator. The entire system is about 4000 km long and as much as 200 km wide and 7 km deep. The system is speculated to have once held water, and possibly life, but its origin is still unknown. The three major regions of interest within Valles Marineris are Tithonium, Hebes, and Melas Chasma. The scientific interest in this region lies in the sedimentary deposits, tectonic features, chemical weathering, and basaltic material. Studies will include: the age, distribution, and composition of sedimentary deposits and clay materials; core drilling; and the distribution of subsurface water. These studies will aid in the determination of the canyon's formation and history and, more importantly, answer questions about whether or not it once held water. In addition, seismic studies will provide historical information on the canyon system. It will also be important to search for any organic remains and life-forming elements or compounds. If organic remains or life-forming elements are found, their ages, distribution, and characteristics will be studied. Atmospheric studies will also be conducted and data will be collected on the equatorial weather of the planet. These studies will ultimately lead to an improved atmospheric model of the planet.

4.2.4. Lunae Planum

The fourth and final region of exploration is Lunae Planum. Lunae Planum is a densely cratered plain with ridges and volcanic material. Studies will include composition and distribution of ridged plain material, volcanic material, craters, and subsurface water. Again atmospheric data will be collected. Another ridged plain area at Fortuna Fossae may also be explored, time permitting. This area is actually located to the west of Lunae Planum, but is included in this section due to its geologic similarity to Lunae Planum.

4.3. Scientific Equipment

In order to conduct these studies, MERLIN will need to carry some scientific equipment. Although samples will be returned to the base camp for detailed study, preliminary analysis of surface and subsurface materials will be necessary to save both time and space. Simple detection of elements in samples can help eliminate both the necessity for further in-situ investigation of certain materials and the need to carry them back to base camp. This equipment is described in tables 4.3.1, 4.3.2, and 4.3.3.

TABLE 4.3.1. Geological Equipment

Equipment	Description	Mass (kg)	Volume (m^3)	Power Required (kW)	Set-up Time (hrs)	Work Time (hrs/day)
Mars Geophysics Package (3)	Water detection, determination of local gravity and magnetic fields, mechanical properties and structure of crust	75	0.06	0.025	2	N/A
Marsnet (3)	Seismological stations to be left at sites for long-term seismic activity of planet interior and near surface climate and wind	75	0.06	0.025	2	N/A
Geological Field Package	Field tools to be used during EVA for close examination of field conditions for on-site decision making	45	0.15	2	N/A	4
Differential Scanning Calorimeter	Primary phase identification of minerals and volatiles	20	0.03	0.04	N/A	N/A
Multispectral Imager	Close range imaging	35	0.16	0.024	1	0.2
Binocular Microscope	Preliminary sample examination and evaluation	5	0.01	0.02	N/A	N/A
X-ray Fluorescence Spectrometer	Accurate elemental analysis	2	0.02	0.01	N/A	N/A
Drill Rig	Collect core samples	450	10	5.5	2	1
Mass Spectrometer	Elemental and isotopic analysis to determine absolute ages of rock samples before further investigation	12	0.04	0.016	N/A	N/A

TABLE 4.3.2. Meteorological Equipment

Equipment	Description	Mass (kg)	Volume (m^3)	Power Required (kW)	Set-up Time (hrs)	Work Time (hrs/day)
Surface Atmospheric Package (3)	Measures temperature, pressure, wind velocity and direction, aerosol content	75	0.06	0.025	2	N/A
Mass Spectrometer	Chemical composition of atmosphere	12	0.04	0.016	N/A	N/A
Surface Interaction Experiment	Chemical interactions between atmosphere and surface	N/A	N/A	N/A	N/A	N/A
Ionospheric Sounder	Measures ion composition of upper atmosphere	50	0.3	0.14	4	0.1
Aerosol Laser Ranger	Measures height and content of clouds	40	0.1	0.3	8	0.2

TABLE 4.3.3. Exobiological Equipment

Equipment	Description	Mass (kg)	Volume (m^3)	Power Required (kW)	Set-up Time (hrs)	Work Time (hrs/day)
Incubator	Incubation of Petri dishes for exobiology and life science experiments	3	0.01	0.03	N/A	N/A
Neutron Spectrometer	Analysis and detection of organic material	6	0.00015	0.006	N/A	N/A
Mass Spectrometer	Elemental and isotopic analysis of soil	12	0.04	0.016	N/A	N/A
Thermal/ Evolved Gas Analyzer	Analyzes gases given off by soil	1.9	0.0014	0.014	N/A	N/A
Specific Electrode Analyzer	Identification of solutes of biological significance	2	0.015	0.002	N/A	N/A
Soil Oxidant Survey	Equipment for analysis of oxidants in soil which may be detrimental to the stability of organics	1	0.005	0.01	N/A	N/A
IR Laser Spectrometer	Detects trace gases in soil or air (which may be indicative of biological activity)	10	0.05	0.02	N/A	N/A
Optical Microscope	High resolution sample analysis	6	0.004	0.02	N/A	N/A

This scientific equipment has a total mass, volume, and power requirement of 1114 kg, 11.5 m^3, and 8.3 kW respectively. Without the drill rig this drops to 664 kg, 1.5 m^3, and 2.8 kW respectively. (The drill is not needed for the excursions to all of the sites.) The scientific equipment has a total set-up time of 21 hrs and work time of 5.5 hrs. The number of man-hours per task are summarized in table 4.3.4.

TABLE 4.3.4. Man-Hours Required Per EVA Task

Man-hours	EVA Task
42	Geophysical Experiment/Geological Examinations
42	Geological Observations/Shallow Drilling
50	Geology/Geophysical Experiments/Deploy Science Stations
50	Extended Geology (includes drilling)
184	**Total**

Breaking this down into 8 hr workdays for the crew, and adding time for sample gathering, etc, a time of 14 days was deemed the maximum necessary to complete all experiments at each exploration site.

4.4. *Vehicle Design Impacts*

The science discussed above has a direct impact on the design of the rover. The rover consequently requires an indoor lab to conduct preliminary science experiments on samples. Based on the sizes of the indoor equipment and the work area necessary to conduct lab experiments the lab area was determined to be a 1 m × 1 m square. The equipment must be restrained in storage areas while the rover is in motion but will most likely not be in use unless the rover is stopped. The rover also requires an outdoor cargo area to hold samples as well as the equipment to be used outside the vehicle during EVAs. This area is accessible by a robotic arm which will be used to collect samples in situations where it is impractical to perform an EVA. For the purposes of assisting EVA, the vehicle will require an airlock/dustlock. Additionally, the rover must be capable of carrying the large drill rig, weighing 450 kg and occupying another 10 m^3 in volume, to the previously mentioned areas. The rover will also need the ability to store scientific data on board as well as return that data to base camp.

