Phobos Base Design

UVM AIAA
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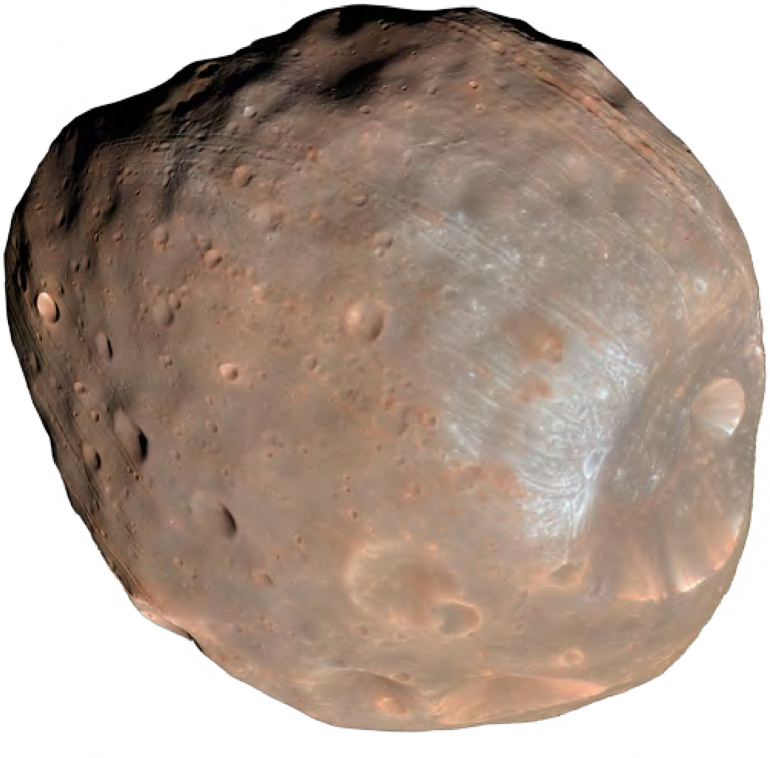
Moritz Thali, Cam Ruffle-Deignan, Duncan Hacker, Sami Connoley

April 2017



Contents

Nomenclature

σ = Boltzman Constant (W/m^2k^4)

η = Efficiency

ϵ = Radiation Emissivity (W/m^2K)

μ = Standard Gravitational Parameter

ν =True Anomaly ($degrees$)

ΔV = Change in Velocity (m/s)

A = Area (m^2)

D = Distance from Suns Surface (m)

H = Hydrogen

O = Oxygen

P = Power (W)

Q = Heat (J)

a = Orbital semi-major axis (km)

Abbreviations & Acronyms

HEO = Highly Elliptical Orbit

ISS = International Space Station

LEO = Low Earth Orbit

SLS = Space Launch System

Subscripts

I_{sp} = Specific Impulse (s)

Q_r = Heat due to Radiation (J)

R_{sun} = Radius of the Sun (m)

T_{sun} = Sun Surface Temperature (^oK)

g_0 = Gravitational Constant (m/s^2)

r_0 = Initial orbital position (km)

1 Abstract

The main focus of space exploration for a multitude of companies and government agencies has become the human landing and colonization of Mars. In order to get to this point many technologies and strategies must first be tested. The ideal testing grounds with the most benefits for such technologies and missions would be the moon of Mars Phobos. This paper will discuss an ideal base design for a test bed to permanent habitat for twelve or more humans. The interplanetary transfer is addressed utilizing three SLS launches and one Falcon 9 launch, as well as the proposed nuclear thermal interplanetary spacecraft on multiple Hohmann transfers. The base is constructed with a conservative amount of modules but results in a large amount of volume. The future Bigelow "Olympus" inflatable spacecraft was chosen as the main habitat, while a custom tower will be constructed to house the majority of scientific laboratories and workshops. A spaceport is utilized at a specified distance away from the base with a tethering system to curb the complication of human transport on Phobos. RECLSS and the life science countermeasures are cared for with similar methods as the ISS, with the exception of a various future technologies, such as methane harvesting, fungus farms, GLCS suits, and hyper hydrogenated BNNT's. Arrival of crew and safety strategies are briefly discussed and the utilization of regolith for 3D printing is proposed.

2 Introduction

Humans have not been outside of LEO in over forty years. Space exploration has been speeding back up to reach past this point once again, but instead it it's reaching even further. This time it is to Mars. This has become the primary focus of many government agencies and private companies, but is a lofty goal. there are many methods and ideas but none have been tried and tested yet. We at the University of Vermont have taken on the task to simplify this process and get us on the path to the Red Planet. One of the best ways to simplify this is to land and set up a base on one of the two moons of Mars, Phobos. Throughout this paper, a trajectory, design, and assembly process was analyzed to find the ideal scenario that will get a twelve person base on Phobos. This will aid humanity and reaching further limits, testing new technology, and setting up grounds to simplify the study and exploration of Mars

3 Requirements Analysis

For organizational purposes necessary analyses for each requirement can be found within the appropriate section or subsection.

4 Concept Key Features

4.1 Timeline

Table 1: Mission Timeline.

Date	Event
October 2023	SLS block 2 launch for the Observatory Tower, Module Joint, Space Port Pad (batch 1).
September 2024	Connect to Mars Transport System.
October 2024	Launch Window - Send batch 1.
November 2024	SLS block 2 launch with the Bigelow Olympus and anchors immediately after first launch.
January 2025	Inflation of Olympus over time begins.
June 2025	Batch 1 enters Martian orbit, lands on Phobos within 12 hours.
January 2026	Inflation of Olympus completed.
February 2026	Falcon 9 with 2-3 Astronauts in Dragon capsule to dock with Olympus and check all systems.
March 2026	Astronauts deport from Olympus.
October 2026	Attach Olympus to Interplanetary travel.
November 2026	Launch Window - Interplanetary travel system begins transports Olympus to Phobos.
July 2027	Olympus enters Martian orbit, lands on Phobos within 12 hours.
November 2027	Olympus docks with Module Joint and logistics are checked before officially sending astronauts.
January 2029	First 6 astronauts are sent on Orion capsule from SLS.
September 2029	First six astronauts enters Martian orbit, lands on Phobos within 12 hours.
February 2031	First launch window for next 6-man crew and rover.
February 2033	Second launch window for next 6-man crew and rover.

5 Interplanetary Transfer

5.1 Earth Departure

In order to eject all necessities from Earth's surface into low Earth orbit (LEO), the Space Launch System (SLS) will be utilized. The powerful multi-stage rocket will transport supplies and base modules on multiple launches because the sum of all the mass would be too heavy to reach Earth's escape velocity, 11.2 kilometers per second, in one go.

The Block 2 configuration will be capable of carrying 130,000 kilogram[11] supply payloads into LEO. All of the supplies needed for initial automated setup of the a base would be in the first two launches. Launch One would contain a spaceport launch pad. a scientific observatory tower, and a joint for connecting various modules. Launch Two, using another SLS, will deliver an inflatable habitat that will be described in more detail later in the report.

Launch Three will use a Space X Falcon 9 to deliver the first six astronauts to LEO. They will rendezvous with an interplanetary spacecraft that will transport them to the mars system.

5.2 From Earth to Mars System

5.2.1 Earth Departure

Once in Low-Earth Orbit (LEO), the craft will begin in a highly elliptical orbit (HEO) about Earth and remain there for roughly five days. This initial period allows for rendezvous of the craft with other orbiting launch vehicles readying for departure as well as rendezvous with the space station for exchange of supplies and/or personnel.

The initial orbital track is shown in Figure 1.

During the waiting period, the orbit will precess due mainly to the oblateness of the Earth. This oblateness is due to the rotation of the Earth about its axis which creates a roughly 40 km bulge at the equator. This effect is typically described by a correction to the equations of motion for the system—coined the J_2 correction. Accounting for this correction requires altering the acceleration term as follows for each of the Cartesian $\{x,\ y,\ z\}$ components:

$$a_{J_2} = \frac{3\left(J_2 \mu_e r_e^2\right)}{2\left\|\vec{r}\right\|^5} \left\{ \begin{array}{c} x(t)\left(\frac{5z(t)^2}{\|\vec{r}\|^2} - 1\right) \\ y(t)\left(\frac{5z(t)^2}{\|\vec{r}\|^2} - 1\right) \\ z(t)\left(\frac{5z(t)^2}{\|\vec{r}\|^2} - 3\right) \end{array} \right\}$$

Plotting the orbital precession over the five day period before departure from LEO results in Figure 2. While the orbit semi-major axis decays over this period, this is not alarming. The craft remains outside the area of appreciable atmospheric drag. It is important to note that the location of perigee is not affected by the oblateness correction—it is also true then that the departure location remains unchanged, though the velocity at this point *will*

Figure 1: Initial steady state elliptical Earth orbit.

be altered. Examining the departure from the sphere of influence of Earth requires some premeditation first.

In order to minimize the energy profile of the flight from Earth to Mars (E2M), a simple Hohmann transfer was chosen in order to simplify analysis. It is necessary that both Mars and Earth be in phase at the time of departure; were this not the case it would be possible to arrive at the destination too early or late for Martian rendezvous.

Assuming that departure occurs while the planets are in phase, the time-of-flight between Earth and Mars can be determined from the equation for the period of an ellipse. Noting that the Hohmann transfer is just a half-ellipse, the time of flight can be determined from Equation (1).

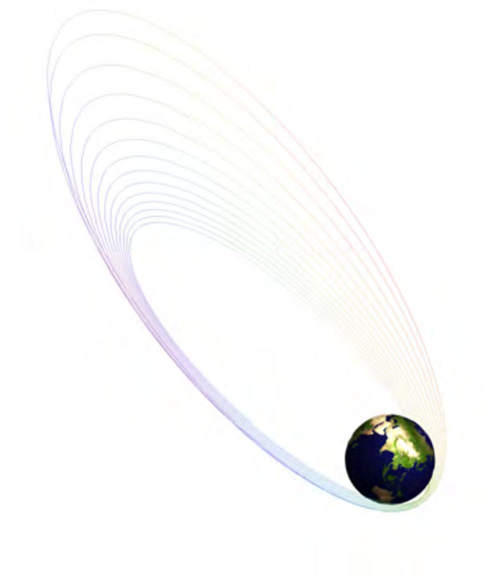


Figure 2: Precession of the elliptical Earth orbit due to the a_{J_2} oblateness correction.

$$t_f = \frac{T}{2} = \frac{\pi a^{3/2}}{\sqrt{\mu}} \tag{1}$$

The minimum time of flight is then solved by substituting the distance between Mars and Earth for a; this yields a value $t_f = 258.82$ days. This time represents a minimum energy transfer approach from E2M. In order to depart Earth the spacecraft must experience some ΔV at perigee in the parking orbit. This ΔV value is determined from the required hyperbolic excess speed and the location of perigee, the resultant equation is given in (2).

$$v_\infty = \left(\sqrt{\frac{\mu_s}{\|r_e\|}}\right)\left(\sqrt{\frac{2\|r_m\|}{\|r_e\| + \|r_m\|}} - 1\right) \tag{2}$$

By taking the difference between the hyperbolic excess speed at departure and the elliptical velocity at perigee, the difference represents the required ΔV for departure from Earth Orbit. Resolving this value yields a result of $\Delta V = 7.26886 km/s$. The anticipated departure trajectory is plotted in Figure (3).

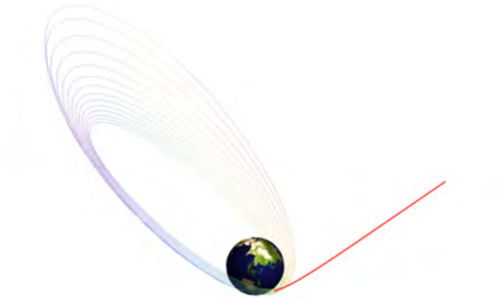


Figure 3: Departure trajectory from Earth following precession.

5.2.2 Earth to Mars Transfer

Following departure from Earth, the spacecraft will enter a Hohmann transfer to Mars; this is a simple half ellipse trajectory from E2M. As such, the speed at both locations is readily calculated by way of Equation (3). Velocity as arrival and departure can be resolved by inserting the appropriate radial distance to Earth and Mars.

$$v_h = \frac{h_h}{\|r\|} \tag{3}$$

In order to enter the Hohmann transfer an impulse of $\Delta V_D = 2.592 km/s$, and for arrival conditions an impulse of $\Delta V_A = 2.36312 km/s$. The total impulse requirements for the Hohmann transfer is then $\Delta V_{tot} = 4.95512 km/s$. The trajectory for a Hohmann transfer is depicted in Figure 4.

Examining Table 2, tallying the transfer and wait times for various trajectories, the travel times can be deduced. For example, the wait time between launch opportunities departing from Earth is 2.13 years, while at Mars this time is only 453.8 days. Additionally, the trip from Earth to Mars utilizing a Hohmann transfer is determined to be 258.8 days; combining values shows that the minimum time for a a manned mission (with return trip) to the Martian sphere of influence will be given by the sum of two transfers and a Martian wait period yielding 2.66 years of travel time.

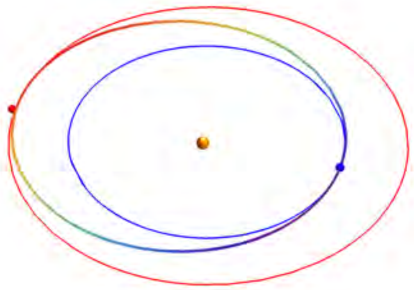


Figure 4: Hohmann transfer from Earth to Mars in elliptical trajectory.

Table 2: Transfer times for E2M missions.

Hohmann Transfer	258.8 days
Earth Departure Phase Wait	2.13 years
Mars Departure Phase Wait	453.8 days
Full Manned Mission w/ Return Trip	2.66 years

5.2.3 Interplanetary Spacecraft

Before departure for Phobos, while in the elliptical parking orbit about Earth, rendezvous and transfer with a Martian-departure spacecraft will occur—transporting mass from LEO to Phobos requires a separate vehicle than the SLS. Instead of using chemical propellants, a spacecraft assembled in LEO will utilize three nuclear thermal propulsion to boost payloads to the Martian moon. The transportation vehicle would not land; it would not be designed to. Instead, a lander with supplies would be ejected to touch down on the surface. The transportation spacecraft, utilizing nuclear power, could have a specific impulse of 900 seconds by superheating hydrogen and ejecting it out a converging-diverging nozzle much like chemical rockets. To reach the necessary ΔV required to go from Earth to Mars, the Rocket Equation can be used represented by Equation (4).

$$MR = exp\left(-\frac{\Delta V}{(I_{sp})(g_0)}\right) \tag{4}$$

$$MR = exp\left(-\frac{7268.86}{(900)(9.81)}\right) = .439$$

The mass ratio, MR, necessary with these engines to get to Mars is 0.439 meaning the final mass, after reaching an orbit around Mars would be 43% of that when it left LEO.

