AIAA STUDENT DESIGN COMPETITION

HUMAN SPACEFLIGHT: PHOBOS BASE

Submitted By:

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List of Abbreviations:

EVA	Extra-Vehicular Activities
ITV	Interplanetary Transfer Vehicle
RFP	Request for Proposal
SLS	Space Launch System
IVHM	Integrated Vehicle Health Monitoring
ISU	International Standards Organization
COTS	Commercial off The Shell
ECLSS	Environment control & Life Support System
RLV	Reusable Launch Vehicle
TPS	Thermal Protecting System
VHM	Vehicle Health Management
HMC	Health Monitoring Control
BEO	Beyond Earth Orbit
PPF	Payload Processing Facility
CITE	Cargo Integration Test Equipment
EUS	Exploration Upper Stage
MLI	Multi Layer Insulation
ILS	Instrumental Landing System
WPA	Water Processing Assembly
UPA	Urine Processing Assembly
OGA	Oxygen Generation Assembly
PSM	Power Supply Module
HSSSI	Hamilton Sound Strand Space System International

MSFC	Marshall Space Flight Center
SRS	Sabatier Reactor Subassembly
CDRA	Carbon Dioxide Removal Assembly
PBM	Phobos Base Module
SPE	Solar Proton Event
BSM	Booster Separation Motor

Acknowledgement:

We are indebted to Assistant Professor Sudip Bhattrai for supervising us and giving us such a big platform. In particular, we owe a great deal to the works cited in references for compiling, extracting and adapting materials in preparing our project. Also, we are grateful to the president of Nepal Astronomical Society (NASO) Mr. Suresh Bhattrai.

Preface

This is the project of AIAA Student Design Competition-Human Spaceflight: Phobos Base. For convenience and higher research our team was further divided into two groups of two members each. One group was given task of selection of rockets, cost of mission and interplanetary trajectory to transfer the spacecraft from earth to cis-Mars system with calculation of Δv. Other group was given the task of entry to Phobos surface and docking process. Also the report is divided into different headings with references given at last. Our project contains deep theoretical knowledge from different references and applications in different software with proper calculations.

Abstract

We the undergraduate team "Phobians" would like to present this project report on "Human Spaceflight: Phobos Base" to American Institute of Aeronautics and Astronautics (AIAA).

The basic theme of this project is to provide idea about the base design in Martian satellite "Phobos" for the exploration of Mars. We proposed to launch our first mission in 2018 May 10 followed by other successive missions. Space Launch Station (SLS) is preferred as the launch vehicle that includes the entire interplanetary transfer vehicle. The vehicle reaches the Martian atmosphere at December 4, 2018. After successive maneuvers we reach the Phobos surface with cargo for the first three missions. The fourth mission includes human beings followed by other two cargo missions. The base is completed

under the supervision of the astronauts. The completed base would be the temporary home for the humans to explore the Martian soil.

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Objectives:

The objective of this project is to produce an integrated, multidisciplinary design solution for a base on Phobos to enable the human exploration of the cis-Mars System. It also includes the interplanetary trajectory from earth to Mars and descent to Phobos.

1. Introduction:

Mars has been the centre of study for scientists, researchers for years. Scientists have been trying since decades to unwrap the mystery and facts lying behind this red planet. Mars though is far from earth in comparison to Venus, has the highest possibility to sustain a life within this solar system. So, the scientists have been studying about this planet for decades and numerous spacecrafts have been sent to this planet from different countries all over the world. But, it seems that there persists a problem on how to deploy and stage the Lander descent and ascent modules over many varying synodic cycles. So, for the human exploration of the mars surface to become reliably repeatable, an orbital platform would be ideal. Fortunately, Mars boasts two moons, Phobos and Deimos, each with potential to serve as the “gateway to Mars”.

Between Phobos and Deimos, Phobos being closer to the mars, larger in size and as being believed to contain water is chosen as the site for exploration. So, the objective of this mission is to produce an integrated, multidisciplinary design solution for a base on Phobos to enable the human exploration of the cis-Mars system, including arrival from Earth and return to Earth, plus routine descent to the Mars Surface and return to Phobos as given by the RFP (Request for Proposal).

The dimensions of this satellite are 27x22x18 km along its three Cartesian axes. The attracting feature of this satellite is its largest crater named as Stickney crater. The crater is 9 km in diameter along the surface and depth is 2 km along the centerline. So, the crater has been chosen as the site to settle a base to support human life and serve as the fueling port for further exploration of solar system. The successive step after the settlement of base in Phobos is the exploration of the Mars.

This report mainly focuses on the construction of the base in the Stickney crater including brief description of the launch from Earth to Mars and the selection of vehicles. The interplanetary trajectory has not been considered in detail as per the project's objective and certain assumptions have been made at various stages of the base settlement. Similarly we have used many systems and technologies as used in the ISS and presented a good sense of using it in the Phobos Base too. The base construction is completed using robotic capabilities as well as the human power who venture into the Martian satellite. As a whole this report provides a sense of visualization of the Phobos Base that will be developed in the coming future.

2. Requirements Analysis:

It is necessary that requirements to settle the base are established in a systematic way to ensure their accuracy and completeness, but this is not always an easy task. So, we have divided the requirements into three major parts. They are the technology, cost and human power requirements.

2.1 Technology Requirements:

The first part of our mission is the selection of the launch vehicle that carries all the materials required for the construction of base in Phobos. So, we propose to use Space Launch Station (SLS) that has a capacity to launch 70 to130 mT of payload to the LEO. Further requirements are the systems and sub-systems that are required to support life in space and the research facilities. Basically, important systems are the life supporting systems that includes air revitalization system, water recycling system, waste management system and growth of food if it's a long term stay. Similarly, modern research labs and control stations also hold immense importance along with the rovers, ascent and descent vehicle required for the exploration.

The water and air recycling system is preferred as a closed loop system but is not achievable on the basis of latest technology. These systems should normally support six crews in the base and must be capable to support 12 crews if necessary. But we need to install optional systems too in case of failure of the original systems. To run these systems efficiently hydrogen gas and liquid water must be carried to the base from earth itself. Similarly the base needs a proper waste management system to ensure sound and safe pressurized environment. The other important aspect is the bio-regenerative system that includes growing of food as fifty percent food is only provided by earth. So, the remaining food required for the crews should be grown in the microgravity environment.

The pressurized volume of our base requires various research and lab facilities to fulfill the objectives of human mars mission. So, we need decontamination and bio-safety labs of level 4 along with dust mitigation and planetary protection methodologies. Other basic requirements of the astronauts can be fulfilled with the modern technologies available in the planet Earth. In order to run all these systems we require energy that is generally provided by solar power.

2.2 Human power requirements:

In order to explore the red planet we need to send capable and experienced astronauts. The astronauts should be selected on the basis of their field of expertise and the training provided to them. The first responsibility of the astronauts is to assemble the base according the proposed plan. The other responsibilities include extravehicular activities (EVA), robotics operations using the remote manipulator system, experiment operations, and onboard maintenance tasks. Astronauts are required to have a detailed knowledge of the systems used in base, as well as detailed knowledge of the operational characteristics, mission requirements and objectives, and supporting systems and equipment for each experiment on their assigned missions. Most importantly, we require physically and mentally sound astronauts to explore the red planet.

2.3 Cost requirements:

The other important factor of the mission is the cost required to complete it. The present estimate of the project cost of SLS is about $7 billion from 2014-2018 and the cost per each launch is about $550 million as per 2012 predictions. The cost for development of Interplanetary Transfer Vehicle (ITV) is about $6 billion and $2 billion dollars for upgrades to the launch pad. Similarly, we have proposed to use inflatable modules that are on the phase of development and cost about $26 million dollars. Similarly the cost to build a lab of bio-safety level four is about $105 million. So the total cost of this project is estimated to be $50-$55 billion dollars.

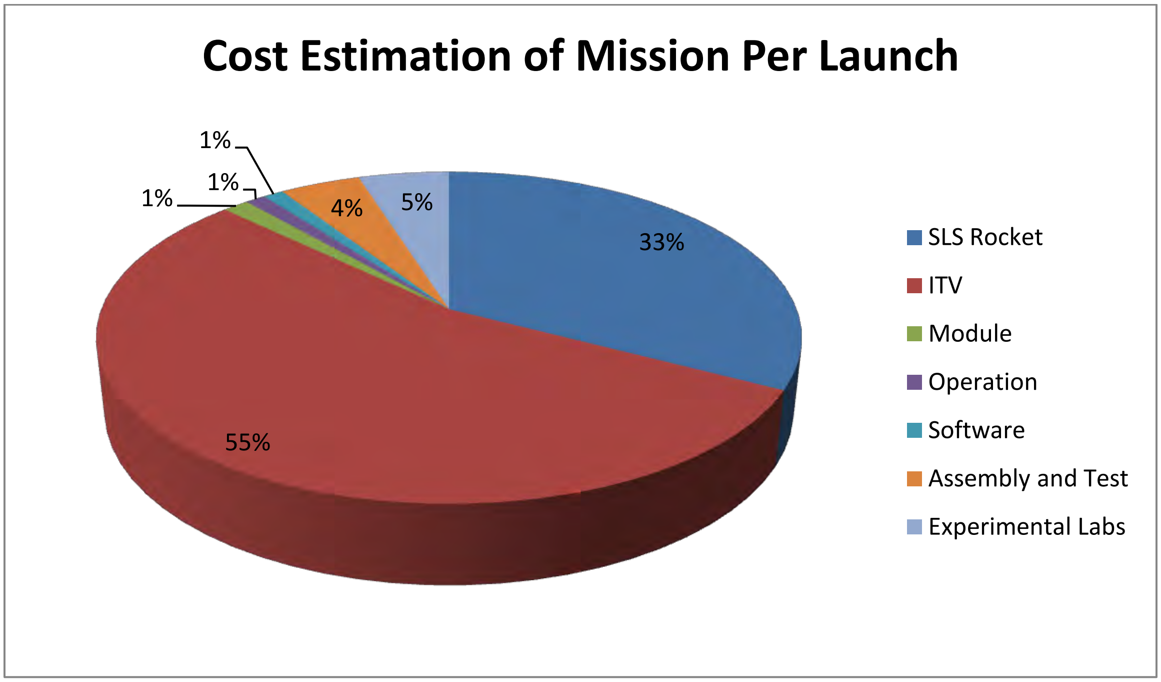

Fig 1: Cost Estimation of Mission per Launch (total mission cost ($50-$55 billion dollars)

3. Key Features of the Project:

The key concepts of this project are its Architecture, Engineering Systems, Infrastructure, Life Science Provisions, Regenerative Life support including the timelines and trajectories. All these are explained briefly below.

3.1 Architecture:

It is inevitable to define good architecture of the spacecraft as well as the base on the Phobos crater. The base after completion comprises of six pressurized modules including the docking volume too. Five modules are connected in a circular pattern to a central hub that is spherical in shape. The pressurized volume of each module is 340 m^3 which is 13.7 m in length and 6.7 m in diameter. The thickness of each module is 46 cm that consists of radiation protection layers. Similarly, the docking volume and a cylinder (part of docking volume) is placed underground and connected to the pressurized module through docking ports of international docking standard. Similarly, each module above the ground are covered with circular cage. A launch pad is placed supported by stands submerged in the ground. The launch pad consists of two docking ports that is connected to the module under the ground.

The docking module is connected to a cylindrical volume that is again connected to the pressurized modules.

Selection of Launch Vehicle:

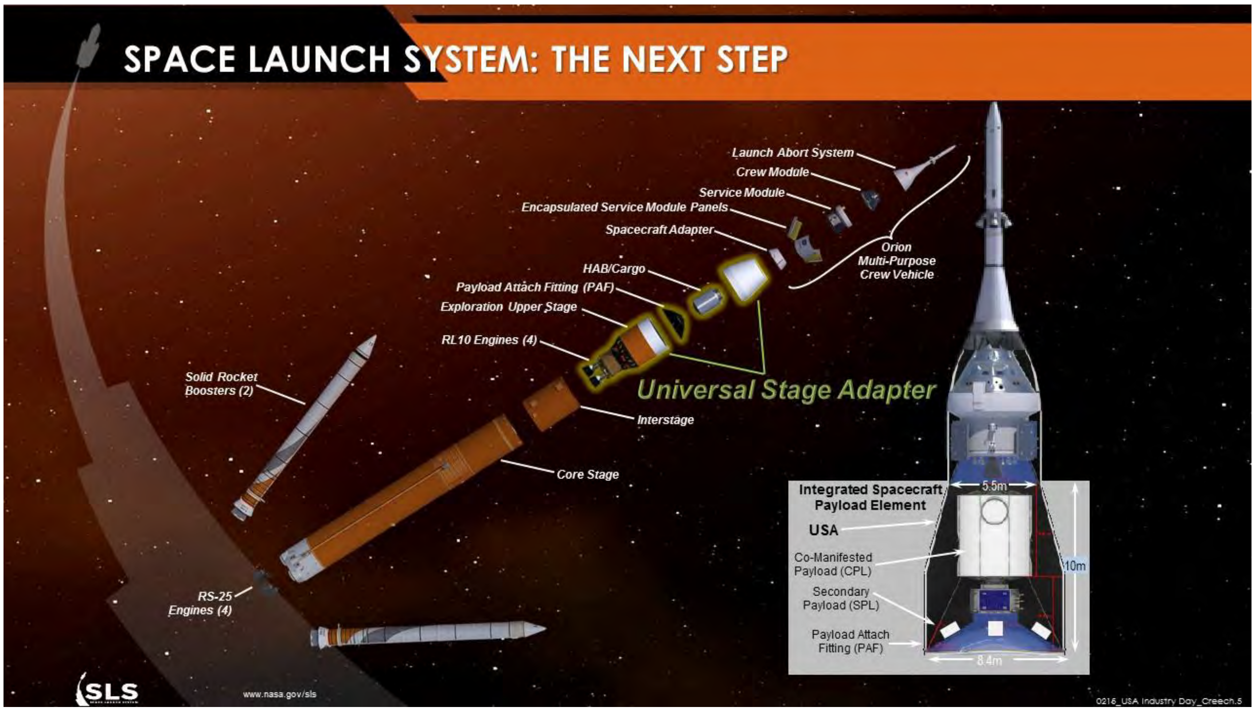

Fig 2: Cut away view of SLS Block 1 B (source: SpaceFlight Insider)

The launch vehicle is selected on the basis of the payload required to launch to the LEO. Further, the habitable volume that needs to be transported in a single flight is about 340 m^3. Thus, the mission plan includes six launches, each carrying the module of 340 m^3 pressurized volume. So a single module with various systems integrated weighs 30-35 mT. The payload capacity of various launch vehicles is illustrated in the table below:

Launch Vehicle	Payload to LEO(in metric tons)
Falcon Heavy	64
SLS	70
SLS Block 1B	105
SLS Block 2	130

Table: Vehicle Comparison

The RFP accepts the Payload ranging from 70 to 130 metric tons. From the table, as the Payload of Falcon Heavy is below the requirement of RFP, it is rejected. Despite of meeting the payload capability by SLS, it is rejected due to safety issues. Similarly, the SLS Block 2 is under designation and is planned to complete in 2020. As we planned to launch our first mission in 2020, it is convenient to use SLS Block 1B.

3.2 Engineering Systems and Vehicle Design:

3.2.1 Software and Hardware:

It is the most important part of designing the spacecraft. Software and hardware should be done in parallel in close synchronization. The software and hardware engineers are in regular communications so they interchange their working process along with feedbacks. This process is done and tested step wise else it may cause many problems. The integration and testing are done early through software prototypes inside the hardware. A perfect spacecraft is produced through it. EPICS IOC is used as software in SLS vehicle. Researchers are thinking about Integrated Vehicle Health Monitoring (IVHM) for the days to come with complex processing capabilities embedded in payloads and avionics. Onboard computers perform the function of spacecraft control, propellant valve actuation, data monitoring, payload functions, data management, communications, and engine control. International Standards Organization (ISO) develops the international standard software. Commercial off the Shell (COTS) software is very essential in Environment Control and Life Support System (ECLSS).

The hardware design considers the Aerodynamics analysis, Performance analysis through testing (flight test, ground test), Heating analysis, Weight and size analysis, Structural analysis, Operational analysis and Cost feasibility.

3.2.2 Thermal Heating

It is one of the important processes in the spaceship transfer. It protects the spacecraft in all phases of flights from overheating and from freezing in deep space when propulsion system is not powered. There is change in pressure and temperature on its surface as vehicle is launched from LEO. It causes pressure fields which results in aerodynamics load, lift, drags and moment forces. High speed causes spacecraft heating and formation of flames and shock wave impingement in boundary layer. As the vehiclerises through the atmosphere on its ascent trajectory, the structure is heated both by thermal radiation and by the forward flow of hot exhaust gases from the engine nozzles, particularly near the base re-circulated zone. As the vehicle rises rapidly through the thinning atmosphere, internal air must be vented from unpressurized compartments of the vehicle in a controlled fashion. To prevent excessive panel loads during rapid vehicle reentry, a corresponding in-venting must be accomplished. The reentry aero heating environment is usually more severe than during the vehicle's ascent phase because of the higher velocities involved. Thermal protecting is done in Reusable Launch Vehicle (RLV).

The Thermal Protecting System (TPS) should be designed in our SLS launch vehicle for its protection from overheating.

3.2.3 Avionics

It includes all vehicle electrical and electronic systems such as communications and data handling, flight computers, sensors and instrumentation, and electrical power. It holds together the different system onboard and handles the communication, command and control functions between ground based and space based mission. In addition it also performs the function of navigation, flight control, propulsion system control, power management, environmental control, payload accommodation, and safe maneuvering.

3.2.4 Integrated Vehicle Health Monitoring (IVHM)

Vehicle health management (VHM) is defined as the ability to verify and Monitor vehicle health and to take the appropriate corrective actions necessary to maintain the vehicle in a functional and safe state. Integrated vehicle health management (IVHM) is defined as "the set of hardware, software, and operations that are implemented for a system to deal with faults. It includes all aspects of the implemented health management, at system, subsystem, and lower levels for a particular system. It is usually implemented as a set of techniques embedded within various subsystems, as opposed to a separate entity". During launch system process IVHM checks the vehicle, failure detection, data processing and system configuration. Elements of IVHM are data collection, and sensors. IVHM is applied to component, sub system and system level elements of the vehicle. Health Monitoring Control (HMC) is a means, by which various parameters can be measured, interpreted and used to evaluate control the vehicle and its subsystem like propulsion during ground and flight operations and provide data for maintenance purpose.

The functions of IVHM are:

- To analyze data and perform decision analysis
- To detect anomalies in sufficient time to respond.
- To provide corrective actions, to correct problems and prevent failures.

3.2.5 Safety of Spacecraft and Reliability

For transfer to LEO, a crew escape system should be provided on the vehicles for safe crew extraction and recovery from in-flight failures for pre launch to landing with probability of successful up to 0.99. Also the vehicles abort modes shall be provided for all phases of flight to safely recover the crew and vehicle or permit the use of the crew escape system. For beyond-Earth-orbit (BEO) missions spacecraft and propulsion systems shall have sufficient power to fly trajectories with abort capabilities and provide power and critical consumables for crew survival. Trajectories and propulsion systems shall be optimized to provide abort options. When such options are unavailable, safe have capabilities shall be provided. The reliability of the vehicle shall be verified by test backed up with analysis at integrated system level prior to the first flight with humans onboard and verified by flight based analysis and system health monitoring for each subsequent flight. The performance and reliability of all the software shall be tested.

3.3 Mission Timeline and Trajectory:

The mission comprises of two phases: first consisting of three unmanned flights and second consisting of one manned and two unmanned flights. The first mission launch is scheduled to be at May 10, 2018. The other two launches are planned to perform from Kennedy Space Center, Florida and Kodiak Launch Complex, Alaska. These launches can be performed with the gapping of 9-10 days each from the first flight. Each of these mission launches consists of the habitable module and is sent along the energy efficient slow transit paths.

The first flight reaches the Martian influence area at December 4, 2018. The other two flights are also assumed to reach within 30-35 days of the first landing. The ITV (Interplanetary Transfer Vehicle) after reaching the orbit of the mars slows down to the desired speed with proper maneuver and retro-propulsion and lands on the surface of the Stickney crater with the acceptance of off placing of radius of 3 km. But this can be avoided as we use instrumental landing system. The second and third ITVs are also safely landed within this perimeter with this same method.

The three modules after landing is analyzed thoroughly to see whether the components are functioning to the desired limit or not. The crew mission will be in standby mode if the elements of the system required for crew safety is not checked out adequately. If the system doesn't run as expected some alternatives need to be proposed. If the system fails to run and correction is out of hand of the technology, manned mission cannot be operated due to risk issues.

If as planned, the mission performs then the manned mission is operated through the fast transit trajectory in order to minimize the risk of the health hazards due to the exposure to galactic cosmic radiations as well as the probability of encountering solar particle events. Reducing the exposure to zero g and radiation helps to reduce the risk of the crews. This mission will consume more fuel but, human health is prioritized to the cost it takes. Thus, the cargos are transferred on low energy, longer transit time trajectories while the crews are sent on a higher energy, shorter transit time trajectories. The two phases of launch windows provides time for the infrastructure to be emplaced and checked before committing a crew to the mission.

