1.0 Introduction

"Mission to Mars", more commonly associated with a Hollywood science fiction movie title, has been on the top of NASA's project list in current years. Mars is the most accessible planet believed to have the capabilities to sustain life. That is, life on Mars is not something only accomplished on the big screen. As with any space mission, the exploration of our neighboring planet introduces new scientific knowledge and technologies that could ultimately benefit mankind. A better understanding of Mars will ultimately open a window to the history of our own planet. Also, similar to the efforts and goals of the International Space Station, the exploration of Mars would bring international cooperation and inspiration to men and women young and old.

Exploration of planets can be categorized into three stages of mission objectives where each mission develops technologies to aid the next. The first stage is to flyby the planet, collecting as much information as possible. In November of 1964, NASA launched Mariner 4. The spacecraft reached Mars on July 14, 1965, taking the first ever close up pictures of the red planet. With stage one completed, NASA pushed on to stage two, orbiting the planet. Mariner 9, launched on May 30, 1971, became the first artificial satellite to orbit Mars obtaining information. The next logical stage from this point is to land on the planet and perform surface operations and experiments. This brings us to Viking 1 and 2. In 1976, NASA successfully landed two unmanned spacecrafts on the surface of Mars to perform experiments. The future of Mars leads in one direction from this point by landing a man on Mars. A manned mission to Mars requires the astronauts to be away from Earth for several years with a narrow window for return. Therefore, prolonged life needs to be sustainable on this planet via a self-sustaining and life supporting greenhouse.

1.1 Mission Statement

As the development of NASA's Mars Direct program proceeds, there will be an increasing need to support and augment the proposed manned missions. Because of the large distance and travel time to Mars, these manned missions must endure a longer duration than any other manned space excursion to date. Therefore the philosophy of the Mars Direct plan encompasses In-Situ Resources Utilization (ISRU)[1]. The MarsPort Deployable Greenhouse (MDG) will support this philosophy by not only growing food, but by also providing a biological filter for the habitable atmosphere and waste products. The initial phase of greenhouse operation will be one mostly of research, determining viable options for further development, and as such will only provide a percentage of the total dietary needs of the crew. As the Mars Direct plan continues, however, the MDG will allow the logistical and financial freedom for the fledgling Mars base to host a large crew. Maintaining a minimal mass/minimal energy approach, the MDG will utilize solar collection to minimize artificial light as well as utilize the CO_2 rich Martian air for the greenhouse environment. The initial growing medium will be hydroponics due to the inconvenience of transporting earth soil to Mars, however an objective of the MDG will be to determine the feasibility of using Martian soil as a growing medium.

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[1] From NASA Design Reference Mission 3.0

1.2 Mission Objectives

Primary Objective:

To deploy an enclosed greenhouse structure on the surface of Mars for the production and storage of viable food for future manned missions.

Secondary Objective:

To provide a laboratory for the purpose of experimenting with the flora in a controlled Martian environment.

To promote public understanding and support for the space program and the exploration of Mars.

To support long range habitation and colonization of Mars.

1.3 Mission Needs, Requirements, and Constraints

Mission requirements for the MDG mission are divided into three categories – functional, operational, and constraints.

Table 1.3.1: Functional Requirements[2]

Requirement	Determing Factors	MDG
Performance	Primary Objective, Payload Architecture	provide 25% nutritional requirements for crew of 6
Performance	Primary Objective	lifetime of 20 years
Internal Environment	Primary Objective	10°C - 30°C
Atmospheric Composition	Primary Objective	0.1 kPa – 3 kPa – P.P. CO_2 >5 kPa – P.P. O_2 <50 ppb – Ethylene gas
Internal Environment	Primary Objective	40% - 90% - rel. humidity
Performance	Payload Architecture	leakage - <1% V_T/day
Performance	Payload Architecture	Auto deploy
Internal Environment	Primary Objective	I_{peak}(light) = 125 Wm^{-2} I_{min} (light) = 50 Wm^{-2} , 12hrs/day
Secondary Mission	As Above	provide a laboratory for experimenting with flora in a controlled Martian environment.

