OPUS
of
Armor Paradise

Space Settlement Concept

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Abstract

The 21st century has seen a huge advancement in Science & technology from creating machines in life to creating life in machines. Space settlement has been a dream for many people from the time of first human space mission. The idea of Space settlement has opened gates for humans to create a life sustaining and friendly environment settlement in space.

"OPUS" Space settlement has been designed to house 1000 member society on-board providing sufficient supplies for life sustenance. Opus focuses deeply on the aspects of the settlement design, Life support systems and Energy, Water & Waste Management. Different techniques for extraction of resources present around Opus, Location chosen (L5), Defence system, Opus dangers and solutions give a basic idea for a space settlement. Emphasis for on-board Space research, astronomical observations, training, selection criteria, technical advancements are also mentioned in this report. With a well-built transportation and communication system, OPUS would be a functional and a small paradise of its own.
The main aim of OPUS is to provide a gateway for new possibilities and expansion using advanced technology.

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1 Introduction

1.1 | Motivation

The idea of a space settlement has crossed the minds of millions of people ever since the first person went into space. Sending a person only 58 years after we discovered how to make heavier-than-air objects fly is a truly marvelous achievement of mankind. Millions of children around the globe aspire to become an astronaut and fly into space, wanting to know what the cosmos really is. While a very select few have gotten the opportunity to do so, sometimes costing them their lives, these people continue to inspire us all with the hard work and dedication that they have towards becoming an astronaut.

Space settlements have been a popular idea in science-fiction for many years now. Movies like *Star Wars, Interstellar, First Man, Gravity, The Martian, Apollo 13, 2001: A Space Odyssey and web series like Lost in space, The 100, Away* and so many more have been inspiring many generations of aerospace engineers, space scientists and future astronauts. The closest thing to a space settlement that we as mankind have, as of October 2020, is the International Space Station (ISS). Being the single most expensive object ever made by mankind, and a true marvel of science, engineering and technology, the ISS has inspired us to create a space settlement concept of our own.

While the ISS was a major inspiration, it was not the only one. The National Space Society hosts a space settlement design competition every year. In this, people from all over the world submit their space settlement design concepts and the best one is selected to win this contest. NSS has been hosting this contest since 1995, and they have the winning concepts publicly available on their website. Going through these various designs, along with the ISS, was a massive inspiration for us to create a space settlement concept.

1.2 | Naming of the Settlement

We call our settlement as **OPUS** of Armor Paradise. **OPUS** refers to creative or artistic work. Armor indicates that settlement offers protective (armor), lovely (amor) environment in all aspects. Paradise is used to say our settlement is a place of exceptional happiness, contentment and fulfilment. Paradise is often considered as a 'higher place' above Earth, which is literally and technically true in our case.

1.3 | Aims and Objectives

The objective of this project was to come with a possible solution incorporating possible technologies to support a space settlement. The natural conviction of the public about such a settlement would be that such an idea is only limited to the realm of science-fiction. Keeping this in mind, the team started working on the project with the aim of creating a proposal which would be more reality than science-fiction. Given that sufficient monetary support is provided, the team has the belief that a space settlement could be set up, capable of sustaining a considerable amount of humans in space with the technology available now.

2

Location Selection

Location is a major factor to be considered for a settlement. The earliest human civilizations thrived on locations that were capable of sustaining civilization. Ample supply of water for agriculture, fertile lands for growing crops are some of the driving factors for early humans to set up civilizations [1]. Hence, before choosing the location for the settlement, multiple factors must be considered to come up with the most suitable spot to place the settlement.

2.1 | Planetary Settlement

A planetary or surface settlement refers to settlements that are set up on the surface of a planet or moon. This section details out the advantages of setting up colonies on other worlds with regards to specific key parameters.

2.1.1 | Resource Extraction

A surface-based settlement is advocated as a viable option for a long-term settlement. The *terrafirma* would help in scaling up the settlement by providing necessary resources that can be mined from the planet or moon as suggested by O'Neill (1979). The surface also provides ample space for a colony to expand as the population increases. The presence of water and other useful minerals on Moon and Mars(Diez (2018)) both of which are being actively considered for an outer space colony, is significantly present on the surface of the above-mentioned celestial bodies.

[1] https://www.nationalgeographic.org/article/key-components-civilization/

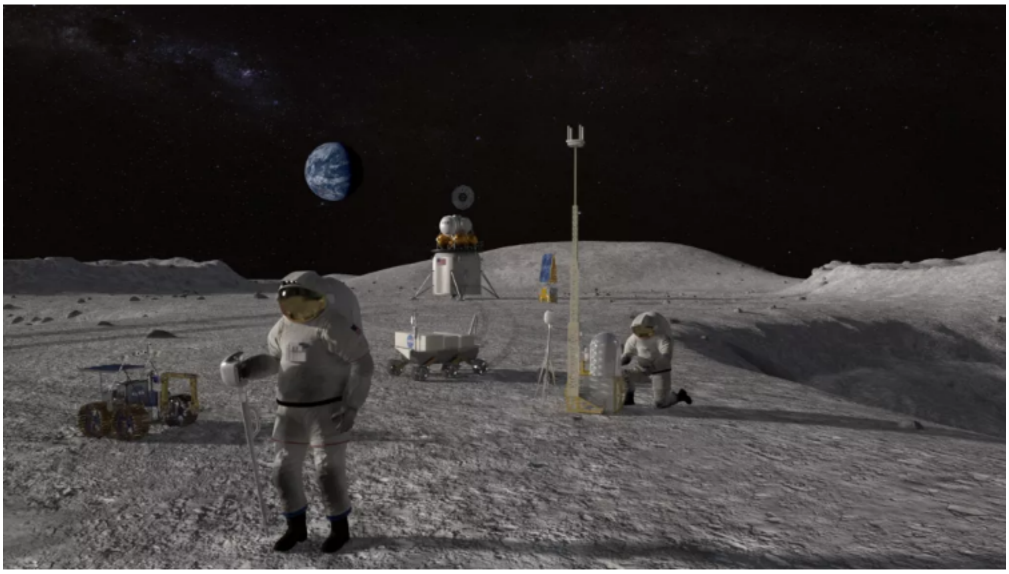

Figure 2.1: An artist rendering of Artemis program. Artemis is seen as a step before humanity colonizes Mars. Source: NASA

2.1.2 | Scope for Expansion

A settlement is not expected to stay localized but would grow both in population and size. Since surface-based settlement would have a whole new planet to explore, there are not any constraints to the expansion of the settlement on another planet. For an orbital station, there exist constraints to expansion. Lagrangian points like L4 and L5, even though stable, are littered with interplanetary dust. Due to the orbit stability, scientists only expect the dust-cloud, called Kordylewski cloud[2], to grow (Slíz-Balogh et al. (2019)) which could seriously hamper station keeping and expansion of the settlement. Expanding an orbital station also brings about other related complexities. Station keeping gets difficult as the size increases and in space, the settlement would not be able to operate any serious industries which means the settlement would have to still rely on Earth-based funds to operate.

2.1.3 | Scientific and Economic Prospects

Space research agencies and private companies around the globe are in an active race to colonize Mars with Lunar surface settlements acting as the proving ground before humans travel to Mars. Orbital stations that are planned now are to act as 'gateway' for missions and would not qualify as permanent settlements. Taking the example of

[2] `https://en.wikipedia.org/wiki/Kordylewski_cloud`

Artemis program, gateway stations[3] act as temporary habitation spaces and communication hubs. Surface-based settlements could heavily reward the scientific community with the amount of opportunity it provides the academia to widen the scope of scientific research. Exobiology, astronomy, planetary geology are some of the many such areas that could profit from a surface settlement.
Surface settlements offer opportunities for mining industries to mine other celestial bodies to support humankind's spacefaring ambitions. By investing in mining on other planets, asteroids, and moons, Earth would be relieved of the negative effects of mining. Pollution would not be a constraint for space mining which is advantageous for the mining industry.

2.1.4 | Space for Agriculture and Recreational Activities

The settlement is not expected to be a dull and joyless experience for the settlers. For a community to thrive it needs recreational activities, spaces to come together, medical facilities, educational institutions etc. A surface-based settlement would provide enough resources and space to provide to that. An orbital station would have to cut some corners in some aspects if it wants to meet such needs.

2.1.5 | Energy Considerations

For an orbital platform, there is a need for uninterrupted energy supply for the whole settlement. Considering the efficiency levels of solar panels(Green et al. (2019a)) it would require a huge solar cell array to produce enough electricity to power the station. However, if such a large array is put up, the radiation pressure[4] from the Sun would be significant enough to destabilize the orbit of the platform. This, in turn, calls for additional attitude maintenance thrusters or even engines for the station, making it very 'energy-intensive'. Such complexity does not even arise for a surface-based settlement. There is also a risk of space debris/meteoroids for an orbital platform and this would call for emergency orbital adjustments making it more energy-intensive.

2.1.6 | Radiation and Environmental Conditions

The concern regarding deadly cosmic and solar radiation is real for both orbital and surface-based settlements. Radiation shielding must be incorporated into any long-term space settlement. For an orbital platform, shielding is purely using structural members

[3] https://www.nasa.gov/gateway
[4] https://en.wikipedia.org/wiki/Radiation_pressure

which adds to the total size of the settlement. However, for a surface settlement, underground settlements are actively studied for Martian and Lunar settlements. Such underground systems would help in shielding the occupants from harmful radiation and also the ill-effects of the planet/moon's weather or environmental conditions. Underground settlements would also negate the threat of any meteorites.

2.1.7 | Gravity

While earth-like gravity can be simulated in space by rotating the station (which itself is a very complex maneuver), it can't be simulated on Moon or Mars. While the Moon has just 16.6% of Earth's g, Mars has a more reasonable 38%. If humankind is to progress as a space-faring species, we would have to take the risk associated with such low gravity[5] environments.

2.1.8 | Initial Investment

The investment for the project would be very huge. The settlement would have to operate for at least a few decades before Return of Investment can be expected.

2.2 | Orbital Settlement

Traveling out of Earth's Gravitation Field is like half the path of Space Destination is covered. Escaping from the Gravitational field and then entering into another (Planetary GField) has little virtue and high Energy Consumption. One cannot spin on the land continuously, its illogical thus Pseudo Gravity can't be generated continuously on the planetary surface. Implying Bone density reduction, Implying Human Body turning into Jelly! In Orbital Settlements Economy prosper due to lesser distances between Settlement and Earth. Economic structures in terms of Solar Radiation and Microwaves Trade can run Settlement economy.

2.2.1 | Resources

We can build a planetary base on the surface of Moon and Mars with robotic technology (Lewicki et al. (2013)) and we can propel the settlement to somewhere in space offering fewer space dangers and we can create normal gravity. We can also create more settlements from the lunar or planetary base for further expanded population and it's not

[5] `https://www.britannica.com/science/gravity-physics/Acceleration-around-Earth-the-Moon-and-other-pla`

Figure 2.2: The International Space Station is the closest thing humans have to an orbital settlement, Credit: Roscosmos/NASA

necessary to keep the settlement on planetary base to use the resources and to construct another settlement or to dig the resources.

2.2.2 | Agriculture

We can use hydroponic and aeroponic technologies where we don't need actual soil to cultivate. Depending on the surface to do cultivation could be a grave danger when we can't exactly predict its nature and environment.

2.2.3 | Atmosphere

We can create an artificial atmosphere inside our settlement through chemical reactions. We can't risk if don't know the complete details of whether the atmosphere exists and if it would support the survival. (We can only create an atmosphere in an enclosed region and the settlement must be self-sustainable i.e., we need to create almost everything artificially).

2.2.4 | Economic and Scientific Prospects

In-space assembly of satellites(Zimpfer et al. (2005)) is a growing sector in the field of space engineering. OPUS can build satellites in space to explore the space and can also

mine precious metals with the resources available on the surface of planets and asteroids. Mining and in-space assembly would provide a considerable amount of economic boost to the settlement.
Space based research could be effectively done on a permanent settlement like OPUS which could house equipment, machinery to do cutting-edge research on space which was unavailable earlier.

2.3 | Location of OPUS

Finally, we chose orbital based space settlement. Then the question is what would be the best feasible place. We chose the Earth-Moon Lagrangian point 5 (L5) as our location. Lagrange points are positions in space where objects sent there tend to stay put. At Lagrange points, the gravitational pull of two large masses precisely equals the centripetal force required for a small object to move with them.

2.3.1 | Lagrangian Points

Lagrangian points[6] are orbital points in a two-body system where the gravitational influence of both the orbiting bodies cancels out. Objects placed in these points would continue to stay there for long periods of time without any need of orbital corrections.

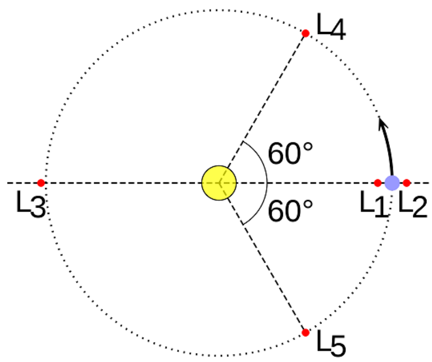

Figure 2.3: Lagrangian Points in a Two-Body system, Credit: Wikipedia

Unstable Lagrangian Points : The Unstable points are L1, L2, and L3. They lie along the line connecting the two bigger mass objects. These points are said to be unstable because the satellites or probes parked in these orbits would require multiple course

[6]https://solarsystem.nasa.gov/resources/754/what-is-a-lagrange-point/

corrections over its stay to prevent itself from falling into the gravity wells. This poses a huge disadvantage for a space settlement that would be forced to correct the orbit frequently which is very energy-intensive.

Stable Lagrangian Points : The Stable points are L4 and L5. As seen from Earth, L4 and L5 lie at 60 degrees ahead and behind the Moon. L4 and L5 are resistant to gravitational perturbations. If the settlement is placed here, frequent orbital corrections are not necessary.

2.3.2 | Why L5?

The major reason for choosing L5 is its stability(Sood and Howell (2016)). A satellite or probe in these 'stable' points suffers less gravitational influence from Earth and Moon and would stay in the location with minimal station-keeping procedures. The points also provide another major advantage to settlement placed here, which would be listed out below. Closeness to Earth and Moon - soon after achieving orbit, a spacecraft could be directed to L5 easily without spending as much fuel, as required to land on the Moon. This proves useful in multiple ways like providing a stable and unrestricted communication with Earth bases or Lunar industrial bases. The closeness would reduce the overall launch cost too since per kilogram cost would not rise for L5 as much as predicted for Moon.

Resource availability - Owing to the closeness of the settlement to Earth and Moon, more resources can be brought in from Earth and Moon for the expansion of the settlement. This would allow for easy expansion of the settlement without much expense incurred. For other lunar or Martian settlements, the cost associated with it would be very huge. The availability of water and Helium - 3 (Johnson et al. (1999)) on the Moon is also a viable prospect for the long term running of the settlement. Ideal location for a propellant depot: a stable point like L5 could act as a suitable location for a supply depot for deep space missions.

Suitable construction base for satellites - Using resources mined from Moon and stray asteroids, the settlement can produce satellites that could be launched towards any destination. This heavily cuts down the launch cost incurred by research agencies as the delta-V required for crossing the atmosphere is huge. By saving up on that fuel, missions with more scientific payloads could be launched.

Perfect destination for space-based astronomy and research - A Perfect destination for space-based astronomy and research- L5 point has been a top contender for space-based astronomical missions[7] over the past years. Space-based telescopes like Hubble,

[7] `https://www.esa.int/Safety_Security/Lagrange_mission`

Kepler, Spitzer have contributed so much to space astronomy. A permanent settlement in space could add on to that providing much better opportunities for academia. As we have seen from the case of the ISS, micro-gravity research has had many implications in real life. A permanent settlement could host research hubs with scientists being able to study in a micro-gravity environment.