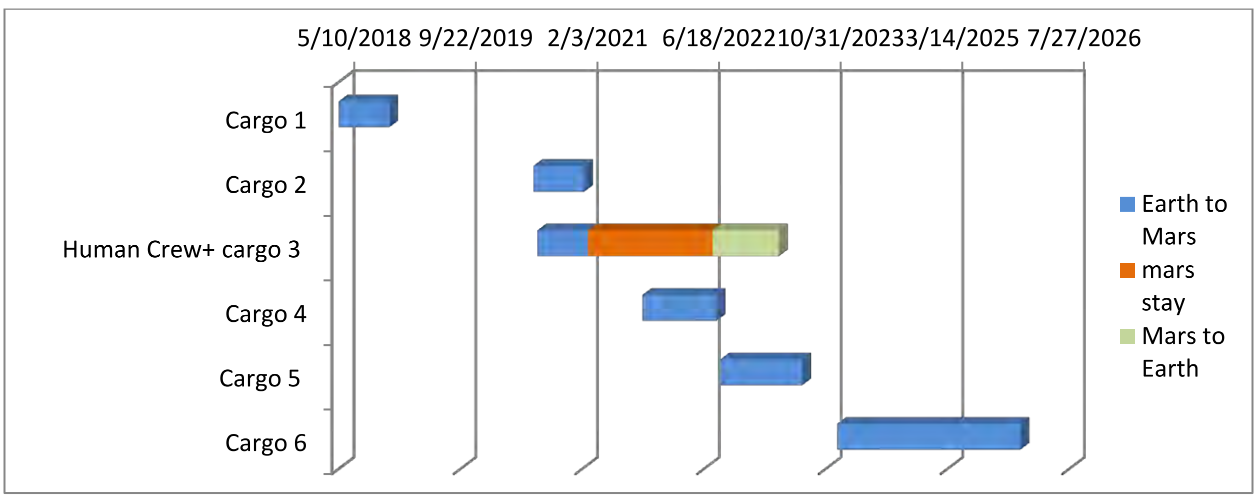

Fig 3: Gantt chart showing the timeline of the mission

3.4 Life Science Provisions and Regenerative Life Support Systems:

The life supporting systems in our base includes the air and water recycling systems along with the facilities of food production. We have proposed to use those systems that are currently being used in ISS. This includes the air revitalization system that soaks carbon dioxide from the pressurized habitat exhaled by the crews and produced during various experiments from different laboratories. Similarly, the water recycling system is also installed to provide water for drinking, washing, laundry, dish washing and supporting plants life. Similarly, the modules contain separate volume to grow green vegetables and rear various insects as we planned to use the concept of entomophagy in our base habitat. Furthermore, the habitable volume also includes the waste management system (liquid as well as solid). Special forms of commodes are used as the toilets that comprises of many fans and ducts to separate liquid and solid recycle those that have possibility. Various sensors along with air conditioning systems are installed to maintain temperature, humidity and sound atmosphere in the pressurized volume. The base habitat is also provided with well equipped with an astrobiology lab comprising Bio-safety level of 4 and decontamination capabilities. Separate areas have been allocated for dinning, laundry, washing, galley, exercise and recreation. The base also possesses various suits like the Lower Body Negative Pressure, Gravity Loading Countermeasure Suits that is to be used by the astronauts in order to counter the microgravity environment. The latest medical facilities along with new medicines are provided in the base to ensure crews health that is important of all. Some devices like Volatile Organic Analyzer, POTOK are also installed to protect the environment from dust and contaminants.

4. Launch from Earth:

The Launch program consists of three unmanned consecutive flights. The fourth launch is a manned mission and the later two launches are again the unmanned missions. The first unmanned mission is set to launch on May 10, 2018 with the tolerance of ± one week. The latter two launches are scheduled accordingly. SLS Block 1B is selected as the Launch Vehicle due to its higher Payload Capacity (i.e. 105 metric tons to LEO), efficiency and reliability. After about 120 seconds of ascent uphill, SLS conducts staging by releasing its two near-expended boosters which will depart from the stack via Booster Separation Motors (BSMs).

With SLS into second stage flight, the RS-25's gimbals to correct any transients caused by staging and to ensure the vehicle continues to be on its correct trajectory towards the Mars.

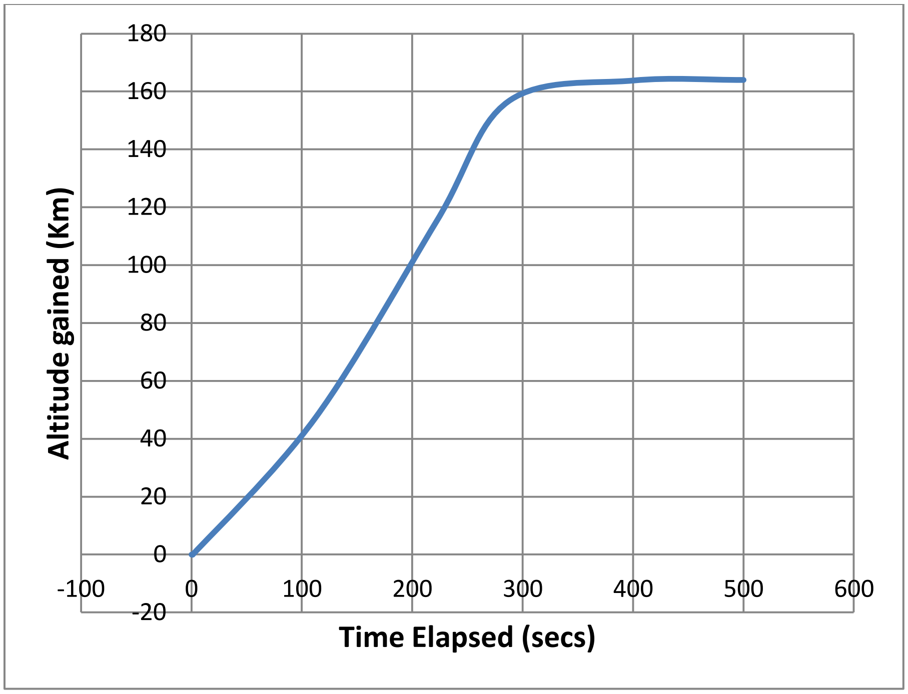

Fig 4: Altitude gained Vs Time elapsed during the initial Launch from Earth

5. Interplanetary Transfer:

This section consists of transfer of vehicle from earth to mars, mars to Phobos as explained below in details:

5.1 From Earth to Mars System:

Mars requires less energy per unit mass (delta v) to reach from Earth than any planet except Venus. The main objective of this Earth- Mars trajectory is to place the ITV in better relative position and velocity with respect to mars so as to successfully have orbital insertion and then finally with effective calculation and maneuvering rendezvous the ITV with the Phobos with the desired and planned impact safe enough for landing.

After the ITV being correctly placed in the right trajectory towards the Mars, the second boosters too get exhausted and are detached from the vehicle leaving ITV the sole piece left for the rest of the mission. The flight duration for the first unmanned flight is designated to be 208 days with the minimum C3 requirement of about 6.9 km^2s^{-2} and initial Δv 3.53 km/s. The ITV then follows the ellipsoidal path with the sun at one of its foci towards Mars. Then on November 22, 2018 it enters the Mars orbit with the backward boost of final Δv 821 m/s.

During this outbound transfer, two to three TCM's may be required to correct the trajectory towards Mars. So, these are closely inspected through the control systems here on earth through the continuous information exchange. The declination angle at the time of earth departure is about 31°. The goal of this unmanned cargo mission is to have the transportation possible on the use of minimum C3 energy as well as the boost of minimum Δv. Both of these goals are met, as this trajectory is placed on the optimization of these constraints.

Date of Earth Departure	May 10, 2018
C3 required	6.9 km^2/s^2
Total Δv	4.36 km/s
Time of flight	206 days

Table: Major Characteristics of first Launch

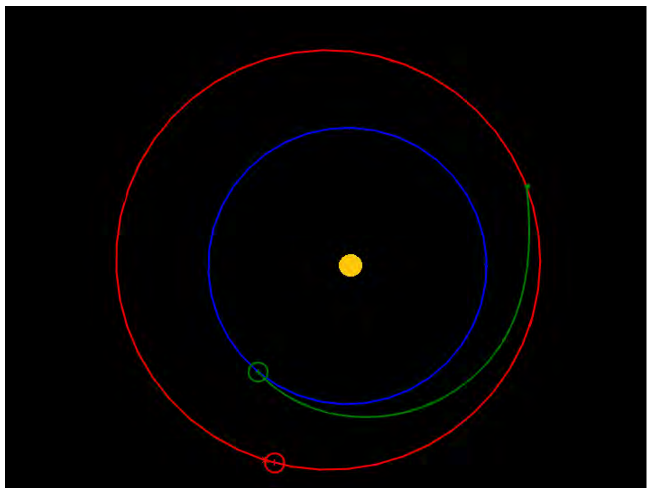

Fig 5: Departure from Earth

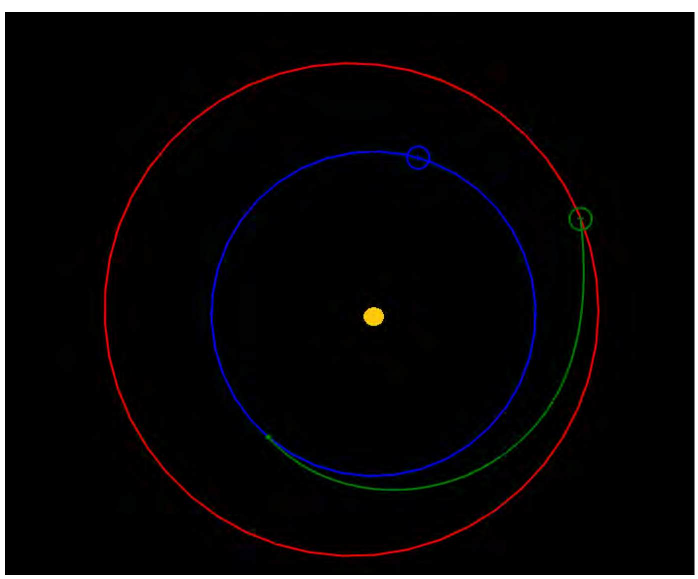

Fig 6: Mars Orbit insertion

5.2 Approach to Phobos:

As soon as our spacecraft enter the Mars orbit, it revolves around Mars under its gravity at a certain attitude. Then our spacecraft is boosted with positive delta v to increase its altitude above the Phobos altitude. The, orbital characteristics of Phobos are:

Periapsis: 9234.42km

Apoapsis: 9517.58km

Semi-major axis around mars: 9376km

Orbit eccentricity: 0.0151

Time to make one orbit: 7hr 39.2 min

From the above orbital characteristics, it makes us clear that semi-major axis, Periapsis, Apoapsis, orbit eccentricity,time to make one orbit of the space craft would be higher than that of Phobos. Our spacecraft would approach the Phobos from the higher attitude so that spacecraft can make use of the gravitational pull of the Mars (which is high in comparison to the Phobos) for landing on Phobos Stickney crater.

Orbital characteristics of spacecraft around mars:

Semi-major axis around mars: 9920km

Orbit eccentricity: 0.03478

Time period to make one orbit: 8.1215 hrs ($T = 2 \sqrt{\frac{a^3}{\,}}$)

Where a= semi-major axis,

μ=standard gravitational parameter

The figure below shows the orbit trajectory at which spacecraft approaches the Phobos. Inner most orbits is of Phobos where as outer most orbit is of spacecraft. Spacecraft would revolve round the Mars in the same orbit until the proper orientation of Phobos for landing.

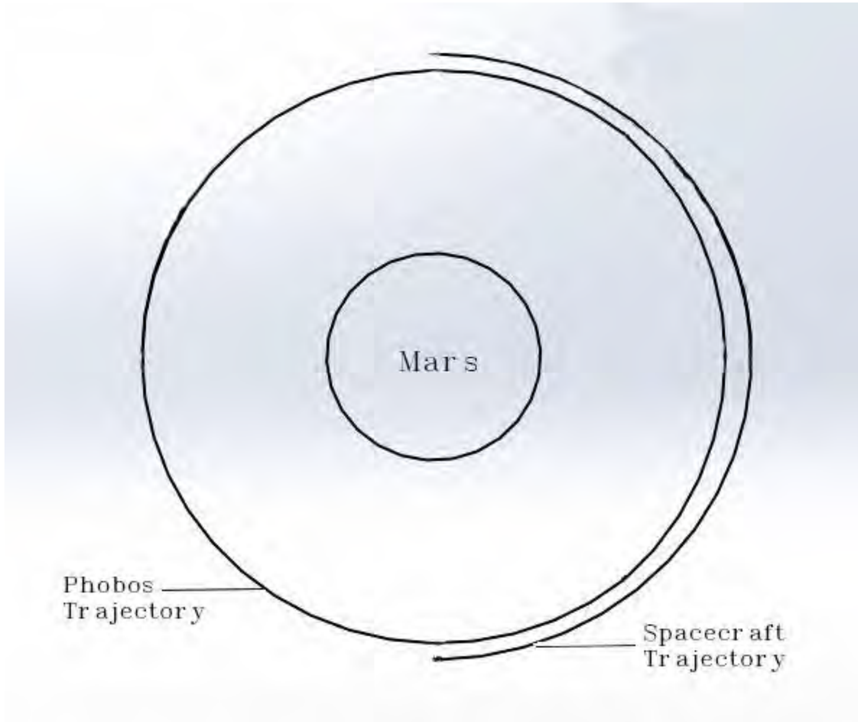

Fig 7: Orbital trajectory of Phobos, Spacecraft

The velocity that spacecraft should maintain to revolve around the Mars making an outer orbit of eccentricity 0.03478 is calculated at different angle made by spacecraft along the Apoasis as horizontal axis is:

$$v = \sqrt{\left\{\frac{2(1-ecos\theta)}{a(1-e^2)} - \frac{1}{a}\right\}}$$

Where, v = orbital velocity of spacecraft

μ=standard gravitational parameter of Mars (GM)

e=eccentricity of the orbit

a= semi-major axis of the orbit

Ө= angle made by spacecraft along with reference axis.

Velocity of the spacecraft at different position along the elliptical orbit at different values of Ө with respect to the reference axis is tabulated below:

Θ(degree)	v (m/s)
0	2001.92
45	2023.69
90	2075.3
135	2125.67
180	2146.2
225	2125.67
270	2075.3
315	2023.69
360	2001.92

Table: v vs. θ

The above result shows that while spacecraft revolve around the elliptical orbit, velocity increases as it approaches Perispsis and decreases to minimum velocity as it approaches the Apoapsis. It shows that spacecraft has high gravitational potential energy at Apoapsis and high kinetic energy at Periapsis.

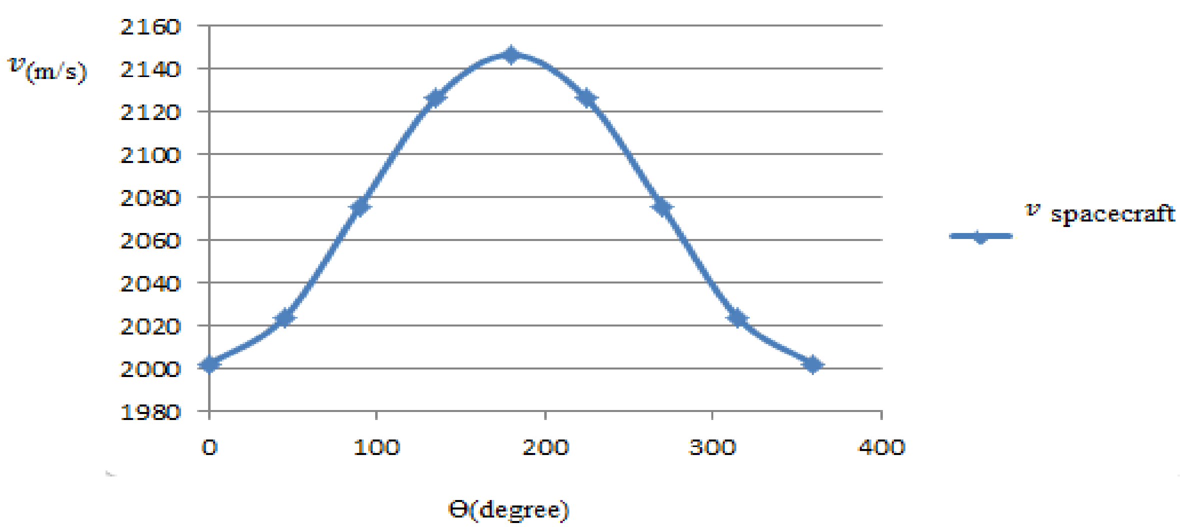

Fig 8: The plot of v vs. Θ

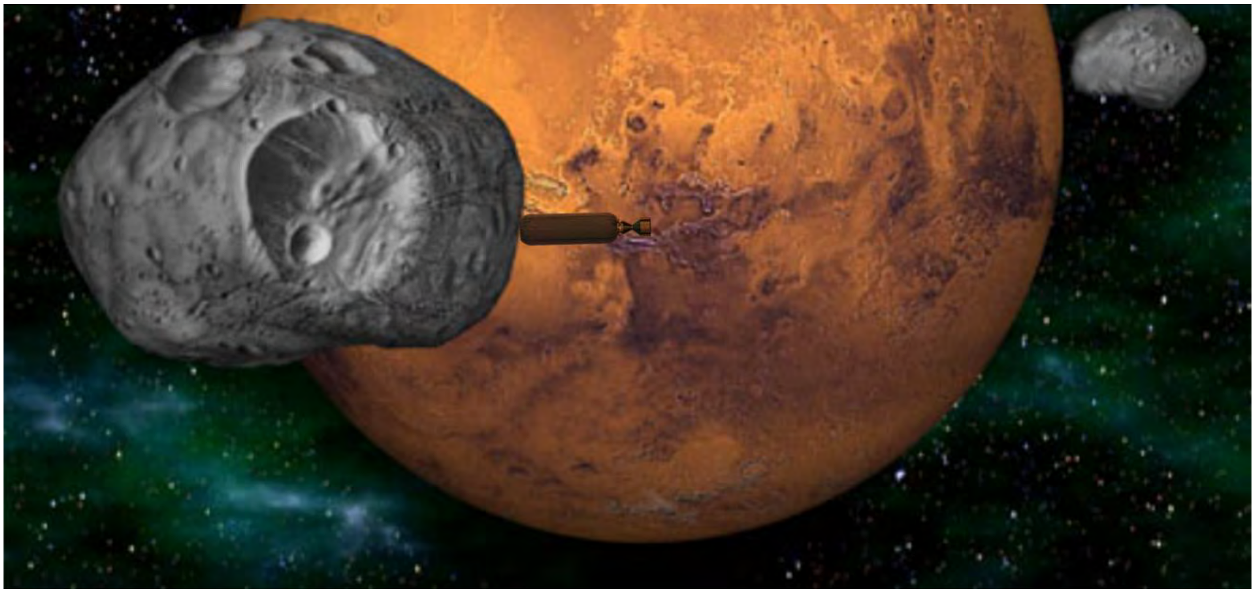

Fig 9: Approach to Phobos

5.3 Arrival at Phobos:

To determine the arrival trajectory of spacecraft to the Phobos surface we made an assumption to determine the position at which to provide delta v to spacecraft. We supposed that Phobos would be at negative 11.02^{o} along the axis of Apoapsis where as spacecraft would be at Apoapsis in the meantime.

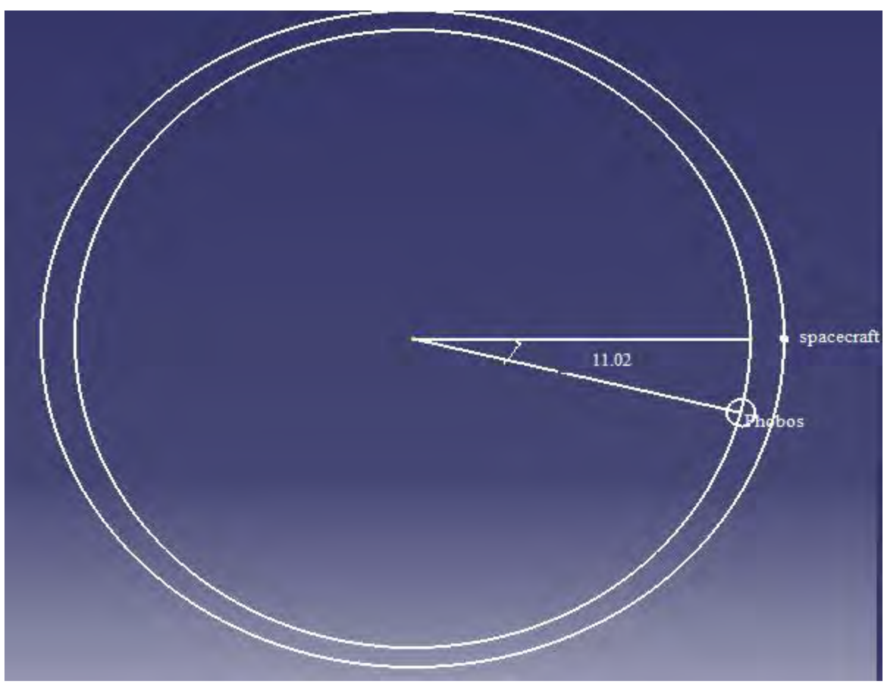

Fig 10: Position of Phobos at 11.02^{0} with spacecraft at Apoapsis

The time period to reach Phobos from apogee is 4.06075hr. So, we need to boost the spacecraft with delta v_1=112.726 m/s to land on the Phobos at perigee. At perigee required delta v_2=-57.437 m/s (calculated using the conservation of gravitational potential energy and kinetic energy at apogee and perigee). So the space craft move along the new trajectory from start point i.e. apogee to end point perigee as shown in figure.