5. Base Camp Location

Once the sites for scientific exploration were chosen, the next decision was the location of the landing site/base camp. Without this knowledge, the total distance MERLIN would need to travel would be unknown. The base camp location has several requirements. It needs to:

- Be in a location in which it is possible to land.
- Have easy access to all of the scientifically interesting sites.
- Be a possible site for long-term human habitation.

Given all of these factors, the following possibilities were considered (see fig. 5.1):

- Near Gigas Sulci
  4°N 136°W
  A flat area near Olympus Mons.
- Near Fortuna Fossae
  8°N 85°W
  A flat area approximately in the middle of the scientifically interesting sites.
- Near Tithonium Chasma
  0°N 90°W
  Near one of the scientifically interesting sites and the gate of Valles Marineris.
- Near Ascraeus Mons
  6°N 101°W
  Approximately in the middle of the exploration region, and very near one of the scientifically interesting sites.

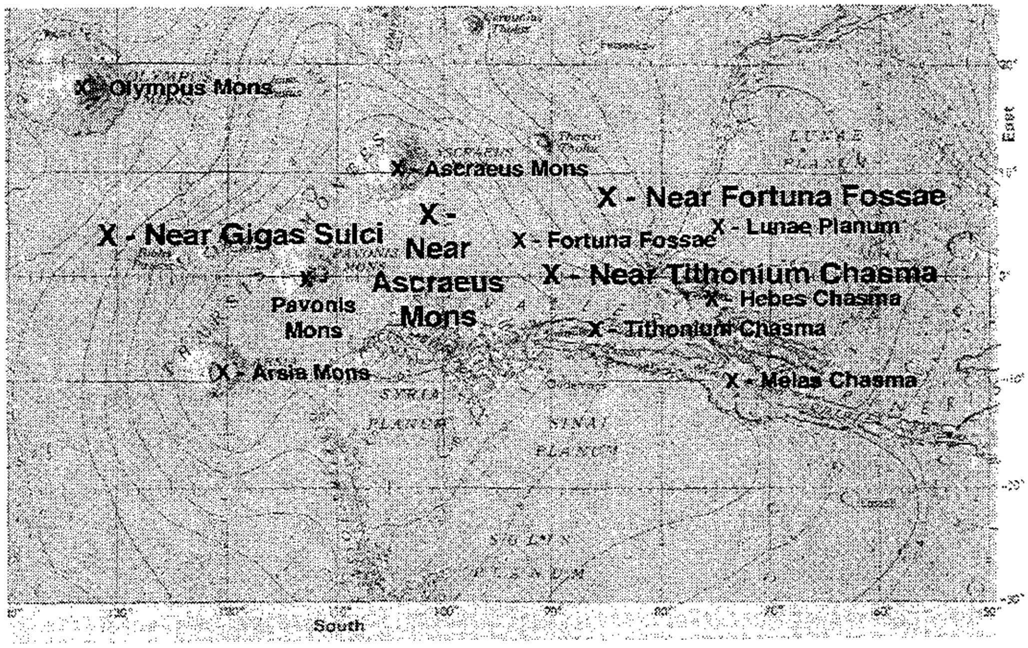

Fig. 5.1. Possible Base Camp Locations and Scientifically Interesting Sites.

Due to its central location and proximity to a scientifically interesting site, the site near Ascraeus Mons was chosen as the base camp location.

6. Mission Scheduling

With the base camp and scientifically interesting sites chosen, the different excursions were decided. These excursions were broken down into two periods — the break-in period, and the working period. All of the different excursions were planned with the following assumptions in mind:

- 500–600 d surface stay
- A maximum of 14 days of science time at each site.
- A minimum of 10 days of contingency time added to each excursion.
- Very conservative estimates of distances were used to account for terrain (35% added to the straight-line distances).

6.1. Break-In Period

When MERLIN reaches the surface of Mars, it will be virtually untested in its actual working environment. In order to ensure that it will perform as expected on the longer excursions, it seemed prudent to schedule a few shorter trips for MERLIN's first few outings. The break-in period consists of two excursions, with a third excursion possible, if deemed necessary.

6.1.1. Break-In Sortie #1

The first excursion would be just a quick trip around the block, so to speak. MERLIN would be driven around the base camp several times, with all systems being tested. No real science return would be expected from this sortie.

Break-In Sortie #2 — Ascraeus Mons

This sortie marks the beginning of MERLIN's scientific explorations. The rover will take its first trip outside of the safety net provided by the base camp. The total distance will be limited, however, since Ascraeus Mons is the closest of the scientifically interesting sites, lying only 500 km from base.

TABLE 6.1.2.1. Break-In Sortie #2

Location	**Distance (km)**	**Travel Time (days)**	**Science Time (days)**	**Contingency Time (days)**
Base Camp	–	–	–	–
Ascraeus Mons	500	2.5	14	–
Base Camp	500	2.5	–	–
	–	–	–	11
Total Distance (km)	**1000**		**Total Excursion Time (days)**	**30**

6.1.3. Break-In Sortie #3 — Fortuna Fossae

The third sortie is to Fortuna Fossae. This location is on the travel route twice for the trip to the Northeast (Lunae Planum and Hebes Chasma), so it becomes somewhat redundant to take this trip. This is merely a recommended trip, should it be decided that MERLIN is not fully broken in after its trip to Ascraeus Mons.

TABLE 6.1.3.1. Break-In Sortie #3

Location	**Distance (km)**	**Travel Time (days)**	**Science Time (days)**	**Contingency Time (days)**
Base Camp	–	–	–	–
Fortuna Fossae	650	3.5	14	–
Base Camp	650	3.5	–	–
	–	–	–	14
Total Distance (km)	**1300**		**Total Excursion Time (days)**	**35**

6.2. *Working Period*

Once MERLIN is considered fully functional, it can begin to fulfill its mission goals of scientific exploration. Four sorties were planned which incorporate all seven of the remaining scientifically interesting sites (not including Fortuna Fossae). The longest sortie is 70 days long, and the furthest point MERLIN will get from base is Melas Chasma, which is 2830 km from base along the route through Valles Marineris.