3

Design

3.1 | Form of the Settlement

We chose hollow cylinder and torus as our main shapes for the settlement. Cylinder offers a large surface area for habitation, energy production and provides ample amount of space for storage. Torus effectively reduces the volume and the material required for the construction.

Figure 3.1: Lateral side of OPUS

Figure 3.2: Inner arrangement of OPUS

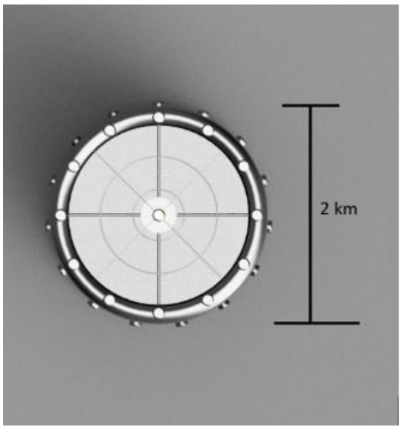

Figure 3.3: Top View of OPUS

Building sequence : : In the initial stage of the building, the first structure to be built would be the micro gravity cylinder followed by the spokes. The micro gravity will be built by joining many small sections together and ultimately forming the whole micro-gravity cylinder. The micro gravity cylinder will be having its own temporary life support system. For energy, temporary solar panels can be placed on the surface of micro-gravity cylinder. After the building of spokes on both the end, torus will be built so that industries can start using the energy produced by the temporary solar panels of micro gravity cylinder. After that, the outer non-rotating cylinder will be built with solar panels and gradually shift from temporary solar panels to main solar panels and complete the outer cylinder.

Once the outer cylinder is completed, we can get the full energy from solar panels and start the construction of habitual cylinders by building it from lunar base and settlement's industry and then assembling it at its place. Rotating cylinder of the settlement will be built next followed by the inner spokes and the glass section. During this time the expansion cylinder will also be built. The glass on both the side will also be fixed and the life support system will be built throughout the settlement. Once the rotating cylinder is built and life support starts to function, hexagonal blocks will be built, and transportation system will be laid throughout the settlement. Once the transportation system will function, construction of buildings can start such as hospitals and basic house in the blocks after planning.

DESCRIPTION	Value
Height of Cylinder	2.2km
Radius of Habitation Cylinder	1km
Radius of Micro-gravity cylinder	300m
Radius of future expansion cylinder	950m
Total usable area of habitation cylinder	13.5 km^2
Total usable area of all 3 torii	21 km^2
Total usable area of micro-gravity cylinder	4.71 km^2
Area of future expansion cylinder	13 km^2
Radius of torus	200m
Approx. gap between rotating and non-rotating cylinders	12.5m - 13.m
Volume of micro-gravity cylinder	6.22×10^8 km^2
Volume of Habitation cylinder	6,73,530,000 m^3
Volume of expansion habitation cylinder	4.42×10^9 km^3
Volume of torus	1.74×10^9 km^3
Rotation speed for 1G torus and habitation cylinder	0.94 RPM
Rotation speed for expanded habitation cylinder	1.045 RPM
Initial Population density	75 / km^2

Table 3.1: Specification of OPUS Settlement structure

3.2 | Allocation of Modules

3.2.1 | Living Area

For 1000 people 14km square area is provided on the inner surface of the cylinder. The cylinder is divided into 3-4 parts (or even more as required) by transparent glass. Each part can have its own atmosphere and temperature and if something happens in one part, that part can be evacuated. In case of any disease, the part can be sealed, and people can be shifted to another sections. The industries towards the infected part or damaged part can still be accessed using the micro gravity cylinder. We can also have blocks on the surface which will be hexagon in shape. Each block can have many houses

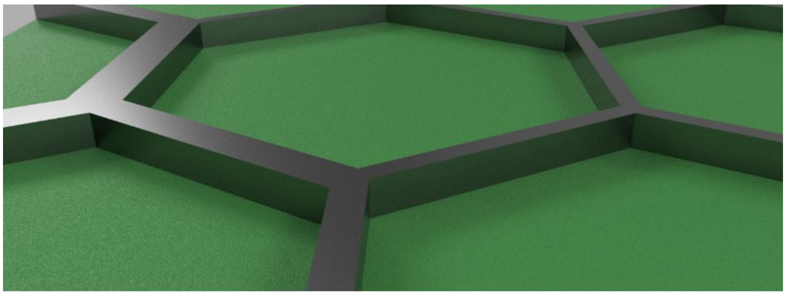

Figure 3.4: A single Habitation Block of OPUS

or buildings. Some blocks can be dedicated to recreational parks and some can be dedicated to ponds and parks and some cane be dedicated for shopping and some can be only for residence. All the areas will be well connected.

Each section in the cylinder will have its own life support system so that if something happens to one section, other section won't be affected. There are many storage areas to set-up life support system in the settlement. And there are many possible ways to set it up at those area. The living area will have normal vegetation such as shrubs, grassed and trees. The trees and vegetation will also be playing major role in producing oxygen. There will be artificial sunlight in the settlement using LED.

3.2.2 | Agricultural Area

The agriculture can be done in the same place where people are living where people can farm and grow and later sell them or we can do agriculture in one part of the torus separately. There could be a part of torus where agriculture can be done for special plants which requires special treatment and special temperature. Agriculture can be done both in torus and habitual area simultaneously. The plants will be provided artificial sunlight using LEDs. If agriculture is done in a part of torus, that part can have window for allowing artificial sunlight to enter whenever possible.

3.2.3 | Industrial Area

The industries will be separated from living area and it will be in the torus. The torus will be divided into different parts for different industries. Each industry will have their own entry and exit and according to the partitions towards the habituate area and each industry can have their own docking areas. The industrial area will also have connection to micro gravity area and the storage area between both the rotating cylinders, both the area for storage can be used for industries. The industries will be a separate unit

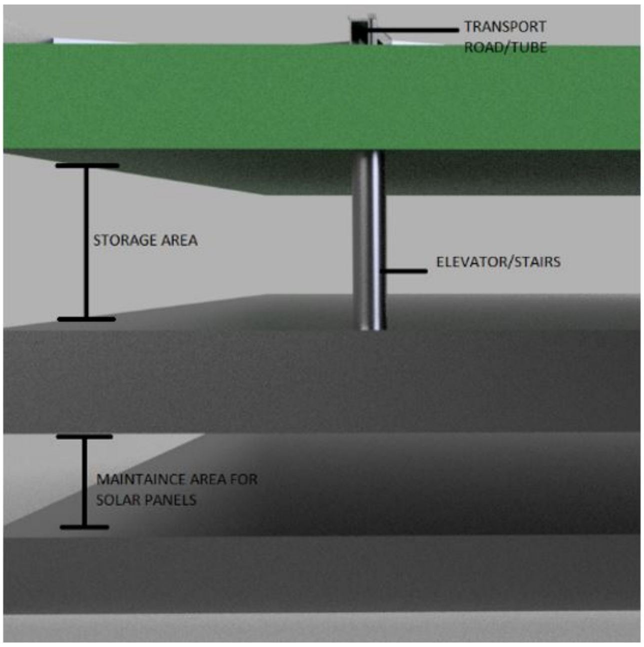

Figure 3.5: Cross-sectional view

and hence vibration wont effect the habitual area since magnetic bearings will be used. To reduce the vibration from traveling from one industry to another, each industry will have chamber and those chamber will be inside the torus. There will be magnetic suspension or mechanical suspensions which will absorb the vibrations and won't allow it to spread in thee torus.Here the inner layer is for chamber, while the outer layer is the torus. The gravity can be varied in industrial area and even in agricultural area if it's done in torus by varying the rpm of individual torus.

3.2.4 | Micro-gravity Area

There will be a very large micro-gravity area at the center axis of cylinder. It will be divided into many parts and it will also be used for storage and transportation since it will be easy to move heavy material in micro-gravity. The micro gravity area will also be connected to many parts of the living area through spokes for transporting raw materials. We can also have area where we can simulate space walking and give training to people for space walking. The storage of axillary power batteries can also be stored in this area. We can also have area where we can create vacuum areas where food can be stored for very long time. The micro gravity area can also be divided into many parts and each part will have their own function. The micro gravity cylinder also have exit

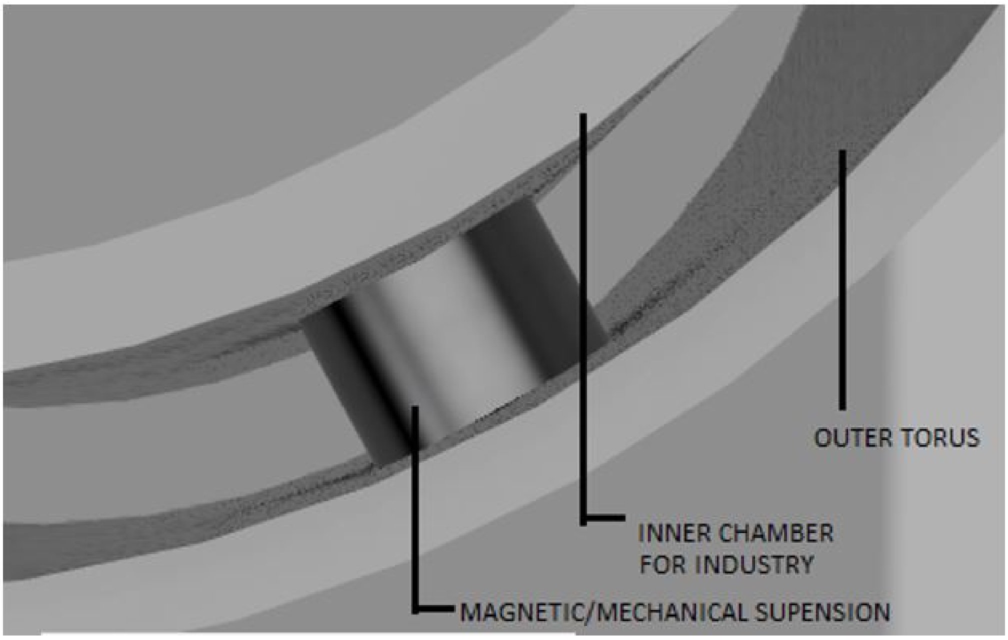

Figure 3.6: Magnetic suspension system of OPUS

way directly to space for escape pods which can be used to evacuate the settlement in case of emergency. The escape pod area will be present at both the ends of the micro-gravity tube and it can be accessed easily from habitual and industrial area in case of emergency.

3.2.5 | Storage Area

There are plenty of storage areas in this settlement. The largest storage area is the area between the outer cylinder and inner cylinder. The area is more than 14 km^2 and the height is about a three-storey high building which will be 15-17meters.

The extra cylinder for further expansion can also be used for storage and the area is about 13km^2. There can be storage areas in micro gravity area also where heavy objects can be stored, and it can easily be moved in micro- gravity. The total storage area is more than 27km^2. The storage area can be accessed by using the same elevator or stairs for going to the walking path around hexagon blocks. Life support system can be placed in the storage area which will be in the gap between the cylinders and also the storage area of micro-gravity cylinder. The cross-section view is shown in the image.

3.3 | Rotating and Non-Rotating Segments

There will be three main rotating parts. The two torus and the cylinder. All the three parts are independent. The outer cylinder which have solar panels will be stationary and the inner cylinder which will have living area will be rotating at 0.94 RPM. The torus will also be rotating 0.94 RPM. The gravity can be varied by changing the rpm. The micro-gravity won't be rotating but to create a little bit gravity, it can be rotated for different purposes and experiments. The rotation of these parts will be on magnetic bearings where there won't be friction and it is easy to maintain. The rotation will be controlled by flywheels.

Rotation Required for Simulating Gravity

For habitat cylinder and torus, for producing g = $9.8ms^-2$ with radius 1000 m:

Equation used: G-force = $1.12 \times R \times (RPM/1000)^2$ $\sqrt{(9.8 \times 1000)} = 98.99ms^-1 = 0.94RPM$

For expansion cylinder, $\sqrt{9.8 \times 950} = 96.48ms^-1$ = 0.939RPM

Flywheel and Control of RPM

There will be a ring made of dense material and it will be mounted on supports which will connect it to the cylinder. The ring will be connected to electric motors which will rotate it at particular RPM so that the cylinder will rotate in opposite direction of the ring. There can be many rings on one cylinder. Each rotating part will have its own ring.

Axis of Rotation

The axis of rotation is the central axis of the cylinder. This is the common axis for all the rotating parts in the settlement. The orientation of axis will be discussed in orientation part. The rotation of the parts will be controlled by flywheels.

3.4 | Volume of Atmosphere

The volume of the atmosphere/air inside is reduced by adding extra cylinder inside whose radius will be 950 m. This cylinder will also help in future expansion of settlement by adding one more independent cylinder to live. When the extra cylinder will not be in use for expansion, it can be used for storage. Initially the volume of air will be required for habitual cylinder will be 673,530,000 m^3. We can't provide atmospheric gases to the whole volume also it will increase the weight on the settlement. So, we are going to seal the settlement to get a considerable amount of volume.

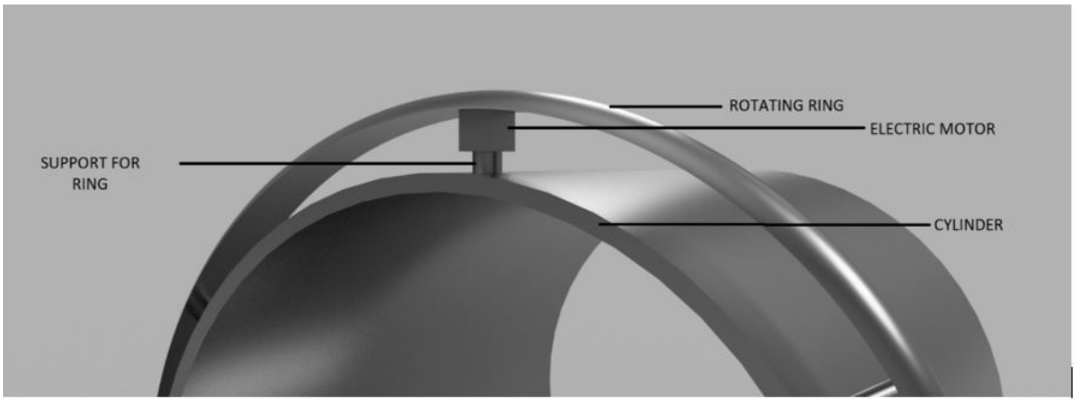

Figure 3.7: Flywheel ring of OPUS

3.5 | Orientation

The axis of rotation of the settlement will be on the axis of the cylinder. The orientation of the settlement will be in such a way that the axis of rotation will always be perpendicular to the sun-rays falling on the settlement and the orbit. In this way the solar panels will always receive sunlight. The orientation is shown in the image.
Note: All images under Design chapter are designed by OPUS team and rendered in Fusion360.

4

Material Selection

4.1 | Factors regarding Selection of Materials

It requires the knowledge of applied material sciences in order to fabricate the materials having high tensile strength, shock absorption, electric and chemical resistance, and radiation protection etc. The sensors technology is needed for installing various sensors like gas leakage detector, temperature detector, fire detector, humidity sensors etc. at different positions of the settlement.