5.3 Approach to Phobos

Upon arrival at Mars, the capture orbit will be elliptical, with an eccentricity of $e = 3.22$. In order to perform a fuel efficient Hohmann transfer an orbital shaping maneuver will be performed at periapsis to being the craft into a circular parking orbit at an altitude of 2500 kilometers. This will require an impulse that imparts $\Delta V = 0.403464$ km/s. Figure 5 depicts the elliptical capture orbit in gray, the parking orbit in green, and the point at which the impulse is applied (black dot).

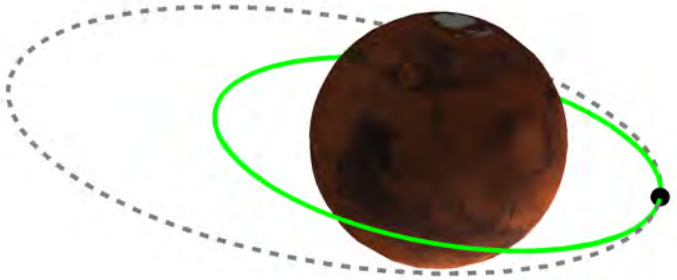


Figure 5: The initial capture orbit (dashed gray) and parking orbit of craft (green).

Once the spacecraft is in its parking orbit the cargo or crew capsule will detach from the interplanetary craft and perform a Hohmann transfer to reach the same orbital altitude as Phobos (5989 km). In order to do this, the capsule's on board propulsion system will first apply a ΔV of 0.259956 km/s. The resulting elliptical trajectory will have a period of 5.6258 hours. After traveling half of this period ($t_f = 2.8129$ hours from Equation1) the capsule will undergo another ΔV maneuver to enter a circular orbit at an altitude matching that of Phobos. The entire Hohmann Transfer will require $\Delta V = 0.552202$ km/s. The Hohmann trajectory can be seen in Figure 6.

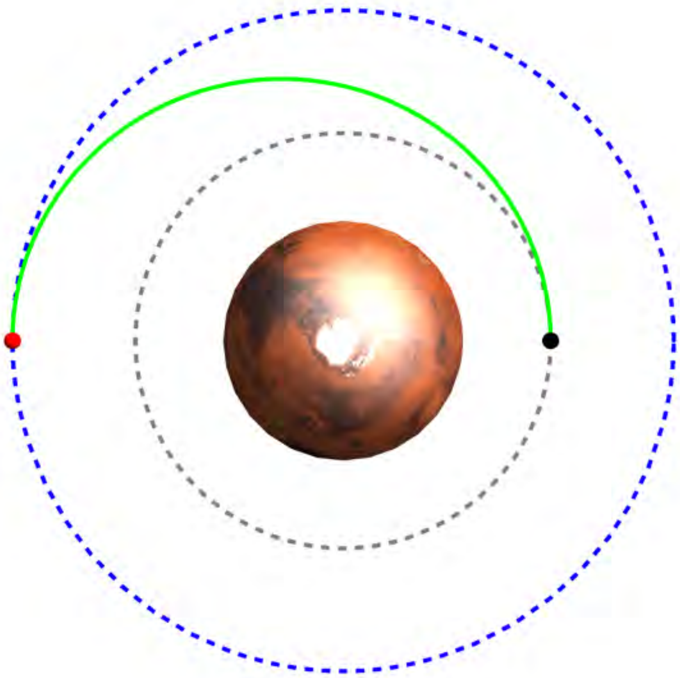


Figure 6: Hohmann Transfer trajectory (green) from the Martian parking orbit (dashed gray) to Phobos' orbital altitude (dashed blue)

The Hohmann transfer will be executed at a prescribed time that results in the craft being ahead of Phobos by 20° in terms of true anomaly. It will remain in this orbit for 2 hours for ground control to communicate with the craft and confirm its exact position relative to Phobos to adjust the final maneuver for a gentle approach to Phobos. While it would be possible to directly rendezvous with Phobos during the Hohmann transfer, the chosen method allows for a more controlled delivery with less room for error.

In order to compensate for the angular discrepancy between the capsule and Phobos the craft will perform a phasing maneuver. In orbital mechanics it is well understood that satellites orbit slower when they are further from the central body. The capsule will take advantage of this fact to adjust its trajectory and approach Phobos. By firing an impulse normal to the orbit, away from Mars, the craft will experience a ΔV of 0.0374974 km/s and enter a slightly elliptical orbit with a larger semi major axis than Phobos' orbit. While in this orbit, the spacecraft will travel with a slower angular velocity allowing Phobos to approach from behind.

After 8.08592 hours Phobos and the craft will have the same true anomaly. This time of flight is calculated from Equation 5 where $r0$ is initial position and ν_1 and $\nu 2$ are the true anomalies in degreed of Phobos and the craft respectively. At this point the craft will again make a ΔV maneuver of 0.0374974 km/s, this time back towards Mars. The gravity of Phobos will begin to act on the craft and draw it in. As the capsule is slowly being accelerated towards Phobos it will use attitude control nozzles to control speed and guide itself to the appropriate landing location. The total ΔV requirements for the entire process from Mars capture to Phobos rendezvous are outlined in Table 3.

$$t_{phase} = 2\pi\sqrt{\frac{r0^3}{\mu}}[1 + (\frac{\nu 2 - \nu 1}{360})] \tag{5}$$

Table 3: ΔV requirements from Mars capture to Phobos rendezvous.

Maneuver	ΔV **Required**
Elliptical to Parking Orbit (Shaping)	0.403464 km/s
Parking to Phobos Altitude (Hohmannn Transfer)	0.552202 km/s
Phobos Rendezvous (Phasing Maneuver)	0.0749948 km/s
Total	**1.03066 km/s**

A capsule with a monopropellant powered rocket engine system will be utilized to land safely. Even though a bipropellant or solid rocket motor may seem favorable for their specific impulses, a monopropellant can be turned on and off (unlike a solid rocket), and requires no cryogenics such as many bipropellants. With no atmosphere on Phobos, there will be no aerobreaking involved with the landing maneuver and retrorockets are needed to slow the spacecraft down. Because the force of gravity is almost negligible, firing attitude control nozzles would be the final step in a soft landing.

A design consideration for the capsule's central, main thrust nozzle, would be to make it retractable. With regolith that may be as deep as three feet, it would be best if no contact was made when landing because it may sink and damage the thruster.

5.4 Landing of Payloads

The first payload to land on Phobos will contain the spaceport, observatory tower, and module joint. On the transfer down from orbit, the joint and tower will rest on top of the spaceport. At an altitude of one kilometer, the payload will stage from the capsule which will return to the interplanetary transport vehicle for the return trip to Earth. Just before touchdown the three components will separate from each other using small on board cold gas thrusters, but still be connected by a triangular tether system.

When they land, the distance between spaceport and accompanying structures will be sufficiently safe for when the spaceport is active. The structures have spikes on the landing faces with screw geometries starting a foot from the tip. These will plunge into the regolith then rotate to properly secure themselves. Once the first payload is properly delivered, the spaceport is technically functional to land on for further payload deliveries.

Payload Two will contain the Bigelow Aerospace's Olympus inflatable habitat along with its four tethered anchoring components. The landing of this payload will be discussed more in depth Section 6

Payload Three is the delivery of human astronauts. They will arrive in the same fashion but land on the spaceport pad in the aforementioned capsule described in Section 5.3.

6 Automated Base Assembly and Construction

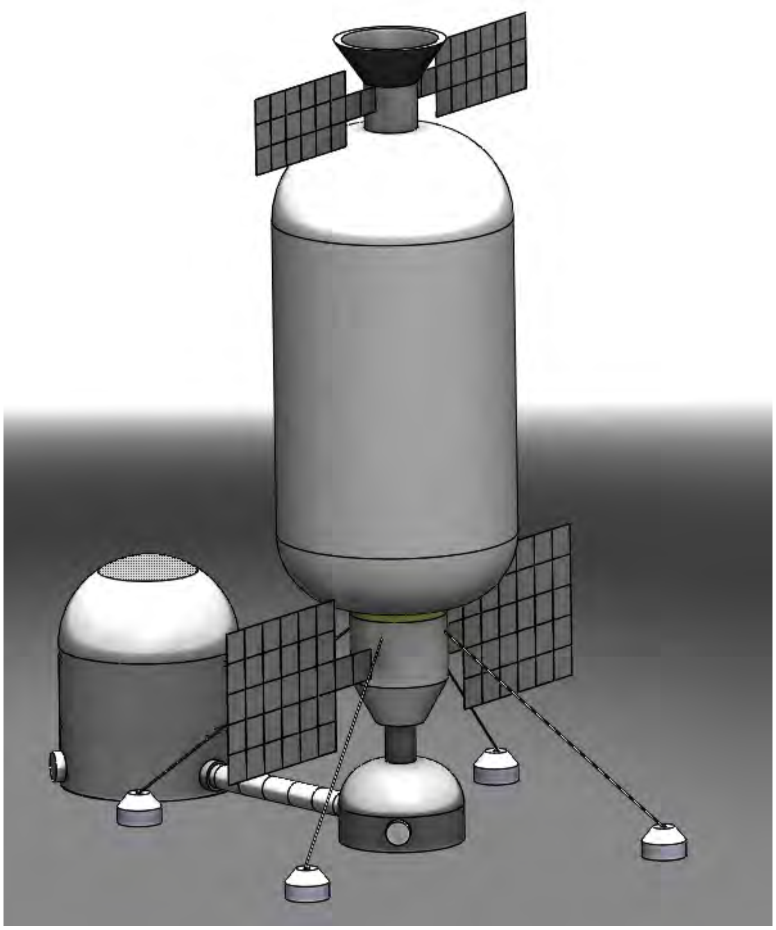


Figure 7: Fully Assembled Base

The assembly of the base starts with the landing of the first payload. The observatory tower,the left most structure in Figure 7, is fully stocked and requires no automated construction other than the supporting legs that screw themselves into the ground. The same can be said for the spaceport pad, and module joint. From start to finish they are all tethered together in a highly acute isosceles triangle.

Payload Two will be highly automated. The already inflated Olympus module will be lowered into the airlock on top of the module joint using retrorockets and attitude thrusters. After a successful joining of the two structures, four screws will eject from the Olympus equidistant from each other just above the airlock. There will be cables attached from supports on the Olympus that are secured into the regolith by these long screws. The purpose is to stabilize the structure and prevent it from tipping due to its high center of mass. A rendering of the full base excluding the spaceport can be seen in Figure 7. The tube connecting the If something were to go wrong during this highly risky maneuver, the mission would most likely be scrubbed.The remaining assembly of the base is to be assembled upon astronaut rendezvous.

7 Base Architecture

7.1 Overall Base

The base will be consist of an observatory tower paired with a Bigelow Olympus expandable space habitat. The Olympus portion of this base will be tethered to Phobos using steel cables drilled at least one foot deep into the subsurface with hardened screws capable of bearing a load from any asteroid impact. Volumetrically the two subbases paired together will have a much higher capacity than what is laid out in the requirements for each individual subsection. The two halves of the base are connected with a transport tube that hooks up to the side of the observation tower as well as the bottom of the Olympus habitat.

The two portions of the base will be connected using a transport tube. All wall thicknesses will be at between 10 and 12 inches thick to ensure security against errant asteroids and space debris as well as protection from radiation. One method of potential radiation shielding for the outer shell of the base is to use Hydrogenated Boron Nitride Nanotubes which are lightweight and have high strength properties. The theoretical density of 2.62 $\frac{g}{cm^3}$ used for HBNNTs.[9]

7.2 Observatory Tower

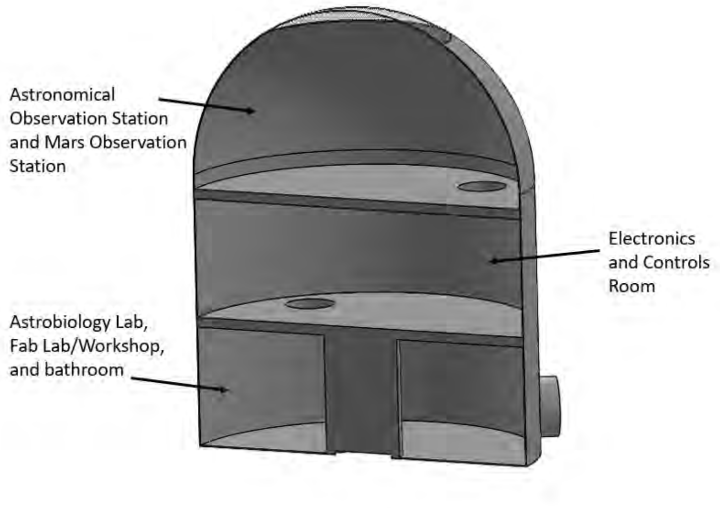


Figure 8: Observatory section view.

The observatory tower is a structurally isolated base that is connected to the Bigelow Olympus section. This section will be comprised of three separate levels with rooms including: a bathroom, an astrobiology lab, a fabrication lab/workshop, electronics/controls, a rover operation station, an astronomical observation station and a Mars observation station. These labs are all grouped together and separated from the Olympus portion of the base in order to create a semblance of privacy within the base.