Sortie #1 – Southeast to Tithonium and Melas Chasmas

TABLE 6.2.1.1. Working Period Sortie #1

Location	Distance (km)	Travel Time (days)	Science Time (days)	Contingency Time (days)
Base Camp	–	–	–	–
Gate of Valles Marineris	1260	6.25	–	–
Tithonium Chasma	510	2.5	–	–
Melas Chasma	1060	5.25	14	–
Tithonium Chasma	1060	5.25	14	–
Gate of Valles Marineris	510	2.5	–	–
Base Camp	1260	6.25	–	–
	–	–	–	14
Total Distance (km)	**5660**		**Total Excursion Time (days)**	**70**

Sortie #2 – Northwest to Olympus Mons

TABLE 6.2.2.1. Working Period Sortie #2

Location	Distance (km)	Travel Time (days)	Science Time (days)	Contingency Time (days)
Base Camp	–	–	–	–
Olympus Mons	2750	14	14	–
Base Camp	2750	14	–	–
	–	–	–	13
Total Distance (km)	**5500**		**Total Excursion Time (days)**	**55**

Sortie #3 – Southwest to Arsia and Pavonis Mons

TABLE 6.2.3.1. Working Period Sortie #3

Location	Distance (km)	Travel Time (days)	Science Time (days)	Contingency Time (days)
Base Camp	–	–	–	–
Arsia Mons	2010	10	14	–
Pavonis Mons	1020	5	14	–
Base Camp	1060	6	–	–
	–	–	–	11
Total Distance (km)	**4090**		**Total Excursion Time (days)**	**60**

6.2.4. Sortie #4 – Northeast to Hebes Chasma and Lunae Planum

It is on this sortie that Fortuna Fossae could also be visited. The travel route passes through Fortuna Fossae on both its inward- and outward-bound legs. The science time for Fortuna Fossae could fit easily into the contingency time built in to the mission, or more time could be added without exceeding the limits of MERLIN's consumables supply.

TABLE 6.2.4.1. Working Period Sortie #4

Location	Distance (km)	Travel Time (days)	Science Time (days)	Contingency Time (days)
Base Camp	–	–	–	–
Hebes Chasma	2090	11	–	–
Lunae Planum	450	2.25	14	–
Base Camp	2080	10.75	14	–
	–	–	–	13
Total Distance (km)	**4620**		**Total Excursion Time (days)**	**65**

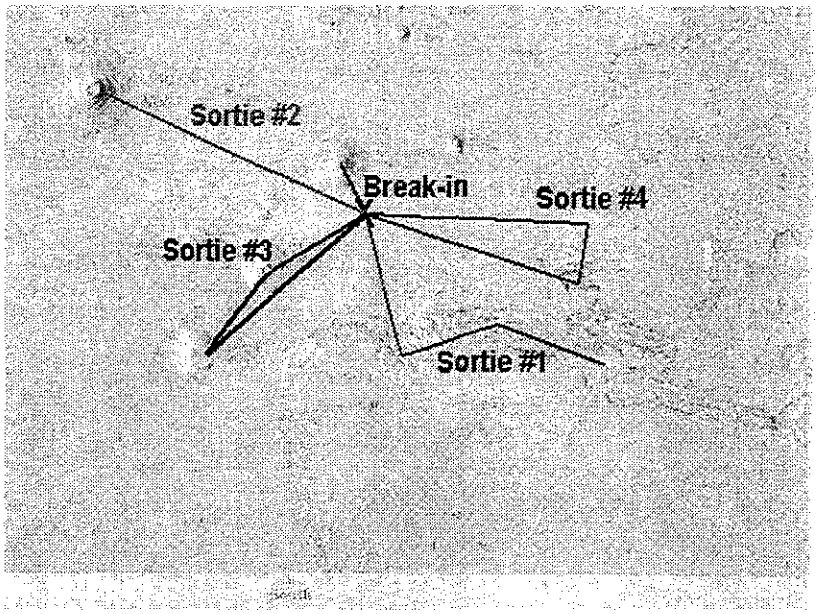

Fig. 6.2.4.1. MERLIN's Sortie Routes.

7. Structures

Now that the basics of the mission have been decided, the actual designing can begin. MERLIN has eight main structural members. These are: the pressure vessel; the front window; the airlock; the undercarriage and main truss; the EVA lift-gate; and the wheels and suspension (see fig. 7.1).

