MARS ANALYTICAL LABORATORY

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Introduction

As mankind continues to explore the solar system, planetary colonization may become an important goal. Permanently manned space stations, bases on the moon, and colonization of Mars will be important steps in this exploration. The colonization and exploration of Mars will be a particular challenge. As mankind one day attempts this colonization, knowledge of the Martian environment and human capacity to live there will become vitally important. The first scientific outposts on Mars will need research laboratories to make discoveries about how we can better live there and use the natural resources of the planet to sustain human life. The design of a laboratory for an existing Martian base is the purpose of this project.

A laboratory on Mars would be very useful to the scientists we send. Some possible focus points for research in a Martian lab are listed below:

- To learn how the human body degrades in the 1/3 gravity condition that exists on Mars.
- To study how to lessen this degradation making long-term stays possible.
- To find ways of using Martian resources to grow food for human explorers.
- To discover ways of using Martian materials to build useful items.
- To explore the current and past geological (seismic, volcanic) activity of Mars.
- To study the past and present history of water on the surface of Mars.
- To study the possibility of indigenous life (past and present) on the Martian surface.

A lab that carries the necessary equipment can address all these focus points. The lab to be designed in this project will be capable of helping scientists study all of these subjects and more. In order to simplify and define the project, some assumptions were made at the beginning of this project. These assumptions are listed below:

- The mission for this project design begins in Low Earth Orbit.
- A heavy lift launch vehicle will be available to lift large payloads into orbit.
- The lab to be designed will not carry astronauts to Mars.
- A small manned habitat will exist on the Martian surface.
  - This habitat will sustain at least six astronauts continually.
  - It will be capable of supplying the life support needs of the lab.
  - It will have a generic 'connection' that the lab can be connected to.
  - The habitat will be set up in a 'trailer park' type configuration with many modules branching off of a large central module.
- The habitat will be located in an area that experiences 'average' Martian weather conditions.

The assumptions listed above enable this problem to be simplified in the following ways:

The first and second assumptions help by allowing the design to ignore the initial stages of the mission. This means that launch from Earth does not have to be considered. If no heavy lift launch vehicle were ever designed, it would require an extremely different laboratory design to effectively launch with the space shuttle.

The third assumption simplifies laboratory design by eliminating the requirement of life support systems for the trip to Mars. A design requiring life support systems would require vast stores of food, water and air reclamation equipment, and heating apparatus. It would therefore be heavier, and also require a shorter trip to Mars, which would be more costly. Once on the surface, however, the water and air reclamation equipment, power source, and heating apparatus would become redundant, therefore being unnecessary. While redundancy will be desired on Mars, having every module provide its own life support needs could make maintenance a problem, and would be very inefficient. Therefore, this module will be one that requires life support from outside sources.

The fourth assumption concerns the habitat that the lab will connect to. The assumption that there will be several astronauts living in the habitat at all times assures the lab will be in use at all times. This enables a lab design that does not require long periods of shutdown. The assumption that it will be able to supply all the life support needs of the lab requires that a large power source, such as a nuclear reactor or a huge solar array, be installed on the Martian surface to supply the necessary power for equipment, heating, ventilation, and air conditioning. It also requires bio-reactors and hydroponics to clean the water as well as filters and the hydroponics to clean the air. The assumptions that the habitat will be set up like a trailer park and that a generic connection will be available enable a mating connection to be designed for the laboratory.

The fifth assumption concerns the weather that the lab will be exposed to. Planning for average Martian conditions enables the design of an HVAC supply system to the lab. If the habitat were in the polar regions of Mars, this assumption would be inadequate, but since at this time it has not been built, its location is unknown, so it will be assumed to be in the middle latitudes.

The scope of this project, therefore, will be as follows:

- A lab will be designed that is capable of supporting scientific investigation on the Martian surface.
- An orbital trajectory will be planned for the transfer of this laboratory to Mars.
- A landing strategy, encompassing all phases of the landing, from atmospheric re-entry to impact will be planned and designed.
- A plan to move the laboratory from the landing site to the habitat and make the connection between them will be made.
- Determine an experimental equipment package that will enable researchers to experiment in the Martian environment.