Creation of natural views can prevent the residents from the psychological problems(Velarde et al. (2007)) like solipsism and hysteria. For which we will have to use transparent material while constructing the settlement. For this the knowledge of materials like super ionic solids and properties of light like reflection, refraction, transmission etc. It requires high tensile strength, shock absorption, electric and chemical resistance, and radiation protection etc.

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The selection of materials for different layers will be done by considering their properties, so that the layers of outer wall may disperse most of the debris and radiations striking the settlement. The layers of Super adobe and Silica aerogel in the wall and

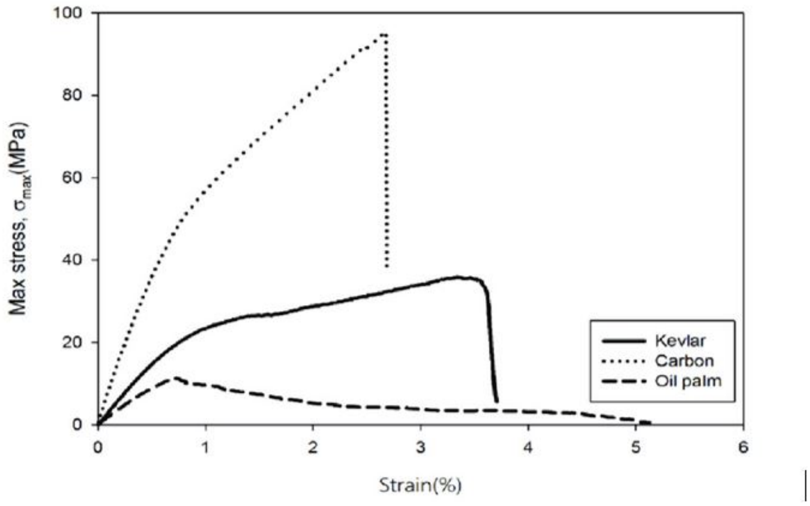

Figure 4.1: Stress vs Strain plot for Kevlar, Carbon& Oil palm, Credit: Jack Holman, Experimental Methods for Engineers,8th Edition

Lead crystal glass in the window will provide protection from radiations inside the settlement(Miller et al. (2009)). In addition, to the layers, the plasma shielding around the periphery of the torus will also provide protection from radiations. When the potential will be sup-plied to the gas (Argon) it will ionize and repel the radiations by its induced magnetic field(Townsend (2001)). It will reduce the radiation intensity to less than 0.1 rem which is very less than the acceptable radiation dosage. Consecutive layers of Nextel and Kevlar-49 in the outer wall and lead crystal glass in the window will shield the settlement against debris.

4.2 | Material Suggestions

OPUS space settlement can be built from much the same kinds of materials we use here on Earth, Steel, Titanium, Aluminum, Glass and even Concrete. Plastics would probably be the one difficult one since oil is a biotic substance, but these can be synthesized chemically from mostly Carbon and Hydrogen the latter of which can be extracted from water ice one of the main constituents of comets.

Some of the most commonly used materials for space satellites and stations are:

1. **Kevlar** : a material used in bulletproof vests and armor, is an incredibly lightweight and strong material making it perfect for space travel. In addition to its high strength, Kevlar also is incredibly resistant to temperature changes making it ideal

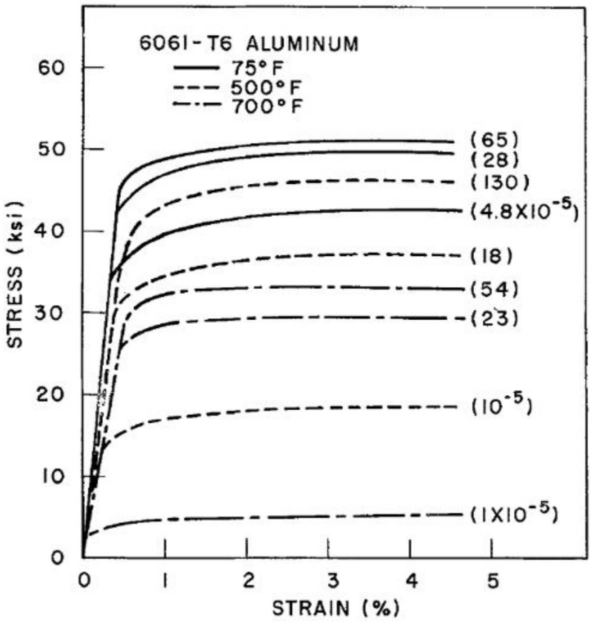

Figure 4.2: Stress-Strain plot for 6061 T6 Aluminium, Credit: Jack Holman, Experimental Methods for Engineers,8th Edition

for the orbiting structures that move in and out of the sun's direct heat as they orbit the Earth . Kevlar's toughness and durability also makes it ideal for protecting artificial satellites from dangerous orbital debris(Destefanis et al. (2014)).
Tensile Strength: 40.3 MPa to 81.80MPa refer 4.1

2. **Aluminium** : Another material that often used in space is Aluminium as it is light in weight. On its own, aluminium is not incredibly strong but when combined into alloys with other metals into it becomes much stronger. Aluminium alloys(Schwingel et al. (2007)) are often strong and lightweight enough to be functional in space structures and satellites. Aluminium is used for the shutters on the windows of the International Space Station in order to protect the windows from impacts. These windows already are made with glass thicker than panes of glass on earth and often with twice as many panes. However, the additional aluminum shutters guarantee the safety of the astronauts within.4.2 **Shear Modulus**: 25-34 GPa
Tensile Strength: 75-360 MPa
Young's Modulus: 68-88.5GPa

3. **Carbon Composites** : Filament wound composite structures are also used extensively for space applications. Solid rocket motors, often used as upper stages for spacecraft, are nearly always filament wound from high strength carbon fiber(Krenkel and Berndt (2005)). Pressurized tanks used for liquid hydrazine fuel and various gasses are typically very thin wall metallic liners wrapped with carbon fiber in epoxy resin. **Ultra-high-modulus**: type UHM (modulus >450Gpa)
   Super high-tensile: type SHT (tensile strength > 4.5Gpa)

4. **Nomex Felt** : For the coldest areas of the outer part of our design that experienced temperatures no higher than 371 degrees Celsius (700 degrees Fahrenheit), we can propose this material. NASA used reusable surface insulation made of coated Nomex felt(Kennedy et al. (2007)). The middle and tail end of the craft in addition to the payload doors had this coating. Nomex strands cannot align during filament polymerization and has less strength: UTS- 340MPa. It has excellent thermal, chemical, and radiation resistance for a polymer material.

5. **Thermal Glass** : The space shuttles needed windows that would allow the astronauts to see out of clearly without allowing heat to pass through the material. Thermal glass proved the solution to protect the astronauts from both high and low temperatures around the windows and the pressures of space travel. **Compression resistance**: 800 - 1000 MPa
   Modulus of elasticity: 70 000 MPa
   Bending strength: 45 MPa
   Thermal conductivity: 0.8W/mK
   Thermal expansion: 9.10-6 $K^{-}1$

6. **Plastics** : Would probably be the one difficult one since oil is a biotic substance, but these can be synthesized chemically from mostly Carbon and Hydrogen the latter of which can be extracted from water ice one of the main constituents of comets.
   Flexural strength: 10–15 MPa at 28 days
   High early strength formulation (flexural strength): 10 MPa after 24 hours
   Young Modulus: > 2 GPa

Although in reality all parts and material undergo non- destructive testing and analysis before material selection, those data can actually be used by us directly. E.g.: NASA selected infrared flash thermography as the method to determine the structural integrity of the reinforced carbon-carbon components. Thermography was a fast, non-contacting, one-sided application that was easy to implement in the Orbiter's servicing environment.

Other Important Requirements

- **Thermal Protection System Materials** : TPS materials[1] which protect the space settlement from the heat of re-entry and also cold temperatures experienced when in space, a temperature range of -121 °C to 1649 °C. There is a complicated array of materials which comprise the TPS to help keep the astronauts and payload safe during flights.
- **Reinforced Carbon Composites** : This composite is able to withstand high temperatures and was used to protect areas of the design body that would rise above 1260 °C. (For temperatures below this, NASA used rigid silica tiles or fibrous insulation)

4.3 | Feature and Function of Materials

- The layers of Super adobe and Silica aero-gel and lead crystal glass in the window will provide protection from radiations inside the settlement. In addition, to the layers, the plasma shielding around the periphery of the torus will also provide protection from radiations.
- Consecutive layer of Nextel and Kevlar-49 in the outer wall and lead crystal glass in the window will shield the settlement against debris.
- Ceramics made from lunar or asteroid soil can be employed for a variety of manufacturing purposes. These uses include various thermal and electrical insulators, such as heat shields for payloads being delivered to the Earth's surface.

[1] https://www.nasa.gov/centers/ames/research/humaninspace/humansinspace-thermalprotectionsystem.html

5

Resource Extraction and Mining

For OPUS to sustain itself, it must generate enough revenue in the form of products or services which can be traded with Earth. One of the primary and most lucrative undertaking for a space settlement to generate revenue would be to partake in space mining.

Studies estimates that there is an abundance of minerals on asteroids and they are in quadrillions(Lewicki et al. (2013)). This makes asteroids a hot-spot for mineral mining. For space exploration and interplanetary travel mining of resources is an important factor to sustain. NASA has been working on mining of the Moon and asteroids mining for quite some time. And according to NASA mining can be done using autonomous robots and humans. Autonomous robots or swarm robots are small and smart robots that are developed by NASA for Martian mining. These robots produced and deployed in groups as they function more efficiently together(Zacny et al. (2013)).

Governments and industrial players are investing more on space-based ventures with the final aim at exploiting the resources of other planetary bodies. It provides more impetus to the idea of space mining as a profitable business for not only a space-based settlement but also to Earth based companies.

5.1 | Monetary Benefits

Asterank[1], a website developed by a former engineer from Google and later purchased by Planetary Resources estimates the value of asteroids. Of the major asteroids listed out, some are already being sampled to identify the composition, taking examples of **JAXA's Hayabusa-2** mission to *'162173 Ryugu'* and **NASA's OSIRIS-Rex** mission to

[1] `https://www.asterank.com/`

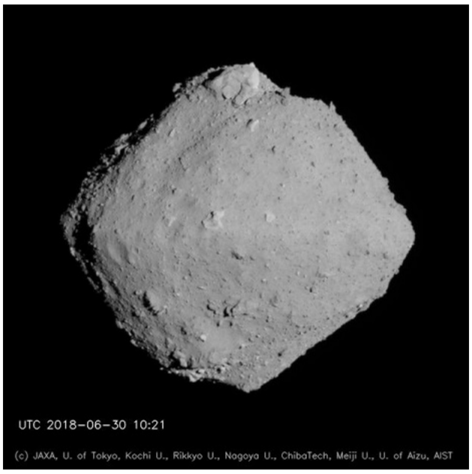

Figure 5.1: Asteroid *Ryugu* photographed by JAXA's Hayabusa - 2, Credit: In pic

Bennu, both of which are classified as near-Earth asteroids. These asteroids are already being valued at $82.76 billion and $669.96 million respectively.

Near earth asteroids are found to be abundant sources of metals, rare metals(Kargel (1994)) like platinum and even water(Takir et al. (2016)). The asteroids found in the Asteroid belt, the space between Mars and Jupiter filled with asteroids, are rich in rare and heavy metals which are not so abundantly found on Earth's crust.

5.2 | Resource availability

Moon : Solar power, oxygen, and metals are abundant resources on the Moon. Elements known to be present on the lunar surface include, among others, hydrogen (H), oxygen (O), silicon (Si), iron (Fe), magnesium (Mg), calcium (Ca), aluminum (Al), manganese (Mn) and titanium (Ti)(Prettyman et al. (2006)). The Moon is the closest near-Earth object at a distance of around 385,000 km, bound by the Earth's gravity. Analysis of the Moon and the 400 kg of lunar rock and regolith surface material already brought back to Earth indicate that it is rich in important and useful elements.

The minerals, metals and gases found on the Moon, asteroids and other near-earth objects can be mined to be either used directly in space, as a source of energy, or to be used in building rockets, satellites and other equipment beyond Earth's atmosphere. Some may be brought back to Earth to support the economic needs of a growing population. The Moon and NEOs contain volumes of every chemical element needed to support an affluent and fully recycling population.

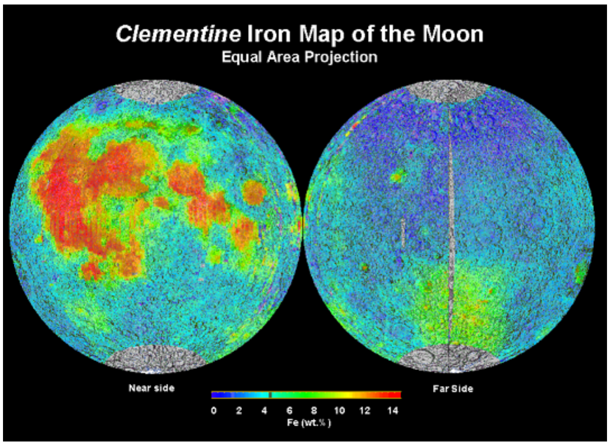

Figure 5.2: Iron map of Moon generated from *Clementine* mission, Credit: NASA

Mars : Mineral resources are in abundance as well, including iron, titanium, nickel, aluminum, sulfur, chlorine and calcium. Clay-like minerals are also ubiquitous in the Martian surface soils, making the manufacturing of ceramics for pottery possible(Vaniman et al. (2014)).

Some of the resources that can be mined are aluminum, cobalt, iron, manganese, nickel and titanium can be used in construction. Water, nitrogen and oxygen can be used to sustain space travelers and to grow plants. Carbon, hydrogen and oxygen are useful rocket propellants. Rare Earth Elements, used in everything from catalytic converters to smartphones, could be brought back to Earth. They include iridium, platinum, silver, osmium, palladium, rhenium, rhodium, ruthenium and tungsten. Difficulties include

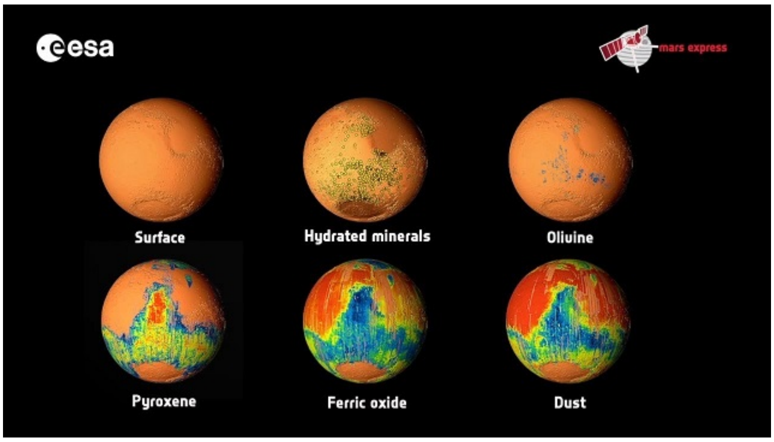

Figure 5.3: Mars Mineral Atlas generated by *Mars Express* mission, Credit: European Space Agency

the high cost of spaceflight, unreliable identification of asteroids which are suitable for mining, and ore extraction challenges(Ross (2001)). Thus, terrestrial mining remains the only means of raw mineral acquisition used today. If space program funding, either public or private, dramatically increases, this situation may change as resources on Earth become increasingly scarce compared to demand and the full potentials of asteroid mining—and space exploration in general—are researched in greater detail.