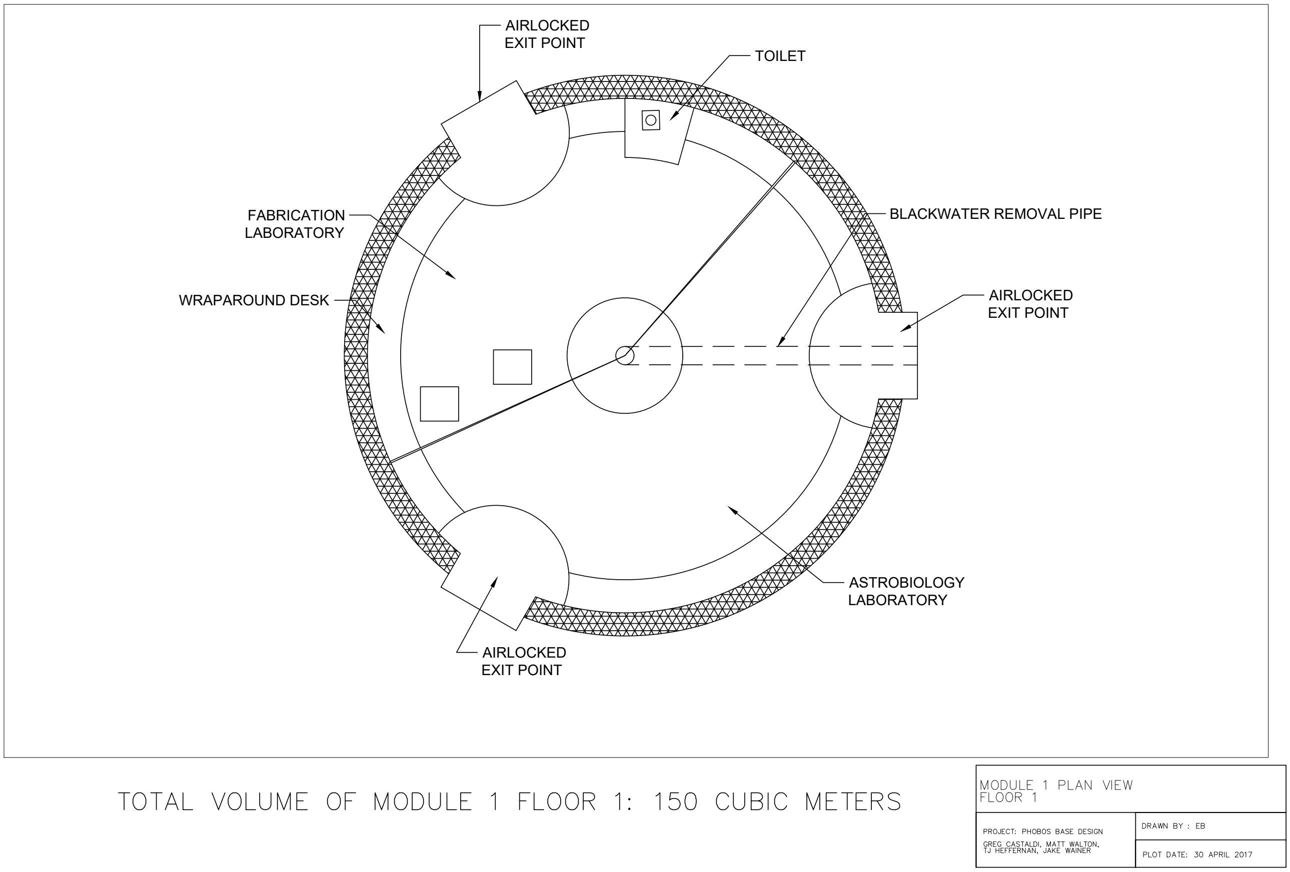

AIRLOCKED EXIT POINT
TOILET
FABRICATION LABORATORY
BLACKWATER REMOVAL PIPE
WRAPAROUND DESK
AIRLOCKED EXIT POINT
ASTROBIOLOGY LABORATORY
AIRLOCKED EXIT POINT
TOTAL VOLUME OF MODULE 1 FLOOR 1: 150 CUBIC METERS
MODULE 1 PLAN VIEW FLOOR 1
PROJECT: PHOBOS BASE DESIGN
GREG CASTALDI, MATT WALTON, TJ HEFFERNAN, JAKE WAINER
DRAWN BY : EB
PLOT DATE: 30 APRIL 2017

Figure 9

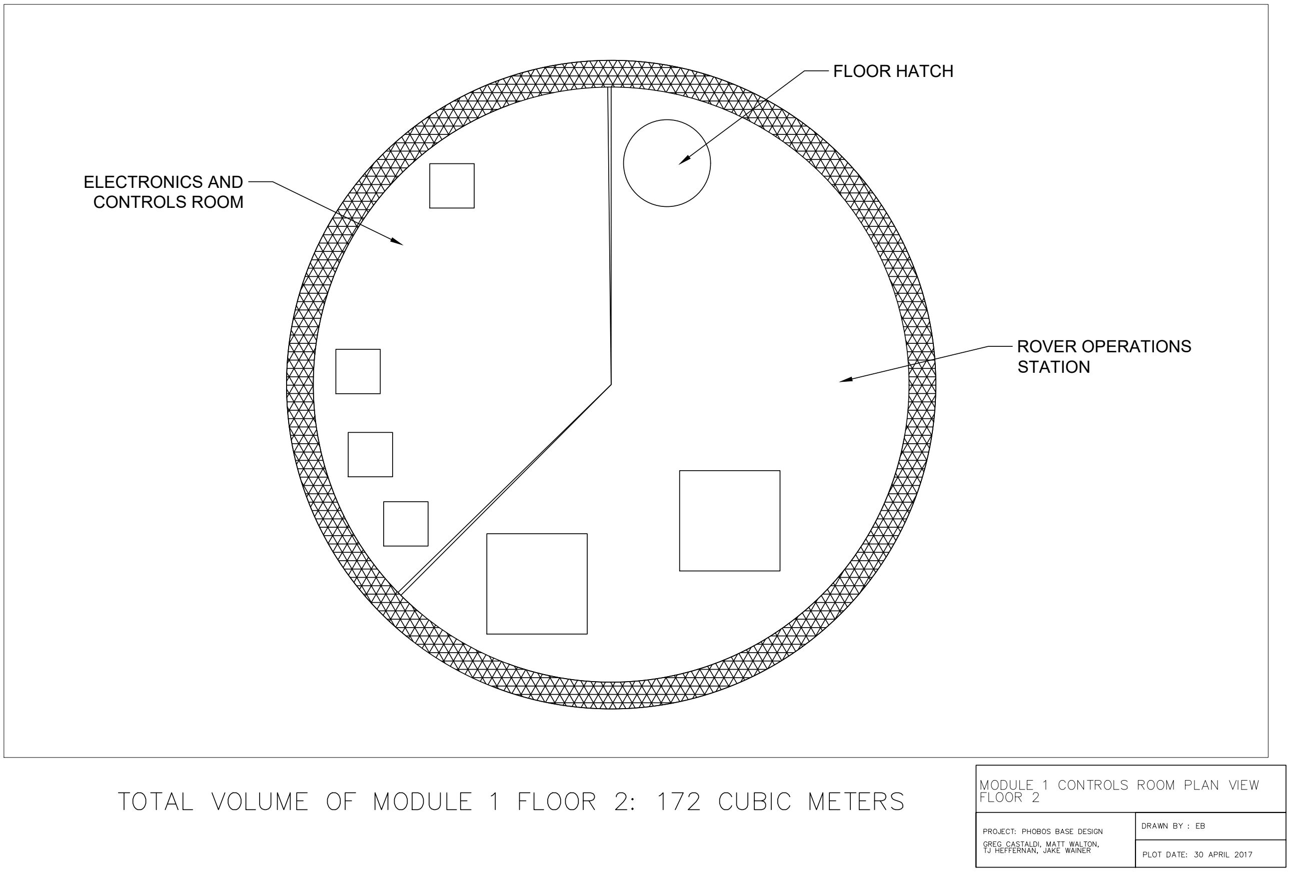

FLOOR HATCH
ELECTRONICS AND CONTROLS ROOM
ROVER OPERATIONS STATION
TOTAL VOLUME OF MODULE 1 FLOOR 2: 172 CUBIC METERS
MODULE 1 CONTROLS ROOM PLAN VIEW FLOOR 2
PROJECT: PHOBOS BASE DESIGN
GREG CASTALDI, MATT WALTON, TJ HEFFERNAN, JAKE WAINER
DRAWN BY : EB
PLOT DATE: 30 APRIL 2017

Figure 10

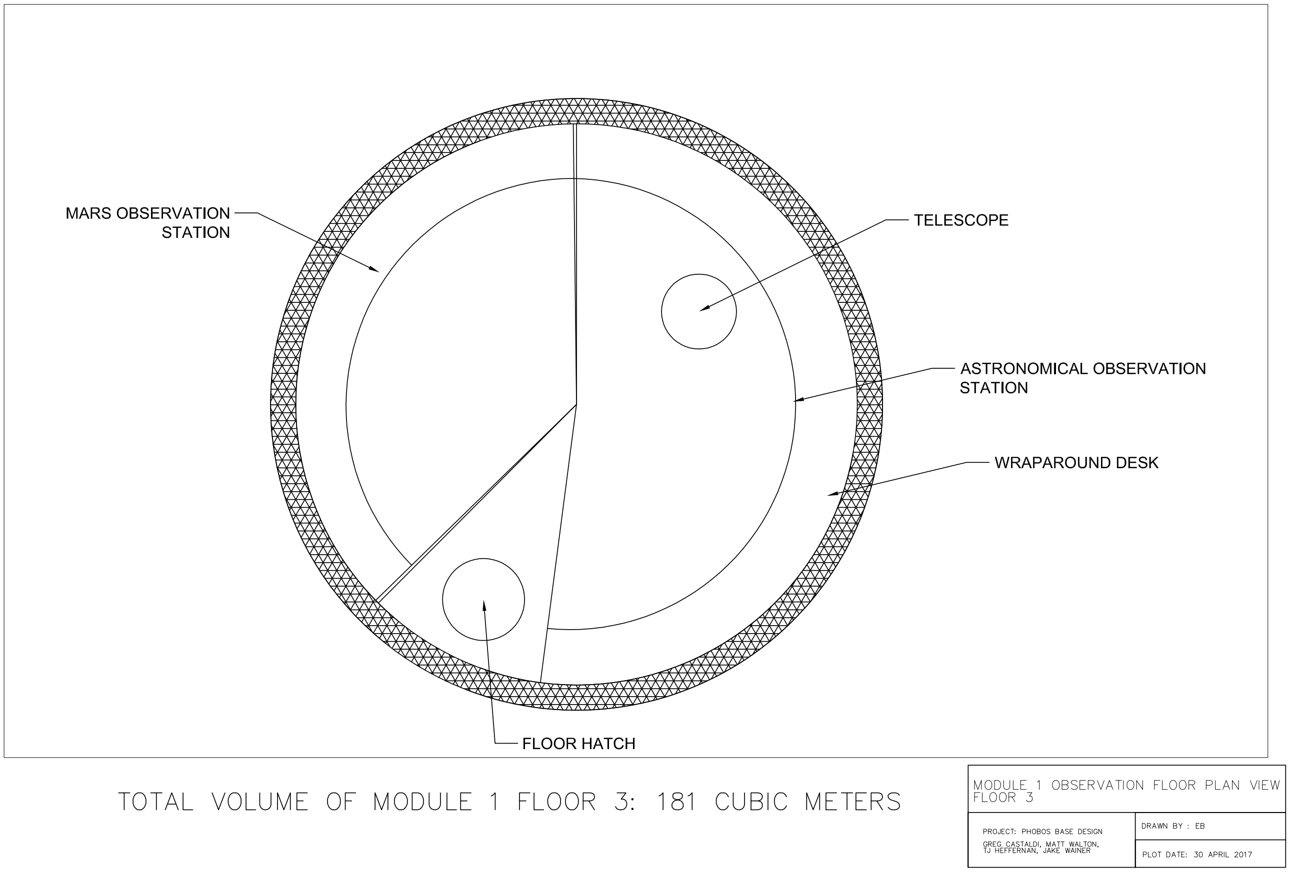

MARS OBSERVATION STATION
TELESCOPE
ASTRONOMICAL OBSERVATION STATION
WRAPAROUND DESK
FLOOR HATCH
TOTAL VOLUME OF MODULE 1 FLOOR 3: 181 CUBIC METERS
MODULE 1 OBSERVATION FLOOR PLAN VIEW FLOOR 3
PROJECT: PHOBOS BASE DESIGN
GREG CASTALDI, MATT WALTON, TJ HEFFERNAN, JAKE WAINER
DRAWN BY : EB
PLOT DATE: 30 APRIL 2017

Figure 11

7.3 Olympus

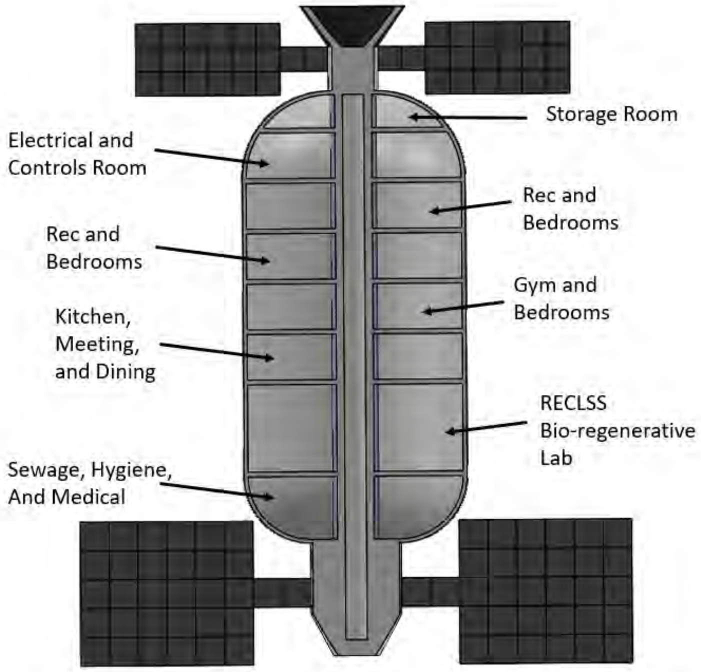


Figure 12: Olympus section view.

The Bigelow Olympus module is a structurally isolated base that is connected to the observation tower. The Bigelow Olympus habitat is an inflated, lightweight but structurally rigid base that houses most life support for the base. This portion of the base will be tethered to surface of Phobos with screws that resist an average load delivered from space debris or asteroids. The entrance at the bottom of the Bigelow structure has a secondary contaminant check to ensure no external impurities from the observation tower enter the larger portion of the base.