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[2] NASA derived constraints for competition

Table 1.3.2: Operational Requirements

Requirement	Impacted Systems	MDG
Duration & Availability	Payload Architecture	start-up, daily operations, shutdown, mothballing
Survivability	Electronics	radiation hardening
Survivability	External Structure	Mars environment
Environmental Management	Thermal Control	collect, store, and distribute waste heat
Production Management	Payload Architecture	maintenance, harvesting, replanting, storage
Environmental Management	Lighting Architecture	incident light and artificial lighting
Environmental Management	Water and Nutrient Control	conservation and recycling of fluid systems
Environmental Management	Atmospheric Conditioning	PSG O_2 separation and storage restoration of CO_2
Accessibility	External Structure	connection ports to outside systems

Table 1.3.3: Constraints

Requirement	Determing Factors	MDG
Cost	Size, Complexity, Current Technology	$#/yr + R&D
Schedule	Technical Readiness Program Size	operating capability within 10yrs
Regulations	Law Policy	NASA Mission
Political	Sponsor International Program	outreach plan
Environment	Transfer Orbit Lifetime	natural environment of Mars and outer space
Interfaces	Level of User	NASA trained astronaut/specialist
Size	Launch Vehicle	projected Ares

1.4 System Drivers

The following are system drivers that influence performance, cost, risk or schedule which the user or designer can control.

Table 1.4: System Drivers

Driver Type	Driver	What Driver Limits
Performance	Power	Payload and bus design, system sensitivity, mission life
Performance	Size	Payload size, payload weight, survivability
Performance	Crop Selection	Nutritious biomass volume, storage requirements
Cost	Size	Launch Vehicle, launch site
Cost	Operations	Pushes demand for autonomy
Schedule	Timeline	Mission Utility

2.0 Mission Format

2.1 Mission Concept

The mission concept is shown in the following table.

Table 2.1: Mission Concepts

Mission Element	MDG
Production	Hydroponics Utilization of Martian Soil
Tasking, Scheduling, and Control	Autonomous prior to crew arrival Martian crew dependent
Timeline	Prior to Crew Launch 20 functional years harvesting and replanting
Secondary Mission	Experimentation Research and Development

2.2 Mission Architecture

The mission architecture is shown in the following table

Table 2.2: Mission Architecture

Mission Element	MDG
Subject	High yielding, fast growing Nutritious Biomass High harvest index Food processing reqmts. Palatability Low growing Horticultural reqmts. Environmental reqmts.
Subject	Wheat, Soybean, Potato Sweet potato, Peanut Rice, Dry Bean, Lettuce Tomato, Carrot, Kale Cabbage, Radish, Onion Mushroom
Subject	Process and purify (evaporate) water Produce O_2 & remove CO_2 Crew solid waste management
Payload	Growth medium for root development to enable biomass filtering

Payload	Management of atmospheric composition (Levels of CO_2, O_2, Ethylene, Humidity)
Payload	Utilizes conservation of energy techniques, maintains interior temperatures to 10-30 degrees C
Payload	Maintains appropriate light intensity for a minimum of 12 hours, utilizes passive natural light collection combined with artificial light to meet required intensity
Payload	Delivers and controls the amount of nutrients and water needed at appropriate temperature, minimizes loss by recycling
Spacecraft Bus	Hypergolic descent thrusters used for final vertical velocity control
Spacecraft Bus	Onboard determination with ground support
Spacecraft Bus	Onboard sensors and RCS for course correction and orbit capture/escape
Spacecraft Bus	Fuel cells with battery backup for autonomous stage, utilizes exterior power source when crew arrives
Launch System	Ares heavy lift vehicle
Launch System	Ares upper stage for LEO to interplanetary trajectory
Launch System	Kennedy
Orbit	Mid Energy Transfer
Ground System	Initial Earth based control Mars based control
Mission Operations	Completely NASA controlled NASA (M.C.) monitored then crew controlled Completely crew controlled
Communication Architecture	Main data computer of user inputs/outputs with functional subsystems Single computer controlled

2.3 Mission Architecture Specification

2.3.1 Production

In an attempt to advance technology while cutting costs for future missions, the production of crops on Mars is to be used as a source of food for long term manned missions to the planet. Hydroponics, or the growth of plants in water, is the most efficient way to accomplish this mission's objective. When grown by hydroponics, plants have greater yields in less time. Also, hydroponics are spatially efficient in a greenhouse structure. At this time the Martian soil is not suitable for plant growth. However, new technologies may develop to a point that will allow the Martian soil to be manipulated for plant growth. The estimated production of crops for this mission is a maximum of 25% of the nutritional requirements for six astronauts in space. Crop selection will be held to those producing the most nutritional carbohydrates and proteins required by the crew to stay healthy.