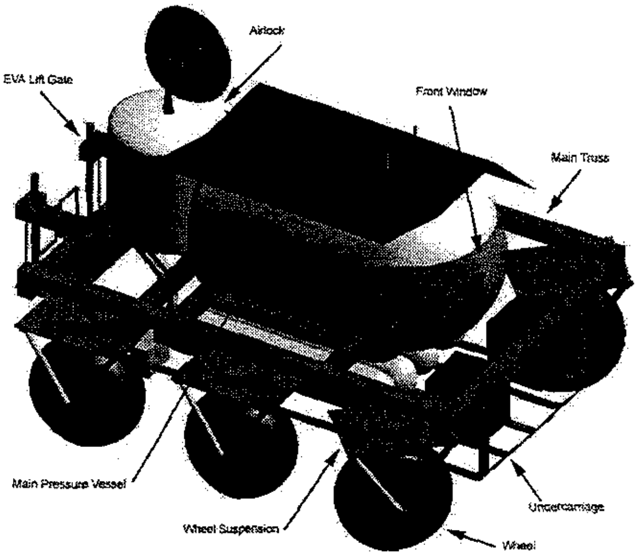

Fig. 7.1. MERLIN's Primary Structural Members

7.1. *Pressure Vessel*

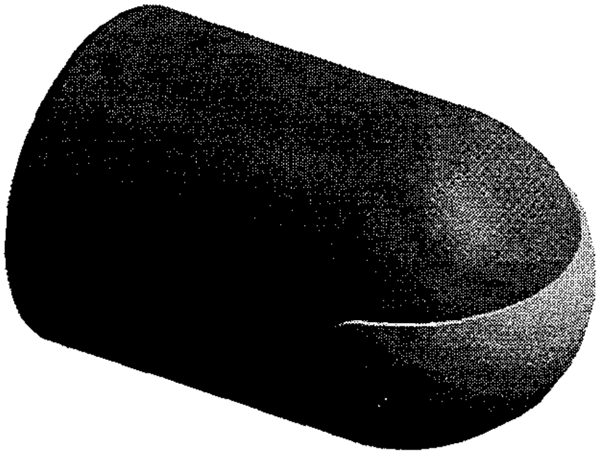

Fig. 7.1.1. Main Pressure Vessel and Front Window

The pressure vessel is designed to encompass the livable interior of the vehicle as well as storage space for major systems (life support, avionics, mission required hardware). The nominal internal pressure, as defined by the Crew Systems team, is 55 kPa, which leads to a required wall thickness of less than 1 mm. The vessel itself is supported from the inside by three circular stiffeners which mate with the cradle of the external truss. The main body cylinder has a radius of 1.8 m, is 3.5 m long, and has a wall thickness of 3 mm. The front endcap, which is hemispherical, has a radius of 1.8 m and a wall thickness of 5 mm. The rear endcap, which is not hemispherical, has a radius of 1.8 m, a height of 0.5 m, and a wall thickness of 5 mm. All of these pieces are made of 6061-T6 aluminum.

7.2. *Front Window*

Also visible in fig. 7.1.1 above is the front window. The window allows for a standing crew member in the cabin to clearly see the horizon while giving members in the control station a clear view of the surrounding area. From the middle of the control station, the window allows for a 180° field of view along the horizon, 15° up, and 60° down. Crew members can see the ground below the front of the truss and between the engines from the control station. The window is made up of panes of 0.5 m^2 (0.71 m × 0.71 m) polycarbonate plastic which is 5 mm thick. Aluminum bands make up the frame which holds the panes together and mounts them to the pressure vessel.

7.3. *Airlock*

The airlock is located outside the main pressure vessel. This is necessary so that when it is depressurized, the structure is not being compressed by the internal pressure of the rover. Both the inner and outer doors are designed to open into the airlock so that pressure assisted sealing can be achieved. Additionally, a series of mechanical latches secure and assist in opening the doors in a manner similar to those currently used for the shuttle airlock. The main cylinder of the airlock has a radius of 1.1 m and is 2.1 m high. The endcaps are 0.25 m high and will be filled with an air-tight, lightweight foam to reduce the volume which must be depressurized. All walls will be 5 mm thick and will be made of 6061-T6 aluminum.

The airlock is designed to allow for two crew members in full EVA suits to exit the vehicle at a time. Two suitcase sized packages can be carried in and out of the airlock to allow for equipment to be to be transferred to and from the rover, as well as to allow for samples to be brought within the vehicle.

A raised grate floor will allow for dust brought in from EVA to fall to a collection area to prevent it from being tracked into the main cabin area of the vehicle. Vacuums, brushes, and other tools will be stored here for the cleaning and maintenance of the suits.

7.4. *Undercarriage*

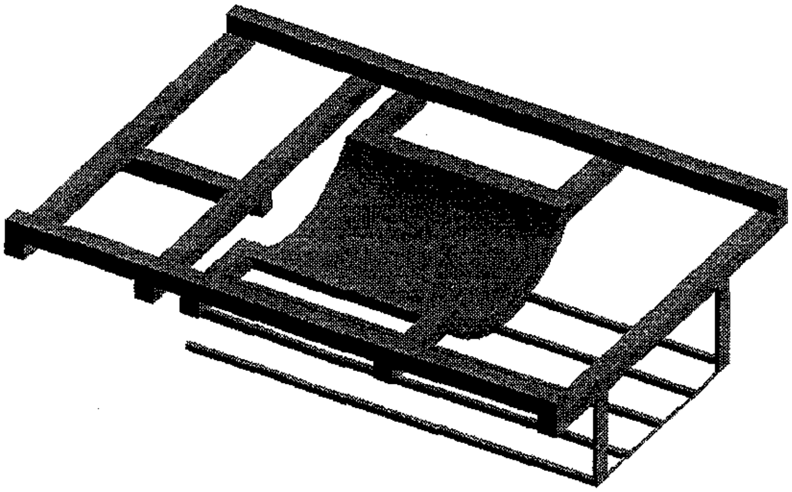

Fig. 7.4.1. MERLIN's Undercarriage

The main truss was designed to be both simple and robust in design. Titanium box beams were selected due to their high strength/mass ratio which is essential in such a critical load bearing structure. The cradle, which makes up the center part of the structure, was designed to avoid point loading on the pressure vessel, thus requiring a high area design. The undercarriage was designed to protect the pressure vessel and fuel tanks from contact with the surface in the event that the rover accidentally bottomed. The rear part of the undercarriage was extended to provide support for the robotic arm and sample storage boxes. The outer frame consists of 10 0.3m × 0.3 m box beams and the undercarriage consists of 5 0.1m × 0.1 m box beams.

FEM analysis revealed a large stress concentration in the center of the cradle. To counteract this effect, and to provide hard-points for mounting objects on the top of the rover, three circular stiffeners were added inside the pressure vessel (not depicted). These stiffeners also aid in transferring the weight of the internal systems of MERLIN outside to the main truss, rather than transmit the forces through the walls of the pressure vessel.
Due to the subsequent design and placement of the fuel tanks and water storage tanks, no support structure was designed to carry them, however their weight was added to the pressure force exerted on the cradle in the

analysis of the truss. Similarly, changes in design of engines (i.e. the addition of a second full size engine) required the removal of the original support structure, which there was not time to redesign. Future work would include the addition of simple supports to correct these missing elements.

7.5. *EVA Lift-Gate*

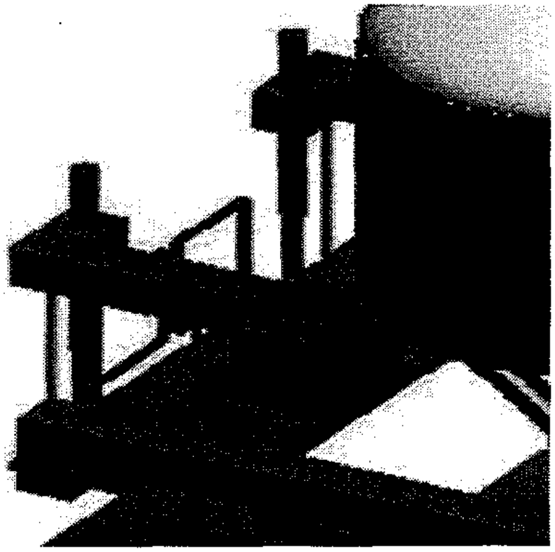

Fig. 7.5.1. EVA Liftgate

The lift-gate idea originated with the tailgate lifts sometimes used on 18-wheelers; a motorized platform that could lift people and heavy cargo easily up to the floor of the trailer. The lift-gate on MERLIN is suspended by four cables (two on each side, only one on either side is visible in fig. 7.5.1) so that it may be raised and lowered via winches. To keep the lift-gate from swinging, two telescoping rods were added. The gate on the lift is actually more of a handrail for the crew as they are raised or lowered. The lift-gate is large enough to take both crewmembers to or from the airlock with any samples they might be transporting.