Orbital Mechanics

The orbital mechanics of an aerocapture system for an unmanned mission to Mars was investigated. A computer code written in FORTRAN 77 was used to develop the orbital transfer mechanics for the outbound trip. It was determined that fast transfers, i.e. departure angles greater than zero, were too expensive in terms of propulsive expenditure despite their shorter trip times. Therefore, as determined from this program, a Hohmann transfer was selected as the most cost effective in terms of energy expenditure for the outbound transfer with a total velocity budget of 5.646 km/s. However, the Hohmann had the longest duration in terms of trip times at 258.9 days. This was deemed acceptable for an unmanned mission.

Another computer program written for MATLAB was used to analyze the aerocapture system. It was determined that at an altitude of 120 kilometers above the surface of Mars, a 240 meter per second reduction in velocity would be needed in order to slow the vehicle into a nearly circular orbit. This yielded a seven pass orbit, with a total maneuver time of 130.7 days. This time in addition to the outbound transfer sums up to 389.6 days or a 12.98 month mission duration with a final, nearly circular orbit eccentricity of 0.0001 and a total propulsive expenditure of 5.986 km/s.

Re-Entry to Mars Atmosphere

This study provides a design of a preliminary lifting entry vehicle for application towards transport of the Mars analytical laboratory from Earth to near the Mars surface. The entry vehicle is required to protect the laboratory from hypersonic impact in space, high heat, and deceleration loads that will be encountered throughout the journey, and provide a economical solution to launch from Earth. By conducting extensive research on hypersonic entry flight, heat protection materials, the use of equations of motion, graphs, a lifting entry vehicle design was created and analyzed. Creating a entry vehicle requires many design considerations which all interact with each other. Assumptions and approximations applied to motion equations provide insight for designing a entry vehicle and the design must consider the hypersonic aerodynamic characteristics and the mission.

Landing Configurations

Multiple runs were made at three different configurations to determine factors of impact velocity, retrorocket burn duration and fuel mass and parachute force exertion.

Configuration #1

As the lab module approaches the Martian surface after atmospheric entry, the module deploys two parachutes at 95,000 m and plummets to the surface front first, deploying two more at 50,000 m. At 40,000 m, two larger parachutes are while the current four are ejected and the lab rotates to a bottom first orientation. At 20,000 m, two additional parachutes of equal dimensions deploy and the module continues to decelerate until an altitude of 2,000 m is reached. At which point, retrorockets providing 55,050 N of thrust fire, slowing the module to a gradual landing. Fuel mass lost during the retrorocket firing phase were not taken into account.

Configuration #2

As the lab module approaches the Martian surface after atmospheric entry, the module free falls in a front first orientation and maneuvers into a bottom first orientation. At which time, retrorockets fire at a force equal to ten times the Mars weight of the module. The rockets fire for a duration of 10 seconds and shut off for a period of 15 seconds. During this shut off period, two parachutes are deployed and the module maneuvers to a bottom first entry. The retrorockets are fired once again at a force equal to 1.5 times the Mars weight of the module close to landing. When the height of the module reaches a distance of one meter above the surface of Mars, the rockets are shut down and the module lands. Again, mass lost due to fuel burn was not taken into account.

Configuration #3

Mass loss due to rocket burn was now taken into account. For this reason, the initial guess of 15,000 kg for lab module weight was increased to 30,000 kg. Starting at a height of 10,000 meters, the lab module free falls to the surface of Mars in a bottom first configuration. The module remains in free fall in this orientation until the retrorockets are fired at a combined force equal to ten times the Mars weight of the module and lands.

Propulsion

The propulsion systems of the Mars analytical laboratory consist of several small maneuvering rockets and four large retro-rockets. The maneuvering rockets utilize a Pressure System, Inc. (PSI) tank (#80255-1) with a hydrazine fuel. The fuel expulsion device is a simple rubber diaphragm. The rockets produce .44 N of thrust each with a mass flow rate of .4 g/s. The throat diameter is .8 mm and the exit diameter is 8 mm. This results in an area ratio of 100.