2.3.2 Tasking, Scheduling, and Control

For this mission to successfully meet its objectives the tasking and control need to be distributed to operators. The greenhouse is to be launched prior to the manned crew responsible for servicing it. The start-up is projected to be mostly autonomous. Plants will begin to grow after the greenhouse is deployed to the Martian surface. This will allow a trial run for the greenhouse being monitored by a ground-based crew. From this point problems can be accessed and the crew will be able to prepare for dealing with any problems prior to their own deployment to Mars. Once a Mars crew is established and has landed on the planet, they will be responsible for operating the greenhouse as far as maintenance, plant production, and research.

2.3.3 Timeline

The MarsPort Deployable Greenhouse will launch prior to the crew. The start-up is projected to be mostly autonomous as far as landing on the surface and ground based communications will aid the initialization of plant growth, thereby allowing for a first hand test of life support technologies without endangering people. The crew will arrive, troubleshoot any known problems, and assume control of the greenhouse for production and experimentation. The greenhouse is to provide food for an estimated twenty years.

2.3.4 Secondary Mission

As with any mission, the technologies developed to make that mission successful can be utilized in applications on Earth. The secondary mission is responsible for scientific research and experimentation. There are many locations on Earth not suitable for plant production. Technologies can be developed by experimentation in the harshest environment known to man: space. This knowledge can then be used on Earth to feed starving countries.

2.3.5 Subject

The subject for this mission is defined as the crop(s) necessary to produce up to 25% of food required for a crew of six based on Mars. When selecting plant(s), an emphasis has been placed on producing a biomass high in carbohydrates and/or protein. Plants will also be selected based on having high yields, fast growing times and having high harvest indices, the ratio of edible to inedible. Since space and power will be a premium, plants that are low growing and have minimal food processing requirements will be preferred. The environmental requirements for the various species of plants, if more than one species is selected, should have minimal variance to optimize the environmental parameters of the greenhouse. As a secondary consideration, the biomass's palatability should enhance the dietary experience of the crew.

Also, the plants should be thought of and utilized as a Bio-regenerative Life Support System, or BLSS for short. The BLSS will be used to provide food and oxygen and remove/reduce CO_2 by means of photosynthesis. Through transpiration and microbiological processes, with the water supply control systems, the BLSS will be used as part of the reclamation of liquid and solid waste process.

2.3.6 Payload

The payload for this mission is defined as the systems or subsystems necessary for the growth and health of the plants selected. These systems include: greenhouse structure, thermal control, atmospheric control, water/nutrient delivery, light delivery system, and the physical growth medium/structure.

The thermal control system uses passive heat transfer between other systems to ensure that the greenhouse maintains a temperature between 10-30 degrees C. This system would use a medium with a relatively high specific heat to reduce fluctuations in temperature, such as water. This system could be used in conjunction with the water/nutrient delivery system to both cool the artificial lighting and redistribute heat.

The atmospheric control system has a multitude of important tasks critical to the health of the greenhouse environment. It must monitor and control the partial pressures of carbon dioxide, diatomic oxygen, ethylene gas, and water vapor. It also must have a means for storing and redistributing excess diatomic oxygen expelled as waste from the plants. The atmospheric control system will work in conjunction with internal life support and connection with a habitat module life support. External Martian air is used as a feedstock for the consumption of carbon dioxide.

The water/nutrient delivery system will control the independent needs of nutrients and water, by allowing the mass flow rate of the nutrients into the water by need. The water travels in a closed system to prevent losses. This closed system can also be a part of the thermal control system.

The light delivery system incorporates both the collection of ambient Martian sunlight as well as controlled artificial lighting. The water/nutrient delivery system can also route heat away from the artificial source to prevent hotspots.

The root structure of the plants provides an opportunity for biomass filtration of human waste products. As such the support structure provides sufficient room for the roots to grow to fit the needs of this option. The structure supporting the hydroponics has the option to autonomously deploy and begin the growth phase.