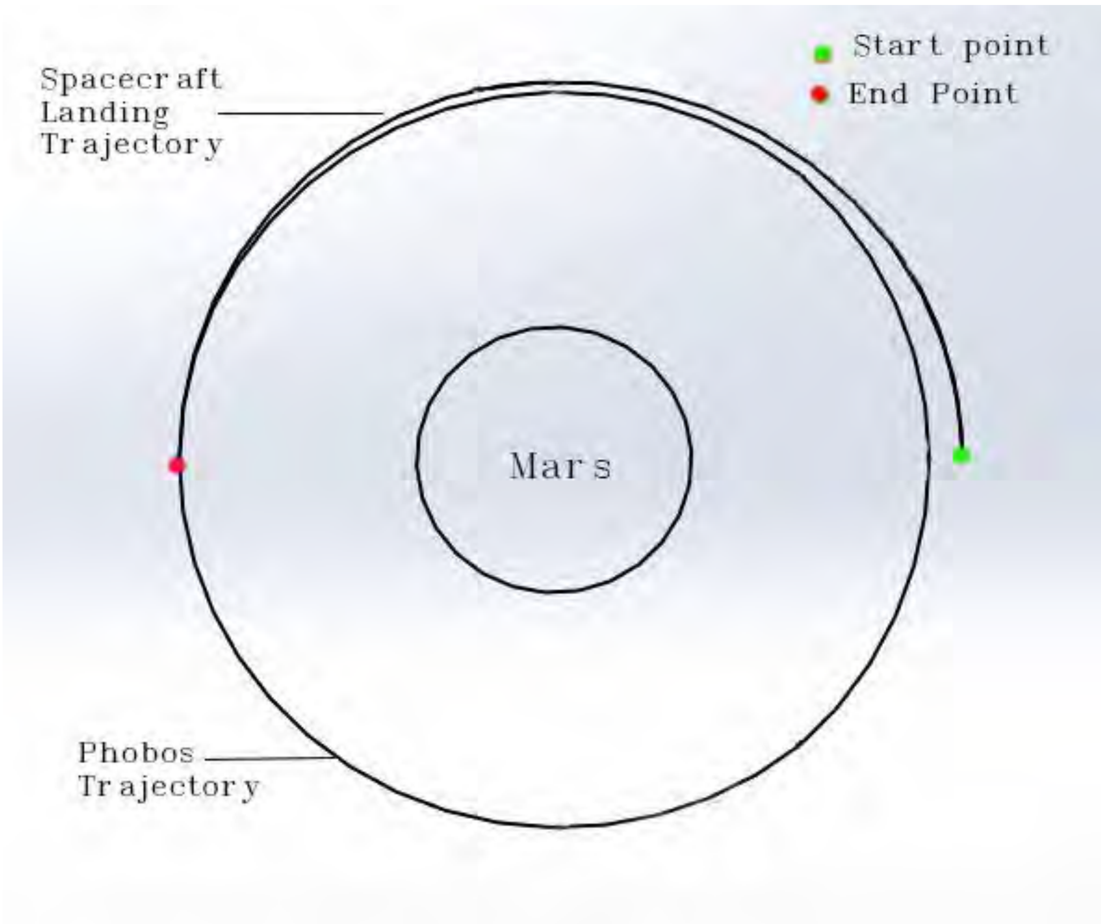

Fig 11: New landing trajectory of spacecraft

New orbit characteristics of spacecraft (i.e. new landing trajectory):

Eccentricity= 0.052032.

Semi-major axis= 9749.7188km

The velocity of spacecraft along the new trajectory after delta v_1 boost at different point from apoagiee till it landed on the perigee varying with angle are:

Θ(degree)	v (km/s)
0	1.9923
15	1.9961
30	2.00716
45	2.02462
60	2.04715
75	2.07308
90	2.1005
105	2.12766
120	2.1526
135	2.17382
150	2.1899
165	2.2
180	2.20346

Table: v vs. θ

It shows that final velocity of spacecraft is approximately equal to the orbital velocity of the Phobos. In this way, spacecraft lands on Phobos.

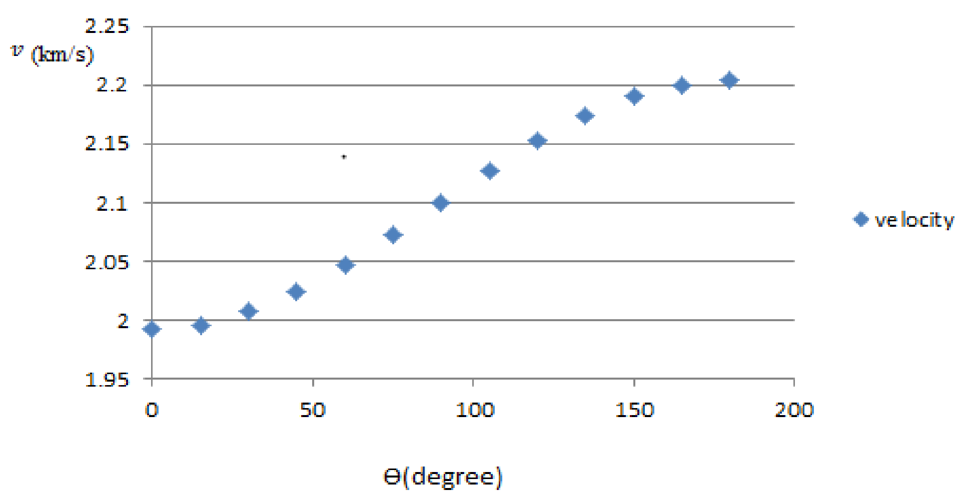

Fig 12:Scatter digram of v (km/s) vs. Θ (degree)

5.4 Delivery and Landing of Payloads:

Payloads are taken at launch sites on various periods ranging from many months prior to launch to just few weeks. Spacecraft launch typically requires months of stimulations to ensure that the orbiter and pay loads flight control teams work harmoniously so that optimum science is obtained from the mission. They must be processed for mounting on launch vehicle with thorough checking. They are inspected through Payload Processing Facility (PFF) and tested through Cargo Integration Test Equipment (CITE).

Payload of a Rocket can be understood as its carrying capacity of useful mass. Developments of rocket has been done down the years to increase the Payload with decreasing the overall mass of the total rocket and optimization of the fuel to be used. In the past, Saturn V was capable of delivering higher payload of about 130 metric tons for the lunar mission. In the present condition, Saturn V is in retired condition and the operational Rockets don't meet this Payload demand. Realizing this fact, to replicate the payload capacity of Saturn V, NASA is developing SLS with comparable payload. The RFP demands for delivery of payload mass in the range 70 and 130 metric tons. The SLS Block 1B chosen for this Phobos Base Mission has payload capacity to LEO of about 105 metric tons. Thus, making its Payload capacity to Phobos about 40 metric tons.

Considering this Payload capacity, the whole base transportation completes in six launches. Since, in a single launch window all six launches is impossible to occur due to inability to develop six rockets within the given time as well as the difficulty in maneuvering of these launch trajectory such as they don’t intercept each other. Thus, the whole base transportation extends between 2018 to 2026 with the first launch on May 2018 and arrival of last base module on Phobos on early 2026. Increase in payload for minimum fuel consumption and minimum dry mass of rocket is the primary issue in the development of the rockets. SpaceX is making rockets on minimum budget constraints with its maximum payload to mars being 13.5 metric tons by Falcon heavy. Since this Payload capacity is much lower than demanded by our mission plan, SLS was chosen. SLS Block 1B uses a more powerful second stage called the Exploration Upper Stage (EUS).On January 2015, test firing of RS-25 engines began for use on SLS and continued in 2016 and 2017 showing positive test results. This signifies the availability of SLS Block 1B for the Phobos Base Transportation.

After the transfer vehicle go to the Phobos surface, the interplanetary vehicle lands on the surface to deliver the base habitat with payloads. So, the cargos that are to be taken to the base habitat should be assembled in a way such that the diameter is not more than 800 mm. This has been proposed since the docking ports have a tunnel of 800 mm according to international standard. The payloads are initially stored in the docking volume and then transported to the respective modules as per the need.

6. Brief Description of the modules:

The inflatable shell has been proposed to use as the pressurized modules in the assembly of base is its compressive nature and lower mass that the conventional steel modules used in International Space Station(ISS). This topic basically explains about the layering of the inflatable shell that has various important properties.

The inflatable shell insulates extreme temperature in the space that may range from 120^0C in the Sun to -90^0C in the shade, is composed of over 60 layers. The shell is composed of five major subassemblies:

1. Inner liner, which is the innermost layer.
2. Triply redundant bladder layers.
3. Woven restraint layer, which withstands four atmospheres of internal pressure and supports the bladder.
4. Restraint and bladder layers, which are protected from micrometeoroid impacts by the debris protection system.
5. The outermost layer, which consists of atomic oxygen protective layers and multi-layer insulation.

The inner layer is the rigid and hard that has resistance to flame and puncture of air. They are made up of Kevlar and Nomex fabric to provide puncture resistance and good acoustical properties required for a friendly environment.

Combitherm is used as the initial baseline bladder material because it has a very low permeability and is flexible. Combitherm consists of nylon, polyethylene, which is placed the outermost surface of the shell, and vinyl alcohol layers, which provide a barrier to gas lose. Each bladder is surrounded by Kevlar felt bleeder cloth, which provides additional puncture resistance. The water in the bladder will shield crewmembers against intense solar radiation.

The restraint layer is required to be folded and inflated on orbit. It is primarily used to support the larger loads incurred from inflating a 6.7m diameter module to 14.7 psi. The materials like Kevlar and Vectran are used in these restraint layers.

Multi layered insulation (MLI) is provided in the shell as a thermal protection system. The MLI consists of multiple Nylon layers, which are reinforced, double aluminized Mylar, inserted between an inner and outer layer of double aluminized Polyamide film. Kevlar cords attach the layer-to-layer and gore-to-gore layer. The MLI would be put together in gore sections and then constructed onto the shell.

Micrometeoroid/Orbital Debris protection system is used to protect the module from hypervelocity impact. The shield includes ceramic fabric (Nextel) bumper layers, which are separated by low-density cored polyurethane foam. The foam is compressed before launch to minimize volume. On orbit, the foam regains its original thickness because of elasticity of the foam. The stronger fabric (Kevlar) layer is located behind the Nextel layer. When the hypervelocity particles impact each of the Nextel layer, they are destructed into smaller, slower particles over a larger area. By the time they reach the Kevlar layer, they are so small they can be stopped.

All these properties of inflatable modules are worth to select it as the module to construct base in the Phobos crater.

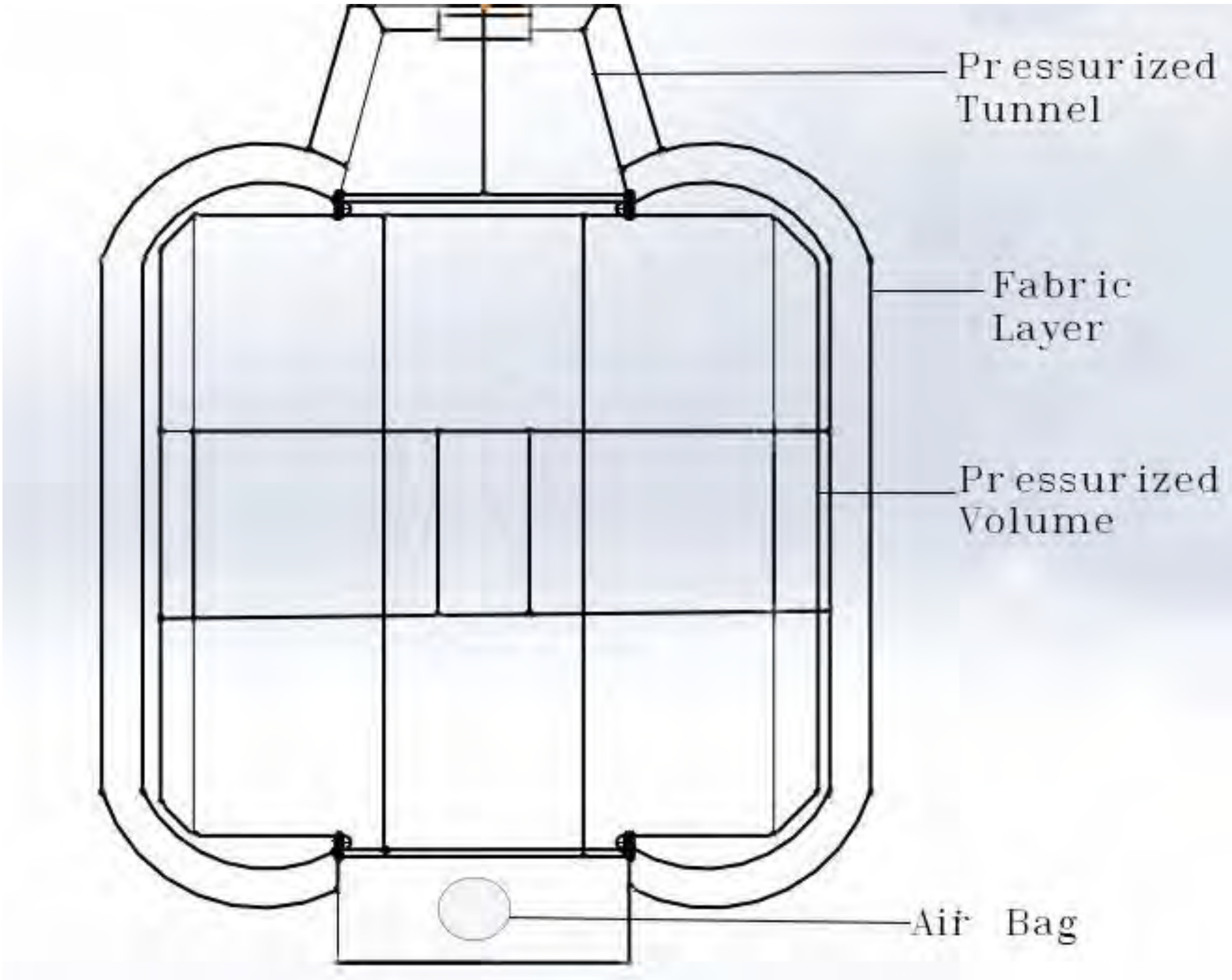

Fig 13: Sectional view of the inflatable modules

7. Base Assembly and Construction Process:

The initial phase of base assembly starts after the landing of our first module to the Phobos crater. The deepest area of the crater is chosen as the site to construct the base the assembly as the site experiences higher gravity of Phobos than any other areas. It is done in order to counter the gravitational pull of Mars which is more convenient than the Phobos pull. However the installation of the base at the deepest part of the crater does not eliminate the problem of Martian attraction. As the mass of our single module is estimated to be 30 mT, the force of attraction on the module by the planet and satellite can be calculated. The gravitational force of Phobos acting on a single module is calculated to be 0.263 KN (assuming the module lies on the central axis). Similarly, the force acted on a module due to Martian gravity is calculated to be 14.603 KN. The calculations are done on the basis of Newton's gravitational law. So, certain mechanisms need to be taken with the modules to prevent the base from flying towards the Mars.

We proposed to use a drilling mechanism to make our base stable and firm. The drilling mechanism is used for central hub (where all the modules are docked) as well as the modules. Simply drilling hub and modules to the Phobos ground cannot hold the whole assembly. So, electromagnets are installed to attach the base to the Phobos surface using magnetic force. In this manner a stable base can be assembled in the Stickney crater. As all the modules do not reach Phobos at a same time, there are various phases in the construction of base.

7.1 Assembly of first two modules:

The first module that reaches the Phobos surface is connected with the central hub and both parts land at the same time. The module before landing on the surface releases a land-based transponder in order to know the distance between the flying module and the landing surface. On the basis of distance measuring equipment the control systems of the module can decide when to open the drilling mechanism to ensure safe landing. If, the drilling mechanism does not open before landing the modules may not rest on the crater surface due to Mars gravitational pull. The gravitational pull of Mars is convenient when the crater faces the red planet. But the gravitational pull of Mars does not cause a problem when the crater does not face Mars.

After the first launch from Earth lands the Phobos surface, the inflatable module and the central hub are inflated to their required dimensions automatically as per the signal received from Earth. The second module arrives the base site after some interval of days. These modules must be equipped with Instrument Landing System (ILS) to align in a proper manner that will be simple for crews to dock it to is helpful to dock it to the central hub. The angular distance between the successive modules must be 60^0 in order to develop a circular pattern of modules along the central hub. The primary construction process starts after the arrival of astronauts which is performed in the third mission. But the third mission is launched only after the approval of sound and safe operation of the previous two modules launched earlier. So, the second module should also be connected to the central hub on its own in order to remain in the crater.

In order to do so, the electromagnetic field generated in the central hub can be of use. Each and every module is covered with metallic cages that elongates before landing on the surface (explained in detail in 13.3). Using a convenient electromagnetic force, the cages can be attracted towards the central hub. As a result the module move closer to the hub as it is enclosed within the metallic cage. When the cage move towards the hub, the berthing mechanism is activated as both hub and module are provided with docking ports of international docking standard. When the ports come very close to each other, soft capture system takes place followed by the hard capture system. In this way we can connect our second module to the hub and maintain a constant pressure within the connected parts. If these interconnected systems perform up to the developed standard, third mission can be launched with 6 crews in the module.

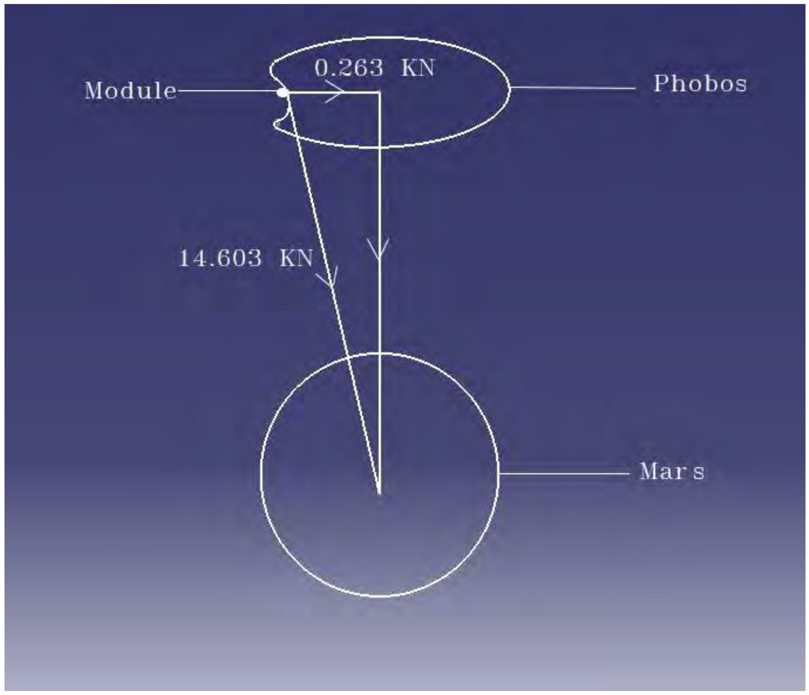

Fig 14: Force on single Module

7.2 Assembly after crew arrival:

The third mission is the most important mission among all as it involves first 6 human beings to reach the area of Martian influence. The module in which crew are present needs to be inflated after reaching LEO as they need to do a six month travel in space. After they arrive to the sphere of influence of Phobos, the base location can be tracked using the land-based transponder that has been used previously for landing. Similarly, the alignment and the distance from the central hub are maintained using Instrumental Landing System (ILS) and Distance Measuring Equipment (DME). The connection of the fourth module is achieved in the same way described earlier, using electromagnetic force and docking port of standard dimensions. After the crew arrives, some physical labor has to be done to make some area for the remaining three modules to arrive.

The fourth and fifth and sixth missions are completed in a similar fashion as the previous missions. But the final module is not connected to our pressurized module as the previous modules. The sixth module acts as the docking port for interplanetary and ascent/descent vehicle provided with a launch pad. The final module is placed underground and connected to a cylinder shaped volume that is connected to the pressurized modules. It has been decided to connect the docking volume to Module 4 as modules may be feasible to connect to the docking port. Module 1 contains galley, private crew quarters, recreation areas that may cause disturbance due to the transportation of required items from docking volume to any other modules. Similarly, Modules 2 and 3 has been installed with airlocks for EVA's that makes them unsuitable to connect it to the docking module. So, module 4 is preferred to connect with the docking cylinder.