7.6. *Wheels and Suspension*

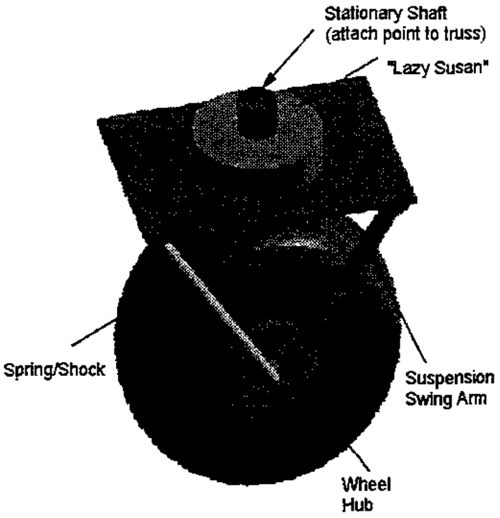

Fig. 7.6.1. Wheel and Suspension

The main design consideration with the wheels was the footprint necessary to keep the rover from sinking into the soft sand surfaces on Mars. On the less cohesive soils, the highest pressure allowable without sinkage was 6 psi. However, more solid surfaces can support much higher pressures and traversing them with a much greater tire contact area than necessary would cause more wear on the tire. To solve this problem it was planned to be able to remotely release some of the pressure when on the soft soil. To re-inflate the tire later, a remotely controlled compressor would use a portion of the CO_2 exhaust from the engine. The wheels have an outer radius of 1 m, and an inner rim radius of 0.375 m. Their pressure can range from 6 to 25 psi.

The suspension system is a modified version of a motorcycle rear-end. The wheels are supported by two bars in the front which are connected to the top plate with a pin joint. The axle of the wheel is supported by these bars and by two springs which are able to rotate in a manner similar to the front bars. This system is fairly simple, while still remaining robust. Springs were chosen with a constant of 27700 N/m in order to have a nominal, flat surface deformation of 10 cm. The swing arm is 2.0 m long and the spring/shock is 1.8 m long giving the wheel a slight offset.

7.7. *Steering*

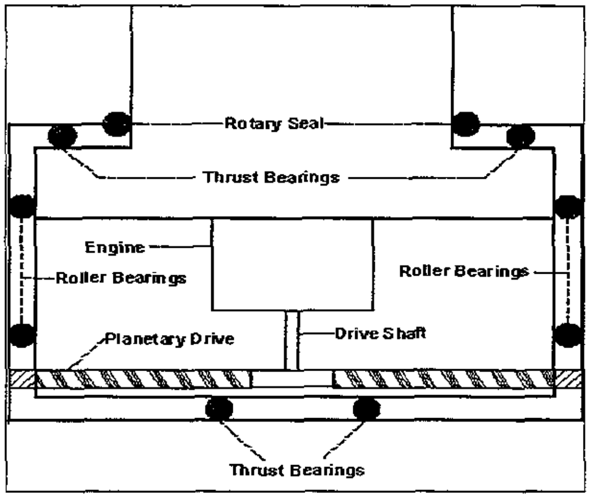

Fig. 7.7.1. Steering Mechanism

The design shown above works as follows: The top shaft is connected to the external rover truss. This point is fixed and does not move. The rotary seals prevent the Martian dust from entering the mechanism and destroying the equipment. The main casing of the design is a cylinder which is affixed to the plate on which the suspension system is mounted to. Thrust bearings at the top and bottom of the cylinder fix the rotating cylinder relative to the shaft that is connected to the truss. An electric motor suspended in the middle of the design rotates a planetary gearing system, consisting of three gears which drive the wheel rotation. Not shown are the power and control wires which run from the upper shaft, through the "Lazy Susan" and down into one of the arms of the suspension to provide power and control to the wheel drive motors.

8. Crew Systems

8.1. *Psychological Requirements*

When there are only six other humans on the planet on which you reside, and your family is (at the closest) almost 79,000 km (50,000 mi.) away, there are bound to be psychological concerns. In order to counteract the loneliness that the crew will feel, frequent communication with family and friends on Earth will be provided through email (voice communication having about a 40 min delay). Also, many forms of recreation will be provided, such as exercise, reading, and watching videos.

Another problem with being in an environment such as that found on Mars, is that all of the people will be confined within extremely close quarters. While humans are known for being able to adapt to many situations, 1.6 m^2 was established as the minimum comfortable personal space required for each person on the rover. This figure was gathered from studies done on submarines and other enclosed spaces which required lengthy stays.

8.2. *Physical Requirements*

8.2.1. Consumables

Each crewmember requires 0.62 kg dryweight/man-day of food and 9.6 kg/man-day of water. The food would be stored in dry form, like that on the shuttle, and rehydrated when eaten. Each crew member will be allowed to change clothes once a week (also similar to shuttle rules), and enough clothes to last for each mission will be brought along to avoid the need of a clothes washer.

8.2.2. Temperature and Humidity Control

The temperature inside MERLIN's cabin should average between 18.3° and 26.6°C, and the relative humidity should stay between 25 and 70% for crew comfort. These numbers were derived from other habitat analogs such as Apollo, Skylab, Shuttle, Spacelab, and the ISS.

8.2.3. Autonomous Driving

A certain level of autonomous driving was added to MERLIN's capabilities when it was discovered that it did not significantly increase the cost, mass, or power required, and it did not overly complicate the avionics system. This would be autonomous in the sense that the crew could set waypoints and desired speed, and then be able to relax in the cockpit. The autonomous driving system would alert the responsible crew member should a problem arise which it could not solve.