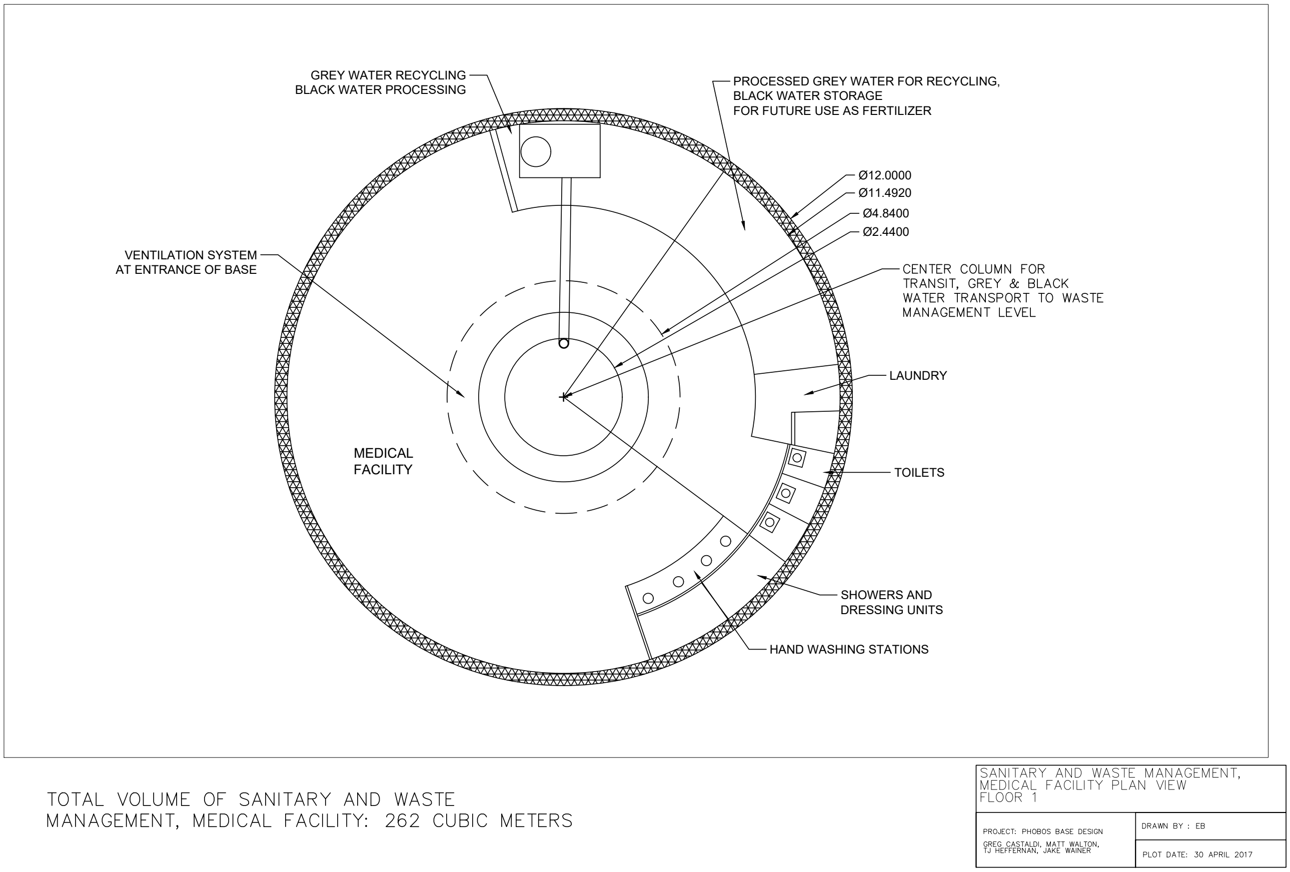

GREY WATER RECYCLING
BLACK WATER PROCESSING
PROCESSED GREY WATER FOR RECYCLING,
BLACK WATER STORAGE
FOR FUTURE USE AS FERTILIZER
Ø12.0000
Ø11.4920
Ø4.8400
Ø2.4400
VENTILATION SYSTEM
AT ENTRANCE OF BASE
CENTER COLUMN FOR
TRANSIT, GREY & BLACK
WATER TRANSPORT TO WASTE
MANAGEMENT LEVEL
LAUNDRY
MEDICAL
FACILITY
TOILETS
SHOWERS AND
DRESSING UNITS
HAND WASHING STATIONS
TOTAL VOLUME OF SANITARY AND WASTE
MANAGEMENT, MEDICAL FACILITY: 262 CUBIC METERS
SANITARY AND WASTE MANAGEMENT,
MEDICAL FACILITY PLAN VIEW
FLOOR 1
PROJECT: PHOBOS BASE DESIGN
GREG CASTALDI, MATT WALTON,
TJ HEFFERNAN, JAKE WAINER
DRAWN BY : EB
PLOT DATE: 30 APRIL 2017

Figure 13

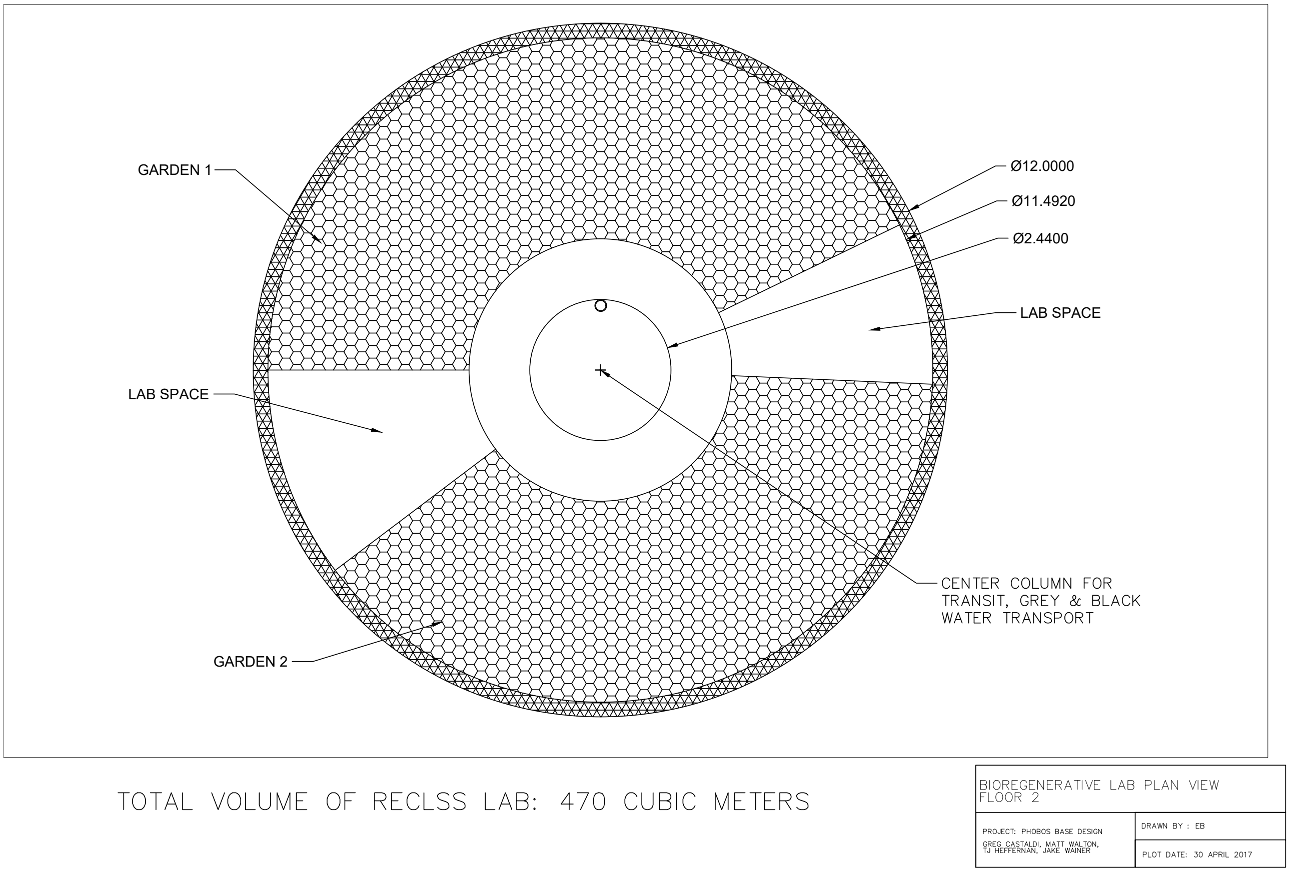
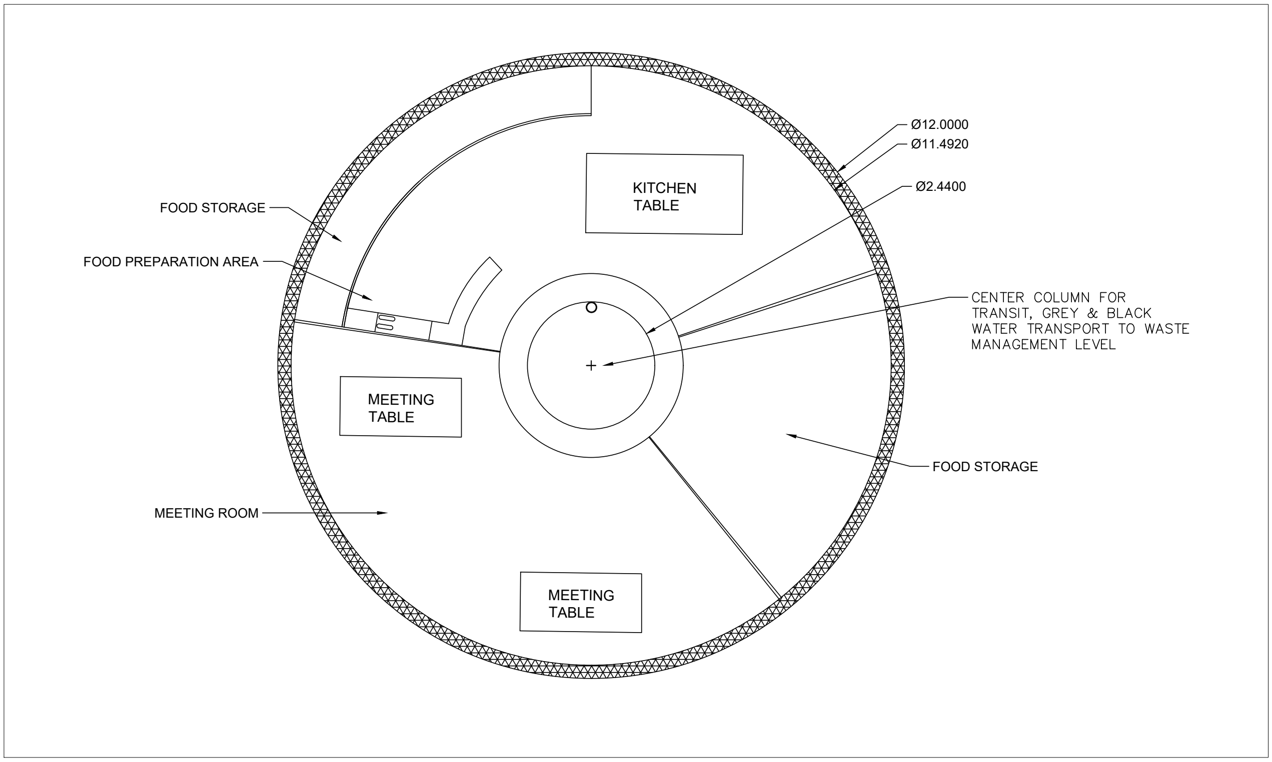

GARDEN 1
Ø12.0000
Ø11.4920
Ø2.4400
LAB SPACE
LAB SPACE
CENTER COLUMN FOR
TRANSIT, GREY & BLACK
WATER TRANSPORT
GARDEN 2
TOTAL VOLUME OF RECLSS LAB: 470 CUBIC METERS
BIOREGENERATIVE LAB PLAN VIEW
FLOOR 2
PROJECT: PHOBOS BASE DESIGN
GREG CASTALDI, MATT WALTON,
TJ HEFFERNAN, JAKE WAINER
DRAWN BY : EB
PLOT DATE: 30 APRIL 2017