In order to install the docking module and a vertical cylindrical module under the sand, some space need to the created for those modules. Basically, the digging of the ground can be performed by human beings using some robotic capabilities. Physically, digging is not a problem at all as the crater surface is covered by 10 m of dusty sand. The main constraint is the dust that may circulate above the ground due to condition of microgravity. Astronauts are connected to the modules by tethering in the circular cages provided in order remain in contact with the module. Water can be poured into the surface of the crater where digging is to be done in order to be safe from the dust that needs to be encountered with. The water used in the digging process should not be wasted at all as it is one of the precious life supporting elements. So, the water soaked by dusty sand can be recovered using water extracting rovers that uses microwave beam to extract water by heating the water soaked sand. Hence, a volume of about 450 m^3 should be dug in order to place the two docking cylinders. After the volumes have been connected to the pressurized modules, the remaining job is to develop a launch pad for the ascent and descent vehicle as well as the interplanetary transfer vehicle.

The important factor to run the base is the electrical energy to run all the systems. Any thermonuclear reactor is not so feasible in the base although it produces tremendous amount of energy. The main constraint is that it requires high amount of energy to initiate chemical reaction. That is why solar panels are the most efficient method to convert solar energy to electrical energy for the operation of the base. Hence, the next job is to install solar panels in an appropriate alignment so that maximum amount of solar energy can be used. General alignment is the tilting position to face maximum part to the sun. Similarly, radioisotope thermoelectric generators can also be used (explained in 13.2)

7.3 Making of Launch Pads:

Generally, it is preferred to use a concrete launch pad as it holds stronger and rigid. It is basically impractical to take the launch pads from earth itself. As the surface of the Phobos crater is composed of dusty sand that can be used to construct launch pad in the base area. But, gypsum and water required to prepare concrete has to be imported from Earth as those materials are not available there. After the preparation of concrete, a shape of huge flat plate is to be given with two docking ports already placed in the required areas. The thick flat concrete plate can be constructed using 3D printing technique that may be less time consuming and easier to do. The question is where to 3D print the launch pad and how to connect that to the ports of docking module. So, four stands of considerable thickness are already installed in an upright position dug in the soil. A frame is developed and installed with the docking ports placed horizontally on the support of four stands. 3D printing of launch pad is done in the frame that eliminates the problem of its installation from other remote sites. The concrete after being rigid can be used as the launch pads. The four stands that have been used are to prevent the docking module to bear the pressure of the interplanetary and ascent/descent vehicles. After the launch pad is ready to operate, the ascent and descent vehicle lands to the Phobos surface that was still orbiting Mars. This vehicle is used for the exploration of the Martian surface and return back to the base with collected samples for testing.

The following figures give us the schematic view of the final assembled base. Figure 1 shows the part of base below and above the sand and figure 2 shows the final assembled view of the base.

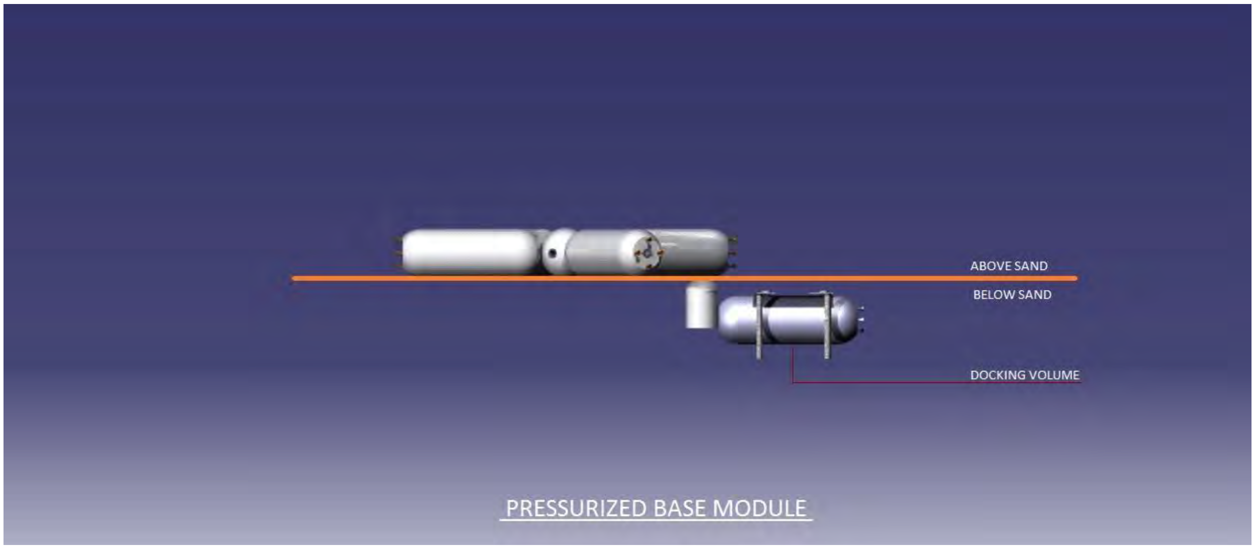

Figure 15: Pressurized Modules Below and Above Sand

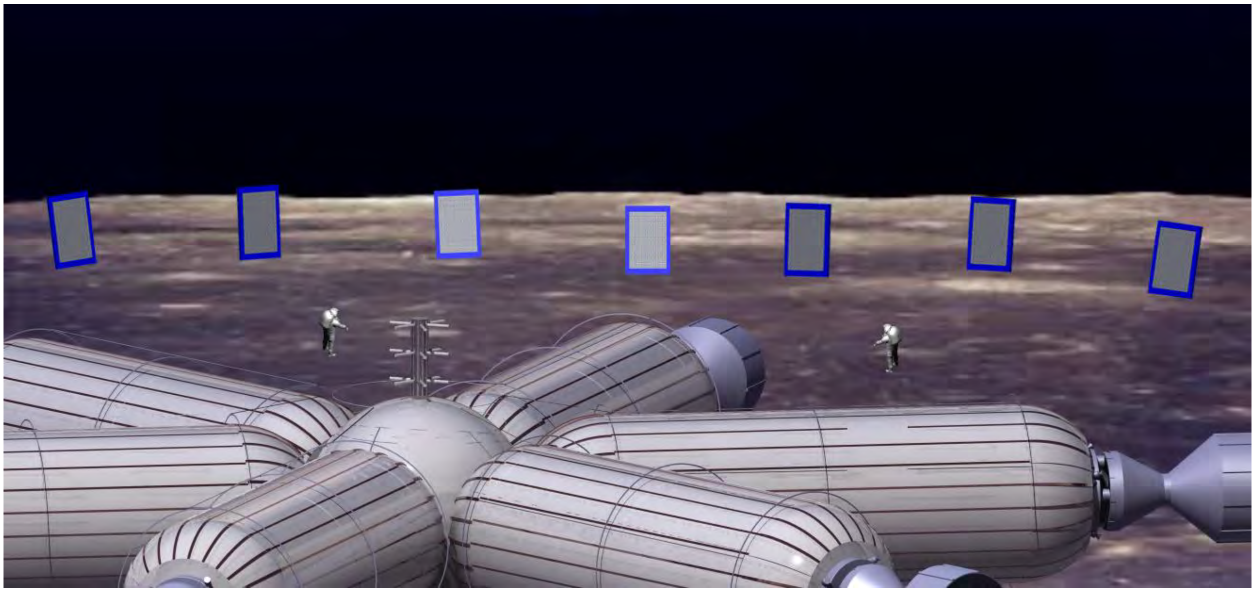

Fig 16: Final Assembly of Base

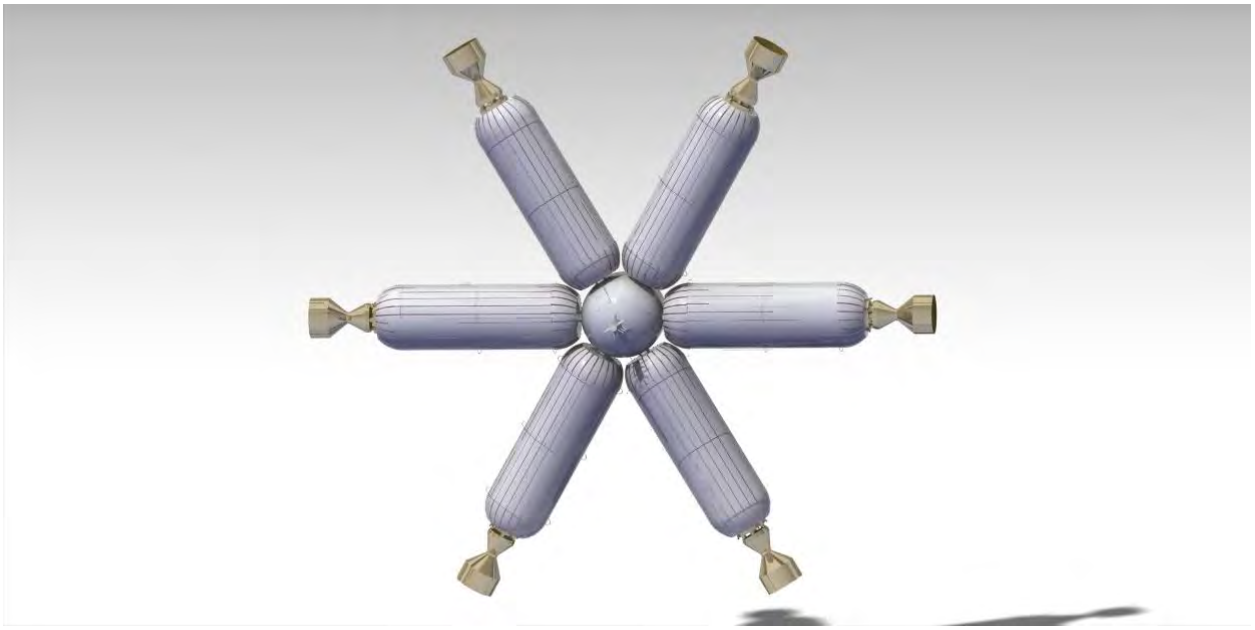

Fig 17: Top view of Base Assembly

8. Space Architecture of the Base:

The architecture of the base is an important factor to determine the efficient and sound operation of the base. As already stated, there are 5 inflatable modules placed on the ground and are connected to the central hub which is held still using the drilling mechanism. The external length of each module is 13.7 m and 6.7 m diameter when fully inflated. The thickness of each module is 46 cm that consists of many layers to protect the astronauts from harmful radiation. The cylindrical volume connected to Module 4 and the docking volume is about 5m in length and 4m in diameter externally. Similarly, the central hub is also an inflatable sphere whose external diameter is 850 mm after inflation with 46 cm thickness.

The volume allocation in each part of the base and special features are explained below:

8.1 Central Hub:

The central sphere consists of systems to induce electromagnetism to make the base stable and counter the gravitational pull of Mars. Similarly, we have allocated three control stations to be installed in this volume with some volume for the circulation of crews within it. They are

- Operation stations to control rovers on the Mars surface in real time
- Astronomical observation station
- Mars direct observation station(s)

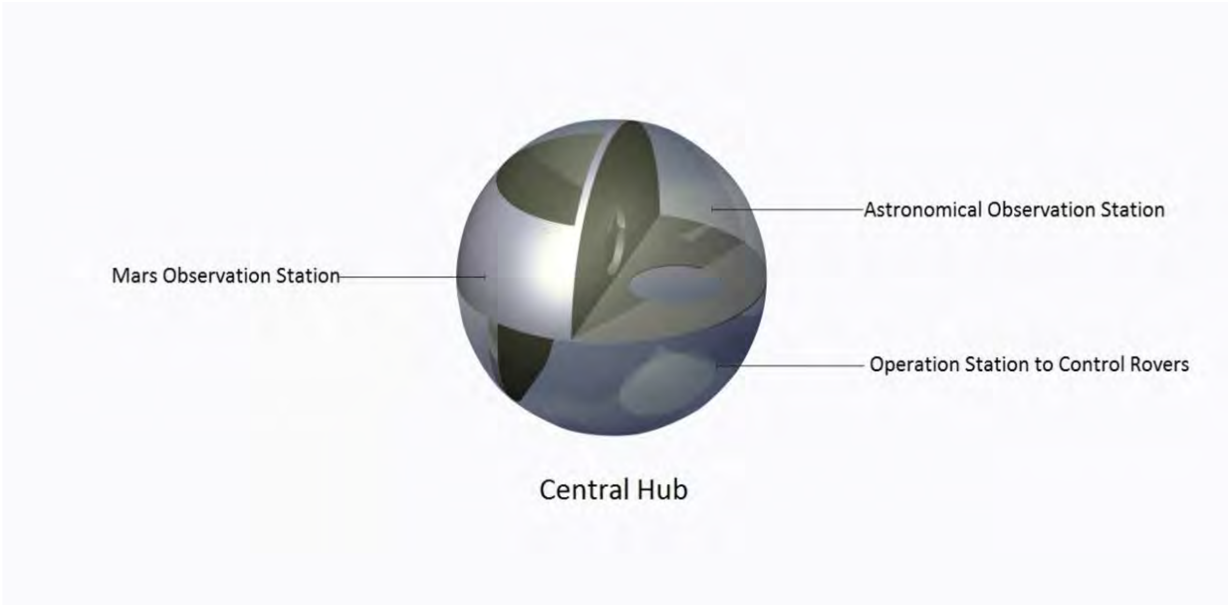

Fig 18: Central Hub

A volume of 20 m^3 has been allocated for the Mars Direct Observation Station. This station comprises of scientific instruments to observe Mars surface and its atmosphere from the base and make decisions on the timelines to go to Mars on the basis of the weather and its atmospheric conditions. Similarly, this station controls various equipments to study about ancient Martian rocks and its water composition that has been proved to exist many years ago.

Similarly, operation stations to control rovers on Mars surface in real time has been allocated with 20 m^3. This station includes a virtual reality display facilities that may include virtual reality video along with the virtual reality glasses. A volume of 10 m^3 has been separated for Astronomical Observation Station that is installed with telescopes to watch remote areas of Phobos as well as Mars.

The docking ports of the central hub are provided with some kind of airlock mechanism in order to prevent the worst case scenario. Suppose any of the modules get strike by any micro meteoroid elements and penetrate the module, air is leaked outside the pressurized modules resulting in the failure of the base. But, this sort of airlock mechanism provided in the central hub closes the passage volume to the target module and hence other modules are safe. The remaining volume is allocated for the circulation of astronauts and the materials of the station.

8.2 Module 1:

Module 1 consists of three compartments as shown in figure: Compartment 1, Compartment 2 and Compartment 3. The volume allocation for each compartment is explained below with figures.

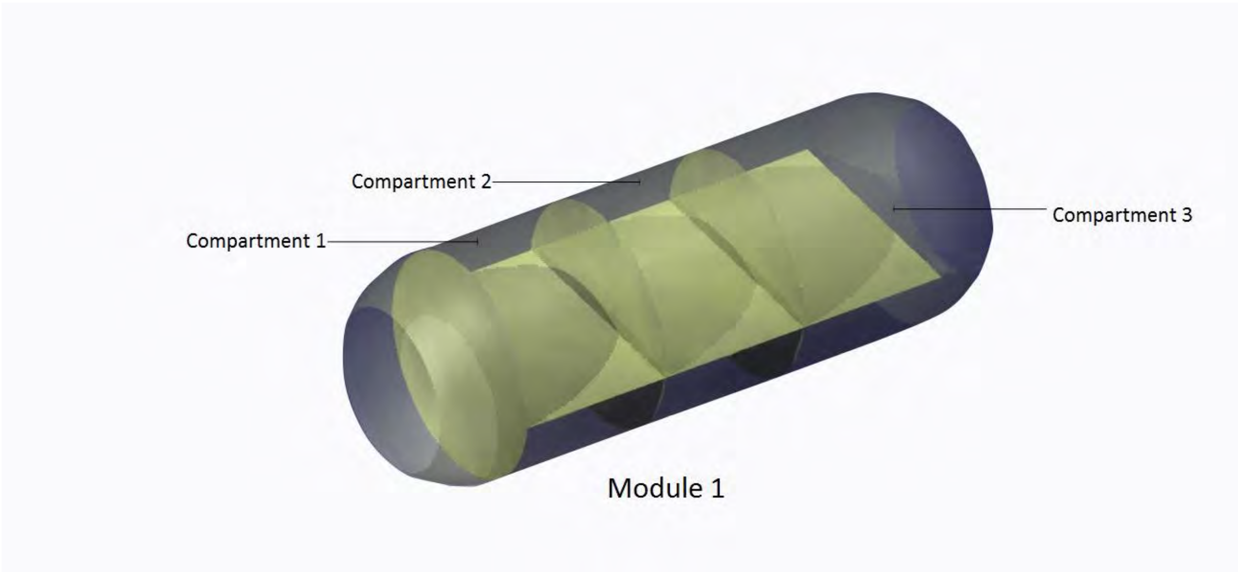

Fig 19: Module 1

8.2.1 Compartment 1:

Compartment 1 is provided with 70 m^3 of private crew quarters generally for six members. But sometimes the number of crew members exceeds six. In this case the crew quarters can be shifted to the recreation areas for some interval of time. The upper part of compartment 1 is provided for group activities area.

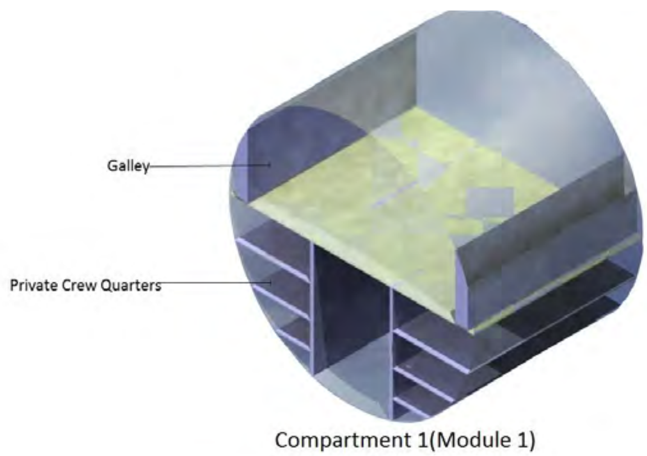

Fig 20: Compartment 1 (Module 1)

8.2.2 Compartment 2:

This compartment is equipped with hygiene and sanitary facilities that includes areas of dish washing, laundry, toilets, dressing and shower areas. Similarly, the upper part of compartment 2 is separated for recreation that should be quiet and isolated. The upper part of compartment 2 is also equipped with food storage areas.

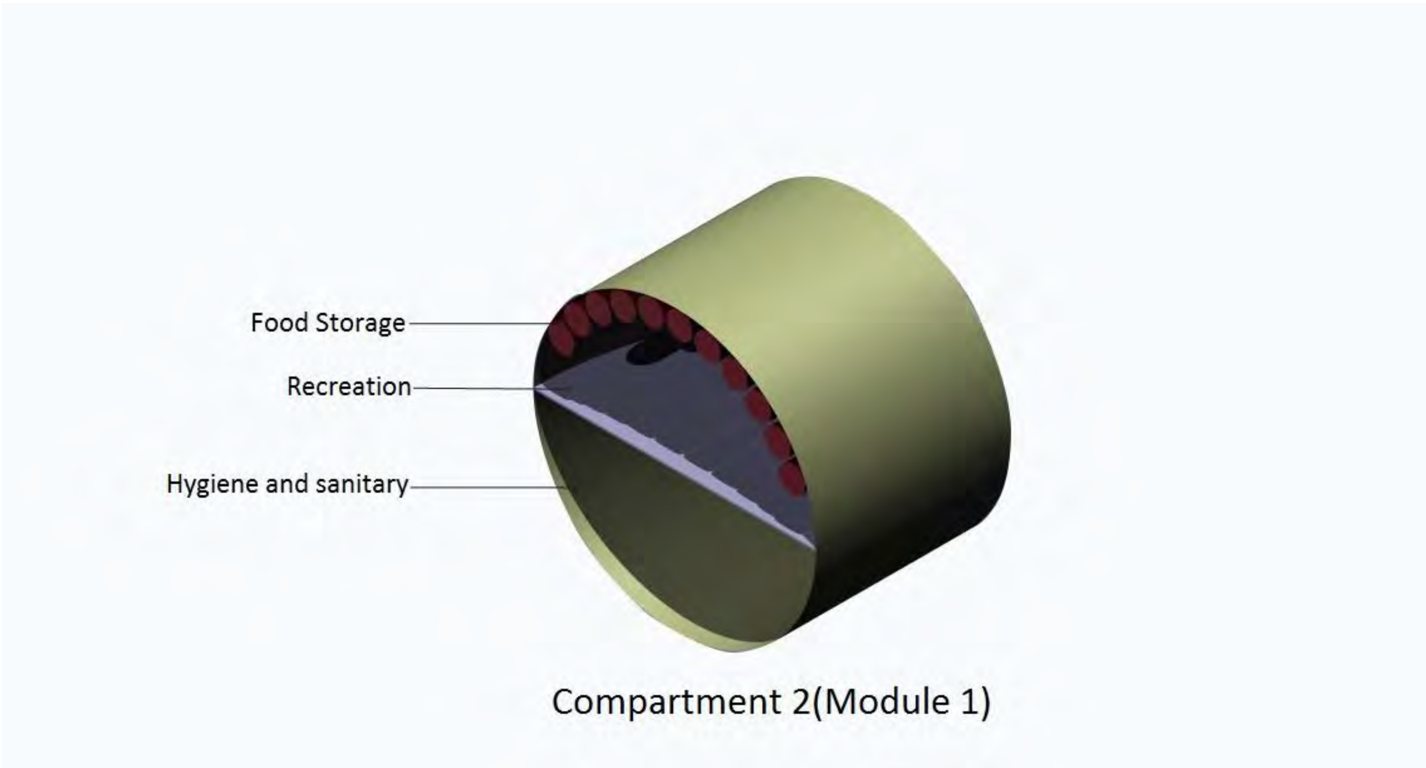

Fig 21: Compartment 2 (Module 1)

8.2.3 Compartment 3:

This compartment constitutes areas for exercise and physical fitness like treadmills, cycling and so on. Similarly the lower part of this compartment is allocated for dinning and meeting. So this part contains equipments like table and chairs that are suitable in the microgravity.