8.2.4. Fire Detection and Suppression

A system, again similar to that on the Space Shuttle would be used to detect and suppress fires. Smoke detectors which detect the ionization levels of the air would be used, as would hand-held halon fire extinguishers.

8.2.5. Atmospheric Systems

The Trace Contaminant Control System would be used for the control of airborne contaminants. This system consists of a set of filters that are projected to be fully regenerable in the future. Also required would be 2.76 kg of breathable O_2 and the removal of 3.06 kg of CO_2 per Martian day. A Solid Amine Water Desorption (SAWD) System would be used to scrub the CO_2 from the air and CO_2 electrolysis would be used to produce breathable oxygen (see fig. 8.2.5.1). Fifteen days of backup supplies would be provided. Among these are 90 kg of LiOH canisters for use in removing the CO_2 from the air and 83.3 kg of $Ca(O_2)_2$ which would be used to produce oxygen.

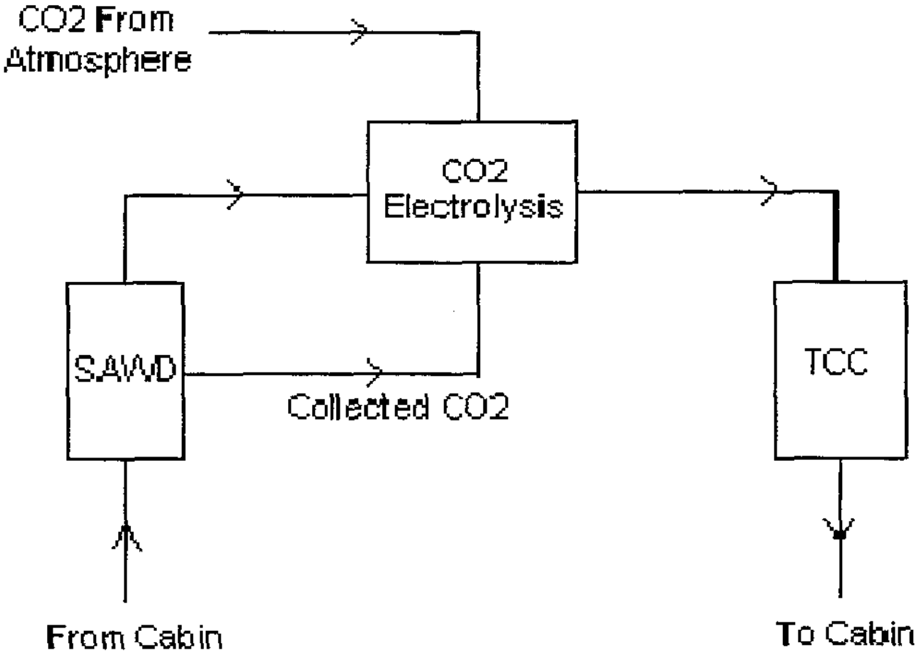

Fig. 8.2.5.1. Carbon Dioxide Removal System

8.2.6. Water Control Systems

A crew of three will nominally need 28.8 kg of water per martian day. This water will be split into hygienic and potable water reservoirs. Water will be reclaimed from toilets, showers, sinks, (see fig. 8.2.6.1) and the cabin air (see fig. 8.2.6.2). It is assumed that water reclamation will occur with a 90% efficiency. Water from the shower and sinks will undergo reverse osmosis, then will pass through a multi-filtration bed before passing through quality monitoring, and being stored in the hygienic water tank. Water from the toilet will pass through a Thermoelectric Integrated Membrane Evaporation System (TIMES) before passing through quality monitoring and being placed in the hygienic water tank. Cabin air will pass through a condensing heat exchanger (CHX), which will return the dry air to the cabin and send the water through quality monitoring to be sent to the potable water reservoir.

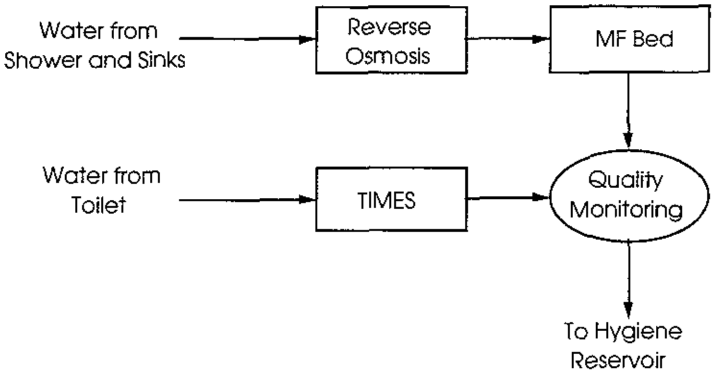

Fig. 8.2.6.1. Water Reclamation System

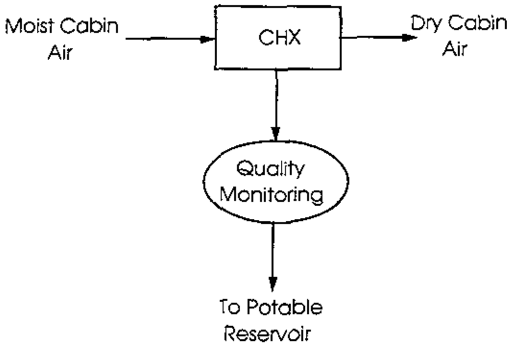

Fig. 8.2.6.2. Humidity Control System

8.3. *EVA Support*

MERLIN will be able to support two astronauts on EVA simultaneously. Video and suit telemetry will be sent back to MERLIN from the suits. The astronauts will require no pre-breathe due to the interior cabin pressure of 55 kPa. The crew will be able to maintain the suits while onboard MERLIN. The maximum EVA duration will be 8 hours.

9. Power, Propulsion, and Thermal

9.1. *Power Requirements*

While at rest, MERLIN will have a nominal power requirement of 4.5 kW. This energy will power all of the life support systems (2.0 kW), the avionics (2.0 kW), and will cover any thermal control systems and heat losses (0.5 kW). At times, power will also be needed for such auxillary items as the airlock (7.5 kW), the core drill (5.5 kW), the science equipment (2.5 kW), and the robotic arm (1.0 kW).

When driving, MERLIN will require power for all of the nominal systems, as stated above, as well as power for the engine (90 kW) and water condensers (5 kW).