Processing in-situ for the purpose of extracting high-value minerals will reduce the energy requirements for transporting the materials, although the processing facilities must first be transported to the mining site. In-situ mining will involve drilling boreholes and injecting hot fluid/gas and allow the useful material to react or melt with the solvent and extract the solute. Due to the weak gravitational fields of asteroids, any activities, like drilling, will cause large disturbances and form dust clouds. These might be confined by some dome or bubble barrier. Or else some means of rapidly dissipating any dust could be provided.

5.3 | Asteroid Mining

Asteroids can be a good source of resource provider for the future us. The location of our settlement does have Trojan asteroids present which could be excavated and the extracted water could be used in our settlement.

5.3.1 | Extraction Techniques

- **Optical Mining** - This method is a part of In-Situ Resource Utilization used to excavate minerals and water from the asteroid(Dreyer et al. (2016)). APIS (Asteroid provided in-situ systems) is one of the missions by Team Astra that has worked on this technology to extract more minerals in space itself. The mission targets to capture an asteroid into an inflatable bag such that high-powered solar energy could pass through it such it breaks up the asteroid and the materials are extracted from it.

  A high temperature resisting bag material is used to capture the asteroid with a small port with a sliding sleeve for telescoping light tube. The volatiles are cryopumped through a multi-meter diameter high-capacity filter system embedded in the lightweight inflatable tube attached to it to act as a passively cooled thin film enclosure where the ice freezes out for storage, transport, and use. These inflat-

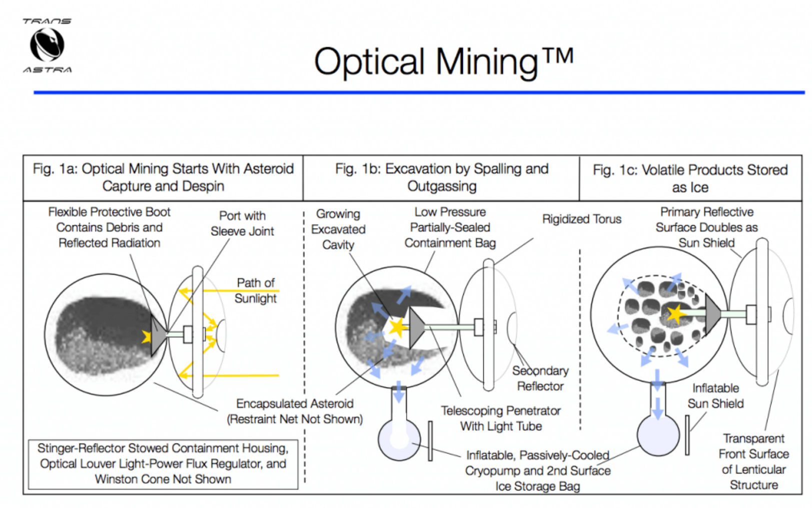

Figure 5.4: Optical Mining process, Credit: TransAstra

able bags store up the water and minerals that are extracted from the asteroid are freezed for the future use.

The hollow spherical surface attached to the spacecraft has can capture about 10-15m in height asteroid. The asteroid is further broken into pieces and then the samples are collected. Through this technique about 100MT tone of water can be extracted. At L5 there are Trojan asteroids could be mined using the optical mining technique or even the asteroids placed in the Low Earth Orbit could be used. This would decrease the distance of transportation as compared to the resources generated from Moon.

- **Surface Mining** - On some types of asteroids, material may be scraped off the surface using a scoop or auger, or for larger pieces, an "active grab."
- **Shaft Mining** - A mine can be dug into the asteroid, and the material extracted through the shaft. This requires precise knowledge to engineer accuracy of astro-location under the surface regolith and a transportation system to carry the desired ore to the processing facility.
- **Magnetic Rakes** - Asteroids with a high metal content may be covered in loose grains that can be gathered by means of a magnet
- **Heating** - For asteroids such as carbonaceous chondrites that contain hydrated minerals, water and other volatiles can be extracted simply by heating.

- **Extraction using the Mond process** - The nickel and iron of an iron rich asteroid could be extracted by the Mond process[2]. This involves passing carbon monoxide over the asteroid at a temperature between 50 °C and 60 °C for nickel, higher for iron, and with high pressures and enclosed in materials that are resistant to the corrosive carbonyls. This forms the gases nickel tetracarbonyl and iron pentacarbonyl - then nickel and iron can be removed from the gas again at higher temperatures.

5.3.2 | Energy to extract Materials

We took the idea from Radioisotope thermoelectric generator, which has been used on many space probes and on crewed lunar missions. Small fission reactors for Earth observation satellites, such as the NASA KRUSTY 6.5 nuclear reactor, that is a potential power source for robotic mining. But then the team collectively decided to not go ahead with the proposed idea as Nuclear reactor is a threat if it is part of the settlement, we can use it on Lunar base or Martian base to get the energy to extract resources.

5.4 | Space Manufacturing

In-Space Manufacturing (ISM)[3] involves a comprehensive set of processes aimed at the production of manufactured goods in the space environment. ISM is also often used interchangeably with the term in-orbit manufacturing given that current production capabilities are limited to low Earth orbit.

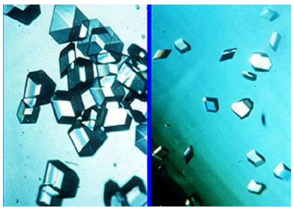

Figure 5.5: Insulin crystals grown in outer space(left) and on Earth(right), Credit: NASA

There are several rationales supporting in-space manufacturing:

- The space environment, in particular the effects of micro-gravity and vacuum, enable the research of and production of goods that could otherwise not be manufactured on Earth.

[2] https://en.wikipedia.org/wiki/Mond_process
[3] https://www.nasa.gov/oem/inspacemanufacturing

- The extraction and processing of raw materials from other astronomical bodies, also called In-Situ Resource Utilization (ISRU) could enable more sustainable space exploration missions at reduced cost compared to launching all required resources from Earth.
- Raw materials could be transported to low Earth orbit where they could be processed into goods that are shipped to Earth. By replacing terrestrial production on Earth, this is sought to preserve the Earth.
- Raw materials of very high value, for example gold, silver of platinum, could be transported to low Earth orbit for processing or transfer to Earth which is thought to have the potential to become economically viable

Due to speed of light constraints on communication, manufacturing in space at a distant point of resource acquisition will either require completely autonomous robotics to perform the labor, or a human crew with all the accompanying habitat and safety requirements. If the plant is built in orbit around the Earth, or near a manned space habitat, however, telecheric devices can be used for certain tasks that require human intelligence and flexibility.

Solar power provides a readily available power source for thermal processing. Even with heat alone, simple thermally-fused materials can be used for basic construction of stable structures. Bulk soil from the Moon or asteroids has a very low water content, and when melted to form glassy materials is very durable. These simple, glassy solids can be used for the assembly of habitats on the surface of the Moon or elsewhere. The solar energy can be concentrated in the manufacturing area using an array of steerable mirrors.

The availability and favorable physical properties of metals will make them a major component of space manufacturing. Most of the metal handling techniques used on Earth can also be adopted for space manufacturing. A few of these techniques will need significant modifications due to the micro-gravity environment.

Various metal-working techniques can be used to shape the metal into the desired form. The standard methods are casting, drawing, forging, machining, rolling, and welding. Both rolling and drawing metals require heating and subsequent cooling. Forging and extrusion can require powered presses, as gravity is not available.

Electron beam welding has already been demonstrated on board the Skylab, and will probably be the method of choice in space. Machining operations can require precision tools which will need to be imported from the Earth for some duration. New space manufacturing technologies are being studied. The methods being investigated include coatings that can be sprayed on surfaces in space using a combination of heat and kinetic energy, and electron beam free-form fabrication of parts.

5.4.1 | Material properties in the space environment

There are several unique differences between the properties of materials in space compared to the same materials on the Earth. These differences can be exploited to produce unique or improved manufacturing techniques.

- The micro-gravity environment allows control of convection in liquids or gasses, and the elimination of sedimentation. Diffusion becomes the primary means of material mixing, allowing otherwise immiscible materials to be intermixed. The environment allows enhanced growth of larger, higher-quality crystals in solution.
- The ultra-clean vacuum of space allows the creation of very pure materials and objects. The use of vapor deposition can be used to build up materials layer by layer, free from defects.
- Surface tension causes liquids in micro-gravity to form perfectly round spheres. This can cause problems when trying to pump liquids through a conduit, but it is very useful when perfect spheres of consistent size are needed for an application.
- Space can provide readily available extremes of heat and cold. Sunlight can be focused to concentrate enough heat to melt the materials, while objects kept in perpetual shade are exposed to temperatures close to absolute zero. The temperature gradient can be exploited to produce strong, glassy materials.

5.4.2 | Products

There are thought to be a number of useful products that can potentially be manufactured in space and result in an economic benefit. Research and development is required to determine the best commodities to be produced, and to find efficient production methods.

The following products are the prospective early candidates:

- Growth of protein crystals
- Improved semiconductor wafers
- Improved semiconductor wafers

As the infrastructure is developed and the cost of assembly drops, some of the manufacturing capacity can be directed toward the development of expanded facilities in space, including larger scale manufacturing plants. These will likely require the use of lunar and asteroid materials, and so follow the development of mining bases.

Rock is the simplest product, and at minimum is useful for radiation shielding. It can also be subsequently processed to extract elements for various uses. Water from lunar sources, Near Earth Asteroids or Martian moons is thought to be relatively cheap and simple to extract, and gives adequate performance for many manufacturing and material shipping purposes. Separation of water into hydrogen and oxygen can be easily performed in small scale, but some scientists believe that this will not be performed on any large scale initially due to the large quantity of equipment and electrical energy needed to split water and liquefy the resultant gases.

Ceramics made from lunar or asteroid soil can be employed for a variety of manufacturing purposes.[citation needed] These uses include various thermal and electrical insulators, such as heat shields for payloads being delivered to the Earth's surface.

Metals can be used to assemble a variety of useful products, including sealed containers (such as tanks and pipes), mirrors for focusing sunlight, and thermal radiators. The use of metals for electrical devices would require insulators for the wires, so a flexible insulating material such as plastic or fiberglass will be needed.

A notable output of space manufacturing is expected to be solar panels. Expansive solar energy arrays can be constructed and assembled in space. As the structure does not need to support the loads that would be experienced on Earth, huge arrays can be assembled out of proportionately smaller amounts of material. The generated energy can then be used to power manufacturing facilities, habitats, spacecraft, lunar bases, and even beamed down to collectors on the Earth with microwaves.

Other possibilities for space manufacturing include propellants for spacecraft, some repair parts for spacecraft and space habitats, and, of course, larger factories. Ultimately, space manufacturing facilities can hypothetically become nearly self-sustaining, requiring only minimal imports from the Earth. The micro-gravity environment allows for new possibilities in construction on a massive scale, including mega scale engineering. These future projects might potentially assemble space elevators, massive solar array farms, very high capacity spacecraft, and rotating habitats capable of sustaining populations of tens of thousands of people in Earth-like conditions.

5.4.3 | Challenges

The space environment is expected to be beneficial for production of a variety of products assuming the obstacles to it can be overcome. The most significant cost is overcoming the energy hurdle for boosting materials into orbit. Once this barrier is significantly reduced in cost per kilogram, the entry price for space manufacturing can make it much more attractive to entrepreneurs. After the heavy capitalization costs of assembling the mining and manufacturing facilities are paid, the production will need to be economically profitable in order to become self-sustaining and beneficial to society.

5.4.4 | Feasibility

According to a study conducted by Kleck Institute of Space Science[4] along with CALTECH reports that the cost for a mission to identify and return a 500-ton asteroid to low earth orbit would be around $2.6 billion USD. However, this price of the mission is not a hurdle compared to the price of the asteroid's resources in the current market. As per a study by Planetary Resources, a company focused in the field of space mining estimates that a single 30-meter-long platinum-rich asteroid could contain $25 to $50 billion USD worth of platinum.

[4] https://www.kiss.caltech.edu/final_reports/Asteroid_final_report.pdf

6 Energy

6.1 | Energy Production

6.1.1 | Solar Panels

The main source of energy will be solar panels. Right now, in 2020, the efficiency of solar panel is 47.1% on earth's surface(Green et al. (2019b)). Taking efficiency as 40%, the power generated per hour will be 2800MW. The panels will also have hydraulics which will allow the panels to tilt towards the sun till some angle. These angles will be controlled by computer. This will increase the efficacy further. The excess energy can be stored in auxiliary battery storage which will be in the space between the stationary and moving cylinder or in the micro gravity area. The distribution of the energy can be done by wires running throughout the rotating cylinder and in micro-gravity area through the spokes. The solar panels will be hexagonal in shape. There will be space for the robotic arms to move around the solar panels for maintenance. In case of major repair, humans can access the solar panel by going between both rotating and outside cylinder without actually going outside the settlement.

The panels can be tilted using the above mechanism where there will be a hinge which will be controlled by actuators. The actuators will move the solar panels to angle so that the panel is pointing towards sun.

Solar Panel Mechanism

The solar panel will be attached to a mechanical single-axis rotating arm consisting of two joints. Each joint will move in opposite directions. The point of contact of the solar panel and the arm will also have a slot mechanism which will move the solar

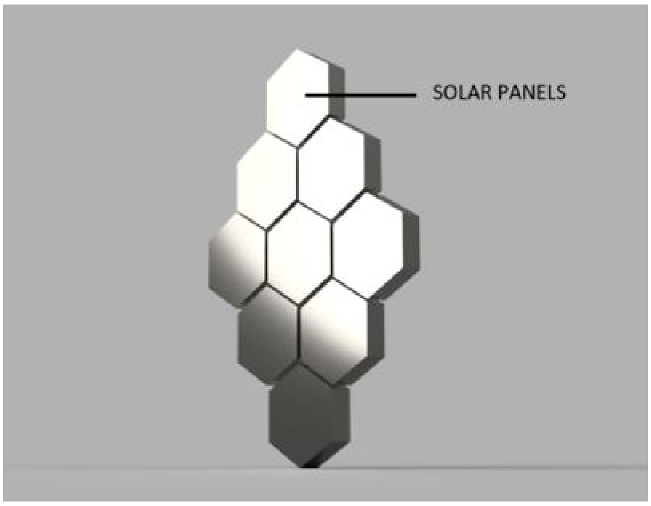

Figure 6.1: Solar panel arrangement in OPUS

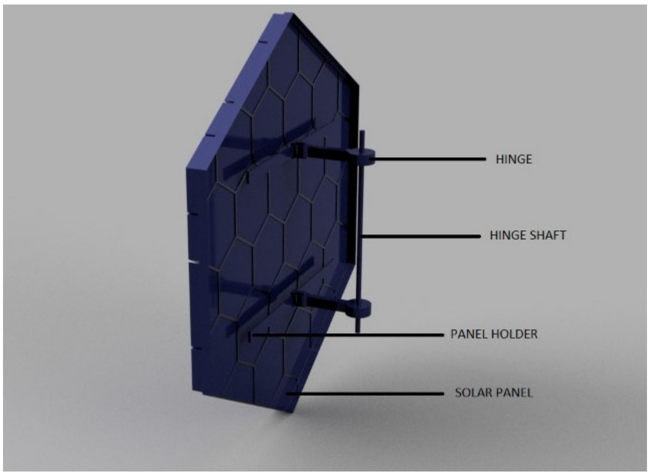

Figure 6.2: The mechanism to attach the panels to the surface of OPUS

panels in right of left direction. When the sun rays fall perpendicular to the solar panel the arm will be perfectly straight and at the center of the slot. When the settlement rotates the arm joints will start to rotate to keep the solar panels perpendicular to the sun rays. The solar panel will also move to the right or the left with the help of the slots so that maximum surface area is open to the sun and does not get covered the other panels. The mechanism helps in increasing the efficiency so that maximum solar energy is generated. The images below will give a visual representation of how the solar panel mechanism will work.