The retro-rockets are composed of a hybrid liquid/solid fuel system. This system allowed for easy throttling and a shorter start-up time of the system. This system uses a Hydrogen Peroxide liquid oxidizer and a Hydroxyl-Terminated Polybutadiene (HTPB) solid fuel cell. This combination allows for easy storage of the oxidizer on the trip and the rapid regression rate of the HTPB. The fuel cell used a circular grain configuration because of the ease of determining the fuel cell geometry. To compromise for a shorter cell length and a larger cell width, an initial port radius of 5 cm was used. This resulted in a final fuel cell length of 2.3371 m and diameter of .5726 m. The chamber pressure was held constant at 10 MPa so that the pressure term of the solid fuel grain regression rate could be simplified. This is accomplished through the use of a pump. The nozzle throat diameter is .1503 m with an expansion ratio of 27.1. From these results, the exit diameter was determined to be .7819 m. To find the length of the nozzle, a quadratic equation was determined. This equation was $y = 0.1x^2+0.75x+0.07515$. The slope of this line is 41°, which is an acceptable slope for avoiding flow separation and shock waves. These retro-rockets will be controlled by automation and perimeter sensors. If a firing failure occurs, the module will be controlled by the ground crew on the Martian surface.

Landing Gear

Many design requirements must be taken into account when designing the landing gear. The laboratory module will be landed on Mars as close to the habitat as possible without harming it. This distance is assumed to be less than two miles. Therefore, the lab module's landing gear must take the impact loads as well as provide a way to move the lab next to the habitat. This will be accomplished by utilizing a manual or electrical winch along with the 10 meter coring drill. The landing gear will have to be able to support the weight of the lab as well as be able to adjust to level the lab. Also, the lab will need to be able to roll across the soft, sand-like, Martin soil without sinking.

Since the lab will be moved across the Martian soil, large boulders and pits in the ground will be hard to avoid. Six landing gears will be used with independent suspensions and hydraulic systems so individual gears can be raised to go over an obstruction without affecting the others. Also, an individual gear can be lifted off the ground, rotated, and set back down to provide a way to turn the lab.

The landing gear was designed for a landing vertical velocity of 3.0 m/s. At this speed, the lab will encounter approximately 104,000 N per landing gear. With a 0.22 m stroke length, each landing gear will absorb approximately 79,400 N of the total 104,000 N landing force per landing gear. Therefore, the cradle is absorbing approximately 24,600 N at each landing gear location. The material chosen for the landing gear was a Titanium alloy, because of its relatively low density compared to other stronger materials such as AerMet100.

The wheels for the landing gear are aircraft rubber tires with a light Titanium rim. Each landing gear will have two wheels, one on each side for balance. The tire chosen is a 0.2032 m wide tire with a 0.61 m radius. This tire is a high pressure, high load tire with a maximum load rating of 55,000 N. From the Sojourner Rover mission, it was determined that the first 6-8 cm of the surface is virtually dust and below that is unknown. So, it is certain that the lab module will sink at least 6-8 cm into the surface of Mars and maybe even more before the labs tires hit a soil that can withstand the 300 kPa of pressure being exerted on the surface. The total mass for each landing gear including tires and rims is 227 kg and the total mass for the entire landing gear system is 1367 kg.