The remaining volume of 90 m^3 is allocated for the circulation of astronauts and materials.

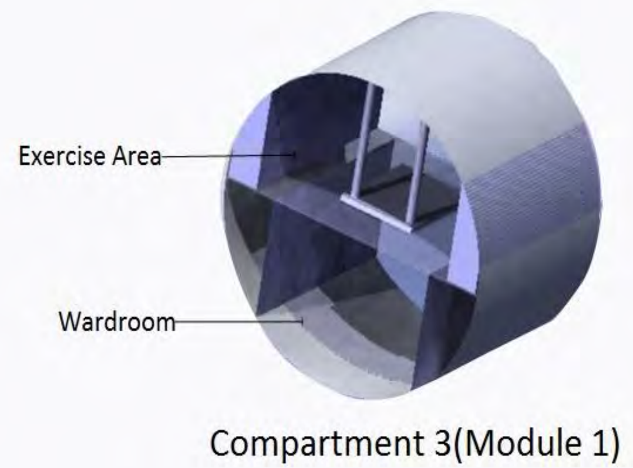

Fig 22: Compartment 3 (Module 1)

8.3 Module 2:

Module 2 is basically equipped with airlock for the extravehicular activities and a toilet is installed in this module connected to the airlock that can be used during the extra-vehicular activities. The volume allocated for airlock is 30 m^3.The major portion of this module is occupied by astrobiology lab to analyze samples return from the Mars surface. A volume of 120 m^3 has been allocated for the astrobiology lab that has Bio-safety Level 4 and is equipped with decontamination capabilities. A workshop is allocated in this module's upper compartment occupying a volume of 75 m^3. Similarly a volume of 35 m^3 has been provided for the supervision of crew's health. The remaining volume of 70 m^3 is allocated for circulation.

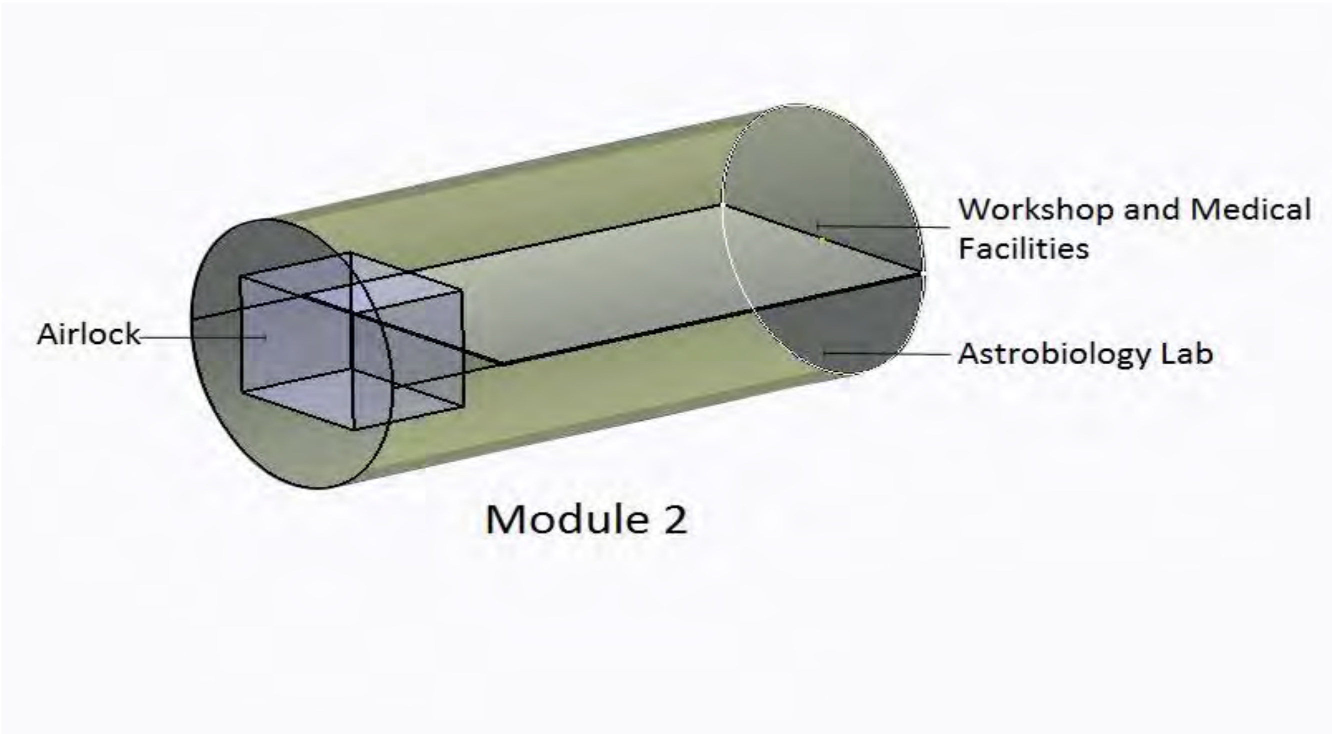

Fig 23: Module 2

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8.4 Module 3:

Module 3 is also provided with an airlock comprising a volume 30 m^3 along with bio-regenerative ECLSS. The bio-regenerative ECLSS comprises a volume 165 m^3 that includes growing food and water recycling facilities. As shown in figure many shelves are provided where different crops can be grown and various insects be reared to feed the astronauts. Similarly, 40 m^3 is allocated for regenerative ECLSS (physical and chemical) that includes water and air revitalization system. The instruments required to maintain a sound temperature, humidity and pressure are also installed here. The instruments include hygrometer, electronic thermometers and barometers. Similarly, a volume of 30 m^3 is also allocated for hygiene, sanitary and waste management facilities.

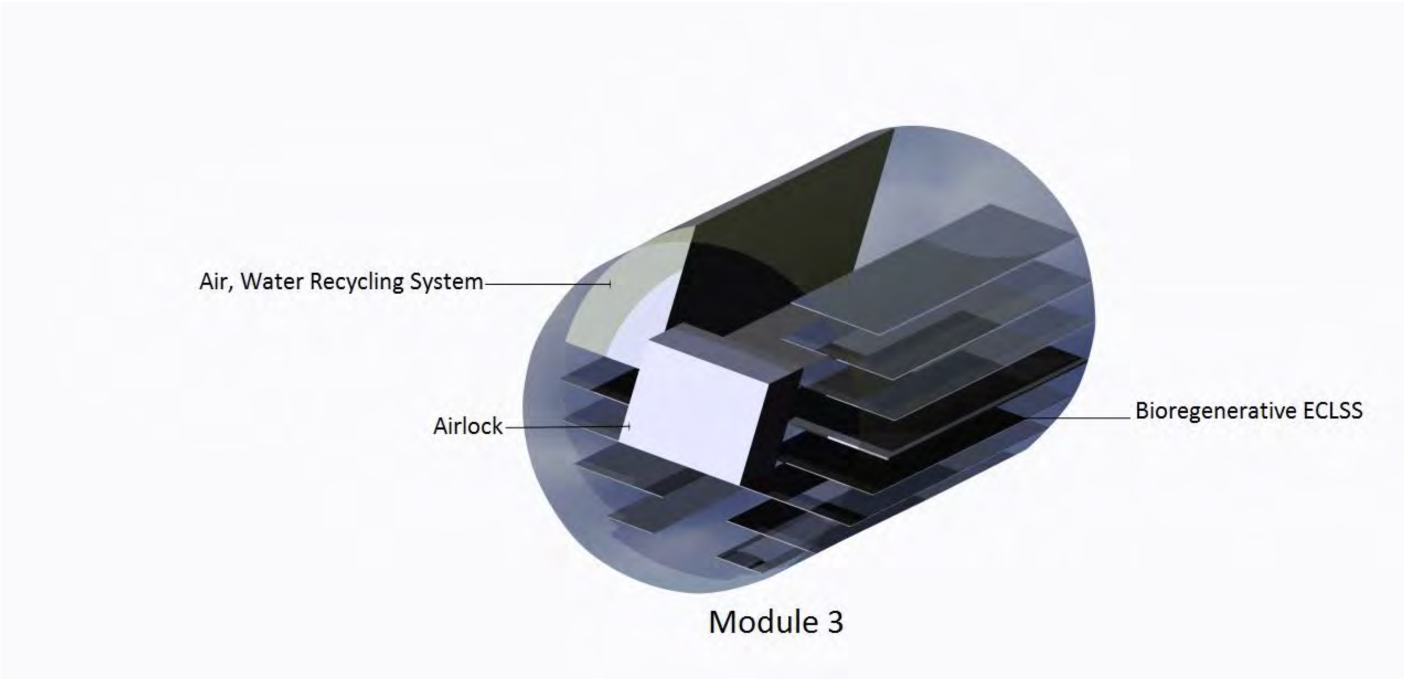


Fig 24: Module 3

8.5 Module 4:

The major portion of Module 4 is covered with bio-regenerative ECLSS covering a volume of 135 m^3. Similarly, a workshop containing various materials that is required for the construction and repair of base is provided in this module too. The other important portion of this module is a room that is equipped with spacesuits that can mitigate microgravity effects on human body to some extent. The remaining 75 m^3 volume is required for circulation of materials and astronauts. This module is connected to the cylinder underground which is a part of docking volume.

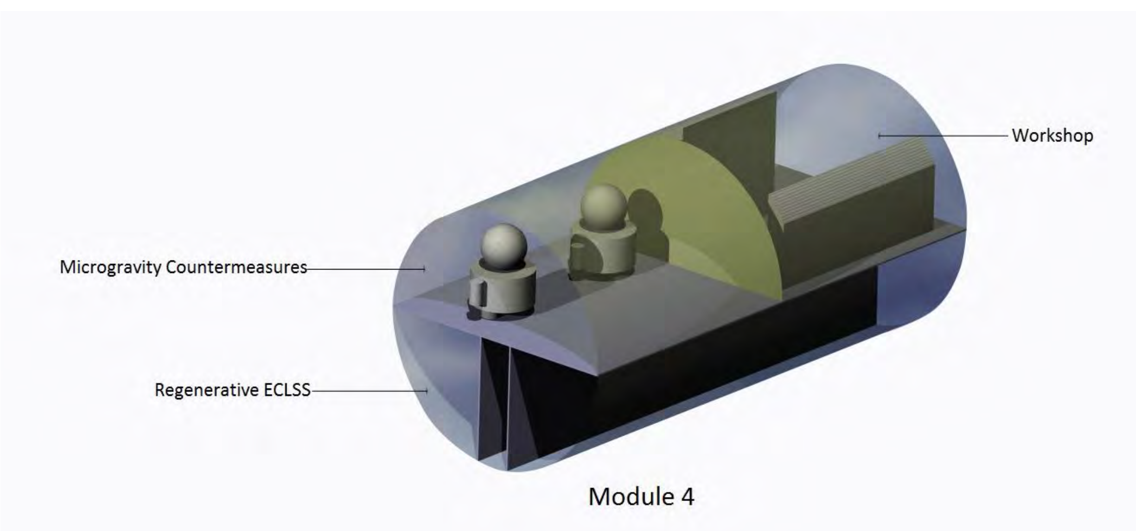


Fig 25: Module 4

8.6 Module 5:

Module 5 is also equipped with airlock required for extra-vehicular activities covering a volume of 30 m^3. Similarly, this module is also provided with measures of regenerative ECLSS covering a volume of 100 m^3. The lower portion of this module is provided with instruments to counter microgravity like the suits that can be used to perform different exercises. The remaining volume is allocated for the circulation of crews and various materials.

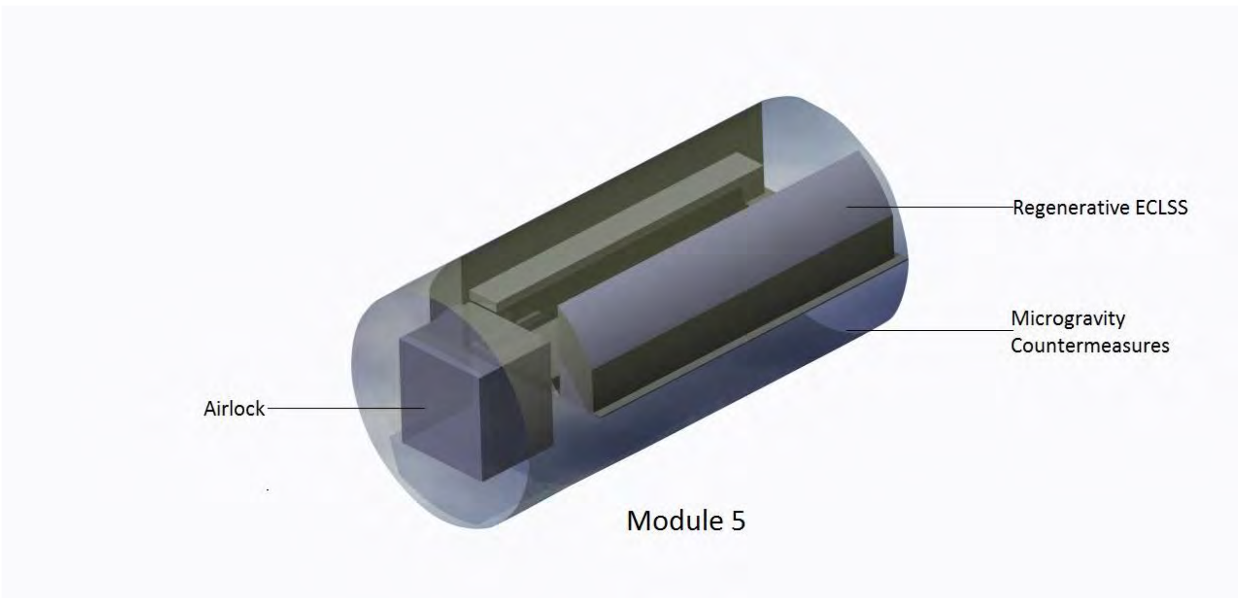


Fig 26: Module 5

8.7 Docking Module:

Docking module is necessary to provide a pressurized path to the astronauts who arrive from the interplanetary vehicle or the ascent/descent vehicle. This module is placed under the Phobos surface and is connected to the pressurized module 4 through a pressurized cylinder that is placed underground too. Similarly this module is used for the storage of materials like fuel, water and so on. The upper compartment is provided with a volume for energy storage to run the base that is provided by solar panels. Similarly, bulk cargo that comes from Earth or from the Martian soil are stored in the same compartment. The lower compartment of the docking module is used for the storage of water required in the base and hydrogen gas required for the operation of air revitalization system.

Similarly, the cylinder that is used to connect Module 4 and the docking module is used to store fuels that are required for Mars ascent and descent vehicle as well as for the interplanetary transfer vehicle.

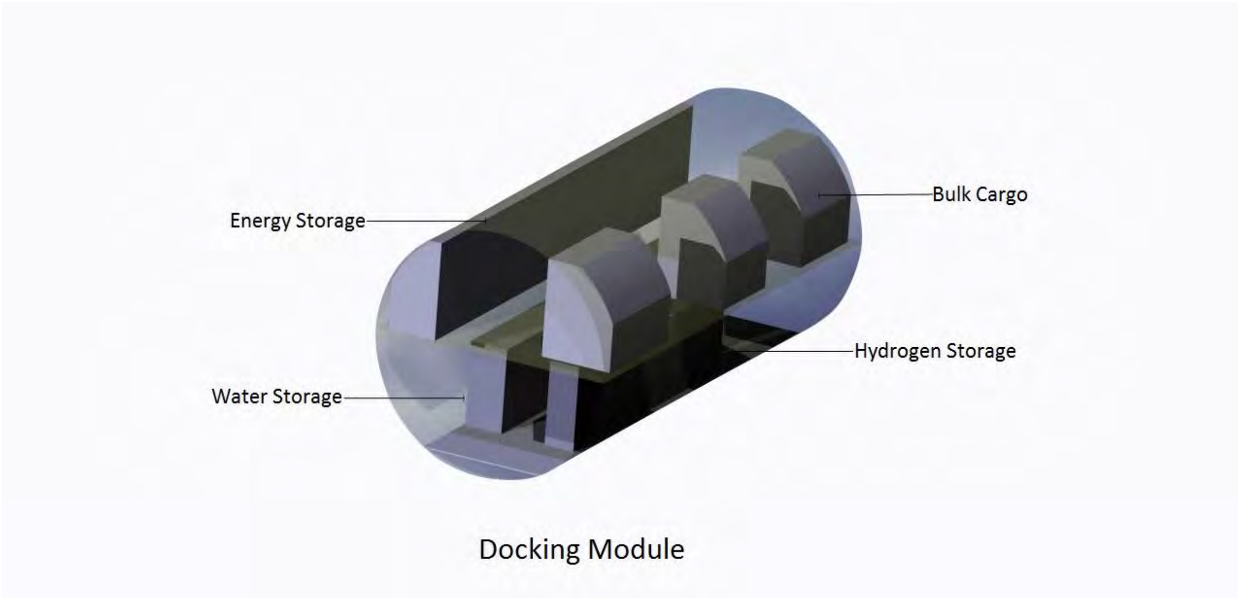


Fig 27: Docking Module

9 Regenerative Environment Control and Life Support System:

The regenerative ECLSS basically includes water recovery and oxygen generation system for the deployment on the base habitat. The major assemblies included here are the Water Processor Assembly (WPA), Urine Processor Assembly (UPA), Oxygen Generation Assembly (OGA), and the Power Supply Module (PSM) supporting the OGA. The WPA and OGA are provided by Hamilton Sundstrand Space Systems International (HSSSI), Inc., while the UPA and PSM are developed in- house by the Marshall Space Flight Center (MSFC). These systems are explained in detail in the preceding sections.

9.1 Water recovery System:

The Water Recovery System will consist of a Urine Processor Assembly and a Water Processor Assembly. The Urine Processor Assembly uses a low pressure vacuum distillation process that uses a centrifuge to compensate for the lack of gravity and thus aid in separating liquids and gasses. Analogous to the system installed in ISS this system can recycle about 93% of waste water including urine, sweat and those included above in the table. Water from the Urine Processor Assembly and from waste water sources are combined to feed the Water Processor Assembly that filters out gasses and solid materials before passing through filter beds and then a high-temperature catalytic reactor assembly. The water is then tested by sensors like (chlorine residual sensor, total organic carbon sensor, conductivity sensor, pH sensor oxygen reduction potential sensor) and unacceptable water is cycled back to the water processor assembly.

Daily Inputs- Nominal (kg)	**Daily Outputs-Nominal(kg)**
Oxygen-0.84	Carbon dioxide-1.00
Food Solids-0.62	Respiration and perspiration water-2.28
Water in Food-1.15	Urine-1.50
Food Preparation Water-0.79	Feces water-0.09
Drink-1.62	Sweat solids-0.02
Hand/Face Wash Water-1.82	Urine solids-0.06
Shower Water-2.45	Feces solids-0.03
Clothes Wash Water-2.80	Hygiene water-3.68
Dish Water-2.45	Clothes wash water-1.90
Flush Water-0.50	Clothes wash latent water-0.60
	Clothes latent water0.65
	Dish wash water-2.43
	Flush water0.50
Total-14.74 kg	Total-14.74 kg

Table: Daily input/output life support parameters for first order sizing

According to the above table, total water consumption in a day is about 13.58 kg by a person. So, 12 crews consume of about 162.96 kg of water per day. As per the capacity of the water recovery systems we can recover about 93% of the water. Hence, 11.4072 kg of water is considered as undrinkable but can be used to generate oxygen and hydrogen. So, 4106.592 kg water needs to be supplied from earth per year to support the crews without considering the discovery of water in Phobos (excluding water recovery from greenhouse) .That means about 10 to 12 tons of water should be carried to Phobos in each launch window (including the water required for oxygen generator system which is about 4314.6 kg).