2.3.7 Spacecraft Bus

The spacecraft bus is defined as the systems required to deliver and maintain the payload to the surface of Mars. These systems include navigation/guidance control, reaction control system (RCS), aero shell, drogue/main atmospheric entry parachutes, power systems, external communication system, module frame, and descent thrusters.

During the outbound journey, the upper stage of the launch vehicle will provide course correction as well as protection. The modules guidance and control systems are used to perform Martian entry procedures. Power comes in the form of fuel cells during the autonomous phase of the operations, which will produce a significant portion of the water needed. Upon arrival of the crew the module will utilize larger power sources already on the surface[3]. The descent thrusters use hypergolic fuels to reduce the chances of failure. The frame structure of the module is to be such that a portion or portions can be inflated.

2.3.8 Launch Vehicle

The Mars Direct plan adapted by NASA prescribes using a heavy lift vehicle not currently in use called the “Ares”. This craft is derived from current Space Shuttle technologies and is designed to carry the Mars habitat module directly from Earth to the surface of Mars. By using the same heavy lift vehicle as is slated for the habitat module, the cost for launch is reduced as well as furthering the development of the heavy lift vehicle.

2.3.9 Orbit

The trajectory will be determined by seed survivability due to radiation concerns. With minimal shielding, a fast trajectory will be required at the added expense of energy in the form of extra fuel. With adequate shielding provided, a lower energy trajectory can be employed to save on fuel cost. A trade-off between the two would be a mid-energy trajectory with minimal shielding which would take about 180 days to arrive on Mars.

2.3.10 Ground Systems

Existing deep space network systems will be used to relay communications between Earth and Mars. A new mission control facility will be used for all human activities on Mars. The greenhouse module will be monitored from this facility until the first crew arrival. The crew will then assume operational control of all functions of the module.

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[3] Assuming the Mars Cryogenic Consumables Station is present

2.3.11 Mission Operations

NASA's Mission Control in Houston is the center of command for the majority of space missions. For a mission to Mars, it would seem more efficient to have a separate mission control center. En route to Mars, the MDG spacecraft would be controlled by a Mars mission control; however, upon landing on the surface, the MDG would begin a status of self-sustaining automation. System diagnostics would be performed automatically. Plant growth and monitoring will be performed by the MDG control systems as well as monitoring from the Mars mission control. NASA technicians will have complete diagnostic information from the greenhouse. However, due to the time lag for communication transit, NASA intervention should be limited to general, daily task management. Several personnel positioned at the mission control center will provide feedback to the MDG automation and provide any adjustments needed. When the first manned crew arrives on the surface, the majority of the MDG system operations will be turned over to manual control. Self-sustaining functions would continue to be mostly autonomous as well as minor hydroponics monitoring.

2.3.12 Communication Architecture

In order to isolate operational failures, a network of subsystems will be responsible for maintaining the functional parameters of the MDG. A main central computer will be "fed" data from subsystems including: thermal control, atmospheric control, water and nutrient delivery, and lighting control. The central computer is linked to the habitat module for crew assessment, as well as mission control (Earth) via satellite. Until there is a manned crew to maintain the network, it is essential that the network of subsystems be highly autonomous.

3.0 Conclusion

The first crew to visit Mars will need a sustainable source of food crop to supplement their daily nutritional requirements. The greenhouse module will provide up to twenty-five percent of this requirement. In order to provide a viable greenhouse, specific criteria must be successfully developed and implemented.

The growth equipment in the MDG will consist of hydroponics and support systems. The exact types of equipment required will be dependent on the selection of crops. Growth and harvest of the crops will be mostly automated until crew arrival. NASA intervention during the initial deployment period will be limited to operational adjustments and commands. The food selected should be based on high nutritional value as well as efficient crop yield. Such crops include soybeans, tomatoes, lettuce, potatoes, wheat, and mushrooms, etc. These crops contain high protein, carbohydrates, and caloric value per unit mass. Crop selection is of great importance since it dictates the structural and growth equipment architecture. The structure of the MDG will be large enough to accommodate the expected crop yield and associated human activities. The outer shell must be sufficiently durable to withstand the differential pressure gradient as well as possible dust storm damage.

The MDG will provide the necessary supplemental nutritional requirements and a suitable pressurized research station for the first human mission to Mars. This module is but one of the many components that will be part of the next era of space exploration.