Pressure Vessel

The pressure vessel geometry consists of a cylindrical mid-section that has a diameter of 4.5 m and is 6 m in length. This diameter allows enough clearance for two floors. Two semi-ellipsoidal end caps, with a semi-major axis of 2.25 m and a semi-minor axis of 1.2 m, are connected on each side of the cylinder. Each end cap has a opening for an airlock at 1 m away from the cylinder along the longitudinal (X) axis. A composite layup is selected for the vessel and for the floors, due to high strength and high stiffness of composite structures. Honeycomb construction is suggested, due to its high bending stress capability and energy absorption capability. The outermost layers of the laminate consists of Kevlar 49 / epoxy woven fabric plies. Then, Scotchply 1002 glass / epoxy and T300 graphite / epoxy plies placed before and after the Aramid honeycomb of 1.905 cm (0.75 in) thick. The laminate configuration, except the Kevlar 49 woven fabric layers, is symmetric around the honeycomb. This will avoid any bending and torsion loads during the cure process. A static structural analysis is conducted, using NASTRAN. The analysis reveals that the laminate failure is critical at the location where the cylindrical portion and the semi-ellipsoidal caps are joined. In addition, the lower half of the cylindrical portion indicates that it is more susceptible to fiber failure than the upper half. Thus, the semi-ellipsoidal caps, upper and the lower halves of the cylindrical section are precured separately and then joined together. The estimated mass of the vessel is about 7500 kg. The manufacturing cost is estimated to be about $ 1,193,151.00, from which 52% is for the material.

Cradle Structure and Radiation Study

The first study performed is that of the design for the cradle structure. The cradle structure is a framework of beams that surrounds the composite pressure vessel. Its purpose is to provide additional support for the entire laboratory module structure as well as to act as the platform upon which many of the various sub-systems, such as the retro-rockets, landing gears, and fuel tanks, are to be mounted. The structural analysis of the cradle was performed by modeling a maximum loading condition on one beam element and allowing a minimum beam tip deflection of 2% in order to find the best combination of beam shape and size. Upon sizing the model beam element, a mass estimate was extrapolated by assuming uniform beam elements. The results showed that utilizing aluminum I-beams of 18.2 cm by 18.2 cm produced the adequate amount of support for the system. Total mass for the cradle structure is estimated to be approximately 5311 kg.

The second part of this study address the radiation protection requirements for the laboratory module. A study was conducted of the various radiation guidelines set by the many agencies, which deal with radiation. These agencies represent the full spectrum of interests from the nuclear power industry to NASA. It was found that NASA's radiation dosage limits are a factor of ten higher than that of the nuclear industry. Also, a brief survey of the expected Martian radiation environment was conducted. It was shown that the amount of radiation received on the Martian surface is expected to be a factor of five less than NASA's dosage limit, but a factor of two higher than that of the nuclear industry. Thus, should NASA's current dosage limit remain applicable for a Mars exploration mission and stay duration is kept low, it was found that no special radiation shield is required for the laboratory module.

Lab Systems

The lab systems design portion of this design project concerns the systems that supply the lab with the necessary life support, power and water for use in the everyday operation of the lab. To accomplish this, the requirements to sprinkle the lab in order to extinguish any fires will be determined and met. Also, the requirements of hot and cold running water will be determined and met. In addition, the electrical power requirements will be determined and met. Then the requirements for heating, ventilation, and air conditioning will be determined and met. Finally, a door will be designed that will accommodate transfer of workers, water, electricity, and heated fresh air. This door will be designed to enable the astronauts to seal it from the inside, while the habitat will have a door that is designed to be sealed from the other side.

The life safety and plumbing requirement were found to be best served by using polybutylene piping at a supply pressure of 53.3 kN/m^2 gage. A 100 watt pump was sized to clear the waste water from the lab. The electrical distribution system was found to require a 60 amp panel, and the electrical usage per day was found to be 90 kilowatt-hours. The HVAC system was designed as a plenum system (air supplied heating), where (4) 26 cm diameter ducts were sized to service the laboratory. The connection was designed from aluminum with a foam core. The masses and costs of the above systems were then calculated and the results are shown in Table 1-1:

	Mass (kg)	Cost
Life Safety	6.21	$ 352.84
Plumbing	8.22	$ 501.77
Electrical	93.94	$ 1,209.00
HVAC	10.00	$ 618.56
Door	278.00	$ 1,234.00
Total	396.37	$ 3,916.17

Table 1-1: Lab systems mass/cost summary.

The system design was kept as lightweight and simple as possible, to make maintenance easy and delivery cheap. The total system design should supply the lab with everything it needs to be a short-sleeve environment for research.