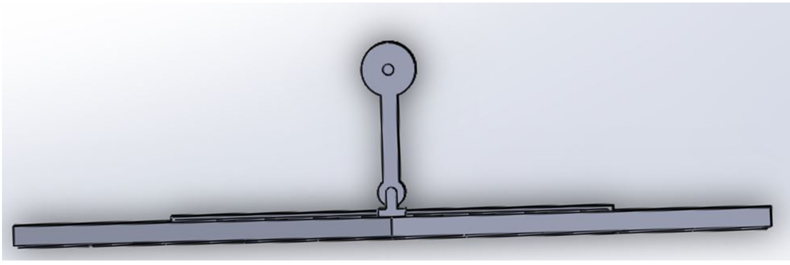

Figure 6.3: Top view of the tilting mechanism

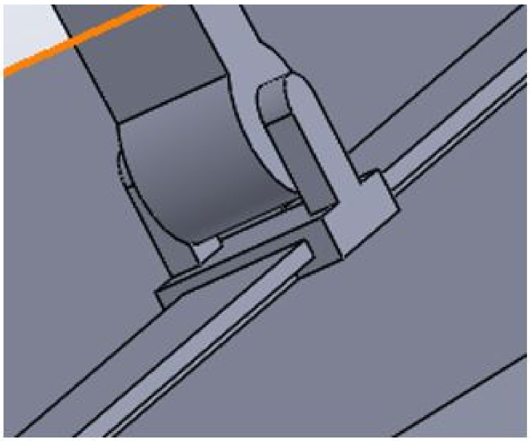

Figure 6.4: Slot for lateral movement

The calculation for Energy (Generation) :

Considering $400W/m^2$ at 40% efficiency,
And taking area as $14km^2$ which is 1,40,00,000 m^2.

$$\text{Total energy is } 14000000 \times 400 = 5600\text{MW}$$

Since half of the settlement will be illuminated with solar radiation,
Energy produced per hour will be 2800MW.

In 24 hours, we will be making 67,200MW.

We can also have nuclear power plant on the axis of rotation of the cylinder away from the settlement for back-up.

6.1.2 | Nuclear Power

The settlement would need a constant supply of electricity to function. Every possible system on the settlement would be running on electricity and hence an interrupted supply of power is critical to the sustenance of life on board the settlement. Electricity production on Earth depends heavily on fossil fuel now but the same can't be followed for the settlement due to the negative effects associated with it. Solar power is a major source of energy for space missions. However, owing to the low efficiency of consumer solar panels (Green et al. (2019b)), we would be needing a very large area to capture enough sunlight to power all the systems on-board the settlement.

The requirements for the energy production system for a space settlement are listed out:

- **Safety** – Since the settlement is an orbital station, the power production facility should not pose any serious threat to the inhabitants or other systems aboard the settlement.
- **Energy density** – Space aboard the settlement is a rare commodity. Expansion of the settlement is not possible without planning and hence every system and structure aboard the station must be optimized to minimize space utilization.
- **Round the clock availability** – The whole settlement would be dependent on the power production facility to support life critical systems for its inhabitants. Power production must be at a nominal level throughout its working period. Power must be delivered without hindrance to all the systems aboard the settlement for smooth functioning.
- **Low cost of power production** – It would defeat the purpose if the power plant produces energy at exorbitant prices. Low cost of power production is primarily driven by the number of users.
- **High efficiency** – A major driving factor for power plants is efficiency. OPUS's power plant must also be sufficiently efficient enough.

Considering the above requirements for a power plant on-board the following power production method are put forward as suitable non-solar options for the settlement. It is difficult to find a suitable option which can satisfy all the above listed requirements. Until the technology matures enough to develop an energy source which suits all the

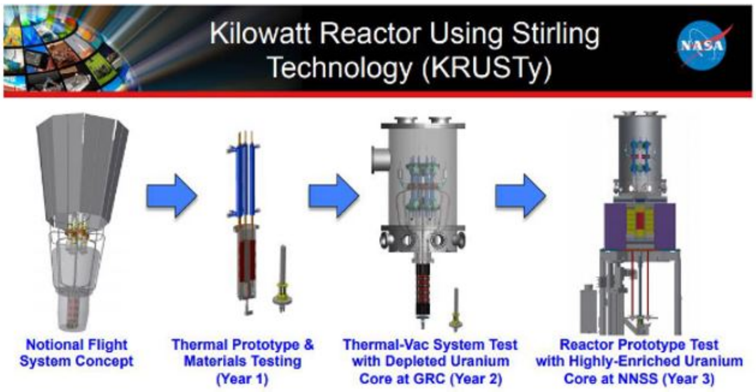

Figure 6.5: KRUSTY Development Roadmap, Credit: NASA

requirements, OPUS would be forced to use the options available right now compromising on some factors. Moreover, nuclear power for powering space missions is tried and tested approach(Bennett (2006)).

NASA - KILOPOWER PROJECT (KRUSTY)

USA's space research agency NASA (National Aeronautical and Space Administration) is working on a project aimed at creating small scale, affordable nuclear fission reactors to enable long-duration stays on planetary surfaces called the Kilopower porject[1]. The reactor is a combination of a Stirling converter and a fission nuclear reactor fuelled by an alloy of 93% Uranium-235 and 7% Molybdenum.

HELIUM - 3

Over the years various missions have been performed on the lunar surface for the detection and abundance of helium-3(Fa and Jin (2007)). The lunar surface is bombarded with helium-3 in a mineral called titanium dioxide (TiO_2) and it is also in the solar wind present on the lunar surface. Helium-3 is basically an isotope which could be used as an energy resource for interplanetary mission and power source for colonizing the planet.

6.1.3 | Non-Nuclear Alternative

6.1.3.1 | PIEZOELECTRIC TILES

Concept of Piezoelectric Tiles can be used in OPUS-Settlement for power generation(Erturk and Inman (2011)) where a small electric charge is generated when a piezoelectric ma-

[1] `https://www.nasa.gov/directorates/spacetech/kilopower`

terial is compressed, squeezed or subjected to any mechanical stress or vibration.

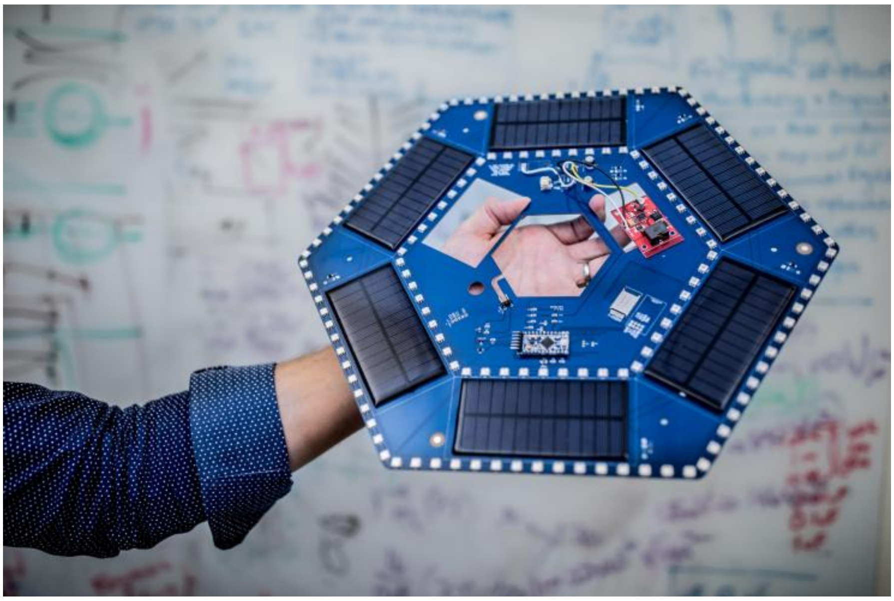

Figure 6.6: Piezoelectric tile developed by Georgia Tech, Credit: Branden Camp,Georgia Tech

This concept can be used in construction of pavements, road ways, Gyms and exercising area, malls, offices etc. inside the settlement. Electric charge is generated when kinetic energy acts upon those tiles when used. The power generated can be harvested and stored in batteries for small scale power utilization. An array of piezoelectric transducer connected in series-parallel can generate electric charge which can power up street lights (considerable numbers), handy electronics like mobiles, tablets, Electric Vehicles etc.
Most commonly produced piezoelectric materials which can be used are:

1. Lead Zirconate Titanate (PZT)
2. Barium Titanate (BaT)
3. Lead Titanate (PbT)

Let us consider one piezotile for calculation of power generated in total usable area for habitual cylinder- 13.5 $km^2$for e.g., Pavegen tile.(Seow et al. (2011)) A Pavegen tile is of 17.1″ x 23.6″ inch. Hence, the area,

$$a = (17.1'' \times 23.6'') = 403.56'' \text{ inches or } a{=}0.26 \text{ sq.m}^2$$

No. of tiles required for habitual area of 13.5 km^2 = 13500000/0.26 = 51,923,076 pieces.

Assuming for 1000m or 1km = 1312 footsteps per person. If we consider 100 people then the total footsteps for 1000m:

$$\text{(No. of people*footstep)} = (100 \times 1312) = 131200 \text{ footsteps/minute}$$

Assuming the total energy harvested by a piezotile = 7W/step
Then, the total power P = 131200 steps × 7 Watts = 918.4 kW
Therefore,
Energy Generated per hour = 55.104 MW

$$\text{Total Energy generated for 24 hours} = 1322.5 \text{ MW per } km^2. \text{ (approx.)}$$

6.2 | Energy Management

Energy consumption on-board OPUS are calculated to the approximate values assuming the comparative energy consumed per person per day on the earth. Considering the total energy consumption survey done in 2019, on an average, a person from India will only consume 19 KWh of per day whereas the person in china uses 75 KWh per day. For a world population of 7.7 billion it can be estimated that the power consumed by a person on an average would be 58 KWh per day.
Now, let us assume that the person on-board OPUS will use only 65% of the energy used on the earth, i.e.,

$$65\% \times 58KWh \text{ per day per person} = 37.7kWh \text{ per day per person}$$

Total number of people on-board OPUS*power consumption per person per day on OPUS,

$$1000 \times 37.7kWh = 37.7MWh \text{ per day}$$

Let us consider the total energy generated by solar panels per day = 67,200 MWh.
Total energy generated for one year = $67,200 \times 365$ = 24528 GWh per year.
Total no. of hubs on-board OPUS = 42
Hence, the total energy consumed per hub = 24528 / 42 = 584 GWh per year. (Approx.)
Considering wild approximate value of few hubs, we can calculate the surplus energy which can be used for storage, emergency purpose and ion thrusters.
E.g. 1 – Atmospheric Control; (20-25 GWh) = 584 – 25 = 559 GWh per year
E.g. 2 – Agriculture; (1-3 GWh) = 584 – 3 = 581 GWh per year

E.g. 3 – Water management; (5-7 GWh) = 584 – 7 = 577GWh per year
E.g. 4 – Waste Management; (5-7 GWh) = 584 – 7 = 577 GWh per year
Hence the surplus energy varies for each hub depending on the power demand and consumption.

6.3 | Energy Storage

A superpcapacitor-battery hybrid would be the perfect choice for storing the power produced in OPUS and distributing it whenever the need arises. It uses a combination of Fe_3O_4/graphene (Fe_3O_4/G) as negative electrode material and a graphene-based 3D porous carbon material (3DGraphene) with high surface area ($\sim 3355 m^2 g^-1$) as positive electrode material.
It exhibits an ultrahigh energy density of 147 $Whkg^-1$ so far the highest value reported of an hybrid supercapacitors.(Zhang et al. (2013))
Lithium Iron Phosphate (Li-Fe) Batteries(Hassoun et al. (2014)) can also be used on-board OPUS for back-up energy storage. Li-Fe has $LiFePo_4$ as Cathode and graphitic carbon electrode having metallic backing as anode. It has a constant discharge voltage at the time of discharging. Most environment friendly & had durability greater than 10 years.
These batteries can be connected in series-parallel combination in batches for each hub according to the requirement of energy consumption. Conservation of energy can be carried out in minimal energy consumption hub. Li-Fe batteries can also be used in Electric cars and scooters. **Note:** All images pertaining to the design of the structure in this section is designed by OPUS Design team and rendered in Fusion360.

7

Life Supporting Systems

7.1 | Atmosphere

An ordinary individual can't live at least for ten minutes without air. So, the creation of atmosphere that can sustain life is extremely important. It is an extremely complex task with a lot of points to consider: We need to create Earth like atmospheric pressure by keeping the molar fractions of gases constant. The composition of atmosphere inside the OPUS will be like this:

GAS	Percentage %
Nitrogen	78.948%
Oxygen	20.95%
Carbon dioxide	0.038%
Traces of other gases and Water vapour	0.102%

Table 7.1: Atmospheric composition in OPUS

7.1.1 | Extraction of Atmospheric Gases

7.1.1.1 | Oxygen

OPUS has population of 1000 persons who would require around 840kg/day of Oxygen[1]. The major production of Oxygen can be done by using the resources available on the surface of Moon and Mars. Rest of the Oxygen is produced by cellular respiration techniques and agricultural region. Oxygen pressure would be kept at 22.7 KPa which is the oxygen pressure at sea level on Earth.

[1] https://health.howstuffworks.com/human-body/systems/respiratory/question98.htm

Oxygen from the Surface of Moon

Oxygen element is present on moon in the form of Olivine, Ilmenite, Pyroxene, Plagioclase and feldspar. The elemental oxygen content in the rocks and soils in space is 42% to 45% by weight(Schlüter and Cowley (2020)). We can also get useful metals by the extraction of oxygen from metal oxides. Metal oxides are very stable compounds. So, the separation of these compounds requires direct energy and chemical reagents.

Methods to produce Oxygen

Carbothermal reduction process

In this process high temperature reaction of oxides with a carbon source is used to extract oxygen(Cutler and Krag (1985)) in multi-step process. It has three basic stages.

$$\mathrm{MO(s)} + \mathrm{CO} \longrightarrow \mathrm{CO_2} + 2\,\mathrm{H_2} + \mathrm{M(s)}$$

1. Carbothermic reduction of metallic oxides: Lunar minerals containing oxides are reduced with a carbonaceous source (in this example, CH_4) which will form Carbon Monoxide and Hydrogen
2. Reformation of carbonaceous compound: Carbon Monoxide formed by the first reaction can be reacted with hydrogen to form Methane and water. This Methane can be reused in for stage 1
3. Electrolysis of water: Water formed by second reaction can be electrolyzed to form hydrogen and oxygen. The hydrogen can be reused in second stage.
   This process can produce oxygen from Ilmenite and silicate materials regardless of their composition. Analysis of Apollo samples says that SiO_2 materials available on Moon contain 40%-50% by weight of the whole oxide mixture. Since SiO2 is abundant on the surface this process can be operated at any location on Moon.

Thermal Decomposition

Oxygen from Lunar ilmenite is also studied(Zhao and Shadman (1990))

- **Stage 1:** Ilmenite ($FeTiO_3$) along with raw lunar soil and rutile will be extracted
- **Stage 2:** Hydrogen is separated from the lunar soil at 600° C by through successive heating and it would decompose into a mixture of iron (Fe) and TiO2 at 900°C. At 1525°C iron (Fe) will melt and leave behind TiO_2 which will decompose into titanium and O_2 at 1640°C. Every 1000g of Ilmenite can produce 317.88g of oxygen.