Figure 14



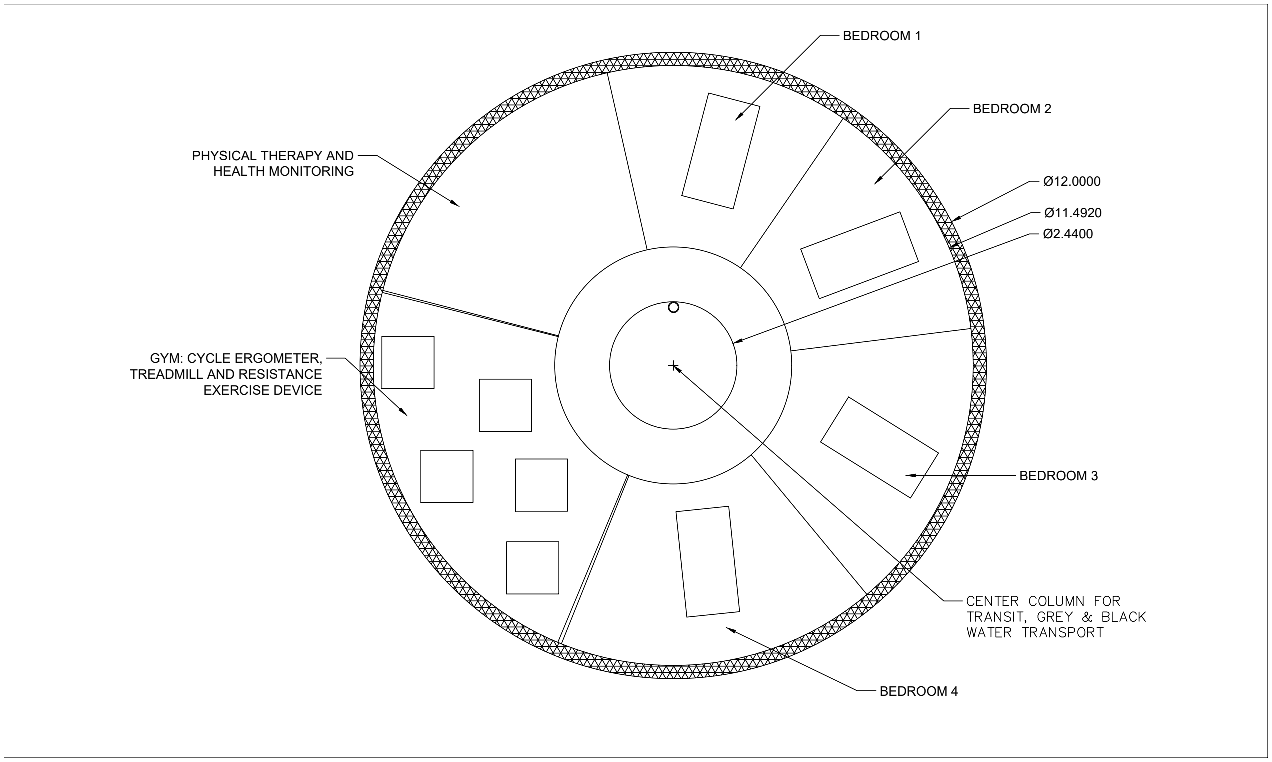
GROUP ACTIVITIES AREA: 246 CUBIC METERS

GROUP ACTIVITIES AREA PLAN VIEW
FLOOR 3

PROJECT: PHOBOS BASE DESIGN
GREG CASTALDI, MATT WALTON,
TJ HEFFERNAN, JAKE WAINER

DRAWN BY : EB
PLOT DATE: 30 APRIL 2017

Figure 15



TOTAL VOLUME OF GYM & 4 BEDROOMS: 246 CUBIC METERS

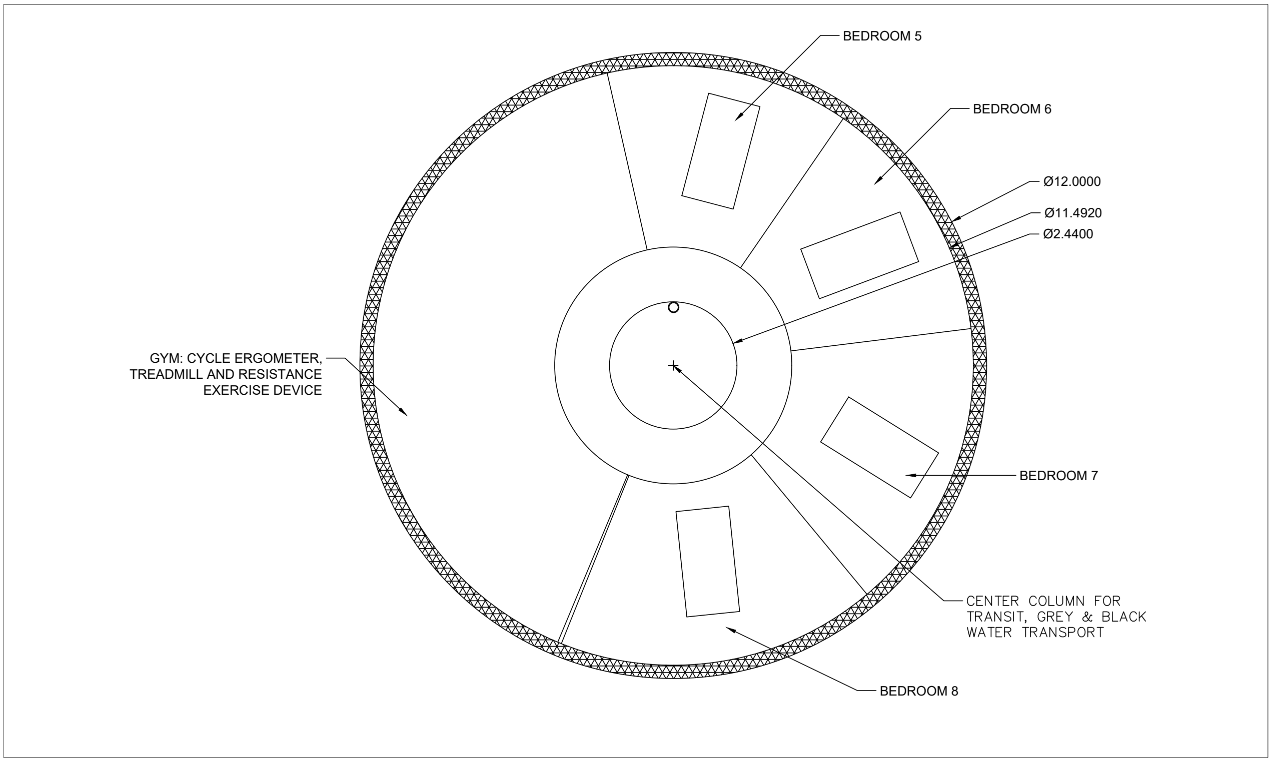
EXERCISE AREA & BEDROOM PLAN VIEW
FLOOR 4

PROJECT: PHOBOS BASE DESIGN
GREG CASTALDI, MATT WALTON,
TJ HEFFERNAN, JAKE WAINER

DRAWN BY : EB

PLOT DATE: 30 APRIL 2017

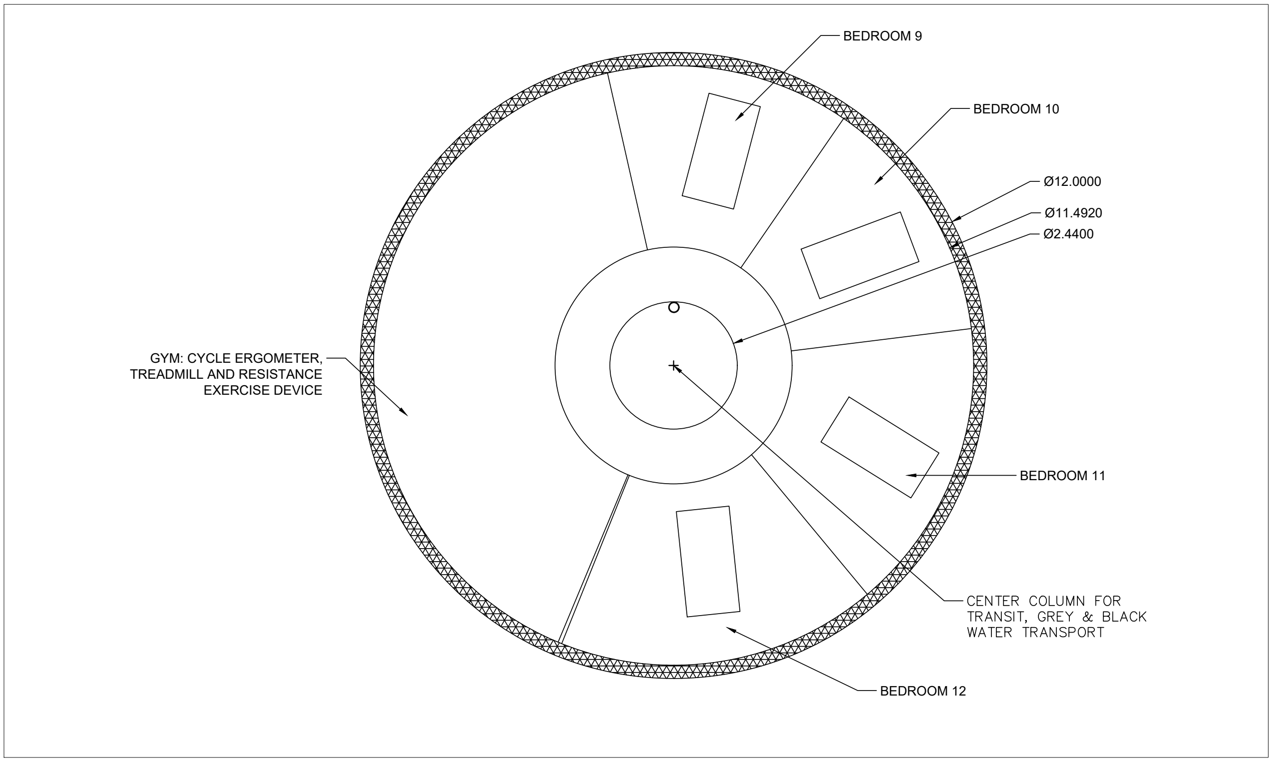
Figure 16



TOTAL VOLUME OF RECREATION CENTER
AND 4 BEDROOMS: 246 CUBIC METERS

RECREATION AREA & BEDROOM PLAN VIEW FLOOR 5	
PROJECT: PHOBOS BASE DESIGN	DRAWN BY : EB
GREG CASTALDI, MATT WALTON, TJ HEFFERNAN, JAKE WAINER	PLOT DATE: 30 APRIL 2017

Figure 17



TOTAL VOLUME OF RECREATION CENTER
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RECREATION AREA & BEDROOM PLAN VIEW
FLOOR 6

PROJECT: PHOBOS BASE DESIGN
GREG CASTALDI, MATT WALTON,
TJ HEFFERNAN, JAKE WAINER

DRAWN BY : EB
PLOT DATE: 30 APRIL 2017

Figure 18

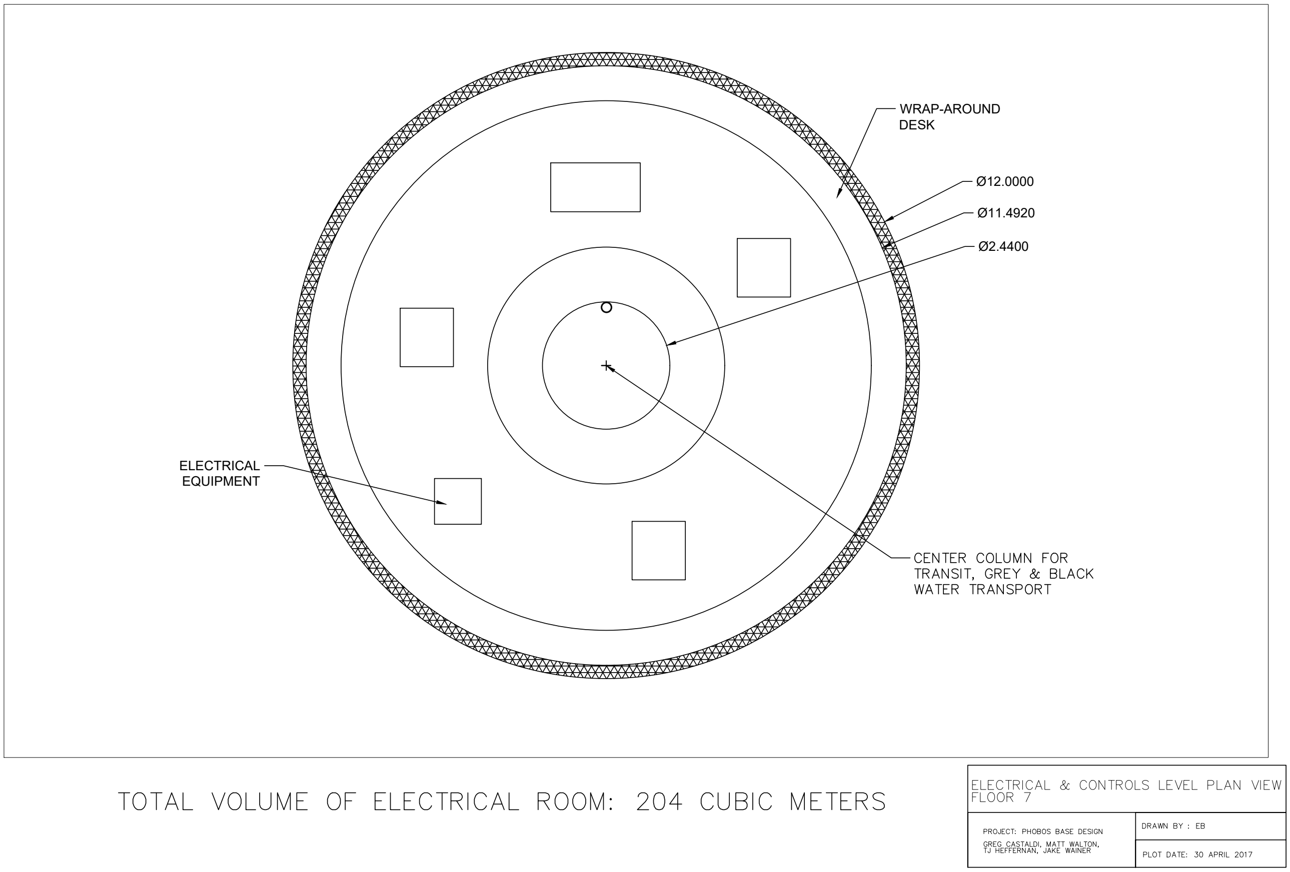
WRAP-AROUND DESK
Ø12.0000
Ø11.4920
Ø2.4400
ELECTRICAL EQUIPMENT
CENTER COLUMN FOR TRANSIT, GREY & BLACK WATER TRANSPORT
TOTAL VOLUME OF ELECTRICAL ROOM: 204 CUBIC METERS
ELECTRICAL & CONTROLS LEVEL PLAN VIEW FLOOR 7
PROJECT: PHOBOS BASE DESIGN
GREG CASTALDI, MATT WALTON, TJ HEFFERNAN, JAKE WAINER
DRAWN BY : EB
PLOT DATE: 30 APRIL 2017