9.2. *Power and Propulsion Systems*

9.2.1. Primary Systems

MERLIN will be powered nominally by an internal combustion engine which will run on stored methane and oxygen. The combustion will occur with 40% efficiency at a 2:1 oxidizer-to-fuel ratio. This engine will provide 100 kW of power nominally and 125 kW in peak usage times. Excess power will be stored for later use in NiMH batteries. The engine will only provide power while the vehicle is in motion. At all other times, the secondary systems will be used.

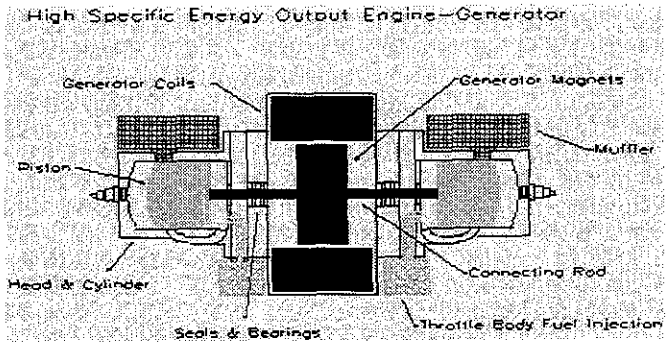

Fig. 9.2.1.1. MERLIN's Engine/Generator

9.2.2. Secondary Systems

While at rest, MERLIN will be forced to rely on its secondary power systems. These include batteries which were charged by the engine while driving, and solar arrays which can be deployed when at rest. The solar arrays will be located on MERLIN's roof and will be stowed while the vehicle is in motion.

9.3. Thermal Design

An engine which is only 40% efficient produces a significant amount of waste heat (187.5 kW). This energy will be radiated away from MERLIN through 6 m^2 of radiator panels and 1.7 cm diameter heat pipes which are located on the vehicle's undercarriage. Methane fuel for the engine will pass by the engine prior to combustion to allow it to vaporize. Engine exhaust will be vented through side exhaust pipes.

10. Avionics

10.1. Computer Systems

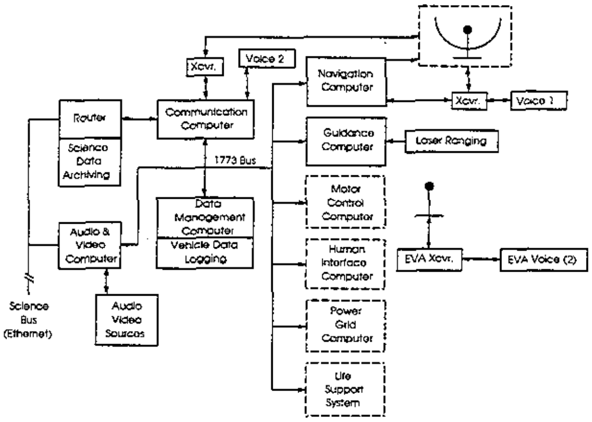

Fig. 10.1.1. Avionics System Block Diagram

As can be seen from the block diagram, the Avionics system is rather complicated. It consists of two main buses — the systems bus, and the science bus. The systems bus is the main bus. It runs over 1773 fiber optic lines. 1773 is a mil spec bus protocol which is redundant by nature. This redundancy provides an added level of safety for all mission critical computer systems. As the science equipment is not necessary to sustain life aboard MERLIN, its systems were kept separate from the systems bus. Since safety is not an issue where science data is concerned, gigabit Ethernet was chosen as the protocol for this bus. This is also advantageous due to its bandwidth and the ease with which it can interface to other systems.

10.2. Communications Satellites

The need for constant contact with the base camp while on an excursion is obvious. In order to maintain this contact, it was determined that three communications satellites would be needed. One of these satellites would support high bandwidth operations, like live video feeds, as well as communications and navigation, while the other two would only support communications and navigation. The navigation transponders would have a low bandwidth of 57.6 kbps and a high beam width of 160°. The high bandwidth relay would receive the main data stream at 11 Mbps, but would have a small beam width (20°). These systems would weigh 70 kg (per satellite), and would require 500 W of power. Due to these small requirements, it would be prudent to put these transponders on future Mars orbiters, as well as enough extra fuel to be able to place them in the proper orbits. The high bandwidth satellite would be placed in Mars-stationary orbit, while the other two satellites would be placed in Mars-synchronous orbit at a 15° inclination. These satellites would have 45° of separation to keep them from being co-linear within the orbital plane.

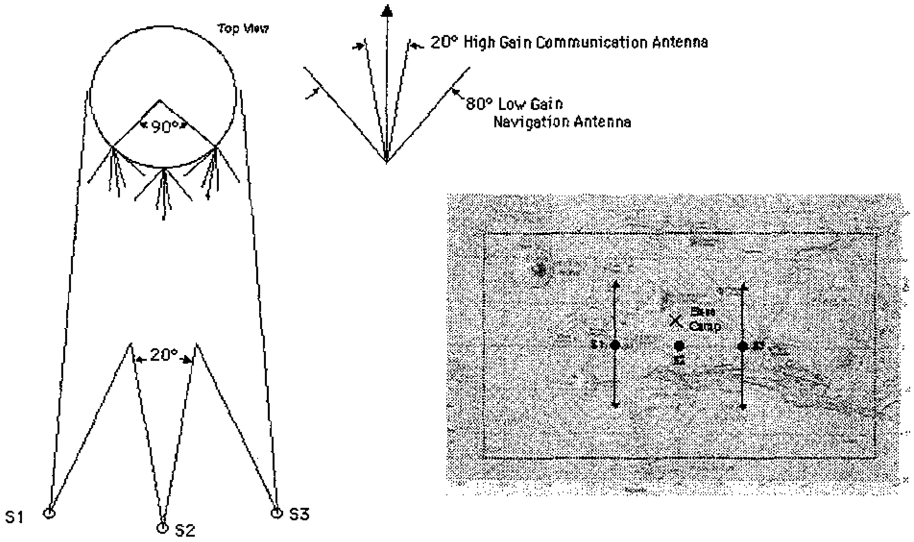

Fig. 10.2.1. Communications Satellite Coverage

11. Miscellany

Two additional systems are necessary for MERLIN's operation — a robotic manipulator, and CRYSTAL BALL.