Oxygen from Martian Surface

According to NASA, Martian atmosphere is 95.32% carbon dioxide[2]. Also, more than 21 million km^3 of ice have been detected at or near the surface of Mars The following three methods can be effectively used to produce oxygen by using these two resources.

- **Ultrasonic Electrolysis (Raw material is Water)** - Ultrasonic sound with a frequency of $\approx$ 42.7 kHz would be passed through heated water making it unstable and disassociate it into O2 and H2.

- **Davis' Process (Raw material is Carbon Dioxide)** - CO_2 can be decomposed in this process. First Argon-Carbon Dioxide mixture in a shock tube and would be heated to 6527°C. Shock waves would be passed through the system which would lead to decaying infrared emissions. Carbon Dioxide would be decomposed into Carbon Monoxide and Oxygen. Carbon Monoxide can be later released into Martian atmosphere.

- **Sabatier Process(Raw material is Carbon Dioxide)** - Hydrogen and Carbon Dioxide are heated at elevated temperatures (optimally 300–400°C) and pressures in the presence of nickel catalyst to produce methane and water. Ruthenium on alumina (aluminum oxide) will makes a more efficient catalyst.

  $$\mathrm{CO_2 + 4\,H_2O \longrightarrow CH_4 + 2\,H_2O}$$

  Then H_2O can be electrolyzed to Oxygen and Hydrogen and CH_4 can be used as fuel.

7.1.1.2 | Nitrogen

Nitrogen extraction using Molecular Sieve Ammonia will be separated from meteorite dust and Martian atmosphere using alumino silicate molecular sieve with pore size of 0.3 nm. It will be separated from other materials using polysulphone amide membrane. The Ammonia obtained would be decomposed thermally to produce nitrogen and hydrogen. Nitrogen and hydrogen can further be separated using fractional distillation.

7.1.1.3 | Carbon Dioxide

Extraction : The CO_2 required for agriculture, industries and for other purposes can be taken from the Martian atmosphere. CO_2 will be captured using molecular sieve

[2] https://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html

with pore size of 0.4nm. Potential technologies for the separations are freezers, selective membranes, selective solvents, polymeric sorbents and zeolites.

7.1.2 | Air Purification

Stage 1 : HEPA[3] (High Efficiency Particulate Air) system uses an aggregate of fibers to disinfect air with an efficiency of 99.97 to 99.98 % (removing particles as small as 0.003 microns). Sheets of thin Aluminum Filter fibers along with activated carbon slab and zeolites would facilitate effective air purification. This air will still contain the microbial bodies which are smaller than 3 nm and cannot be separated from the air simply using the Silver (Ag) Nano Particles. To remove all organic non-gaseous impurities from air i.e. dust, dirt, pollens and smoke which are smaller than 3 nm, an increase in size of these bodies will be applied by reduction and calcination at 450 °C.
Stage 2 : In this stage air is brought in contact with Activated Carbon by using polarized electric media. All particles passing through this field would get polarized and would tend to cling to the activated carbon slab. Activated carbon will also separate Volatile Organic Compounds (VOCs) and other organic compounds and odor from air.
Stage 3 : Air will be ionized till all the particles get separate charges and attract each other and will reach a stage where they are too heavy to stay in air. At this stage the dust will start falling which will be cleaned by vacuum suction.
Stage 4 : Ultraviolet air purifiers will be used to deactivate the microbes which will be present in the air like bacteria, viruses, germs and allergens. UV light will be emitted using UV-C germicidal light bulbs which can kill 99% of the microbes present in the air.

7.2 | Climate

The residents of OPUS need an appropriate climate and humidity control system. So, we are incorporating the artificial season's plan where the essential conditions like temperature and humidity are controlled to mimic the conditions on Earth. There will be three seasons: Summer, winter and spring. Temperature and humidity levels will be estimated later based on the residents and their previous climatic conditions.

7.2.1 | Temperature Control

To control temperature, it is essential to know what influences temperature. Major influencers include environment, control system and heater design. Thermal induction will

[3] https://en.wikipedia.org/wiki/HEPA

be used to increase the temperature. Waste water will be heated during this process. The gases produced during this process can be recycled and used for atmosphere.

Thermo-Acoustic Refrigeration(Garrett and Hofler (1992)) will be used to reduce the temperature. The source from which acoustic waves are produced emits a sound frequency in a tube filled with high pressure nonflammable mixture of inert gases (helium, argon and air). This tube is known as the resonator. Between the tubes there is a "stack" of porous material which is solid in order to block the path of the sound frequencies. Then thermos-acoustic effect takes place in order to cool down the other end and produce refrigeration. Using this technique on large scale can produce artificial air-cooling in OPUS.

7.2.2 | Humidity Control

Ultrasonic humidifiers(Turpin (2003)) can be used to increase the humidity levels. They have a metallic diaphragm which pulsates at a frequency that can't be heard by the human ear. And this frequency will produce water droplets. Molecular sieves can be used to remove the excess humidity levels. These sieves will have a pore size of 0.19nm. Controlling humidity in industrial spaces can be difficult because these areas are not as insulated as residential spaces. A powerful dehumidifier is the best way to avoid high humidity issues.

7.2.3 | Pressure Control

Proportional pressure controllers can be calibrated to work any range of pressure we desire to operate. The lowest positive pressure range of (full scale) calibration is 0 to 2 inches of water column – the same range is available for vacuum also. Units can be calibrated from full vacuum to atmosphere as well or any point in between. Precision is often important and we offer repeatability of $\pm 0.02\%$ of full-scale calibration, accuracy as high as $\pm 0.2\%$ of full scale and resolution as high as $\pm 0.005\%$ of full-scale calibration. A separate pressure sensor is not required to verify pressure when using a Proportion-Air electronic pressure controller.

Monitor output signals are available from most Proportion-Air units. This signal can be used for data acquisition or display. Flows of a few cubic centimeters to thousands of cubic feet per minute can be achieved. A wide range of volatile and non-volatile gases can be controlled.

When we have to transport from pressurized zone to the un-pressurized zone airlocks will be used to prevent the loss of air from the atmosphere. The Ventilation, Humidity and Temperature Control System maintains comfort environmental standards inside the pressurized modules. The continuous flow of air inside pressurized modules and between them keeps the atmosphere homogeneous

7.3 | Food and Nutrition

Maintaining a healthy diet throughout the life helps to prevent malnutrition as well as a lot of Non-Communicable diseases (NCDs). A balanced and healthy diet will vary depending on individual characteristics like age, gender, lifestyle and degree of physical activity, cultural context, locally available foods and dietary customs. However, the basic principles of a healthy diet remain the same. A balanced diet provides all the nutrients a person requires. By eating a balanced diet, people can get the nutrients and calories they need. Many nutrition institutes across the world recommend eating foods from five groups and building a balanced plate[4]. Half of a person's plate should consist of fruits and vegetables. The other half should be made up of grains and protein. They also recommend accompanying each meal with a serving of low-fat dairy or another source of the nutrients found in dairy.

Here are the crops we intend to give more preference in OPUS agricultural unit:

Vegetables : Leafy greens, red or orange vegetables, starchy vegetables, beans and peas (legumes) and other vegetables, such as eggplant or zucchini. People may enjoy vegetables raw or cooked. We must remember the fact that cooking vegetables removes some of their nutritional value.

Fruits : A balanced diet also includes plenty of fruit. Instead of getting fruit from juice, nutrition experts recommend eating whole fruits.

Grains : There are two subgroups in this group: whole grains and refined grains. The body breaks down whole grains slowly, so they have less effect on a person's sugar level in blood. Additionally, whole grains tend to contain more fiber and protein than refined grains. Refined grains are processed and tend to have less protein and fiber, and they can cause high raise blood sugar. Whole grains usually contain more protein than refined grains. At least half of the grains that a person eats daily should be whole grains. Healthful whole grains include Oats, Brown rice, Barley and Buckwheat.

The above three groups of crops can be cultivated using vertical farms.

Protein : Nutritious rich protein choices include lean beef and pork, chicken and turkey, fish, beans, peas, and legumes. We know that meat is an expensive animal protein. The consumption of animal meat can involve different environmental, human

[4] `https://www.usda.gov/topics/food-and-nutrition/dietary-health`

health, food safety and security issues. Intensive use of farm animals result pollution due to excrement and massive gas emissions, climatic change; food-borne and zoonotic diseases; and suffering of animals. So, we are planning to incorporate cultured meat system using cell agriculture. We can grow meat with characteristics from a combination of animals or enhance lab grown meat with healthier fats and vitamins. We can even taste the flesh of animals that nobody would think of slaughtering for food. This synthetic meat is like real meat in terms of calories and has more fiber and less cholesterol. While cultured meat's impact on the environment is multifaceted.

Insects are also high in protein(Verkerk et al. (2007)) and rich in essential micronutrients, such as iron and zinc. They can be eaten directly or used as a processed food supplement. Insects don't need much space. They can be reared in scraps under warm conditions. There is arguably less of an ethical issue with raising and eating insects for food than there is with higher animals.

Dairy : Dairy and soy products are a vital source of calcium. Low-fat dairy and soy items include low-fat milk, yogurt and soy milk. As animal husbandry would take a lot of effort and money. We thought of artificial ways to produce milk. DNA is extracted from dairy cows and certain sequences are inserted into yeast cells. The yeast culture is then can be grown in industrial-sized petri-dishes at just the right temperature and concentrations, and within a few days, the yeast will produce enough milk for harvesting. According to WHO[5] energy intake (calories) should be in balance with energy expenditure. To avoid unhealthy weight gain, total fat should not exceed 30% of total energy intake. Intake of saturated fats should be less than 10% of total energy intake, and intake of trans-fats less than 1% of total energy intake, with a shift in fat consumption away from saturated fats and trans-fats to unsaturated fats, and towards the goal of eliminating industrially-produced trans-fats. Limiting intake of free sugars to less than 10% of total energy intake is part of a healthy diet. A further reduction to less than 5% of total energy intake is suggested for additional health benefits. Keeping iodized salt intake to less than 5g per day (equivalent to sodium intake of less than 2g per day) helps to prevent hypertension and reduces the risk of heart disease and stroke in the adult population.

7.4 | Agricultural Practices

Vertical farming (Kozai et al. (2019)) is the main choice of our agricultural practice. It is of growing crops in vertically stacked layers. It can also be considered as controlled

[5] https://www.who.int/news-room/fact-sheets/detail/healthy-diet

environment agriculture. Vertical farming can be made effmore efficient by the inclusion modern agricultural techniques like:

1. Hyrdroponics - Using mineral nutrient solutions in an aqueous solvent instead of soil
2. Aquaponics - Combination of aquaculture and hydroponics
3. Aeroponics - Growing crops in air or mist environment

Benefits :

- Production of a larger variety of harvestable crops because of its usage of isolated crop sectors
- Soilless farming
- Unlike traditional farming, indoor farming can produce crops year-round. All-season farming multiplies the productivity of the farmed surface by a factor of 4 to 6 depending on the crop
- Over eight to ten times the crop yield per acre than traditional methods
- Controllable Environment
- Needs can be optimized

The vertical farming model is an indoor farm which resembles the multi storey building. Its diverse features include innovative use of recycled water from a desalination plant, automatic air-temperature and humidity control, and controllable 24-hour LED illumination. The LED equipment can be controlled throughout a growing season to emit a programmed spectrum of light that is optimal for photosynthesis for different types of crops.

Blue wavelength in LED lighting, has been found to change the concentrations of nutritionally important primary and secondary metabolites in vegetable crops. In addition to wavelength, controlled lighting with respect to intensity and time duration is another area where optimization strategies are possible. The concept of spectral sensitivity may also be expanded beyond the visible wavelengths and into the ultraviolet and infrared bandwidths with potential effects on growth rates.

Plants can be grown with their roots irrigated by aerated water containing an optimum mixture of nutrients. In vertical farming it is easier to keep all growing areas free from

plant pathogens. Nutrient balance can be monitored and maintained continuously for optimum growth. Liquid waste containing nutrients such as urine can be recycled directly and diluted to form part of the liquid feed. Plant roots will not survive if immersed continuously in water, so these systems often use a root support on inert materials such as pumice over which water containing nutrients flow as a small stream while leaving enough air gaps for the roots to absorb. Pumice as the support medium for hydroponics . It may be available from volcanic sources on the Moon.
Air conditioning provides a constant flow of air which can be enriched with carbon dioxide (CO2) to further advance plant growth and development. Both ambient and nutrient temperatures can be held at specific levels that optimize the rate of plant growth. Any nutrients and water not absorbed by the roots could be recycled without getting lost to the system.

Aquaculture

Aquaculture usually means the rearing of fish in ponds but could also describe the growing of water plants for food. A suitable range of water plants could also constitute for a balanced diet. There are several edible freshwater plants such as water chestnuts and rice. A significant difference from the plants grown hydroponically is that water plants can be grown all around the year and will be at the optimum conditions of the habitat. Water plants also grow vigorously, and the large quantity of excess biomass produced is harvested regularly and recycled.

Algae Tanks

We can increase the production of oxygen by feeding nearly pure CO2 through the algae tank system. We can achieve this by using a system of hydroxyl modified poly amino amine (PAMAM) dendrimer membranes, which show a selectivity of $\sim$ 4000 for CO_2 over N_2 and O_2. This system filters CO_2 out of our breathing air, and produces a mixture of N_2 and Ar, which can be separated to yield the individual gases, and whenever it is used it produces oxygen that we can catch and store it. This oxygen can be pressurized or even liquefied to perform a variety of applications. The oxygen produced here will not be in its pure state. By using this technology, we can have an excess of oxygen to store, the algae growth can be harvested for food, and extra oxygen can be converted into useful fuel or materials. Algae tanks can also act as a recycling system by taking CO_2 from the atmosphere.

Energy for agriculture: Solar Energy (Storage batteries)

The energy requirements associated with vertical farming, however, is much higher than the traditional methods of food production. For example, lettuces grown need an estimated 250kWh of energy a year for every square meter in traditionally heated greenhouses in the UK of growing area. The lettuces grown in a vertical farm need an estimated 3,500kWh a year for each square meter of growing area. Almost, 98% of this energy use is due to artificial lighting and climate control. So, we can easily assume that we may need more than a GWh for cultivation for a year.

Water Supply

The automated nutrient film analyzer (ANFA) is developed by scientists in collaboration with National Institute of agricultural engineering to sense and controllers will be used to operate the parameters involved in the agriculture. This apparatus is controlled by a microcomputer. It selects which solution is to be measured, which sensor is to be interrogated, acquires and processes the data and prints out the results. A special electro-chemical interface has been developed to connect the microcomputer to the sensors. This interface may be divided into two parts-digital and analogue. The sensors and their flow system are housed in a Faradaic cage in order to reduce noise.

Harvest, Storage and Transport

Automated robots will sow, monitor and harvest plants and crops and send them for processing and packaging. The food grains and supplies will be stored in dry, clean and isolated area under low temperature to avoid bacterial growth and pest attack. The perishable fruits, vegetables, meat and dairy products shall be stored in refrigerators under required conditions. Refrigerated trucks will be used to deliver the food products. A system will also be maintained to ensure regular delivery of food items to the residents in the settlement through small refrigerated vehicles.

7.5 | Water Extraction and Management

Everything that is needed to survive indefinitely in a space station without resources like earth has to be provided from somewhere. Water is one such thing. Space agencies like NASA can't keep sending water every now and then. It's way too costly, so they came up with innovative ideas like restoring water. But how can water be restored if there's no water to begin with in first place.