Figure 19

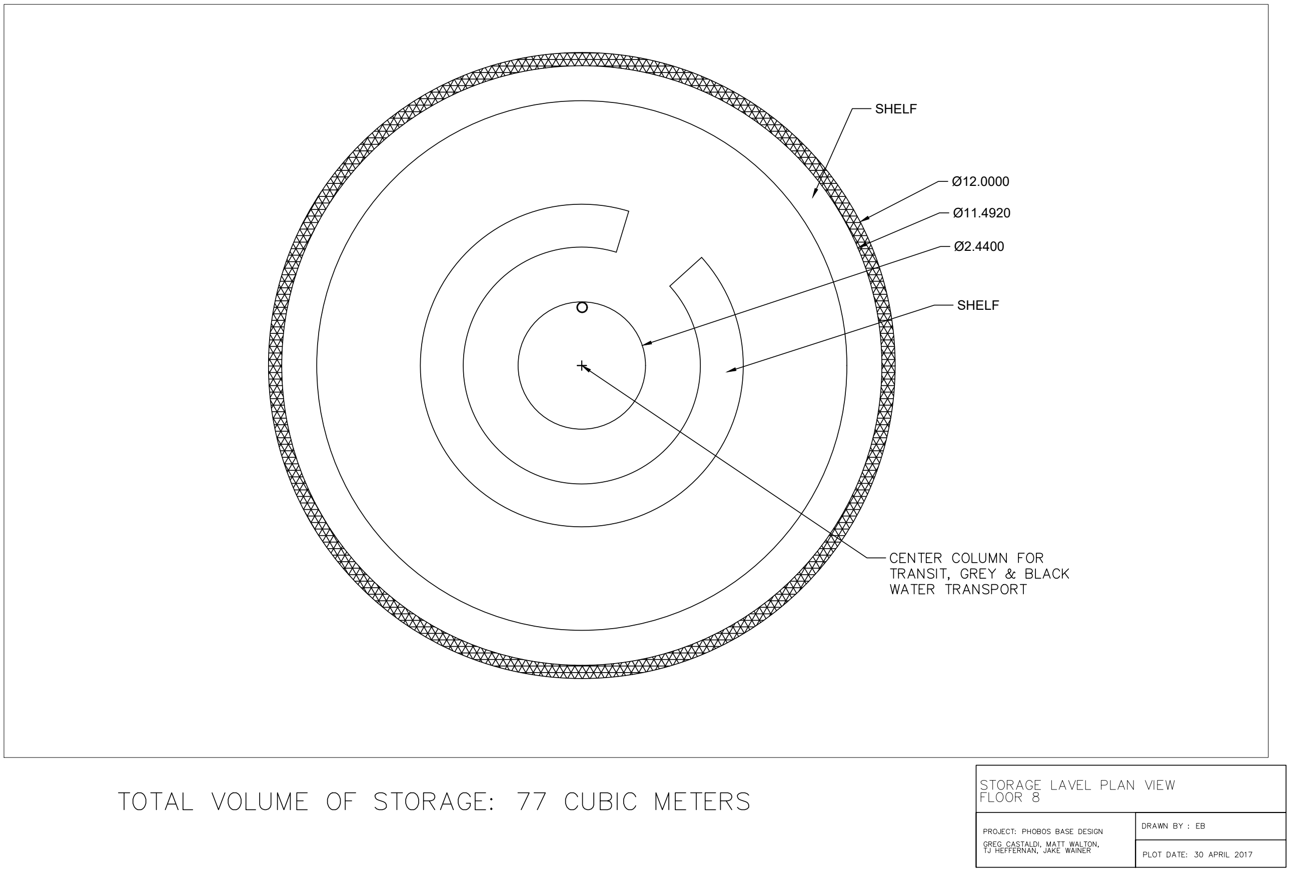

Figure 20

7.4 Space Port

7.4.1 Overview

In this base design the spaceport is the center of transportation for extra-planetary vehicles. The primary function of this system is to receive/send off cargo and astronauts from the Phobos Moon Base. It will consist of one main pad capable of receiving incoming vehicles and two cables from the side of the pad leading to an airlock on the observatory tower and the module joint respectively.

7.5 Modules

7.5.1 Launch/Landing Pad

This is the area for spacecraft to land and leave the moon. Overall, the platform takes a octagonal profile from a top view. It's surface will be composed of an embedded steel plate in order to withstand heat generated from the thrust of spacecraft taking off or landing on the surface.

The structure of the platform must be extremely strong in order to withstand the forces and moments generated upon its controlled crash landing into Phobos, yet it must be light enough for its journey to Phobos. This could be manufacturing in a multitude of different methods, likely it would be a type of titanium alloy based structure re-enforced with a series of composite or ceramics.

On the underside of the platform is an array of four folding surface holding piles. These piles are arranged like the legs in a "card table" so that they can be stowed during transit, and deployed just before ejection onto Phobos' surface. At the end of each of these piles are long tungsten composite drill bits that will be driven into the surface, through the covering regolith. A cold gas thruster initially mounted to the top of the platform will provide an additional impulse to push the piles further into the ground.

After the platforms impact with the surface is complete, the platform will change over to leveling mode. In leveling mode, the drive motors used to deploy the piles in orbit will be re-purposed to spin the piles about their longitudinal axis. These rotating piles can be individually controlled by the on-board gyroscopic computer to act as power screws to adjust the corner heights of the platform.

7.5.2 Transport

In order to transfer supplies back and forth from the spacecraft at the port to the base, a transfer system must be established. As mentioned earlier in the report, tethers come pre-attached to the other modules. They will be undergoing extreme tensile impact loading during the landing procedures of the separate modules. As a result, it makes sense to fabricate them from a weave of a durable materials such as carbon fiber. Astronauts will be able to pull themselves along the cable to get from spaceport to base and later on a cart could be attached that rolls along the tethers.

7.6 Positioning

When deciding the position of the spaceport site, it is crucial to consider the dangerous effects of rocket launch on a human. On Earth humans have maintain a safe distance from a launch not only due to radiation and convection movement of heat, but also the dangerous vibrations of the air. For safety purposes on Phobos atmospheric vibrations are a non-issue.

Above all of the largest dangers limiting the distance of the launch pad from the base is the possibility of the craft exploding while on the platform, or not far off of the surface. During the shuttle launch program it was advised to stay at least 3 miles[15] from the launch site, unless protected by an extensively armored structure. Even though the base is covered with hyper-velocity protection systems such as Whipple shielding, this type of protection is not reliable for objects larger than micro meteors. Since reaching escape velocity on Phobos is much easier than on Earth or Mars, thrusters on spacecraft will not be as powerful and the spaceport can be much closer to the base. Half a kilometer away should be sufficient enough to keep the base safe from catastrophic failure but close enough to traverse the distance.

8 Regenerative Environmental Control and Life Support System (RECLSS)

8.1 Power & Utility Systems

To supply Phobos with the necessary power to support a moon base solar panels will be utilized to convert solar radiation into electrical energy. To determine how many panels are needed, important assumptions must first be made. While the solar irradiance of the moon changes with time, a constant value will be used. This is found using Equation (6) based on the distance Phobos is from the surface of the sun, D, roughly 227.9×10^9 meters. This also assumes Phobos is at a constant distance from the sun in a circular orbit. The Stefan–Boltzmann constant is represented by σ and equals 5.67×10^{-8}. The radius and temperature of the sun are also needed to find the solar irradiance.

$$G = \sigma \, T_{sun}^4 \left(\frac{R_{sun}}{D} \right)^2 \tag{6}$$

$$G = (5.67 \times 10^{-8})(5778)^4 \left(\frac{696 \times 10^6}{227.9 \times 10^9} \right) = 589.4175 \; W/m^2$$

By knowing how much power can be harvested at the surface of Phobos, the next step is determining how much power is needed for the base. To determine this, the international space station (ISS) was studied. There are people constantly living on the ISS. On average the station generates 84 kilowatts[2] of power with its solar array. They need to produce more power than is actually required to store in batteries for when the station is in eclipse. The same idea can be applied to the base on Phobos. Assuming the moon base will require twice the amount of power that the ISS needs (168 kilowatts) because the residents are doubled, the area of solar panels can be calculated. If the assumption that solar panel technology will continue to increase efficiency in the years to come, then the current 46% maximum attainable efficiency will rise. For these calculations, the assumed conversion efficiency including all other losses, η, will be 55%. Equation (7) represents the power generated from a certain area of solar panels A. This can be rearranged to solve for area as seen in Equation (8).

$$P = \eta \, GA \tag{7}$$

$$A = \frac{P}{\eta \, G} \tag{8}$$

$$A = \frac{(2)(84,000)}{(0.55)(589.4175)} = 518.231 \; m^2$$

This would mean that roughly one tenth of a football field's area filled with solar panels would be necessary to supply power to the base. Excess energy would be stored in batteries, like with the ISS for times when the solar panels are eclipsed by Mars.

The placement of the power processing unit (PPU) would be somewhere within the base's walls to allow the energy loss in the form of heat to disperse in the living quarters. Air conditioning systems that heat the base would do less work and if there was an issue with the PPU, an EVA would not be necessary.

A backup system that can supply power to the base will also be established. Instead of relying strictly on harvesting solar energy, a combustion generator can be integrated to activate if power levels in the batteries are dwindling. The system would run on methane gas produced by the decomposition of dead plant matter and human excrement. The storage of a combustible gas such as methane posses risk to the occupied habitat, thus the decomposition tank would be sufficiently isolated and pose little risk.

Heat generated from the methane combustion would drive a closed loop steam power plant. Complete with a water pump, heat exchanger, turbine and condenser; the fully combusted gas would then be separated into different tanks to store the reactions products, one part carbon dioxide and two parts water as seen in the stoichiometric Equation 9. The water could be harvested for other uses as well. It is important to note that this system would be strictly operated when the decomposition chamber approaches dangerous levels of methane or there is a dearth of power from solar irradiation.

$$CH_4 + 2O_2 \Rightarrow CO_2 + 2H_2O + Q \tag{9}$$

8.2 Atmosphere

The atmosphere will be similar to Earths, composed of roughly 80 percent nitrogen, 20 percent oxygen. The pressure will be kept at one atmosphere, or 101.3 kPa for the comfort of the astronauts. Some oxygen will be produced by the plants on the base. Any leftover production will be generated using electrolysis of water. Hydrogen produced by this process will then be used for a chemical reaction with CO2 known as the Sabatier reaction.[14] This involves combining the hydrogen and carbon dioxide at high heat and to produce methane and H2O. The water can be used either as potable supply, or to generate more oxygen. Each isolated section of the base will have its own generator, as to have redundancy, and to allow each section to remain survivable in case of hull breach.

An average person requires 550 liters of oxygen per day.[13] For twelve astronauts, this becomes 6600 liters. By the ideal gas law:

$$m = \frac{MPV}{RT} \tag{10}$$

$$m = \frac{0.032\frac{g}{mol} * 101.3kPa * 6.6m^3}{8.3144621\frac{J}{mol*K} * 293} = 8.75kg \tag{11}$$

This means that 9.02 kilograms of water will be required per day to provide oxygen for the crew.

Emergency chemical oxygen generators will be stationed in each section. These will be similar to the oxygen generators found on commercial jets, utilizing sodium chlorate. As this reaction is highly exothermic, proper insulation and fire prevention precautions must be taken. The oxygen will be either expelled directly into the base, or through air masks directly to the astronauts, depending on the situation.

8.3 Potable Water Supply

The potable water aboard the base will be primarily supplied by recycling the onboard water using technology already implemented aboard the International Space Station. This system gathers all available greywater aboard the base and keeps it completely separate from the blackwater. Greywater can be defined as all available moisture that has not been contaminated with fecal matter. This means all moisture from the crew members exhalation, sweat and urine as well as dirty dish water, and laundry water will be piped to the processing center on the "ground floor" of the Bigelow Olympus portion of the base. Processing entails both removing contaminants from the greywater as well as adding chemicals to improve the taste. Once an appropriate amount of contaminants are removed the water can then be tested to ensure potability. The processed greywater will then be stored in tanks and await further use.

Once reconnaissance missions to Mars begin, there is potential to harvest methane from the surface of Mars. Burning this additional methane will produce additional potable water for crew members to use. Upon initial inspection, this seems to be the best way to both produce energy while creating new water for the crew to use.

8.4 Dust/Contaminant Control and Detection

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The most important step taken in the base to prevent dust contamination is air-tight seals on all joints or ports. Space suits are locked and ensure that no dust can enter the suit and suits are stored in an air-lock chamber. All dust is removed from them with strong air currents between missions. Regular cleanings by crew members will maintain cleanliness.

Bacterial contamination is another issue that must be handled even more carefully than dust. All waste ports in bathrooms will have vacuum suctions that are active whenever the sealed ports are open. Bathrooms will not operate until the door is shut and sealed to keep germs from spreading due to an unsealed door. The doors will not reopen until the crew member has taken an antibacterial wipe from the dispenser and disposed of it properly.

When the bathroom door is sealed after use a strong UV light will slowly sweep the room to kill any remaining bacteria.

Bacteria will also be monitored to make sure no germs are spreading through the crucial areas of the base. Automatic testing of drinking water will occur and an alarm will sound if anything dangerous is found.

The soil will be tested on a weekly basis by crew members trained in the appropriate techniques to ensure that plants and fungi are growing in safe conditions. One silkworm per week will also be chosen at random and checked for a number of health metrics.

8.5 Thermal Control

Temperatures on Phobos range from highs of $25^\circ\ F$ $(-4^\circ\ C)$ to lows of $-170^\circ\ F$ $(-112^\circ\ C)$. This means that thermal management on Phobos will be necessary to maintain temperatures that are suitable for human and plant life as well as operation of all base components, tools, and computers. In order to do so, the base must have a heat source, passive thermal management, and active thermal management. Fortunately, there is a readily available heat source built in to our design by default.

As discussed in the power requirements (Section 8.1) there is an assumed 55% power delivery efficiency in our system. This leaves 45% of the energy reaching our solar panels unaccounted for. A portion of that number correlates to the actual efficiency with which the solar panels can convert solar energy to electrical energy. An estimate based on current technology is that one quarter of energy losses are due to this process. Technology by the time of this mission should have reduced these losses greatly so we use an assumption of 20% to be safe. The remaining 25% of the missing energy is lost in the form of heat during transport of the electricity within the base. For our 168 kilowatt system this translates to 76 kilowatts being introduced to the base in the form of heat. This is found by first calculating the total power (Equation12), then taking 1/4 of that value (Equation 13).

$$P_{total} = \frac{P_{system}}{0.55} = 168/.55 = 305\ kW \tag{12}$$

$$P_{excess} = P_{total}/4 = 76\ kW \tag{13}$$

To determine whether this is enough to heat the entire base we must determine how much heat is lost. On Phobos the only forms of heat loss will be radiation and conduction. The legs of our base provide minimal contact with the moon's surface so conduction will be negligible. This leaves only radiation. The surface area of our base is $A = 1451\ m^2$. Equation 15 is the radiation equation where ϵ, and σ the emissivity coefficient and Stefan-Boltzmann Constant respectively.

$$Q_r = \epsilon\sigma(T_{atm}^4 - T_{base}^4)A \tag{14}$$

Assuming an average internal temperature of $20°C = 293K$ and the lowest external temperature of $-112°C = 161K$ we can quantify how much heat is being lost due to radiation. An emissivity coefficient of $\epsilon = 0.1$ will be achievable based on current insulation materials. This insulating material is the passive thermal management system as well as protecting from harmful radiation.

$$Q_r = 0.1 * \sigma(293^4 - 161^4) * 1451 = -55.1\ kW \tag{15}$$

The calculations show that the base will only be losing 55.1 kilowatts to radiation. This means that it will actually be necessary to have active thermal management systems that dump additional the additional 20.9 kilowatts. This will be achieved with a system of cold plates and radiators. First, inside the base, water from the gray water system will circulate through rooms absorbing heat in cold plates and carrying it to different areas that are not receiving enough heat. In these rooms heat will be expelled with radiators. In this way different rooms can be maintained at the necessary temperature. Additional heat will be brought to the internal-external interface heat exchanger.