11.1. Robotic Manipulator

To avoid unnecessary EVA, and to provide some heavy lifting power for MERLIN, a telerobotic manipulator was designed. This manipulator would be placed at the rear of MERLIN, on the starboard side of the airlock and lift gate. It would be within reach of two small sample storage containers. This would allow the arm to pick up rocks, or other samples, which could be carried inside the rover at a later time by an astronaut on EVA. The arm would have five degrees of freedom and would consist of a roll-pitch-pitch-pitch-roll configuration. This would limit the number of possible singularities while allowing a significant amount of mobility within the workspace. In order to be as capable as possible, three end effectors would be required: a claw to pick up rocks, a scoop to pick up soil, and a small core sample drill with which to get 6" diameter, 2' long core samples.

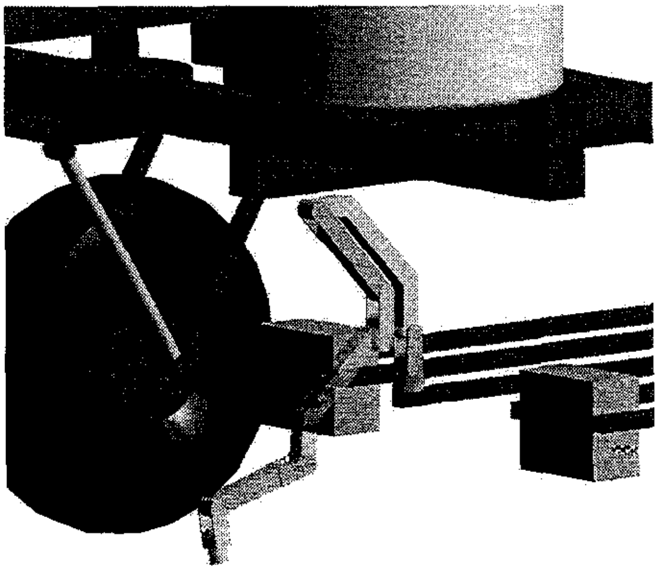

Fig. 11.1.1. Robotic Manipulator

11.2. CRYSTAL BALL

The CRYogenic STorage And Local BALlistic Lander (CRYSTAL BALL) system is basically a network of gas stations on Mars. Each CRYSTAL BALL installation would have about the same configuration as that of the Mars Pathfinder lander, in that it would have the three petals of solar panels, with machinery inside. These would be launched from Earth similarly to Pathfinder, and would be placed at seven locations which would provide the necessary fuel for MERLIN's travels.

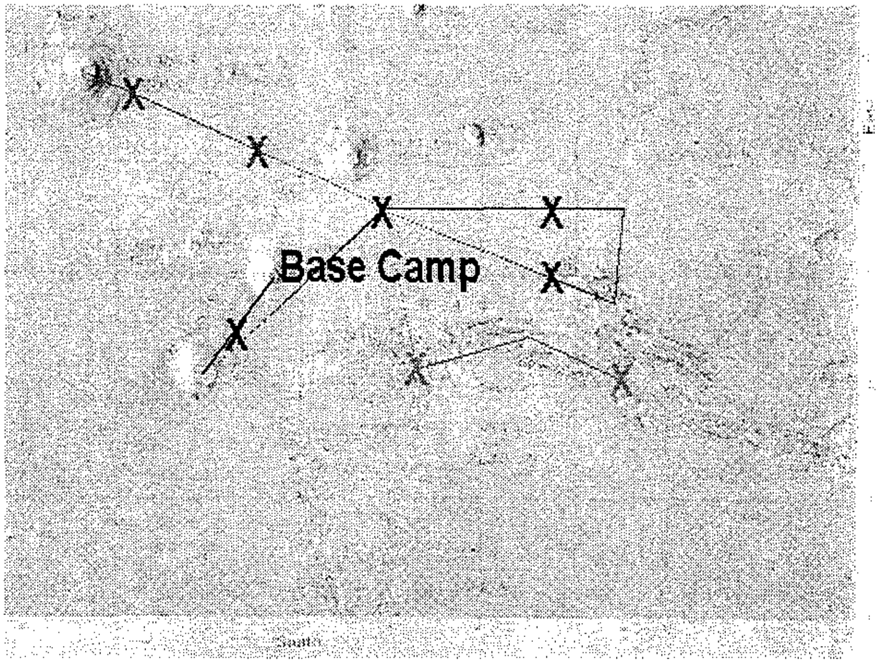

Fig. 11.2.1. CRYSTAL BALL Locations

The fuel and oxidizer would be produced with a Sabatier/Electrolysis Reaction system. The Sabatier rection would produce methane from carbon dioxide (from the atmosphere) and liquid hydrogen (stored). The water by-product from this reaction would then be electrolyzed to produce more seed hydrogen for re-use in the Sabatier reaction and oxygen. These would be stored until needed by MERLIN. Should MERLIN produce excess water (as is expected by the Power, Propulsion, and Thermal group), it will be possible to leave this water at any CRYSTAL BALL location to increase the lifespan of the installation. As they are designed currently, there will be enough seed hydrogen to be able to produce 3000 kg worth of propellants for MERLIN.

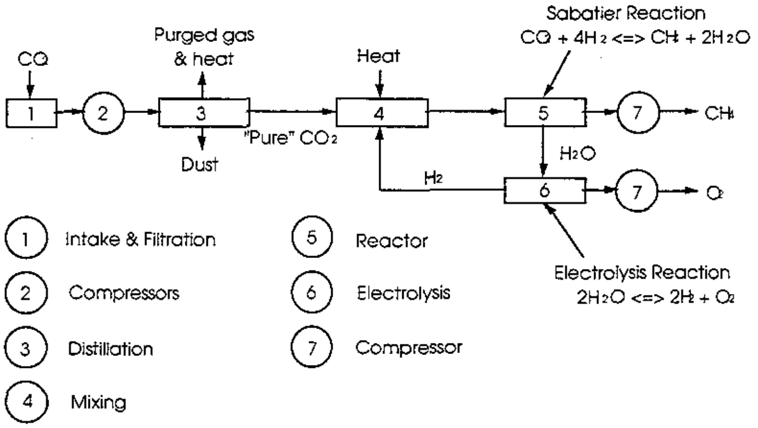

Fig. 11.2.2. CRYSTAL BALL System Block Diagram

12. Conclusions/Recommendations

It is recommended by the senior design class of the University of Maryland, College Park department of Areospace Engineering that the above design be considered as a possible design for a pressurized rover for use on Mars. While this design still contains many flaws, most of the ideas are technically sound and, many times, innovative.

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