9.2 Air revitalization system:

The three systems shown above are the carbon dioxide removal assembly, the oxygen generation assembly and the carbon dioxide reduction assembly. The carbon dioxide removal assembly collects and concentrates carbon dioxide and feeds it to the carbon dioxide reduction assembly. The OGA electrolyzes water for crew oxygen and feeds the by-product hydrogen to the carbon dioxide reduction assembly. The carbon dioxide reduction assembly react hydrogen and carbon dioxide to form methane and water. The water is returned to the oxygen generation assembly, thus partially closing the oxygen loop. The carbon dioxide maintenance sub assembly includes the compressor and accumulator. The system includes the 4-bed molecular sieve (4BMS) carbon dioxide removal assembly (CDRA), the Sabatier reactor subassembly (SRS), the mechanical compressor and accumulator, and the temperature swing adsorption compressor. The ISS CDRA, developed by Honeywell (1), uses a four-bed molecular sieve process that consists of two desiccant beds and two CO_2 sorbent beds. Ancillary components include a blower, air-save pump, heat exchanger, valves, and sensors.

The four-bed molecular sieve uses a double cycle to remove CO_2 from the modules atmosphere. The Sabatier Reactor sub-assembly makes use of waste products, CO_2 from a 4BMS/CDRA and H_2 from the OGA (Oxygen Generating Assembly), which would otherwise be vented. The chemical reaction is as follows:

$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$

Water produced can be sent to water recovery system where it can be made potable. Similarly, the methane produced can be collected in a separate assembly which can be used to produce propellants during Mars exploration as per the Mars Direct Plan proposed by Dr. Robert Zubrin. But this may not be feasible due to energy deficit in our base.

The mechanical compressor is used to provide a vacuum for 4BMS desorption as well as compression of CO2 for efficient storage and controlled delivery to the Sabatier. Similarly, The TSAC (Temperature Swing Adsorption Compressor) is a solid-state device that compresses CO2 using a temperature swing adsorption process on a CO2 selective molecular sieve. The temperature swing adsorption process combines the functions of a compressor and accumulator in one device.

As an alternative, a system like Russian Vozdukh that will remove carbon dioxide from the air based on the use of regenerable absorbers of carbon dioxide gas.

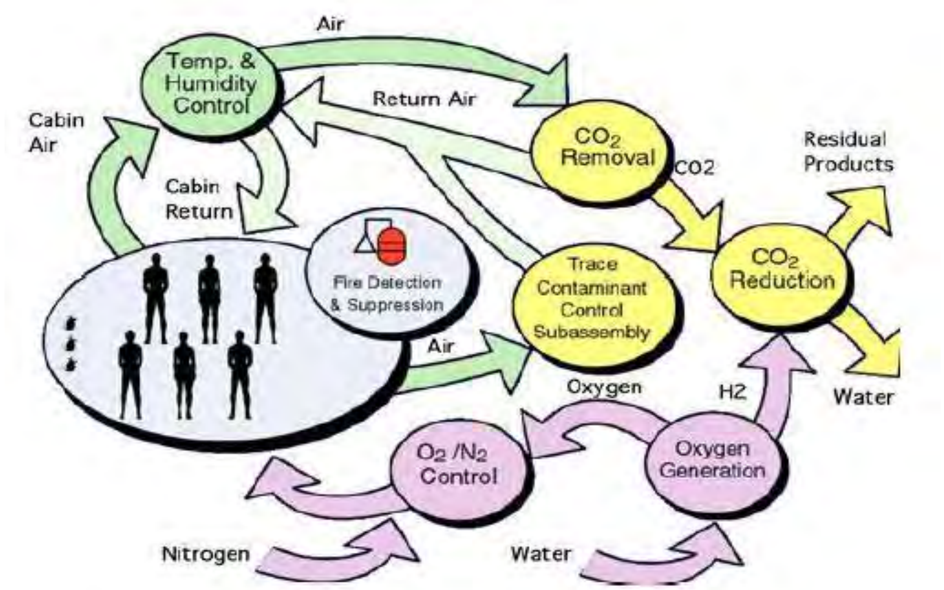


Fig 28: Closed Loop Air Revitalization System (source: NASA.gov)

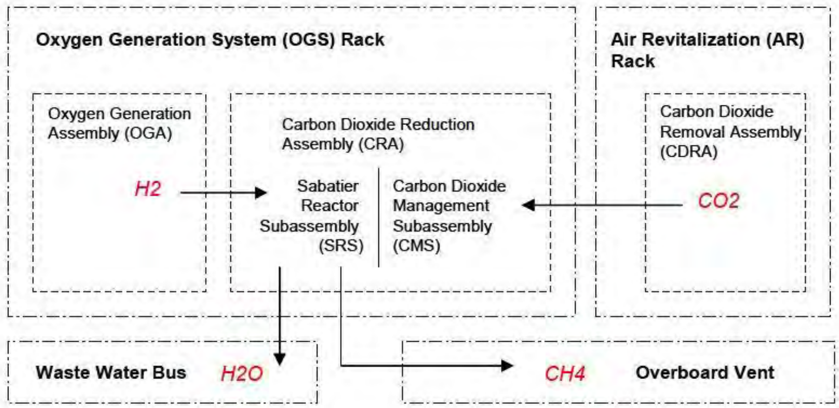


Fig 29: Air Revitalization System and sub systems (source: NASA.gov)

9.2.1 Oxygen Generation Assembly:

The Oxygen Generating System (OGS) is designed to electrolyze water from the Water Recovery System to produce oxygen and hydrogen. The oxygen is delivered to the cabin atmosphere and the hydrogen is sent to the Sabatier reaction sub assembly. During normal operations, approximately 23 liters of water per day is used by the OGS with a constant current of 50 ampere to each electrolytic cell in the OGS system. The oxygen generator system developed by NASA has a capacity to provide oxygen for only 6 crews. So, we require two such systems to provide oxygen for 12 crews in the base. As, an alternative we can use Solid Fuel Oxygen Generator which is a chemical oxygen generator. It uses canisters of solid lithium perchlorate, which are burned to create gaseous oxygen. Each canister can supply the oxygen needs of one crewmember for one day. Similarly we can also directly reduce CO_2 as follows

$$2CO_2 \rightarrow 2CO + O_2$$

This reaction is possible if the temperature can be raised to 1100^0C that will separate carbon dioxide into carbon monoxide and oxygen. The free oxygen so produced can be electrochemically pumped across a zirconium ceramic membrane by applying a voltage, thereby separating the oxygen product from the rest of the gas.

9.3 Temperature, Humidity Control and Atmosphere:

An air conditioning system is installed that can control the temperature and humidity of the habitable modules. A temperature of about 22^0C is assumed to be maintained and the relative humidity of about 50-55%. Similarly, the pressure is maintained to 14.7 psi, same as on the sea level with the atmosphere containing gases like nitrogen to prevent fire in our module. Basically, electronic thermometers, latest pressure measuring instruments like electronic pressure sensors and ionization sensors. The humidity of the pressurized modules and various laboratories may be different. So, hygrometer should be installed in the required places in order to control the relative humidity to maintain safe environment.

9.4 Waste Management Systems:

Two commodes (toilets) are used to collect the wastes that comprises of urine, stool, toilet papers, cleansing papers (for women). The WCS consists of a commode, urinal, fan separators, odor and bacteria filter, vacuum vent and waste collection system controls. The commode contains a single multilayer hydrophobic porous bag liner for collecting and storing solid waste. When the commode is in use, it is pressurized, and transport air flow is provided by the fan separator. When the commode is not in use, it is depressurized for solid waste drying and deactivation. The urinal is essentially a funnel attached to a hose and provides the capability to collect and transport liquid waste to the waste water tank. The fan separator provides air flow for the liquid. The fan separators separate the waste liquid from the air flow. The liquid is drawn off to the waste water tank, and the air returns to the crew cabin through the odor and bacteria filter. The filter removes odors and bacteria from the air that returns to the cabin.

9.4.1 Solid Waste Management:

Solid wastes in Phobos base may contain feces solid, urine solid, sweat solid, trashes like plastic/paper bags, inedible parts of plants and corrugated cardboards. The plastic and paper wastes can be collected in stowage area and can be used in-situ or various other surface exploration processes. Human solid waste after it has been treated can be used in growing foods in other modules. A nominal value of 0.17 kg of solid waste is collected in a day from a single person i.e. 60-65 kg solid wastes per year. Similarly, the wastes like plastics and hard woods that cannot be recycled can be collected in a certain cabins and burned off when in excess. The hard woods and inedible vegetables can be acted upon by insects like silkworm, hawkmoth as we proposed to use the concept of entomophagy in our base habitat.

9.5 Energy calculation for ECLSS

System	Heat Generated(KW)	Power (KW)	Volume(m^3)	Mass(kg)
Water	1.999	2.211	3.255	890.935
Waste	0.363	0.363	2.063	277.765
Food	4.18	4.18	5.28	3028.63
Atmosphere	3.8643	3.8863	16.588	5897.3
ECLSS system total	10.406	10.64	27.186	10095.3

Table: ECLSS Total Mass, Power, and Volume Estimates/ISS

So, to support the total crew of 12 members we need these systems that may contain a volume of about 30-40 m^3 and mass of about 1 -1.25 metric tons. So, the total power consumed to operate these regenerative systems is about 21 KW.

9.6 Food and Greenhouse:

Food is the thing that cannot be regenerated generally in space due to various difficulties. But the Phobos Base will include artificial greenhouses to grow foods. Generally for a 600 days surface mission to Mars the total food required for the crew members of 6 would be about 11088 kg (as per the MOB

Final Report). But we need to support 12 crews and hence food growing becomes somewhat inevitable. The packaged food may consume a volume of about 31.68 m^3.So, we need to produce about 11000 kg of green food in the base annually. The basic plants that are proposed to be grown are rice, soybean, sweet potato and green leafy vegetables. The best combination of these four, in terms of nutrition, was determined to be the following, per person per day: 300 g rice, 100 g soybean, 300 g green–yellow vegetable, and 200 g sweet potato (fresh weight). Criteria used for this selection were: total energy intake, amino acid score, adequacy of supply of each nutrient, and the energy ratio between proteins, lipids, and carbohydrate. Similarly, we also propose to use the concept of entomophagy in our base habitat. The insects that are chosen are the silkworm, the hawkmoth, the drugstore beetle, and the termite. These insects do not compete with human in terms of food resources, but convert inedible biomass or waste into edible food for humans.

Regarding the use of space farming and entomophagy an appreciable amount of CO_2 and oxygen is required to grow plants and animals. Carbon dioxide used for the plants is provided by humans and insects and the nitrogen supply should be provided for the plants through a special unit. The temperature and humidity control for plants and animals is done by an extra air conditioning system (sometimes can be used for the purpose of crews too) installed in our modules.

Thus for a manned mission, consideration of food must be one of the primary focus. The food consists of re-hydratable, temperature-stabilized, irradiated and natural-form foods. Most of them can be simply eaten by the addition of water and heating. Fresh foods such as fruits and vegetables cannot be stored as other foods so must be consumed within the initial days of flight before they spoil.

With the development of the food items for the astronauts through the years of experiment in the ISS, the varieties of food has been increased with the growing importance of fulfillment of appetite of astronaut which otherwise would result in the weakening of bone. The food items available include creams, macaroni, cheese, chicken, beef, ham, scrambled eggs and cereals and so on. According to the analysis, an astronaut consumes about 1.83 pounds (0.83 kilograms) of food per meal each day of which 0.27 pounds is taken by packaging material.

As a backup in case for any delay within the mission about 15,000 kilograms of food must be carried. As prior to the manned mission, on July 18, 2020 second Cargo is sent the food load can be split into half. Further, RFP demands for the provision of production of 50% food on the base itself the total quantity of food to be carried is reduced to 7500 kilograms. But, taking into account the risk associated with the failure of food production program in the base, as a backup the food is sent from the Earth required for the overall mission duration. The success of the program would be beneficial for the second manned mission through the preservation of food materials. Thus, each launches carrying about 7,500 kilograms of food.

Water being heavy attempts is made to minimize the amount of water carried on board. Water can be produced from fuel cells as a byproduct. But as the electrical power generation in the PBM is from the solar panels rather than fuel cells, water cannot be produced. The water required can be obtained in some quantity from cabin air onboard which after recycle can be used. On average, about 11 liters of water is used by an astronaut per day. Also, water will be generated through the ISRU program

9.7 Astrobiology Lab:

These labs are basically designed to test various samples that are brought from the Martian surface to the base. As we do not know about the Martian soil in detail and hence their toxic nature is not known. So the samples from the Martian surface need to be tested to a laboratory that has decontamination capability and Bio-isolation level 4.

9.7.1 Bio-isolation level 4 and Decontamination Capabilities:

Bio-isolation level 4 is the highest level of biological safety, BSL-4 lab consist of work with highly dangerous and exotic microbes that pose a high individual risk of aerosol-transmitted laboratory infections and life-threatening disease that is frequently fatal, for which there are no vaccines or treatments, or a related agent with unknown risk of transmission. Highest level of isolation is required to maintain the safety of the surrounding environment of the laboratory. Astronauts working in the isolation lab should follow certain code of conduct to maintain the safety such as:

- Astronauts are required to change clothing before entering, shower upon exiting
- Decontamination of all materials before exiting
- Astronauts must wear appropriate personal protective equipment from prior BSL levels, as well as a full body, air-supplied, positive pressure suit.
- Two-personnel rule must be applied, whereby no individuals work alone.

BSL-4 lab must be isolated from the surrounding module environment. BSL-4 lab will be set up in lower compartment of module 2 with the confined volume of $120m^3$ which features dedicated supply and exhaust air, vacuum lines and decontamination. BSL-4 lab must be facilitated with the following components which features the safety measures and decontamination methodology.

- Module automation system including remote monitoring and control sites.
- Pressure-driven-air flow control
- Bio-seal doors and dampers
- Module pressure sensors
- Ventilation and filtration
- Breathing suits
- Chemical showers
- Emergency power
- Liquid effluent-treatment system
- Emergency strobes and alarms
- Architecture
- Laboratory refrigeration system
- Breathing air system
- Fire detection and suppression system
- Water backflow prevention systems
- Electrical and mechanical penetration seals
- High-efficiency particulate air (HEPA) filtration systems
- HEPA decontamination systems
- Chemical decontamination system

The above systems can be set up as shown in fig 2 to maintain the required level 4 of safety.

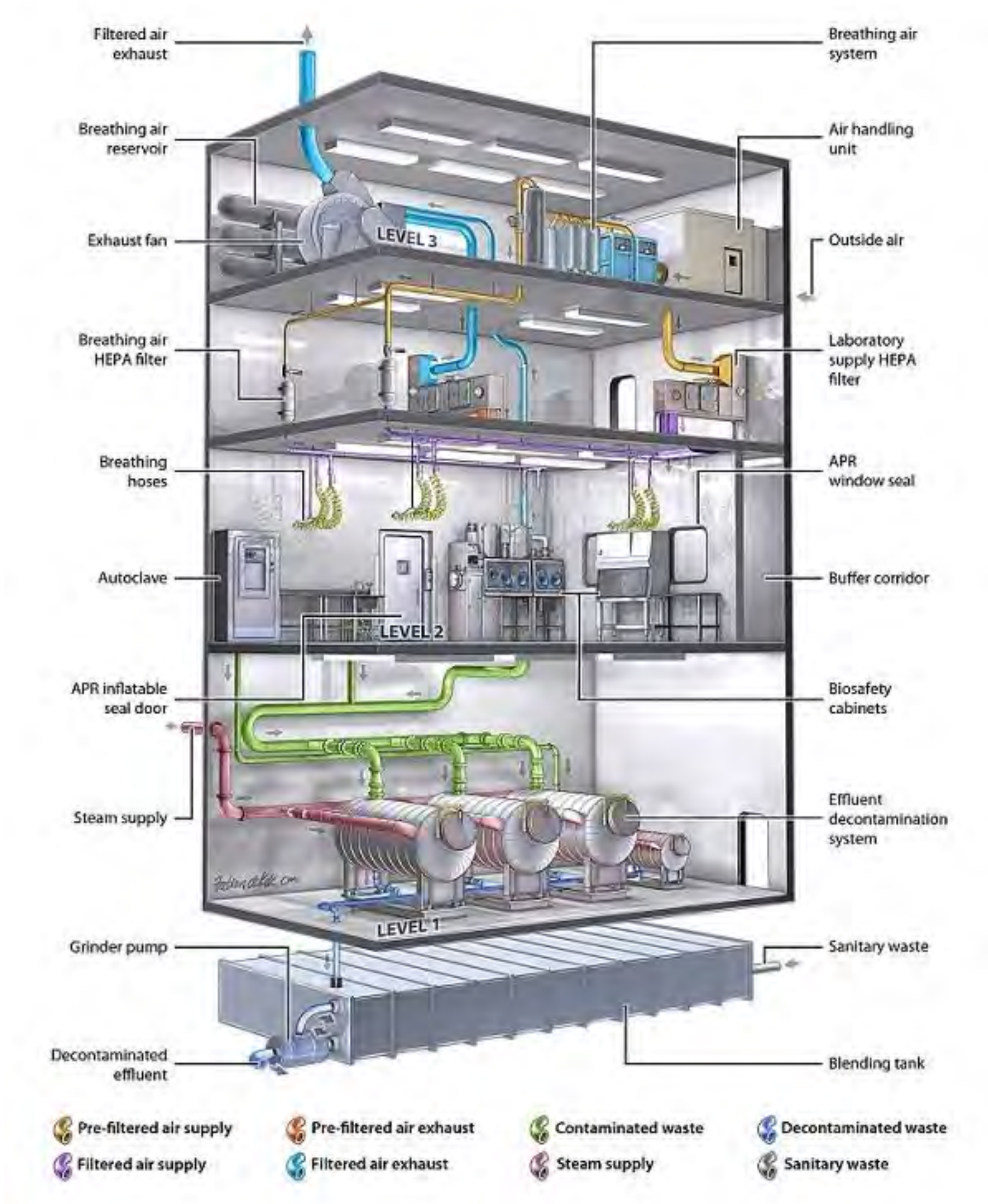


Figure 30: BSL-4 laboratory (source: Integrated Research Facility, NIAID)

10. Life Science Countermeasures:

It is the most important aspect that is to be considered to settle a human base in the Phobos crater. This may include the protection measures from microgravity, radiation in Phobos, dust and contaminants and the planetary protection too. They are explained in detail below:

10.1 Microgravity Countermeasures:

The term micro-g environment is more or less a synonym of weightlessness and zero-g, but indicates that g-forces are not quite zero, just very small. Exposure to microgravity, whether simulated or actual, has been shown to result in reductions in ventricular mass , blood volume , breathing frequency , balance control , nervous system sensitivity and reserve , arterial tone , bone mass , immune function , muscle mass and space motion sickness.

Lower body negative pressure (LBNP) provides an effective cardiovascular countermeasure. As this requires a high pressure (53 mm hg) to provide 1 body weight, it is not so comfortable and does not fully attenuate the occurrence of supine-standing test intolerance. So LBNP can be used often. Exercise countermeasures form a crucial element of the astronaut training regime designed to prevent the loss of bone, muscle and cardiovascular function associated with disuse. It may include hour's sessions of exercise, consisting of 4-6 treadmill sessions a week, 2-3 cycle sessions. Similarly, the Gravity Loading Countermeasure Suit developed at MIT can be used during exercises for long as well as short term. The skeletal loading on the body when standing at Earth's gravity is not constant at every joint but is cumulative; at the feet you have the entire bodyweight, at the hips the upper torso, while the neck supports only the head. This suit has been chosen instead of the Russian made "Penguin" suit as Penguin suit loads a specific weight up to 40kg in three places only; the Gravity Loading Countermeasure Suit uses a bidirectional weave to stretch and load in hundreds of stages. Pilot studies at King’s College London have shown it to be both thermally tolerable and viable for integration into cycling and resistance based exercise, whilst providing a passive loading regime of approximately 0.8g. Similarly, using centrifuges to create artificial gravity is also an idea but it is not referred in our base habitat as it is totally impractical.

10.2 Radiation Protection:

Generally the radiation in space are ionizing and non-ionizing. The ionizing radiation includes the Solar Particle Events (SPR), Galactic Cosmic Rays and Secondary Neutrons. Non-ionizing (or non-ionizing) radiation refers to any type of electromagnetic radiation that does not carry enough energy per quantum (photon energy) to ionize atoms or molecules. The main threats to the health are from the non-ionizing radiation.

The radiations that are listed above causes various types of disorders in astronauts. The radiation effects include carcinogenic disorders like leukemia and solid cancers. Similarly, the degenerative tissue effects include Heart Disease, Cataracts, Respiratory Disease and Digestive Diseases. Likewise, the damage to central nervous system is also the possible effect of radiation in space. The potential outcomes of the radiation exposure are Reduced Life Span, Performance Degradation and Morbidity.

The main threat is due to highly charged cosmic rays comprising high energy protons and atomic nuclei. The other threats are due to the production of secondary neutrons when they strike the base habitat. The materials with low atomic weight can block these neutrons. So, hydrogen is the best to protect from these neutrons. As liquid hydrogen is not feasible to use it can be used in various other forms like composites. Basically, the bladders used in the layering to develop inflatable modules also protects from intense radiation as the bladders have water inside it.