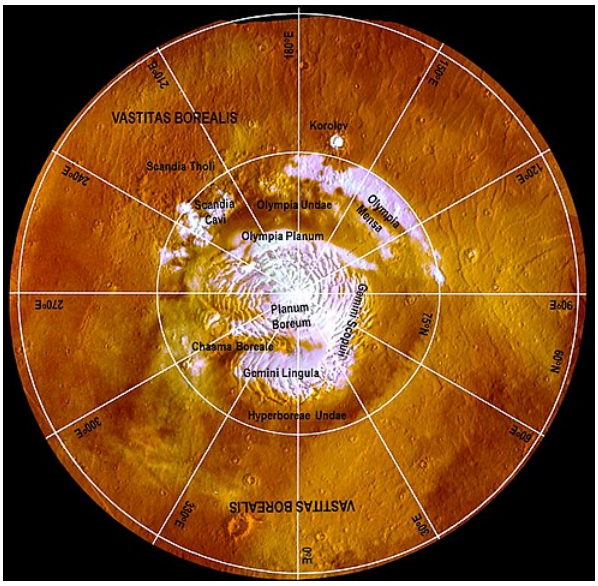

Figure 7.1: Northern polar ice caps of Mars captured by *Mars Orbiter Mission*, Credit: ISRO

It is pretty exciting to know that water is actually present in space but not at all in liquid form all around. Because of no atmospheric pressure almost all water around evaporates in a fraction of second. Water is actually observed in its solid form 'ice' on the upper layers of some rocky celestial bodies and after Saturn there are a bunch of rocky objects which are fully covered with ice.

7.5.1 | Water Extraction

Hydrogen reduction reactors and microwaving the moon for the extraction of water can help in extracting water. A Hydrogen reduction plant is a chemical process. By adding hydrogen to the regolith or dirt of the Moon, it reacts with iron oxide to produce water. These hydrogen reactors heat up the regolith to about 1000 degrees Celsius for the pop proper chemical reaction to occur. NASA has tested these hydrogen reduction reactors on the volcanoes in Hawaii. When this method was tested in Hawaii it produced 660 kg of oxygen from Rocky soil containing 5% iron oxide. Water mined by these methods can be used to provide oxygen and water to the astronauts and fuel for the lunar missions. NASA has come up with another method to extract water which can be done by microwaving the moon. In this method, beamed microwaves are used to vaporize 98% of water ice and capture the extracted water in the gas form. This method can be done without using drilling or digging. But this method is not given much importance because it is expensive to test even on Earth and can be done easily by computer modeling.

Thermal Mining

Under energy resources, water was the main source that I had been working on at first. The RESOLVE Project which I had suggested previous week wasn't quite a well-suited process for bulk water generation.

$$\text{This reaction is: } FeTiO_3 + H_2 \longrightarrow FeO + TiO_2 + H_2O$$

The two main challenges that this proposal had were:

1. When 45mg of ilmenite was heated up for 1 hour at 900 °C then 17μmol of water was produced which is quite less. This means for 1kg of water only 0.4gm of water could be yielded.

2. Another thing was to maintain a temperature of 900 0C for an hour. Moon has a temperature of about 108-119 °C during the day which is quite not enough for the process to happen

The new way for water extraction technique that could be used is surface heating or using drill heating techniques for it. These methods have been tested well and are ready to be done on the Lunar surfaces as well. For this method one of the main problems is that while heating the water can't be heated too much such that the vapors escape and settle somewhere else. But the method mainly focuses on how the surface could be heated up using incoming solar power to be concentrated at one place to generate 10^4W such that the water starts melting around. Pipes are placed near to this process such that it could collect the incoming vapors which are again purified and then stored for future use.

A concept of thermal mining[6] which is similar to this has also been explained here, where the craters on the Moon are taken for generating water from it. Through the process of sublimation there will be a loss of water vapor as well but still the amount of water generated from this process would be enough to sustain the future industries and even to support our settlement in case of any emergency.

The water collected is refined and then purified such that we can use it for different purposes. This water can be further electrolyzed such that we have oxygen and also the hydrogen obtained can be used as a propellant for future missions. This process can

[6] George Sowers, Thermal Mining Ices on Cold Solar System bodies, NIAC Phase I Final report

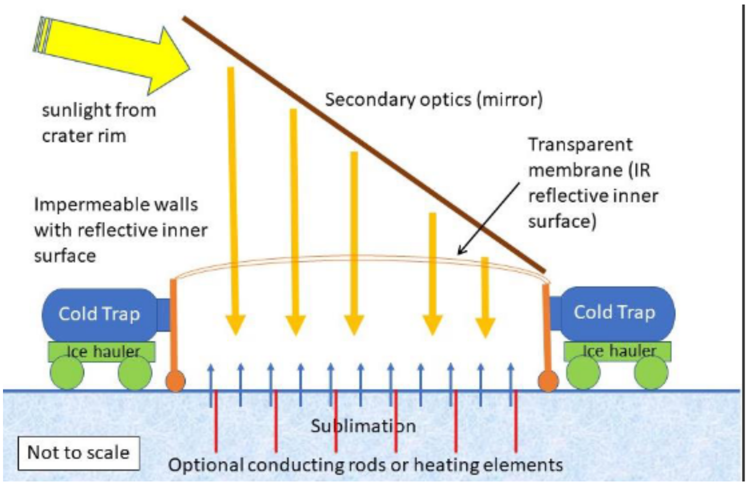

Figure 7.2: Thermal mining concept for mining Ice, Credit: George Sowers

be also done on asteroids for mining out water and storing them for future use. Even the distance would be less between the settlement and the respective asteroid in L5 as compared to the Moon.

Chemical Method

Water mined by this method could not only keep astronauts supplied with a drink but may also provide oxygen and fuel for lunar missions. A process known as electrolysis can then split the extracted water into pure hydrogen and oxygen, either for rocket fuel or astronaut air supplies. One promising technology takes advantage of the chemistry of the moon dirt – or regolith - by adding hydrogen, which then reacts with iron oxide in the moon dirt to produce water. Such hydrogen reduction reactors heat the regolith to about 1,000 °C so that the proper chemical reactions can occur. NASA has already tested a hydrogen reduction reactor on Hawaii's Mauna Kea Volcano(Mueller and Townsend (2009)). During a year-long operation, it produced 1,455 pounds (660 kg) of oxygen from a rocky soil containing 5% iron oxide.

Microwave System

Permafrost is ground that continuously remains frozen. Permafrost does not have to be the first layer that is on the ground. This system is used to extract water from the lunar permafrost since we know water is present at the poles in the form of ice. MWS is one of the methods by which we can extract water from forzen ice caps(Ethridge and Kaukler (2009)). In this method, beamed microwaves are used to vaporize the ice. The vapour is collected and processed for further use. The beam heats the ice and produces vapour. Vapour will be collected using succussion or by dehumidification. Dehumidification is an electrical appliance that reduces and maintains the level of humidity in the air. This can be used to collect water. The water the dehumidifier collects is actually very clean water. We can build succussion domes that can be connected to a spacecraft that has storage tanks.

Labour time in space will be more than that of Earth. The National Academies of Sciences, Engineering, and Medicine determined that adequate daily fluid intake is about 15.5 cups (3.7 litres) of fluids for men and about 11.5 cups (2.7 litres) of fluids a day for women. These recommendations cover fluids from water, other beverages, and food.

Since our settlement will have a population of 1000. And if we consider 4L of water is required for a person per day, then 4000L of water must be processed in order to sustain, which is impossible. The spacecraft which is used to transport water from the moon to the settlement should weigh 5000kg approx. Hence this process can be an additional resource but we cannot rely on this process.

Excavation of the soil and heating in a chamber is a possibility, but this would require excavation equipment, extra infrastructure, and could produce large quantities of dust.

Microwave heating has the unique advantage for extraction of water because it heats from the inside. By delivering the microwave energy to where the water is, excavation would be nearly eliminated. Also, we would not have to "strip mine" the moon to extract the water. Since the microwave penetration depth is dependent on frequency, measurements of the dielectric properties of lunar regolith simulant permit the calculation of the penetration depth that can be used to maximize the efficiency of operations. The methods for water extraction would be directly applicable to Mars because of its rarefied atmosphere.

7.5.2 | Water Storage and Distribution

Water has been found in many places. It has been shown in the atmospheres of planets outside of our solar system, in comets, and in many other places. The most exciting examples are some of the moons in the solar system, specifically on Europa, a moon of Jupiter, and Enceladus, a moon of Saturn. In both cases tidal forces "knead" the moon, and like play-dough in your hands, warms up the cores of these moons. The heat, in turn, melts ice that surrounds the moon. The outside of the moons is exposed to very cold space, and they are of course frozen. But we have very good reason to believe that below the ice there will be several miles deep ocean, where life might have been evolved.

There is water in the deep shadows of the craters on our Moon's South pole, and there is water ice on Mars. This is important because astronauts could use solar or nuclear power to split the water into hydrogen and oxygen as rocket fuel or as breathable air.

Researchers found a lake of water so large that it could provide each person on Earth an entire planet's worth of water—20,000 times over. Yes, so much water out there in space that it could supply each one of us all the water on Earth—Niagara Falls, the Pacific Ocean, the polar ice caps, the puddle in the bottom of the canoe you forgot to flip over—20,000 times over[7].

7.5.3 | Water Recovery

Water is transported in Contingency Water Containers, usually during assembly missions. They are duffel looking bags and each can hold up to 90lbs. Now comes the ECLSS Water Recycling System(7.3) into play. It takes water from anywhere possible, be it from the urine or the humidity or the shuttle fuel cells or the personal hygiene, anywhere if water is being used even a single drop, the WRS(Carter et al. (2013)) will recycle it. Without this technology, NASA would have to send over 40 thousand pounds of water to ISS to resupply a crew of four.

It costs somewhere around $10,000 to send a pound of payload into space, now you can imagine the total cost that'll incur only to supply water. Water is recycled on the International Space Station. Waste water from cleaning, urine, even condensate from the air is all recycled. (Surprisingly, exhaled water vapor from the astronaut's lungs is a large component of this.) Over 70% of the water used on ISS is recycled, which cuts down on the amount of water that must be shipped up from earth quite a bit. Even, the CO2 that the astronauts exhale is reacted with hydrogen to generate water, which can then be split to generate more oxygen. All that reduces water consumption to a manageable level.

Forward osmosis is the natural diffusion of water through a semi-permeable membrane. The membrane acts as a barrier that allows small molecules, such as water, to pass through while blocking larger molecules like salts, sugars, starches, proteins, viruses, bacteria and parasites. The station's life support machinery has kept the crew alive by recycling oxygen from water using electrolysis. The hydrogen this produced was considered waste gas and vented overboard. So, too, was carbon dioxide—generated by crew metabolism—vented overboard. The water purification machines on the ISS will cleanse wastewater in a three-step process.

[7] https://www.nasa.gov/mission_pages/station/research/benefits/water_in_space/

The first step is a filter that removes particles and debris. Then the water passes through the "multi-filtration beds," which contain substances that remove organic and inorganic impurities. And finally, the "catalytic oxidation reactor" removes volatile organic compounds and kills bacteria and viruses.

7.5.4 | Water Quality Monitoring

The real time monitoring of water quality in IoT environment. In order to ensure the safe supply of the drinking water the quality needs to be monitor in real time. The system consist of several sensors is used to measuring physical and chemical parameters of the water. The parameters most commonly monitored include stream flow, dissolved oxygen and biochemical oxygen demand, temperature, pH, turbidity, phosphorus, nitrates, total solids, conductivity, total alkalinity, and fecal bacteria. There are several types, but the simple parameter detects the presence of water by its conductivity. Tap water contains dissolved ions that permit conduct of electricity (pure distilled water won't conduct electricity.

The sensor is generally a set of parallel wires, one set connected to a positive power source such as a battery and the other to a negative source. The two sets of wires do not touch, so no current flows between them. But when the sensor gets wet, a current will flow between the positive and negative wires. This current can be used directly to turn on a LED light, or fed into an amplifier to provide an audible alarm or other device. An optical sensor paired with a light guide can detect liquid level. The light guide will reflect more or less light depending on how deeply it is submerged. Or one that uses a light guide and a linear light detector can detect how much liquid is present by how many pixels in the liner detector are illuminated. Some optical sensors can only detect if liquid is present or not at one level.

There are many options available which are listed below:

- **Capacitance Level Sensor** : Based on change in capacitance with varying water level.
- **Radar Level Sensor** : Based om reflection of waves from liquid interface (Through Air Radar/ Guided Wave Radar)
- **Differential Pressure Sensor** : Based on pressure difference between two level points
- **Magnetic Float Level Sensor** : Based on movement of a buoyant float and subsequent activation of a reed switch

The selection of level sensor will depend on many factors such as process pressure, temperature, process medium, continuous/discrete measurement, head space, mounting provision, seismic and vibration requirements and cost. Details can be explored based on your requirements. So, crew members on the Space Station use a Water Recovery System to recycle their urine , condensation from cabin humidity and wastewater to reuse it as their clean drinking water. Without this process, 15,000 pounds of water and other consumables would need to be launched from Earth every year to support the six crew members living on the Station. The Water Recovery System uses a low-pressure vacuum distillation process to recover water from urine. This occurs inside a rotating distillation assembly, which compensates for the absence of gravity and aids in the separation of liquids and gases in space. The water that's recovered from the urine gets combined with all the other wastewater from hand washing and showering and all of that gets delivered to the Water Processor for treatment.

Before the crew can use the water that's been recovered, it has to meet stringent purity standards. The water processor removes gas and solid materials such as hair and lint. Then a series of multi-filtration beds purify the water even further. Finally, a high-temperature catalytic reactor assembly removes the remaining organic contaminants and microorganisms. Since any contaminants in the water coming out of the system would increase the water's conductivity, electrical conductivity sensors are used to check the water's purity. If the water is unacceptable, it gets reprocessed over again. Eventually the clean water is sent to a storage tank, where it's ready for use by the crew.

7.6 | Waste Management

OPUS space settlement involves proper waste management techniques in addition to the drainage systems. There are different ways to process the waste and reuse it according to convenience. The produced waste is separated into various sub-types using techniques as:

- **Drum screens or Trommel Screen** : The waste is fed into the drum and is lifted up by the rotation and aerated as it falls back down. This action is repeated as with each rotation along the length of the drum. The smaller fractions pass through the openings while the large fractions tumble towards its eventual exit at the rear of the drum. There can be more than 2 splits.

- **Eddy Current Separator** : After feeding the waste into the separator it extracts the

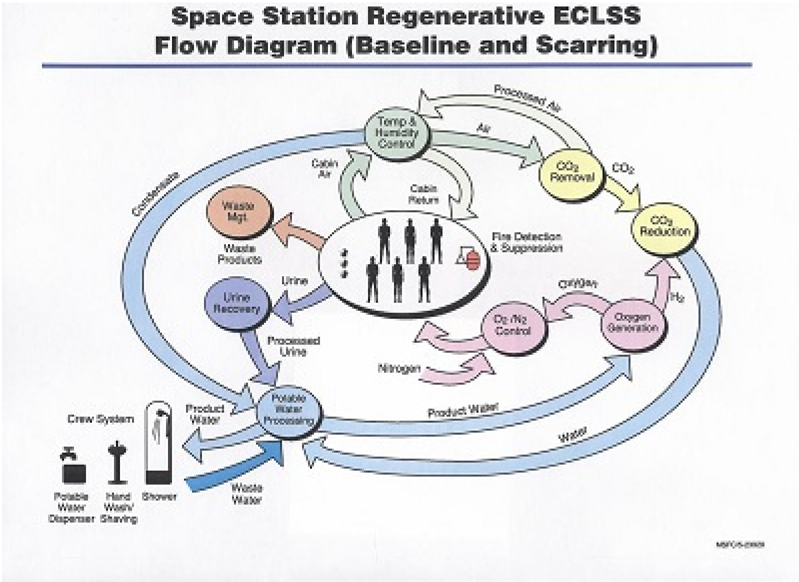

Figure 7.3: ISS Environment Control and Life Support System flow diagram, Credit: NASA

ferrous materials from the waste and separates the non-ferrous waste by arranging magnets inside it. The device makes the use of eddy currents. The eddy current separator is applied to the conveyor belt in which it collects the ferrous material and throws out the non-ferrous waste.