Equipment and Layout

During the design process, the equipment and interior secondary structure (cabinets, tables, counter-tops) was limited to a mass of 5000 kg. Because of this, it would be impossible to take equipment to study all possible scenarios of may be discovered. Most of the equipment for the lab was chosen based on ability to test for many different things as opposed to single specialized purposes. It was assumed that if more specialized equipment was needed, it could be brought on a later mission. With this in mind, a list of equipment was compiled and a mass study performed. The total mass of the equipment and interior secondary structure is approximately 4750 kg including a 10% margin for error.

Since the laboratory will be a permanent structure on Mars, it was designed to be as module as possible. Although the equipment and interior secondary structure mass was limited to 5000 kg, the structure was designed to accommodate 6000 kg. This provides flexibility to add additional equipment brought by later missions.

The laboratory is divided into two levels as shown in Figure 1-1. The 1st level holds mostly planetary science equipment while the 2nd level holds mostly life science equipment.

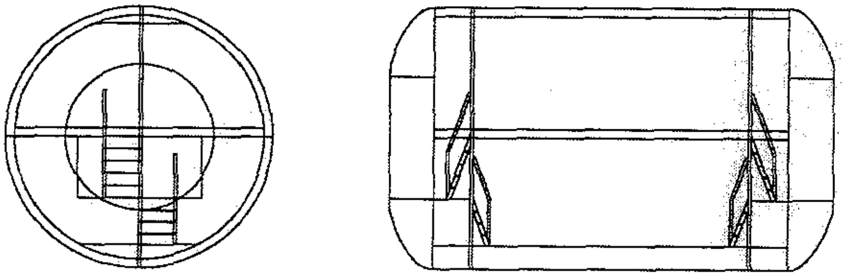

Figure 1-1: Layout of Mars Laboratory

It was not possible to determine an exact interior layout since only volumes (not dimensions) were available for much of the equipment. It was assumed the equipment was cubical based on volume unless exact dimensions were known. Based on this assumption, a layout was designed that took into account the location of power outlets and the comfort of the researchers (Figure 1-2). An estimated center of gravity study was performed to verify the feasibility of the design. Extra supplies sent on the lab during its flight to Mars would be positioned so that the center of gravity is as close to the geometric center of each level as possible.

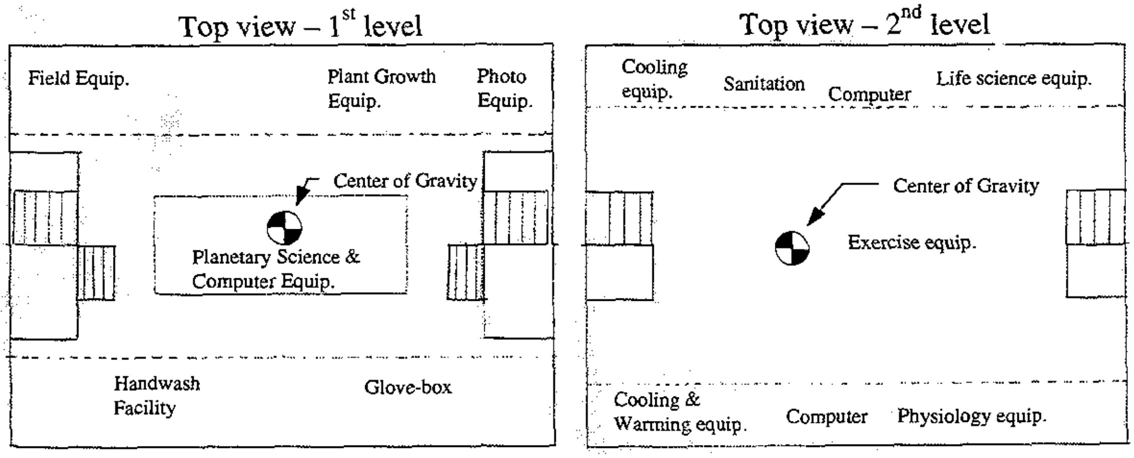

Figure 1-2: Mars Laboratory Equipment Layout & Center of Gravity Location