The dose equivalent in the case of water shielding is between 1 and 1.2 mSv/day. Similarly, the water tank inside our module on the level of crew quarters is a good protection to the non-ionizing radiation. Similarly, we propose to use the internal covering core using Hydrogenated Boron Nitride Nanotubes (HBNN's). The B10 has an effective neutron capture cross section suitable for low energy neutrons ranging from 10^{-5} to 10^{4} eV and hydrogen is effective at slowing down high energy neutrons. As the Young's Modulus of this composite is about 732-736, it can be considered strong enough to work as the hard central core of our module. The dose equivalent of BN (Boron Nitride) + 5% hydrogen (30 cm thick) is less than 1 mSv/day which is an appreciable value than other materials like water, aluminium, Boron Nitride. Similarly, the crew quarters, galley and wardrooms interiors are made of polyethylene that will stop the induced neutrons. As per the NASA's data, the dose equivalent in the case of Mars mission (estimated 3 years) is about 1200 mSv. As 1200 mSv is a huge value that results in serious health hazards, our protection system is estimated to protect the crews from radiations. Similarly the use of drugs to reduce the effects of radiation can also be done in a scheduled way.

Similarly, the site for the base assembly can also be taken into account. The intensity of exposure to radiation in Stickney Crater is less than that at Phobos or Mars surface.

10.3 Dust and Contaminants:

It is an important aspect to maintain the fresh and healthy environment within the habitable modules in our base habitat. The closed environment of habitable modules must be monitored for contamination to ensure the health of the crew living and working on it. Contamination of the closed environment can be caused by off-gassing of vapors from items (plastics, tape, etc.), as well as microbes (bacteria and fungi) growth carried to base for crew supplies. Similarly, food, experiment devices may also lead to contamination of the atmosphere.

Air sampling systems are installed that periodically checks the air for potential hazards. Advanced air filters are also installed that removes the harmful vapors from the air along with the routine to clean the filters. Regular water and surface sampling must be done to ensure the safety against contaminants. Volatile organic analyzer (VOA), an atmospheric analysis device that uses a gas chromatograph and ion mobility spectrometer to detect, identify, and quantify a selected list of volatile organic compounds must be used. Similarly, POTOK air filtration device can be used as employed by Roscosmos in ISS to disinfect and inactivate microorganisms by electrostatic pulses and charged ions. Compound Specific Combustion Product Analyzer that looks at potential toxic products of combustion, such as a fire, onboard the spacecraft and analyzes carbon monoxide, hydrogen cyanide, hydrogen chloride, and oxygen particles in the air should also be installed. All these systems can trace out the hazards inside the habitable modules environment. If any contaminants are found in any source, it should be treated and made safe.

Similarly, the dust that can enter the modules due to surface exploration may also lead to problem in the habitat. The dust related hazards could be sorted into nine categories. These categories are: vision obscuration, false instrument readings, dust coating and contamination, loss of traction, clogging of mechanisms, abrasion, thermal control problems, seal failures, and inhalation and irritation. One way to protect our habitat from dust is to suit covers that are kept in the airlock system. After the extra-vehicular activities and surface exploration by the crews the cover must be cleaned out using brush or other robotic systems and is taken out. So, the spacesuit remains clean and free of dust. Similarly, wet pieces of clothes must be applied on the floors and our equipments to collect the dust inside the pressurized habitat. Also vacuum cleaners can also be applied to the extent of its compatibility.

10.4 Planetary Protection:

Planetary protection is a guiding principle in the design of an interplanetary mission, aiming to prevent biological contamination of both the target celestial body and the Earth in the case of sample-return missions. There are two types of interplanetary contamination. Forward contamination is the transfer of viable organisms from Earth to another celestial body. A major goal of planetary protection is to preserve the planetary record of natural processes by preventing introduction of Earth-originated life. Back contamination is the transfer of extraterrestrial organisms, if such exist, back to the Earth's biosphere.

Generally the forward contamination is protected to a level through sterilization methods during fabrication and assembly. We can apply vapor phase hydrogen peroxide that uses aromatic rings and sulphur bonds. Similarly, ethylene oxide can be used for materials that are not compatible with hydrogen peroxide. Portable 'clean tents' must be used while testing the module before and after assembly. Dry heat treatment method can be applied-exposing the modules to a temperature of about 110^0C to 125^0C for several days. Advanced Life Support systems are also the leading factors of forward contamination. So, the solid wastes or exhaust gases like methane should be sterilized before release. The best way is the development of ideal life support systems. This is important to avoid false positives and an understanding of Earth-sourced organic contamination, whether living or non-living.

Similarly, back contamination must be protected to protect the people from unknown contaminants (i.e. from Mars). It is basically achieved during EVA's. So, a contingency system must be installed in our habitat in Phobos Base. This may include on-board capability to detect hazards, sterilization capacity like those explained above, and personnel isolation system and so on. Exploration, sampling, and base activities should be accomplished in a manner to limit inadvertent exposure to the subsurface or to otherwise-untested areas of Mars. The biological nature of our landing and research site can be tested through the initial robotic missions and then the systems are developed as per the requirements. A quarantine capability for both the entire crew and for individual crewmembers shall be provided during and after the mission, in case potential contact with a Martian life-form occurs. This includes the basic tests of the medical condition of the crew and their potential response to pathogens or adventitious microbes shall be defined, provided, and employed regularly on the mission.

Robotic spacecraft to Mars are required to be sterilized, to have at most 300,000 spores on the exterior of the craft—and more thoroughly sterilized if they contact "special regions" containing water, otherwise there is a risk of contaminating not only the life-detection experiments but possibly the planet itself.

10.5 Medical Monitoring:

It involves the collection of health data of all the crew members during space transportation at regular interval. Long duration spaceflight prolongs recovery of heart muscle, causes cardiovascular illness, susceptibility to arrhythmia, back pain injuries, and loss of body weight. Crew activity in the spacecraft like floating between modules, aerobic and resistive exercise and injuries caused by extra vehicle activity (EVA) causes the musculoskeletal injuries. Microgravity affects the body's balancing mechanisms. The Crew Health Care System (CHeCS) is the suite attached to the hardware of spacecraft to provide medical and environmental capabilities to ensure health and safety of the crews.

Crew health before, during and following the spaceflight is very important parameter in the mission success. Pre flight medical evaluations are performed by Crew Surgeon. Screening of Coronary Artery Disease (CAD) is conducted. Psychiatrist or psychologist checks the behavioral health status of crews and monitoring of their mood. In flight evaluations are done by Crew Medical Officer (CMO) as radiation monitoring, and physical fitness tests.CMO undergoes medical training within 18 months before missions. Post medical evaluation is done to evaluate post flight crew health, monitor rehabilitations and to ensure crew return to preflight medical status. Bio-dosimetry data is collected before and after flight to check the aberrations in chromosomes occurring in the space flight.
We have both male and female crew in our mission. Female crew has higher incidence of experiencing the symptoms without actually fainting during stand tests than male. Ground based tests show that female crew has more susceptible to fatigue, and injury. The past missions show that the musculoskeletal injuries are more in female than male crew.

11. Arrival of the Crew:

As we have already indicated that first six crews arrive the Phobos base habitat in the fourth mission and further assemble and construct the base.

11.1 Crew transfer from ITV to the base:

After we reach the Martian influence the transfer vehicle slows down and we orbit the planet at an aphelion distance of 10265.176 km. Before delta v is applied the interplanetary transfer vehicle separates and descent vehicle attached with the module carrying crew gives a negative delta v required to land on Phobos. The other portion of the interplanetary vehicle orbits the Mars above the Phobos orbit and is used to reach the Martian surface through docking with the ascent vehicle from the base assembly.

Before the crewed mission lands the incomplete base assembly they check the location of the base using the signals from land based transponder. As there is no spaceport built till this mission, the crews must land on the base site very close to the central hub and in a proper angular alignment to join the crewed module with the pressurized modules. The dynamics behind the approach to Phobos has already been explained in previous sections.

The base module carrying crews after landing obviously creates a dusty atmosphere due to impact and boosting phenomenon. So, they cannot just land out of the module and enter the pressurized assembled base. The use of vacuum cleaners is not possible as there is no atmosphere. So, the crew needs to connect their module to the central hub and then enter the base habitat. But after the final assembly of the base, the crew does not have the problem of landing as spaceport is ready.

11.2 Process by which crew activates and verifies the base:

The partly assembled base does not open for everyone as we do not know the risk factors of that place very far from home. So, a certain procedure needs to be followed by the crews and the systems installed to open the base for astronauts who reach the Phobos surface. Each and every module is loaded with a sensor that senses the signals from the crews and forwards it to the controller in Earth. After it has been verified that crews reached the base, a signal is transmitted from earth to the modules to confirm that the signal was from the crews who arrived the base. The modules that are in hibernation are activated by the signals from Earth. It is now possible for the crews to attach their modules to the pressurized modules as the docking ports are active now. The crews enter the other modules and operate all the ECLSS equipments that are essential to support astronauts though the primary focus should be on growing of plants (food).

11.3 Further assembly, outfitting under crew supervision:

Before the arrival of the crew there would be 2 modules including the central hub in preferred location landed on the surface at precise accuracy using the ILS(instrumental landing system).As soon as crew landed on the surface there main focus would be on further assembly of the base. Crew would use the robots and inbuilt systems to move the modules to the central hub for docking. As the gravitational force of the mars is more convenient on the Phobos surface, base assembly should be done considering the benefits of mars gravitational force (as mention above) which would make easier to move the module to the required point. The ring cage would help to maintain the interlocking force between the surface and module through magnetic field. Since the module and central hub are equipped with the sensor that detects the whether the docking port are in level for soft docking. As soon as sensor commands the astronauts about the perfect level, soft docking procedure starts then hard docking. After the hard docking the connecting space between the central hub and the module are pressurized. The process is continued till all the modules are docked and other remaining modules are ducted later after their arrival at base site. All these modules are drilled to Phobos surface. As base assembly is ready, astronaut would enter the Phobos surface through docking port. Further astronauts would place the solar panel and RTG system to fulfill the energy required for base assembly. After all these assemble, crew would use rovers to dig up the surface to maintain the place for docking volume, which would be under the land surface docked with the above base assembly as shown previously.

12. Operation of the Base:

The concept for the operation of base is basically explained after the completion of the base that was designed in the Earth. The operation of the base includes the schedules to perform various jobs on the modules regarding life supporting systems, maintenance and repair, extra-vehicular activities. It also includes the schedules of the ascent to Mars and return to the base back on the basis of weather and conditions in Mars.

As first crewed mission to Mars must be a short stay time (about 100 days) as it is new place for human beings to stay for a longer period. The successive human missions to Mars may be the long stay missions as the requirements and hazards in the base is known from the previous crews who had a short stay in the Martian region.

It is assumed that six crews always be in the Phobos base to operate the base and control the operations in Mars surface. At least three crews should be sent to Mars to perform various researches and collect many samples. Each Martian stay time is estimated to be 30 earth days or less in case of emergency. So, the crews exploring the Martian surface are changed every 30 days (excluding the ascent and descent time to and from the base). It is quite necessary to schedule each and every task among the crews to maintain smooth operation of the base.

Extra-vehicular activities are basically performed on daily basis (excluding some unfavorable conditions) by three crews either by walking or using the rovers explained above. The change of astronauts for EVA is basically done after the astronaut reaches a conclusion regarding the job given to him/her. Similarly, two crews are employed on a routine basis to check the overall system's condition and report it the control station in Earth. If any system goes out of operation, the astronauts of respective expertise should work upon with and repair as workshop is available in the base habitat. But if the crews cannot repair the damaged system, this should be reported to earth and solutions need to be searched for as soon as possible. Research labs should be visited by the crews to perform various experiments on the basis of their respective field of expertise.

In order to run the base operation efficiently, a commander need to be selected to take the major decisions and maintain an unbiased routine of various internal works like cleaning, washing, preparing dinners and so on. Everyday food should be eaten in a same time by the crews in base as well as in the Martian surface as it may counter the adverse effects of eating in an unscheduled way. Similarly, the astronauts in the base should always sleep and wake up at same time every day. Regular wakeup alarms must be compulsory for all the crews and the time is allocated by the experts in Earth. Every crew members need to perform exercises on a daily basis for 3-4 hours a day in order to counter the microgravity effects that may be seen in human body. Exercise is the one and only way to counter microgravity hazards in the base. Likewise, a routine should be made by the commander for preparing dinners, dish washing and cleaning on the consent of every crew members. The crews in the base habitat should have a regular medical checkup and report it to the control station in Earth. On the basis of the advice and prescriptions provided by the health specialists medicines are to be taken.

Considering the progress made in finding many elements in Phobos or the Martian surface, new constructions can be started that may reduce the things to be taken from earth in the successive missions. If we are able to find silicon on the Phobos sand or somewhere in the Martian sand, the astronauts can build solar panels on their own in the base that is the most efficient source of energy for the operation of base. As, per some scientists belief about the existence of water in Phobos (13% water by mass) holds true after exploration of the surface it becomes very useful. The water enclosed inside the surface can be extracted using microwave beam and extracted. This water can be used for the daily operation of base if that can be made edible to use. Otherwise, we can build ice house using 3D printing in order to provide astronauts with highly radiation resistant habitat where they can spend some of the time of recreation. The concept of extracting water from the Phobos or Martian surface if present is explained as follows:

The basic mechanism of using microwave beam to extract water is just heating up the water to a certain extent so that it can be converted to vapors. The formed vapor moves out to the surface where it can be collected using cool plates and used later on. The distinct advantages of using microwave radiation to extract water from the Phobos or Martian surface is that it eliminates the effort of digging the soil. Consequently, use of heavy instruments to dig the surface is eliminated. Similarly, we don’t need to worry about the underlying geology since hidden or buried rocks (that have no water) could damage digging equipment. The idea of kicking up dust by digging on the surface possesses a problem for equipment and astronauts if the abrasive dust finds its way into the wrong places.

An important concept of the use of microwave is the melting of the regolith surface to make it dust free. Such surfaces can be used as working surfaces to stabilize equipment and floors or roadways for astronauts to live and travel on. Conventional bricks, blocks or walls can also be prepared this way without bringing adhesives or special cements to the base.

12.1 Spaceport in Phobos:

Generally, spaceport is the site which is capable of launching spacecraft to the orbit of earth. But in this case the term earth cannot be used as the spaceport is in the Stickney crater of Martian satellite Phobos. As already discussed in the assembly of base about the development of launch pad, it is not necessary to discuss about its development again. The launch pad should have a capacity to launch ascent and descent vehicles to the Martian atmosphere. Generally the interplanetary transfer vehicle is not taken to the Phobos surface, so the launch pad does not need to be stronger enough to hold this vehicle along with ascent and descent vehicles. Similarly, the launch pads do not need to hold the force during takeoff from the Phobos surface as its gravity is too weak to attract the vehicle. The launch pad is supported by its legs totally merged inside the ground that helps in distributing the stress developed in it during any vehicle ascent. The other important function of this spaceport is that it should provide the facilities of refueling the vehicles prior to the landing of Mars. The long term mission is to make this port as the refueling station for the further exploration of the solar system.

12.2 Rovers for EVA's:

It is a space exploration vehicle which is designed to move across the surface of planet or other celestial body. In our Phobos base a rover is used to move across the surface to move crew members, collect dust, rocks and modules. The rover may weight 185 kg (408 lb) and total cost up to $820 million dollar. There were two rovers Spirit and Opportunity used by NASA’s Mars exploration mission. Spirit was active until 2010 and Opportunity is active as of May 8, 2017. So in our mission Opportunity rover can be used.

Opportunity rover is six wheeled robot of height 1.5 m, 2.5 m wide, and 1.6 m long. Six wheels enable mobility and each wheel has its own motor. Its average speed is 0.89 centimeters per second. The solar power on the rover generates the power up to 140 watts per Martian day and rechargeable lithium battery for night.

The rover has an X band low gain and an X band high gain antenna for telecommunications with earth. It also has cameras like Panoramic Camera (Pan cam), Navigation Camera (Navcam) and Hazcams for images up to 1024 by 1024 pixels, magnets, Spectrometers Microscopic imager, and Rock Abrasion Tool (RAT).

Similarly other robots that would assist these crews would likely include the 176-pound (80-kilogram) K10 scouting rover, along with the All-Terrain, Hex-Limbed, Extra-Terrestrial Explorer (ATHLETE)- a six-legged, heavy-lift cargo carrier. The Space Exploration Vehicle (SEV), an updated version of Apollo's old "moon buggy," would also be sent to the Phobos surface. Astronauts would drive around in SEVs, which are pressurized with air, meaning they can sit inside them without wearing their bulky space suits. The SEV has pivoting wheels, allowing it to move sideways as well as forward and backward. The SEV is protected from radiation by thick shielding. The operation all these rovers are performed through tethering mechanism along with drilling mechanism for the rovers too as we have already discussed about the convenient force of Mars acting on the Phobos surface.

12.3 Repair and Maintenance Workshop:

During the operation of PBM, on the time being system failures and other minor problems are bound to come, sometimes in an unexpected way. So, the maintenance must be done as quick as possible for the safety of the crew and the sound implementation of the mission program. The crew consists of people from various fields. Although all the astronauts are made familiar with the use and repair of simple problem issues, it consist a person capable of handling such issues, such as maintenance and repair, inspection and control of the system.

The issues that are more probable to occur are the OGS failure, minor leakage, waste accumulation, venting of gas, computer failure, cooling system failure etc. Thus for overcoming all such problems, there is a provision of a workshop. The workshop consists of the tool equipments that are essential for repairing the issues. It also includes the extra part to replace in case of the total damage of the part of PBM. Although some maintenance issues must be solved on the site of occurrence, some parts that can be disassembled from the system and portable are brought to the workshop for the maintenance. The leakage of air in the base can be traced by using an ultrasonic probe. The issue with the OGS failure is likely to be caused due to the formation of the gas bubbles in the unit cell. Sometimes, fumes from the oxygen generators may trigger a momentary fear about a possible fire. In such cases, the ventilation system must be shut down in order to prevent the spread of the some or contaminants to the rest of the module. So, the workshop must contain the spare parts to repair such issues.

The Computer failure provides the main threat to the crew onboard. The whole system operation is maintained by the computer. Sometimes, in an unknown and unexpected way these threats like failure and malfunction of the computer may occur. So, on realizing this threat, PBM uses two main computer systems, one for the normal operation and the other for the backup. When the main computer malfunctions, the backup is operated and the main one shuts down until the repairmen takes place. Thus, after the failure of the computer system, it is shut down and then the maintenance program initiates. The crew allocated to perform such maintenance task does the rest of the work. The problem is identified and if possible it is repaired else is replaced with the new ones.

The radiator failure that may occur due to the damaged cooling panel requires in situ repair or replacement in order to prevent the potential leakage to the External Thermal system (ETCS) of the station, possibly leading to the unacceptable loss of the ammonia coolant. The most occurring problem issue is the leakage in different sites of the base modules. Other likely problems come around from the failure of the Carbon dioxide removal assembly. Thus, in general a lot of system failures and maintenance issues are bound to occur in a completely unexpected way. Some may not be a great threat and could be repaired with time but, some other may be a life threatening and should be instantly repaired or replaced. As the mission occurs very far from the home Earth, the provision of supply of the spare parts is not possible and if possible takes a long time before another launch window arrives and that is quite a long time. Thus, provisions must be made to take the spare parts in the same launch programs as well as the maintenance specialists because nothing is more important than the safety of the human crew.

Technological advancements have lead to the invention of more reliable and efficient equipments and made the repair and maintenance easier with the evolution in the robotic sectors. The future promises us that in the days to come the robots will be performing these maintenance tasks that pose a great risk to the human. Thus, with the realization of these facts and problems, PBM will have a large workshop to fulfill all the needs and tackle all the immediate threats. It also will board an astronaut for performing such activities. He/she will be given the responsibility to inspect the system performance, identify the failures and replace it safe and sound before it produces a deadly scene.

13. Optional concepts:

We have proposed to use the concept of electromagnets in the central hub to hold the base along with the possibility of using thermo nuclear reactor for the source of energy. Similarly, the circular cages that cover the modules and used for the tethering for extra-vehicular activities are also explained here.

13.1 Electromagnets:

From the calculation we were acknowledged that gravitational force exerted by a Mars on our module is far greater than by Phobos at average distance of 9Km i.e. site location of module at Stickney crater from the center of Phobos. It is observed that (gravitational force exerted by Mars (F_m) on a single module is 14663N where as at same module force exerted by Phobos (F_p) is 263N. Since Phobos rotates in its own axis, Stickney crater faces most of its rotational time away from the Mars. But for 1/4th period of time it would face towards Mars as shown in figure in next page.

During the period of time when crater faces away from Mars, the friction force that module acts on the Phobos surface makes the module stay on the Phobos surface. When the crater is facing in opposite direction to the Mars surface the module would be more stable. From the observation we made an assumption that friction force would be less to hold the gravitational force of Mars for about 40^0 as it faces Mars surface. From the calculation we observed that Phobos takes approximately 22 minutes to cross 40^0 of displacement. During this period of time our base is highly vulnerable to detach from the crater. To counter measure this problem we planned to use an electromagnet as an optional equipment to hold the base on the crater as electromagnet has been proved as good measure to lift the heavy equipments. Experimental results had shown that small magnet can levitate the large mass of body. Here we prefer to use electromagnet as good optional measure to encounter the gravitational force of attraction acting on the base module. Pulling Force exerted by electromagnet on object is given by

$$F_{pull} = (n \times I)^2 \quad \frac{A}{(2g)^2}$$

Where, F_{pull}=force exerted by electromagnet on object,

n= Number of turns,

μ= permeability of free space

I= current flowing through the wire

A= area in m^2.

g= gap that is separating electromagnet and the object.