In this device, the heated water enters a chamber and flows over hundreds of small tubes.

Liquid methane from pipes outside the base is pumped through these small tubes. This system allows the hot water to pass its thermal energy to the liquid methane. The cooled water is then cycled back to absorb and distribute more heat from various area of the base. The liquid methane is cycled back outside where it enters radiators to expel as much heat as possible. The flow rates of water and methane can be controlled via thermostat to control temperature.

Sizing the external methane-based radiator surface area can be done by rearranging Equation 15 to solve for area, but this time using the maximum temperature on Phobos to simulate the lowest radiation values. The emissivity of these radiator fins will be assumed as $\epsilon = 0.9$.

$$A_{rad} = \frac{Q_{excess}}{\epsilon\sigma(T_{atm}^4 - T_{base}^4)} \tag{16}$$

$$A_{rad} = \frac{20893}{0.9 * \sigma(293^4 - 269^4)} = 191\ m^2 \tag{17}$$

The radiators must have a minimal surface area of 191 m^2 to dissipate the proper amount of heat. The system will compose 450 1x0.5 meter fins to increase surface area without having an extremely large footprint. The total surface area of 225 m^2 will provide a factor of safety and account for any deterioration that could happen over time. The radiator will be located 20 meters from the base in a fenced off area. This design choice provides a safe distance so from base operations but allow for quick access in the case that emergency maintenance is necessary.

8.6 Humidity Control

As the humans breath and sweat they add moisture into the air. High humidity levels can be uncomfortable for crew members and also cause problems for both plants and electronics. In order to counteract these effects, humidity control will be handled in conjunction with thermal management.

A system of ducts and fans will circulate air throughout the entire base. Humid air will be drawn out of rooms towards the heat exchanger described in Section 8.5. It is then passed through a series of coils that contain cold, liquid methane bled off from the feed system for the exchanger. As this happens water vapor in the air condensates and becomes liquid water. This water drips from the pipes and is collected, then introduced to the potable water supply.

8.7 Hygiene

Hygiene on Earth often requires large amount of water which will not be a possibility on the base. Each crew member will have a daily allotment of water which is mostly for consumption purposes.

Using the bathroom is one of the foremost concerns in this regard. Rather than using water to carry waste, air currents will be used. Liquid waste will be pulled directly into a water purification chamber and re-purposed as potable drinking water. Solid waste will first enter a biodegradable bag that then detaches from the toilet and is sucked into the decomposition room to generate useful methane.

After using the bathroom or performing other minimally unsanitary activity with their hands, the crew will not wash their hands with soap and water unless necessary. Instead antibacterial wipes will be used for day-to-day instances like this.

To perform full body washes the crew will be provided with no rinse soap and water. The process is to first apply water to a select part of your body then carefully rub on the soap to cleanse. This can then be removed with a towel rather than rinsing.

8.8 Food Production

The three primary food sources will be plants, fungi, and insects. Many species of plants and fungi are capable of growing in the microgravity of Phobos.

8.8.1 Plants

Plants take in carbon dioxide and release oxygen. Many can be eaten raw or cooked. They require gravity so that they can sense which way to grow starch granules in their roots fall down in response to gravity, which alters the flow of auxin, which signals to the roots which way they can grow.

A possible way of addressing this issue is to genetically modify the plants. The amount of starch granules in the roots is determined by the amount of the proteins expressed that form these starch granules from plasmids. The gene promoters could be altered so that these proteins are more highly expressed, and therefore more of these starch granules could be present. This would theoretically increase the plants' sensitivity to gravity, allowing them to respond to lower levels.

Another possibility is to breed plants for lower requirements of gravity through artificial selection. The plants could be grown in a simulated slightly lower level of gravity on Earth, and the ones that survive the best could be bred with one another. Each generation, the simulated level of gravity could be decreased, until the only crops that survive are the ones that are capable of functioning in low gravity environments. It would then be possible to do a transcriptome analysis of these healthy plants in low gravity environements compared to their siblings in Earth's gravity environment, which would show which genes are expressed more highly in low-gravity environments. This could inform future genetic modifications of crops to be grown in microgravity environments. Such transcriptome analysis could preliminarily be done with *Arabidopsis thaliana,* as it is one of the most commonly studied plants, is a very easy plant to grow quickly, has a sequenced genome, and is a member of the *Brassicaceae* family, which also has many crop plants.

The edible part of crops can be the fruit, which often requires pollination (or simulated pollination, depending on the plant). This is often a long and energy-intensive process. Therefore, it would be better to cultivate crops of which the vegetative part is edible, like potatos, carrots, and lettuce. In addition, cauliflower could be a successful option for a crop in microgravity. Cauliflower is the same species as brocolli, but instead of eating the floral inflorescense (like people eat in brocolli), the caulfilower is actually a tumor that results from over-expression of a plant hormone (cytokinin) that lead to a shooty tip. This means that the cauliflower doesn't need to differentiate its cells much when it gets to the edible part. In addition, the principles that lead to the uncontrolled growth in cauliflower could be used to form tumors in other edible crops. The high ratio of cytokinin to auxin in the shoot apex leads to this edible tumor; it is possible that cytokinin combined with a polar auxin transport inhibitor could be applied to other crops to create this type of edible tumor.

To introduce crops with fruits for a more varied diet and good source of sugar, it would be possible. Another concern in microgravity is reproduction to form a fruit. When a pollen grain germinates on the stigma surface, a pollen tube grows quickly down the style until it reaches the ovary, which triggers the formation of a fruit. Therefore, it would be best to focus on growing plants that are able to form fruit without being pollinated, or plants that form fruit after being pollinated but before being fertilized.

Some plants, especially leafy greens, can be grown in an aquaponics system. This would be grown in PVC pipes, with water with supplemental nutrients flowing through. Other plants could be grown in soil with supplemental compost. The lights could be optimized for the type of crop grown; in general, red and blue light are ideal (not green light), to optimize plant growth.

8.8.2 Fungus

Another food source is fungi. They are great to grow with plants, because they take in oxygen and release carbon dioxide, and can therefore cycle oxygen/carbon dioxide with the plants. Mushrooms must be cooked in order to be digested by humans since humans can't digest chitin. Mushrooms also require gravity to reproduce to know which way to release the spores, but it might not be necessary as they grow. There are two main parts of a fungus, the mycelium and the mushroom. The mycelium is the vegetative, thread like part of the fungus, analogous to the shoot/root system of a plant. The mushroom is the fruiting body of the fungus, analogous to the flower of a plant. Generally, people grow mushrooms with the following steps:

1. Prepare a substrate by pasteurizing or sterilizing it (there are many different methods including heat, pressure, steam, hot water, and hydrogen peroxide) - this is supposed to eliminate other competing microorganisms.
2. Inoculate a substrate with fungal spawn (some mycelium) - mix it in and put the inoculated substrate in a bag/bucket or some sort of container to mimic a natural log. slice holes in multiple locations on the bag (this is where the mushrooms will fruit out of).
3. Keep the artificial log in a damp, dark place. After a few weeks or a month depending on how far along the spawn is and what type of fungus it is, it will start to fruit out of the holes.
4. Harvest.

The old mycelium and substrate could be used as an excellent compost for the plants grown in soil.

Some potential substrates for the fungus are:

1. Kitchen waste - for example, some mushrooms can grow on coffee grounds, while others are happy to grow on compost (including human waste). *Agaricus* (including button mushroom) grow well on this.
2. Straw substrate: Agaricus (including button mushroom), Oyster, shiitake, reishi, and Lion's Mane grow well on this.
3. Wood substrate: Oyster, shiitake, reishi, and Lion's Mane grow well on this.

8.8.3 Silkworm Farm

The third source is a silkworm farm. Silkworms have traveled to space on many different occasions for scientific purposes and survive very well in microgravity. The benefit of silkworms are numerous.

Silkworms are very high in protein, vitamins, and amino acids which would round out the crew's diet extremely well. Their cocoons are also edible when chemically treated. The resulting liquefied cocoon can be flavored and used as a jam to add additional nutrients into the crew members' diets.[12]

Growing silkworms would put little strain on the base's resources. They can live in small areas and reproduce very quickly. Compared to other protein sources they require a relatively small amount of water.

9 Life Science Countermeasures

9.1 Microgravity

To protect astronauts against the harmful affects of microgravity, "Gravity Loading Countermeasure Skinsuits" (GLCS) will be used. The GLCS is a mesh suit which creates tension in the z-axis fibres, gradually inducing a weight bearing load on the wearer. It increases tension in hundreds of stages compared to the 2 stages of the Pingvin anti-zero-gravity suit, creating a much better resolution of gravitational force. It simulates the force of 1 g with less than 10 mmHg of compression on the wearer and data from prototypes tested in parabolic flights suggest that astronauts will be able to work, exercise, and sleep normally while wearing the suits. Unlike the Pingvin suit, the GLCS uses circumferential fibres of the elastic weave to connect the upper and lower sections, will need less skin pressure to stop the suit from slipping axially, and will be comfortable enough to wear throughout the day. The GLCS will be used in conjunction with daily excercise and advanced medicine such as Bisphosphonate to help prevent bone mass decay caused by the micrograity.[4]

Bisphonate is an agent which increases bone mass and decreases chances of bone fractures. It has been used as a therapeutic treatment for those with osteoporosis and is currently being tested in space through a study by JAXA and NASA crew members. Early results of the studyt sugest that taking Bisphosphonate one a week will reduce the risk of bone decay and fractures, when paired with nutrients such as calcium and vitamin D, and exercise.[1]

9.2 Radiation

Main Harmful Particles

The main harmful radiation that astronauts will face on the mission are Solar Energetic Particles (SEP) and Galactic Cosmic Ray Particles (GCRP). SEP are released from the sun in a steady stream and in large quantities from solar flares and coronal mass ejections but consist mostly of protons with low energy which can be shielded by most structures. The GCRP are released by galactic cosmic rays from other stars in our galaxy and others which accelerate to almost the speed of light. The consist mostly of protons but also can contain even the heavy elements which can break through structures and space suits allowing more sub atomic particles and radiation in to the system.[6]

Radiation Protection

In order to protect against the GCRP and SEP, hydrogen containing substances will be used. Because hydrogen has the highest charge to mass ratio of all elements it is the best element for shielding against radiation of thermal neutrons present in the GCRP and SEP. A combination of hyper-hydrogenated Boron Nitride Nanotubes (BNNT), polyethelene plastic, and water will be used in the structure of the base to create a safe environment against radiation.[7]

Hyper hydrogenated BNNTs have a hexagonal crystalline structure which is both very structurally sound and can be stored with hydrogen and have hydrogen atoms covalently bonded to the B and N through hydrogenation. BNNTs have chiralities, are chemically inert, structurally stable, and are electrically isolating with uniform electric properties which are independent of size and chirality. BNNTs have a Young's modulus of almost 1.2 Tpa, a high thermal conductivity of around 600 $\frac{W}{m-k}$ in a plane, and are chemically stable up to 800° Celsius in air.[3] They are inert to most chemicals, have a high resistance to thermal oxidation, have a uniform band gap of 5.5 eV (thus always semiconducting), and have a high sensitivity for sensor materials. Their mechanical and thermal properties, and efficiency as electrical insulators, make them a structurally stable and and sound nanofiller for isolating polymeric materials and a suitable filler in the fabrication of mechanically and thermally enhanced polymer composites. They help preserve the electrical isolation of polymer matrices and also give mechanical reinforcement, high thermal conductivity, and low coefficient of thermal expansion in a matrix.[3]

Despite having similar structural strength to the BNNTs, Carbon Nanotubes (CNT) will not be used. BNNTs have a higher thermal conductivity and a larger band gap, allowing BNNTs electrical properties to not be dependent on their chirality and diameter. BNNTs have a higher electrical insulation, despite a high thermal conductivity. Finally, BNNTs have about twice the hydrogen storage capacity as CNTs. For these reasons BNNTs will be used instead of CNTs.[3]

Spacecraft

The human bearing spacecrafts will have hyper hydrogenated BNNTs in the walls to protect against radiation during the space flight. The space craft will have a Mesh double-bumper shield to prottect against micrometeorites. It will consist of an outer layer of aluminum mesh in front of a stuffed whipple shield of aluminum walls and Kevlar fabric.[8]

Base

On the surface of the base will be a 3d printed aluminum chain-mail to protect against micrometeorites. The first main structural wall of the base will consist of Hyper-hydrogenated BNNTs to give a strong and structurally sound protection from all radiation. After the structural layer of hyper hydrogenated BNNTs, there will be a layer of polyethylene, a comparably cheap and light wait radiation protection. The life support water system will run through the walls of the base, adding extra protection from radiation.

Spacesuit

Mechanical Counter Pressure (MCP) space suits will be used instead of gas pressurized suits to allow more mobility, reach, and dexterity while performing space walks and operations. The elastic weaves of the MCP suit prevent tears from propagating, thus causing a small tear to no longer be fatal as it could be when using gas-pressurised suits. Use of the MCP suit will reduce risk of fatigue and errors because of its greater mobility and lightness. On top of the safety benefits of the MCP suit, it will also cost less to make, cost less to maintain, and also be much lighter than gas-pressurized suits.[5] Fabric made out of hyper hydrogenated BNNTs will be used over the suit to add radiation protection.[7]

9.3 Dust and Contaminants

See Section ?? which includes both dust and contaminant prevention and detection.