Using above formula, we consider gravitational force F_m i.e. 14663N act on each base module by Mars as the required amount of force to be exerted by electromagnet on base acting in opposite direction to $F_{m.}$ The resultant force of these two gravitational and magnetic force becomes zero, which results in the stability of the base module. From above formulae we put different available values of F_{pull}, μ and we assumed the value of g, n, A to determine the suitable value if current supply required to produce the required amount of field force

Where, F_{pull} = 14663N,

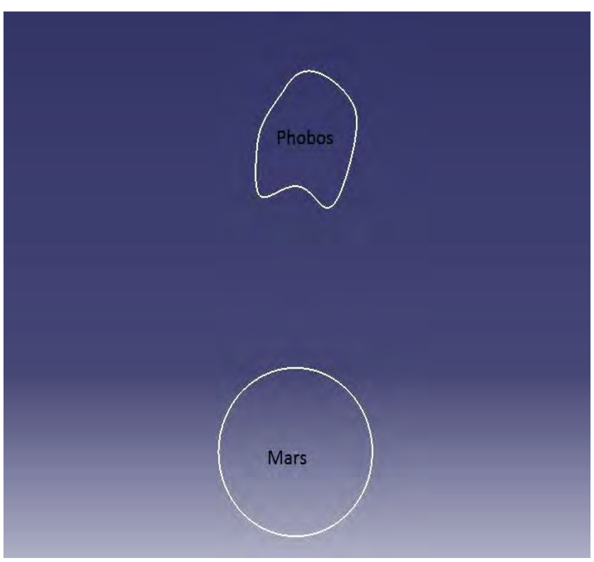
$\mu = 4 \ \times 10^{-7} NA^{-2}$

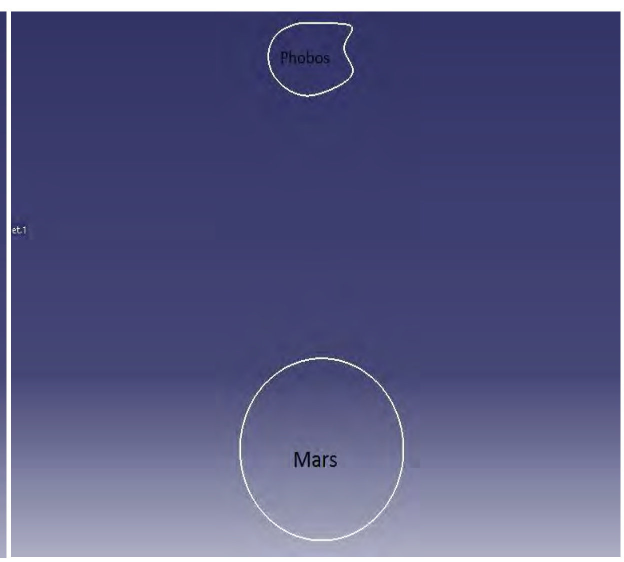
n=10000 turns,

A=100m^{2,}

g=2m,

we calculate I= 4.2899A which is the required amount of current need to be supplied for approximately 22 minute to overcome the gravitational pull force of Mars while crater facing towards the it,19.07928 Megawatts amount of energy is preferred.





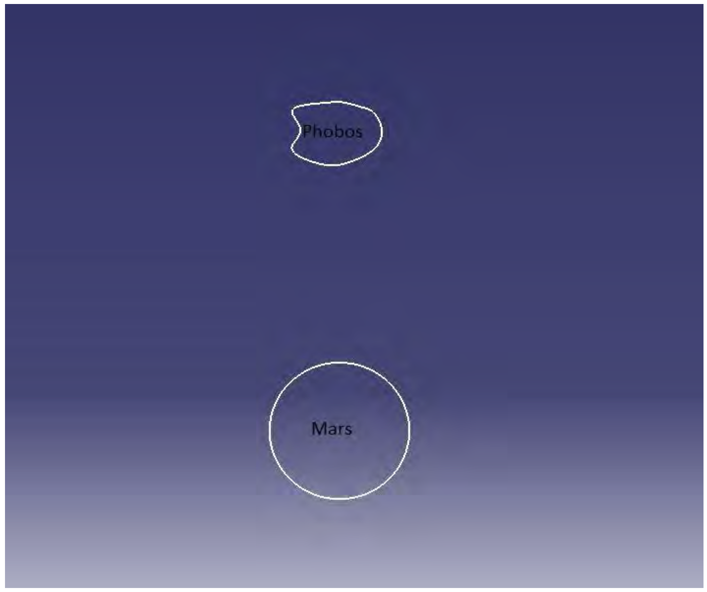


Fig 31: Alignment of Phobos respective to Mars due to its rotation along its axis

13.2 Optional Energy Sources:

Radioisotope thermoelectric generators:

Solar energy is the common and main source of energy in almost every space mission till date. The importance of such mission can be illustrated by Rosetta mission that landed Philae probe on comet 67P/Churyumov-Gerasimenko in 2014.Euqipped with batteries and solar panel, the position in which Philae came to rest on comet's surface-shielded from Sun's ray cliff. So, the Lander was unable to make use of solar energy and was able to send data for only about 64 hours till batteries last.

Such cases of being fully depended on solar energy might cause failure to the mission or might not be able to produce required amount of energy to run the base. It has been estimated that 44% of solar energy that reaches earth surface reaches the Martian surface that has a thin atmosphere. From this data we can conclude that 40-45 percentile of solar energy that reaches earth's surface reaches Phobos. To fulfill the base energy requirements, large number of solar panels is required. Considering this it will increase the cost of the mission and payload of the system.

The latest plutonium-powered RTG is a 290-watt system knows as the General Purpose Heat Source (GPHS) RTG. Each GPHS contains four iridium-clad ceramic Pu-238 fuel pellets, weighs 1.44 kg. Multiple number of GPHS can be use to meet the required amount of energy. A total of 4.8 kg of plutonium oxide produces 2kW thermal power which can be used to generate about 110 watts of electric power, 2.7 kWh/day. So, as per the energy necessity of the base module apart from the energy provided by solar energy, nuclear energy can be used as a main supplement.

Though nuclear reactor can be used as vital source of energy, leakage of it might cause disaster in the space. To avoid probability of leakage different coolant and water circulation should be used. Closed loop water circulation can also be used to heat the module, as the temperature drops to minus in Phobos.

Reactor must be placed aside from the base architecture as it might easily kill the astronauts due to immense radiation it produces when the nuclear elements break.

13.3 Ring Cage Support System:

As we have already discussed about the use of ring cage support made of metallic iron to help extra-vehicular activities and join the base modules using under the influence of magnetic force.

Rings are shown in the base architecture (10cm×10cm×10cm) assembly surrounding every module. Every ring cage support are jointly connected by a flanges(10m×10cm×10cm) at modules staring end, where as they are stretched and interconnected with each other by mother ring cage at Sphere module as shown in figure. These cages are closely compact as like as cylinder while they are in space. As module enters the orbit of the Phobos they get detached automatically. These rings are connected by two straight flanges as shown in figure. Some of the portion of these rings are under the surface of the crater and also helps in digging. Friction force between ring and surface would provide rigid position to the module; they won't slide due variable gravitational force acting on the module due to its rotation along its axis. Astronauts can tether on these rings to move on the outer surrounding environment of the crater.

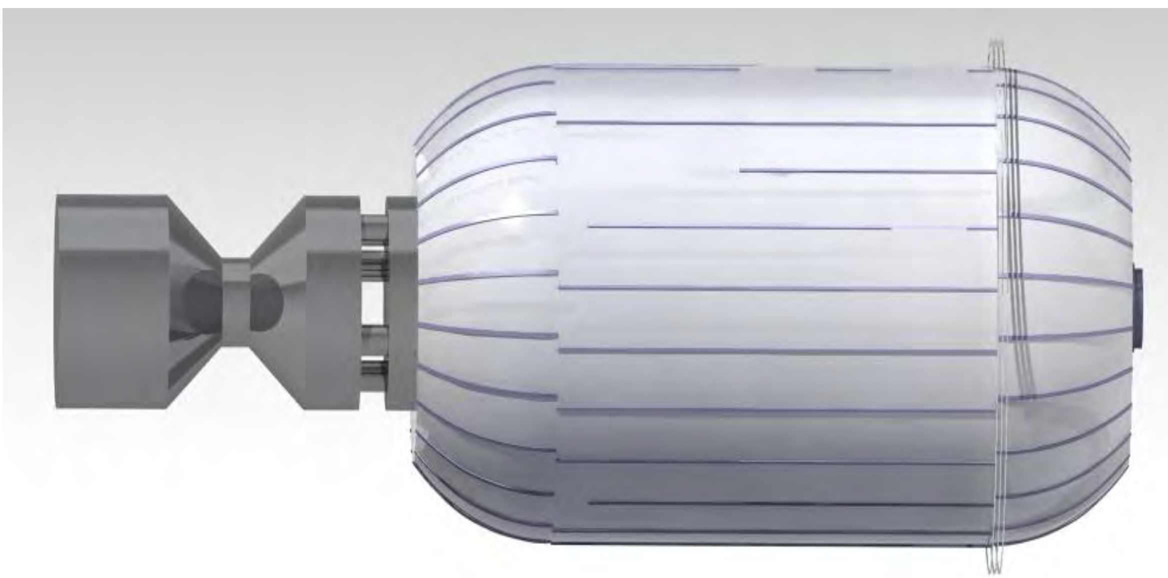


Fig 32: Module at orbit of Phobos showing detached rings

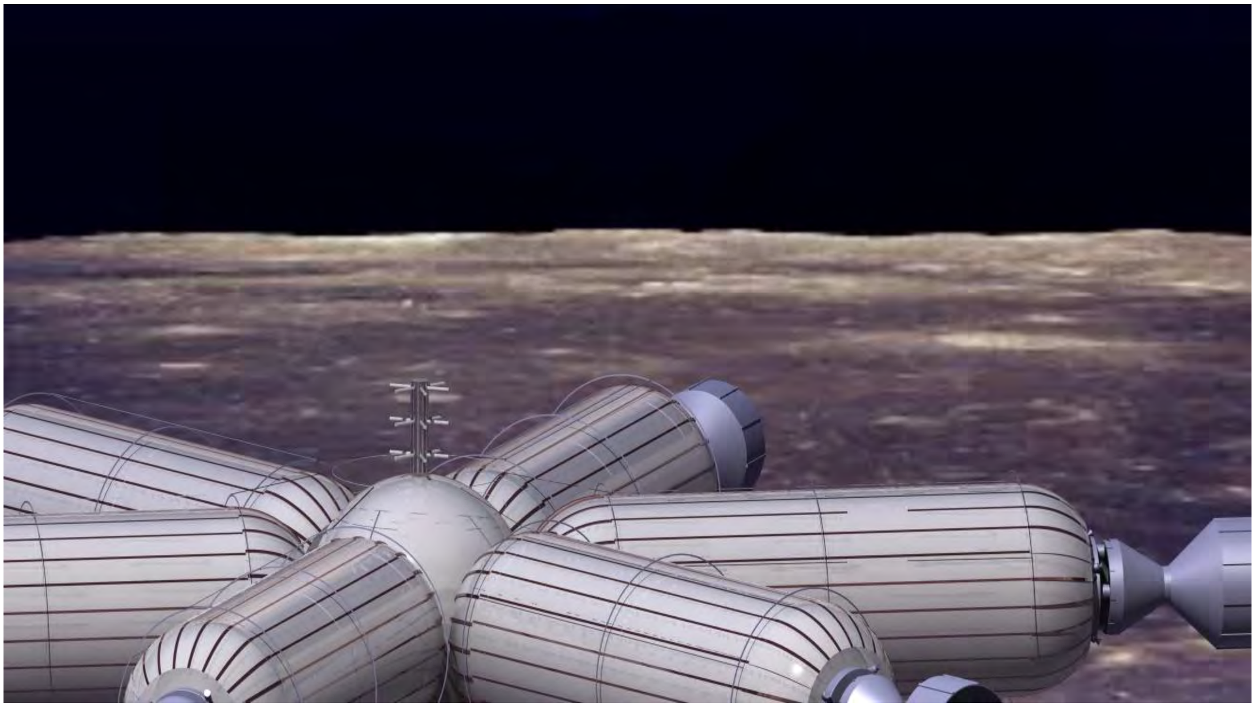


Fig 33: Base assembly architecture showing adjoint rings.

13.4 Microwave Beam:

Microwave beam can be used to extract water lying underneath the surface of the Mars. This method required no digging and could be more efficient. Phobos is believed to contain water by 13 % mass. The microwave beam is used to cook the rock regolith and soil on the surface of Phobos. The heat then vaporizes the frozen water which is then collected and condensed on a chilled plate.

The research shows that if the regolith can be warmed from a minus 150 degrees Celsius to minus 50 degrees, the vapor pressure of the water mixed in with the regolith particles is much higher than the Atmospheric pressure of the surrounding environment. Then the vacuum environment of the Phobos percolates the water vapor to the surface through the regolith particles. The water vapor then collects on a cold (below minus 50^{o}C) plate where it forms as ice and is scraped off for human consumption or it can also be converted to hydrogen and oxygen by electrolysis so as to be used as a fuel or oxidizer that can be used for further space travel.

`The use of 10 KW devices can speed the process of collecting water and make it more effective method. The microwave process can penetrate into the surface at least two meters deep thus eliminating the need to dig into the surface to get ice. Water absorbs microwaves (short electromagnetic waves) very well, but ice doesn't, so the microwave beams actually heat up the rock, which heats the ice upon contact. Thus, the utilization of the in-situ resources can prove to be huge step towards the outer space exploration and future manned mission.

14. Technology Readiness Level:

The technology readiness level has to be specified for every systems and technologies that are supposed to be used for the construction of base in Phobos surface. The Space Launch Station (SLS) rocket has a TRL of 7 as its systems and sub-systems are still in the phase of development. The inflatable module also has a TRL level of 7. The HBNN's proposed to use for the radiation protection has a TRL level of 3. The thermo nuclear reactor that was proposed to be used has a TRL level of 7. The use of microwave oven has a TRL level of 8 as it has been tested and demonstrated in earth. The air and water revitalization system along with the astrobiology lab of bio-isolation level 4 have TRL of 9 as they are already demonstrated and used. Whereas, the virtual reality that for the Mars Observation Station has technology readiness level of 7. The methodology of farming crops in many shelves is not practiced yet. So, its TRL is 4. Waste management systems have a TRL of 9 along with the suits used to counter microgravity.

15. Risk and their Mitigation:

. Effective project on space transportation depends on the concepts of risk management. The risks on the projects are:

1) Safety
2) Technical
3) Cost
4) Schedule

NASA's motto of "Faster, Better, Cheaper" projects is for the systematic management to reduce risks. FMEA, FTA, PRA are different techniques for analysis of the risk in the projects.

15.1 Risks to Human:

The risk undertaken by the Human crew must be considered vital component for the space mission and must be minimized to the point possible. The risk is generally benign once the launch is successful. Then the human crew will encounter the in-space environment, active space environment and the planetary surface environment.

The human crew must go through various energetic events so that the risk is relatively high. The fatal accidents generally occur at the time of launch or landing. The consequences encountered in the deep-space environment are relatively low from the point of view of explosions and other spacecraft accidents. However, there are important and potentially deadly environmental hazards (such as radiation and meteoroid damage) which must be addressed. Two radiation hazards exist. First and most dangerous is the probability of a solar proton event (SPE). However, shielding with modest amounts of protective material can alleviate this problem.

15.2 Risk to Mission success:

The risk of the mission success is measured by the degree to which the objective is accomplished. The objective of the mission can be accomplished with the successful implementations of plans from both the human as well as system side. The risk related to human side includes the health, safety and performance of the human crew whereas the risk related to system side includes the successful operation of the system, programs with the continuous communication as well as the transfer of the information needed. For the success of the mission, the human crew must be able to perform well and sound and the system has low failure rates, have robust backups for the parts that may fail or require repair.

15.3 Risk of Micrometeoroid Penetration:

The base modules in the Phobos surface may incur with high velocity micrometeoroid that may cause damage to our modules. Sometimes the micrometeoroid may penetrate the layers of the inflatable modules that results in destruction of our habitat. Although the layers are highly resistant to hypervelocity impacts the case is not the same every time. So, there has to be some ways to mitigate those hazards.

The leakage of air from a single module may not puncture all other modules. It is possible as the docking ports in the central hub are provided with other port along the docking axis that closes when the leakage of air from any modules is recognized. This type of mechanism is provided in the cylinders of docking modules too. The temporary repairing of the penetrated modules can be done using the 3D printing concept of "Space Fabrics" initiated by NASA. This concept was started to protect the spacecraft and astronauts from meteoroids. The space fabrics have four essential functions: reflectivity, passive heat management, fold ability and tensile strength. One side of the fabric reflects light, while the other absorbs it, acting as a means of thermal control.

Conclusion:

This mission hovers around the designation and proper architecture to make the base on the Stickney crater on Phobos that is habitable and be able to sustain 12 people at maximum. In this mission, the habitable PBM is designated with the proper constraints as per mentioned in RFP and is transferred to the site in the available launch window between 2018 and 2026. In this mission, the primary focus was given for the safety of the human habitat and then the cost was considered and optimized to the limit such that it won't risk the human life.

The total budget was estimated by comparing with the past missions to the Mars by NASA. Multiple launches were a compulsion as the maximum payload that can be delivered by a single launch couldn't bear the total mass of the desired PBM designation. Furthermore, the multiple launches minimize the overall risk as a single launch is relatively riskier than the multiple launch. This space design was able to achieve a habitable base on Phobos which is vital for the future mars exploration as it provides the gateway to Mars with the research team being able to explore Mars and return back to base safely and research the data's collected during the exploration. The base module consists of every components and facilities required for the human to stay as well as carry out research and experiments within the module itself rather than sending back the samples to Earth. This brings the opportunity to study the soil components that may prove vital to know the history of the red planet as well as for the resource utilization. The module having experimental labs has the capability to conduct experiments thus reducing the cost which otherwise have to be sent back to earth.

The overall mission was planned to cover the aspects as demanded by the RFP. Yet, there are several constraints in which the mission plan seems to be weak. It was due to interlinks and connection in between the constraints due to which optimization of one resulted in the impairment of other. Thus, the plan was conducted with the optimization of constraints with relatively higher value. Although provisions are made and discussed still this mission plan is unable to explore the resources underlying the surface of Phobos. The utilization of the in-situ resource by the base is not done to the extent demanded by RFP.

The development and evolution of the technologies is going in a pace due to the healthy competitions between different countries to be the pioneer in the deep space manned mission. The technologies have really seen lots of improvements in past decades and promises to keep on surprising with new inventions that make the mission more efficient and reliable. Our mission of making base stands as the pioneer in the deep space base settlement with the first ever manned mission to mars. Thus, a lot of drawbacks are bound to occur as per the lack of the information, knowledge and experience with these concepts. This base design may prove to be the foundation for the advancement of the base habitat that offers more facilities, is more comfortable for crews and is capable of conducting more research and experiments as well as capable of generating more energy and utilizing in situ resources. This base design can hold maximum of 12 crew members consists of different compartments in each module for specific tasks.

After the establishment of the PBM, it proves to be a huge step towards the exploration of mars to the depth. Till date, only robotic rovers have been sent down to the surface of the red planet. And only few portions of the Martian surface are scratched. With the base on Phobos, the crew can visit the surface of the mars, make research and return back to the base. There they can perform different experiments and so sending back of samples to the earth is not necessary. Further, the robotic rovers are only capable of performing simple experiments that doesn't provide the reliable information about the surface of the Mars. The robotic rovers are very slow in actions and require the inspection and permission from the earth for taking each decision which delay the process. Also, due to the lack of self-judgment when stuck on its way may sometimes lead to the end of the mission. On the other hand, crewed mars program can bring in a lot of important information and unwrap the surface and its resources. Thus, the discovery of the mars surface, the resources beneath the surface and extraction can be considered to be a success with the establishment of Phobos base.

In the future, we are hopeful that the evolution in the technology will make the working of the human crew much safer with the use of much advanced robots. These robots will perform task that are risky to the human crew. The mission stresses on the minimization of the human risk. Thus, the future promises with the development of new advanced robots capable of making quick judgments, are fast, reliable and logical. For the future research, we expect the extraction of resources, in-situ water extraction that can sustain the crew life as well as the production of food on the base. Also, the extraction of fuel believed to lie under the Martian surface can be considered a big step towards the future deep space exploration. This could provide a fuel resupply for the further deep space missions back and forth Earth. Thus, there is a vast space to explore in our own solar system and learn the history of its formation and this base establishment on Phobos will provide a link between our home Earth and outer space exploration.

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