10 Arrival of Crew

10.1 Crew Transfer

Upon touchdown on Phobos the crew will have to make their way from the spaceport to the module joint which is interconnected with the Bigelo. This will be done using the established tether system and EVA suites. Much like a person pulling them self along a pool lane line, transportation from spaceport to base will be powered almost entirely by the astronauts arms. As a safety precaution a carabiner will connect the EVA suits to the tether system. The tether transportation method that initially connects all three structures will continue to be utilized between the spaceport and two base modules in vacuum, but the one between the module joint and observatory tower will be pressurized. Once safely inside the module joint, crew transfer is complete and activation of the base can commence.

10.2 Base Activation

The first step to activating the base is checking all systems. Since the Bigelo has the solar panels and living quarters this will be prepped first. Activating life support systems would occur then all subsystems. An inventory of all materials and resources will be recorded and communications with Earth from on board electronics will be established. Once all of this is complete, focus can be moved to the observatory tower.

Power lines need to be connected between the observation tower and the module joint. These would be located directly under the tether already connecting both the tower and module joint. The tower will be accessed through its airlock behind the undeployed bridge that will be discuses in Section 10.3. Once pressurized the tower's life support systems will be turned on and the same process for inventory will be followed. After nominal operation of the space lab tower is established, the closed connection between the two pressurized structures can be joined.

10.3 Further Assembly

A major step in assembling the entire base is connecting the bridge between the observation tower and the module joint. A telescoping tubular mast, nested within the side of the observation tower would need to be extended. To do this, a built in motor will extend it, guided by the tether directly aligning it with the unoccupied module joint airlock. Once bolted together and properly sealed, the airlock on the joint can be opened to allow air to fill the tubular mast. This should be a slow process so the rest of the pressurized, operational sections do not rapidly decompress.

The next step is integrating all the separate electrical, plumbing and life support systems. The modules are designed for rapid and easy connectivity of all aspects. Most would require a mechanical fastening method and a manual control entered into a computing unit.

11 Concept of Operations

11.1 EVA Systems

The base, when fully assembled, will have two airlocks that lead to the spaceport pad, two that are always in for the tubular mast, one used for the Olympus, and one that is open to the Phobos landscape. To minimize atmospheric loss, due to depressurization, the airlock chamber size is minimized. Each airlock module consists of a service portion and a chamber portion. The use of a mechanical counter pressure space suit will minimize the total volume of the astronaut. To account for helmet diameter and clearance the airlock will be 0.75

meters in diameter. To account for a 95th percentile astronaut in addition to boots, helmet, and clearance, the height of the airlock chaimber will be 3 meters. The total volume of the airlock chamber will be $1.325m^3$. Like the Mars one habitat, our airlock will have an accepted loss of 10 percent of the atmosphere. Our airlock has a loss rate of $0.133m^3/cycle$. Oxygen and nitrogen will be stored in pressurized tanks to allow the airlock to replenish any losses. These tanks will be replenished with each delivery of supplies from earth. The airlock service module units will have a total volumetric area of $100m^3$ when a rover is delivered in a later mission. This will be built on site, prior to delivery of the rover and second round of astronauts. The Mechanical counter pressure space suit will have a traditionally pressurized helmet. Standard life support systems that have been validated during the operation of the ISS will be used during spacewalks to maintain acceptable conditions.

11.2 In Situ Resource Utilization (ISRU)

Using Phobos as a celestial base for Mars travel will be pivotal in future missions. Once these missions have started, Phobos crew members could have access to water on a much larger scale. This would allow for more Earth-like sanitation, experiments, and plant life on base. It would also create an interesting construction opportunity.

While the thick layer of regolith on Phobos poses some design challenges, it is also a valuable resource that can be taken advantage of. Concrete is made from 3 simple ingredients: cement, water, and aggregate. Aggregate can be a variety of materials, and the dusty rocky surface of Phobos could be a perfect choice. Although resources on base are initially scare, the future holds great promise for the use of Phobos regolith for this use.

If future missions to Mars or Phobos bring cement, it would be possible to create concrete for 3D printing on a large scale. Concrete dwellings would not be possible due to the lack of oxygen on the moon, but concrete structures could be used for shelter from radiation or errant space debris.

11.3 Safety Strategies

Every aspect of each system in the Phobos base is designed with safety as a priority. Some major safety strategys implemented are:

- Spaceport site is geographically removed from base site. If any issue occurs during takeoff or landing the safety of the remaining base and its inhabitants can be ensured.
- Use of multiple base modules. Each module can be atmospherically isolated from each other with the use of redundant life support systems. If an issue is detected, hatches between modules will be closed.

- Setup of majority of the base is automated and to be done before the departure of crew. Functionality of the base systems will be checked before the arrival of the crew.
- Many vital systems, such as the airlocks, are redundant.
- The first harvest of food will be conducted via an automated system, before the departure of first crew. Harvested foods will be automatically stowed in opaque, vacuum sealed packaging. This will insure that crew have all necessary resources when they arrive at the base.
- A redundancy of communications systems is to be established in the base, mainly one per module.
- A constellation of cube satellites orbit Phobos to visually monitor progress

12 Critical Tech and TRL

Table 4: Technology Readiness.

Critical Tech	**TRL**
Bigelow Olympus	1
NASA Nuclear Thermal Rocket	3+
SpaceX Falcon 9	9

13 Conclusion

This Phobos base design would be the largest, most impressive space station ever created. By implementing technology from both NASA and the private sector it allows a 12 member crew to explore, experiment, and expand our knowledge of the solar system and universe all at once.

The base itself a large, self-sustaining unit that allows for long term missions through its RECLSS system that makes sure air, water, and food are constantly safe for humans and readily available.

In the future, this base lends itself to further expansion on Phobos. The large crew and low gravity make it possible for large scale assembly feats to be achieved relatively easy especially with the assistance of robotics.

In the future, this base would serve as a great jumping-off point for missions to Mars. Currently, repeat missions to Mars are completely unfeasible. With this base it becomes possible to have a long-term stay on Phobos with low cost visits to Mars to explore one of the most exciting planets in our solar system.

There are still details to fine tune and technologies to develop, but this design is a step towards the future of human space travel. In under two decades we could see mankind land on a foreign moon make the first steps towards colonizing a new planet.

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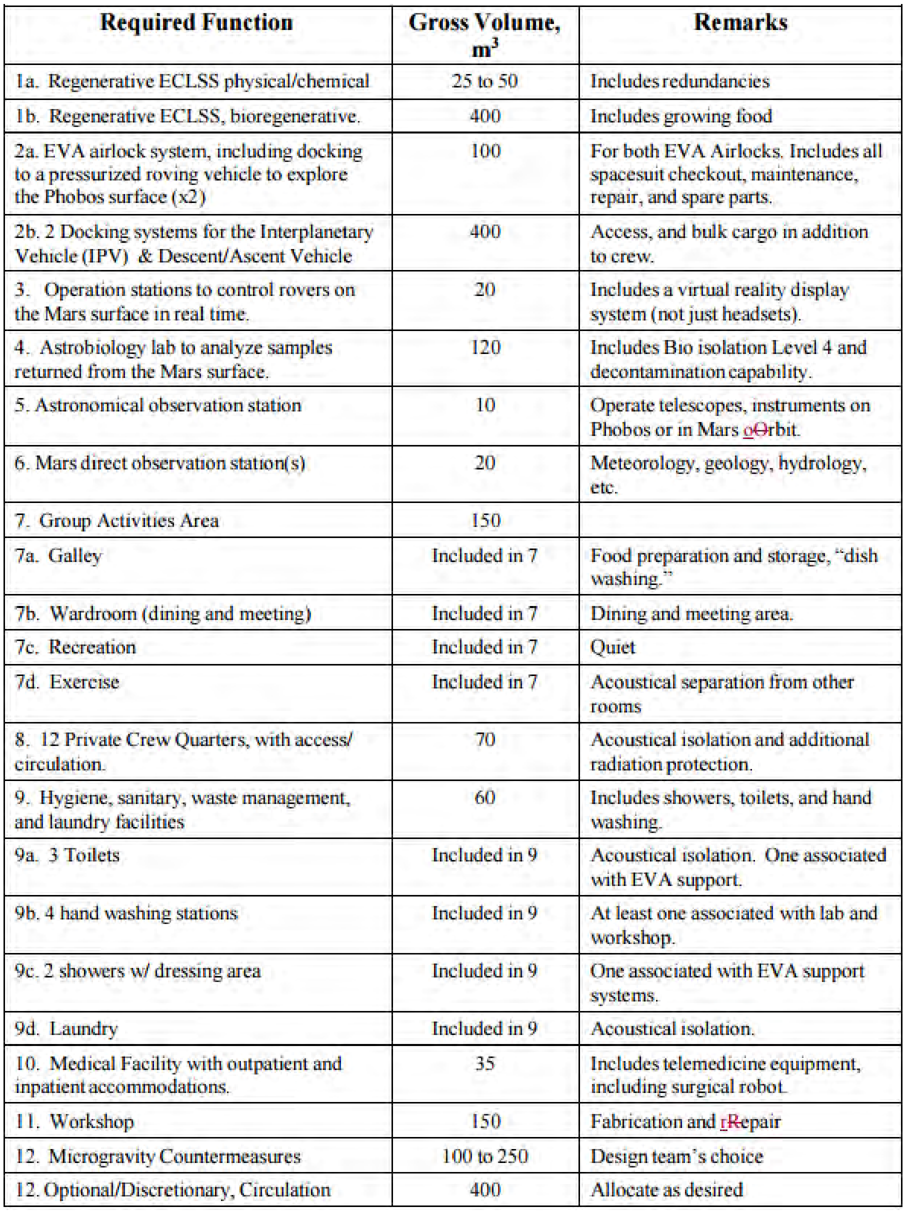

Required Function	Gross Volume, m^3	Remarks
1a. Regenerative ECLSS physical/chemical	25 to 50	Includes redundancies
1b. Regenerative ECLSS, bioregenerative.	400	Includes growing food
2a. EVA airlock system, including docking to a pressurized roving vehicle to explore the Phobos surface (x2)	100	For both EVA Airlocks. Includes all spacesuit checkout, maintenance, repair, and spare parts.
2b. 2 Docking systems for the Interplanetary Vehicle (IPV) & Descent/Ascent Vehicle	400	Access, and bulk cargo in addition to crew.
3. Operation stations to control rovers on the Mars surface in real time.	20	Includes a virtual reality display system (not just headsets).
4. Astrobiology lab to analyze samples returned from the Mars surface.	120	Includes Bio isolation Level 4 and decontamination capability.
5. Astronomical observation station	10	Operate telescopes, instruments on Phobos or in Mars o~~O~~rbit.
6. Mars direct observation station(s)	20	Meteorology, geology, hydrology, etc.
7. Group Activities Area	150	
7a. Galley	Included in 7	Food preparation and storage, “dish washing.”
7b. Wardroom (dining and meeting)	Included in 7	Dining and meeting area.
7c. Recreation	Included in 7	Quiet
7d. Exercise	Included in 7	Acoustical separation from other rooms
8. 12 Private Crew Quarters, with access/ circulation.	70	Acoustical isolation and additional radiation protection.
9. Hygiene, sanitary, waste management, and laundry facilities	60	Includes showers, toilets, and hand washing.
9a. 3 Toilets	Included in 9	Acoustical isolation. One associated with EVA support.
9b. 4 hand washing stations	Included in 9	At least one associated with lab and workshop.
9c. 2 showers w/ dressing area	Included in 9	One associated with EVA support systems.
9d. Laundry	Included in 9	Acoustical isolation.
10. Medical Facility with outpatient and inpatient accommodations.	35	Includes telemedicine equipment, including surgical robot.
11. Workshop	150	Fabrication and r~~R~~epair
12. Microgravity Countermeasures	100 to 250	Design team’s choice
12. Optional/Discretionary, Circulation	400	Allocate as desired

Figure 21: Volumetric requirements for specific areas of the base.

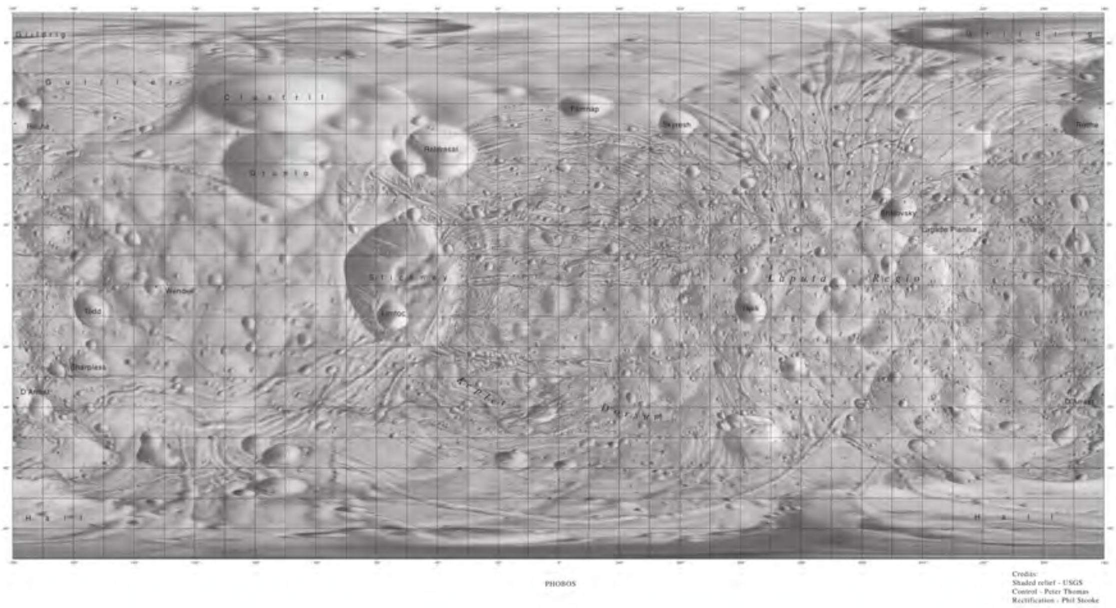

Figure 22: Detailed map of the surface of Phobos

Figure 23: Bigelo Aerospace Olympus Habitat