- **Induction Sorting** : Induction sorting material is sent along a conveyor belt with a series of sensors underneath which locate different types of metal and this metal is separated by fast air jets linked to the sensors.
- **Near infrared sensors** : When the materials are illuminated, they mostly reflect light in the near infrared wavelength spectrum. The NIR sensor can differentiate between various materials based on the light they reflect.
- **X-Ray Technology** : X-rays can be used to separate the waste based on their density.

There are many types of wastes that would be created on the settlement. Even though these products are labelled as 'waste', they can be effectively used for a wide variety of uses. For the settlement to achieve high re-usability, processing these products from the inhabitants into useful by-products is necessary and the technology required to do so is already in use on Earth. These wastes and recycling processes are as follows:

Organic Waste

The major contributor to waste products from the settlement would be human waste itself.Human excreta have typically targeted water, energy, carbon, nutrients, metals, or a combination of these resources.The waste is initially separated into solid and liquid waste.It is observed that an average healthy human being with a balanced diet produces about 128 grams of solid waste/day and 1.4 litres of urine/day.(citation).For a settlement of 1000 inhabitants, the net production of human waste alone would 128kg of solid waste and 1400 litres of urine per day and also dried solids contain about 13% Carbon, 14–18% Nitrogen, 3.7% Phosphorus, and3.7% Potassium.

Without a potent waste management system to treat this daily production of waste, it could pose a serious threat to the settlement and moreover, to the inhabitants.At present, in the International Space Station(ISS) human solid waste is stored and later disposed of by stowing it away in an Earth-returning cargo capsule and burns up on re-entry. For OPUS, feces is a valuable resource for the agriculture sector due to it being a very good fertilizer for plants. Human feces consist of about 75% H_2O by weight and 25% solid material, mainly organic matter.

Treatment Process of the above mentioned human and organic waste are discussed as follows:

- **Bokashi Buckets** : The first one includes sending organic waste to Bokashi Buckets containing Bokashi mix which includes grains and saw dust. These materials speed up the fermentation process. These Bokashi Buckets are a good replacement for ordinary dustbins and Vermi-Composting methods.
- **Anaerobic Digestion** : The second method includes Anaerobic Digestion. This involves microbial digestion of solid, semi solid and liquid waste into Carbon Dioxide and Methane. Methane is used as fuel while Carbon Dioxide is sent to agricultural torus.

Urine Treatment

Urine is predominantly composed of water. About 91-96% of human urine is water(Putnam (1971)). For a space settlement, water would be the most scarce and most important commodity. Water can be extracted from urine and the technology is in effect in the International Space Station (ISS) which is akin to a small-scale space settlement. The Urine Processor Assembly (UPA) in ISS can recover a minimum of about 85% water from the astronauts' urine. Urine is also composed of salts of phosphorus and nitroge-

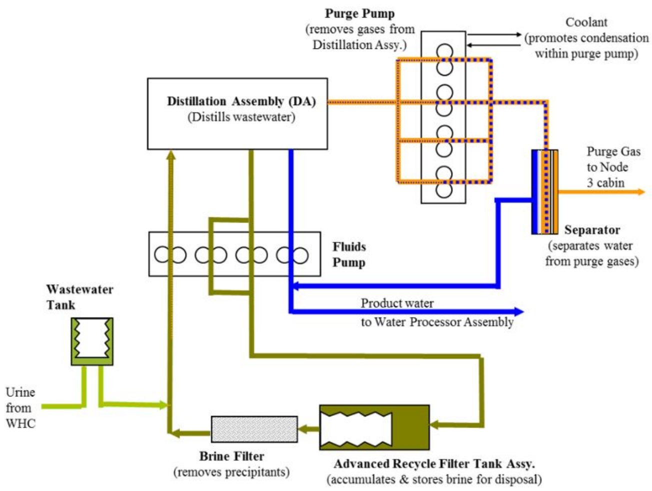

Figure 7.4: Urine Processor Assembly schematic, Credit: NASA

nous compounds which can be used as an effective fertilizer for crops to be grown in the settlement.

7.6.1 | E-Waste

E-Waste is nothing but electronic waste. The parts of various e-waste can be stripped away and the pats which are in good condition can be reused. E-Waste is recycled such that the rare products are reusable. It involves sending the E-Waste to PCB (Polychlorinated Biphenyls) E-Waste Recycling Machine to crush the waste more efficiently. Metals like Copper, Aluminium, Steel, etc. are also recycled for further use. Since we will not be getting supply regularly from the Earth, we need to make use of every part in order to sustain(Kang and Schoenung (2005)).

7.6.2 | Glass

Glass is classified into three types according to its chemical composition, such as the soda-lime glass (used in general packaging, civil construction and cars), Pyrex-glass (used in domestic appliances which can resist thermal shocks) and leaded glass (used in cups, champagne flutes and adornments). When glass is crushed and screened to pass through a 5 mm sieve, it closely resembles natural sand and has engineering properties similar to other fine aggregate materials. Hence, the waste glass aggregate (WGA) is given due consideration as a feed-stock substitute for construction aggregates.

Glass before recycling is labelled into different types like Glass bottles, colours, slabs etc. All the labels, metals are removed, if any, before sending to the recycling machine. Glass bottles are recycled in Glass Bottle Recycling Machines which melts the glass and moulds into the desired bottle shape. The bulk or glass slabs go through a two stage recycling process which involves crushing and melting of glass with 99% purity(Samtur (1974)).

Applications

- Application of waste glass in cement mortar - Mortar is a building material made of lime and cement mixed with sand and water that is spread between bricks or stones so as to hold them together when it hardens
- Application of waste glass in paving blocks
- Applications of waste glass in construction industries

Currently recycling of glass from electrical and electronic equipment is relatively limited. This is partly because glass from these products is often contaminated with other substances. Moreover, many electrical and electronic products contain scarce elements whose high market value detracts from the recovery of glass. For instance, the interior of fluorescent tubes is coated in a layer of phosphor, which itself will also have become contaminated with toxic mercury. This renders the quality of glass unsuitable for recycling, and emphasis is thus placed on recovering valuable mercury and rare earth phosphors from the lighting elements. Nonetheless, technologies are being developed to efficiently remove the contaminated phosphor layer, which may realize better opportunities to recover the glass.

Closed-Loop Recycling of Glass

The introduction of waste glass (“cullet”) back into the glass making furnace will cause it to melt and mix with the other raw materials. This recycling process sometimes referred to as “remelt” can be repeated indefinitely without any loss of performance. Processes include:

- Hand sorting to remove obvious contamination
- Crushing
- Sieving to also remove some foreign materials such as metals and plastics

- Magnetic sorting to remove ferrous metals
- Eddy current sorting
- Vacuum sorting

Open-Loop Glass Recycling

These involve re-melting glass, but involve forming into very different products. Other applications involve melting glass in the presence of other materials, with different effects depending on the manufacturing conditions.

7.6.3 | Other Non-Biodegradables

Apart from the above-mentioned types, all the non-biodegradable products shall be collected and recycled via a technique called Thermal depolymerization. In this technique complex organic molecules are converted into simpler ones by applying intense pressure and heat and produces useful crude oil and glass.

8

Transportation

8.1 | Internal Transportation

There will be large varieties of transportation in the settlement. There can be paths between different blocks and there will be spokes which connects the micro-gravity area. The spokes will be a very efficient transportation system and it will be a shortcut to travel from one side of the cylinder to another side through micro-gravity cylinder.

The hexagonal block will have transportation tubes/roads which will be spread throughout the settlement. On the above surface there will be path for people to walk or cycle. Each block will have opening which will lead to the road/tube in almost all the wall of the block.

The road/tubes can be used to run anything like trains, cars or other means of transport. If we would be running trains, then we can have stations at the opening which leads to the road/tube. The cross-section view is shown in the image.

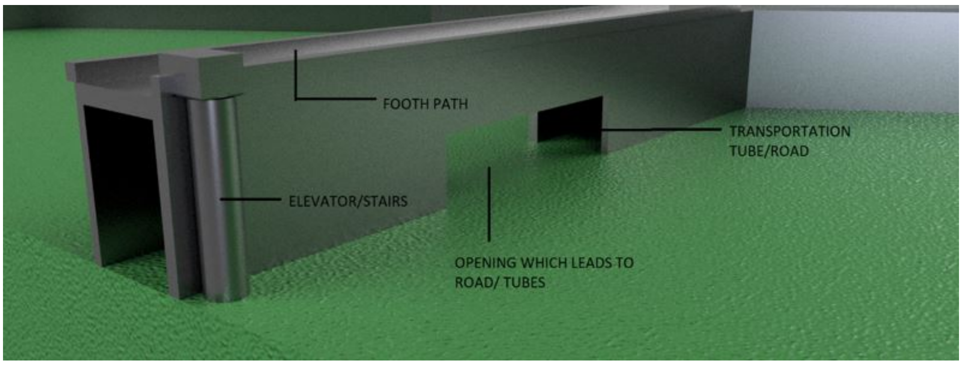

Figure 8.1: Internal transportation structures in OPUS

8.1.1 | Transportation Vehicles

1. **Advanced Bicycles & Roller Skates** : These are the safest means of transportation on-board OPUS. These Bicycles will have maximum speed of about 25 kph considering the safety of other pedestrians. The battery can be charged either by solar energy or through the kinetic energy generated through peddling. Pillion rider provision will be provided with a carrier and headlights in the front. Safety gears are must for safe transportation. A safer version of tricycle will be provided for children below 12 years of age and must be accompanied by an adult. The Speed limit of these tricycles will be limited to maximum of 20kph considering the safety of the child. Wearing safety gears is a must for children. Roller skates can also be used as a means of transportation in OPUS. But will have a Speed limit of 15kph. Wearing safety gears is a must while using roller skates. It is mandatory for Bicycles and roller skates to follow lane discipline and using pedestrian lane is strictly prohibited. But can use other lanes only at the time of emergency.

2. **Conveyor Belts** : Conveyor belts of multiple speeds can be installed in hanger and docking hub to transport heavy goods to other hubs except micro-gravity hub. The speed of the conveyor belts is customizable according to the purpose of transportation. Only one Conveyor belt of fixed speed will be installed in habitual area and can be used by citizens. This is majorly used in the maintenance hub to carry out the works smoothly. Anyhow the speed of the conveyor belt will be limited to 10kph.

3. **Elevators and Escalators** : Elevators in micro-gravity hub can be used as goods carrier to transport heavy goods such as industrial machines, research equipment, Diagnostic equipment, Space crafts, Satellites, Launch vehicles etc. These elevators can be used to move from upper levels to lower and vice versa. To save on the Energy consumed by the elevator it can work in counter weight concept. Elevators can serve as major human transportation system as the settlement houses approximately 1000 members and also considerably helpful for future expansion.

   Escalators can be installed in each levels of buildings, malls, restaurants, stadiums and other entertainment area. These can be also used to transport small goods and other required amenities to different levels. The maximum speed of the escalators will be limited to 10kph.

4. **Electric Cars** : Electricity driven cars and scooters are employed on-board OPUS as major and emergency vehicles. EV's will have batteries installed that are driven by

both solar power and electrical power. These can be also used as Ambulance services, public transportation, tourism, professional travel. These Electric vehicles can be owned by the public on permission to avoid unnecessary traffic, pollution & consumption of energy.

The speed limit for electric cars used for ambulance will be limited to maximum of 50kph and for other transit vehicles the maximum speed limit would be 40kph. Similar speed concept would be used for Scooters but the speed limit of 40kph for emergency transit and 30kph for regular transit vehicles. The speed limit is subjected to modifications based on the major factor considered at the time of implementation of this concept on-board OPUS.

8.2 | External Transportation

External transportation vehicles are used for unmanned and manned space missions. These serve as the major transportation system between the source and the destination of the travel. Usually Spacecrafts are used as external transportation modules and also as resupply mission module. Advanced spacecraft systems will be used by OPUS for external transportation which encompasses advanced AI technology for communication and navigation.

These spacecrafts can be used to visit Lunar and Martian surface for intricate research considering the future surface settlement on them. These Spacecrafts will be commanded by the OPUS Captain Bridge and also with the ground station on the earth and lunar surface.

Two major types of external transportation system will be considered for OPUS:

1. **Crewed Spacecraft** – Crewed spacecrafts will be designed in such a way that it supports life system on-board. It can be maneuvered using Artificial intelligence and manual controls

2. **Uncrewed Spacecraft** – Un-crewed spacecrafts are used for robotic spaceflights without humans on-board. These spacecrafts are controlled by the OPUS settlement and AI.

Spacecraft subsystems comprises of various equipment required for space exploration and also to last long enough for humans to survive on-board the craft for at least a week at the time of crisis. These subsystems are listed out below.

(i) **Life Support Systems** – The life support system on-board the human spaceflight should be well equipped with required amount of supplies for survival. Proper Medical facilities should be provided for regular health monitoring. It should also harvest supplies for the time of emergency.

(ii) **Attitude Control** – A Spacecraft should have advanced attitude control systems for efficient maneuvers required for the spacecraft to achieve mission objectives and to place itself in exact orientation required for active communication and power generation.

(iii) **Guidance, Navigation and Control** – Guidance module basically steers the spacecraft according to the command given. Orbital elements and positioning systems are determined using Navigation system of the spacecraft. The path of the spacecraft is adjusted according to the mission requirements using the control system module of the spacecraft.

(iv) **Command and Data Handling (CDH)** – CDH module of the spacecraft performs the on-board functions according to the commands received through the communication module from the settlement by validating and decoding the command received after which it has to distribute the command given to that particular subsystem components. This is carried out for multiple components at once. CDH also should be capable of receiving and processing the commands and storing them in the data recorder/black box and also transmit these information to the ground station

(v) **Communication** – the communication module of the spacecraft should have active communication systems for uninterrupted communication. This module sho - uld also house compatible optical and RF communications.

(vi) **Power & Thermal control** – Proper electrical power generation and distribution system has to be installed which can power up the whole spacecraft and also store the surplus energy for emergency usage. The solar panels should be well connected with a proper AC-DC converter and a surge proof mechanism should be provided to avoid unnecessary power surge in the module due to faulty connections.

Thermal controllers are the major shielding provided as the outer layer of the spacecraft which can withstand the high temperatures at the time of transit while escaping or re-entering a planet's atmosphere. Active thermal controllers' use louvers (actuators) and electrical heaters to control the drastic temperature changes and operate them within the specific range provided.

(vii) **Structures and Payloads** – the structure and payload of the spacecraft must be engineered to withstand heavy loads and stress exerted by the launch vehicle and the gravitation force acting on it. The payloads should properly be attached to the deployer and the launch vehicle as to detach itself from the main body at required location as per the mission requirements. The structure of the spacecraft should be capable of handling stressful environment in the space and at the time of transit through any planet. A typical payload will have specific instruments like cameras, telescopes, particle detectors, cargo or a human crew.

Escape Pods

Escapes pods are provided at the emergency exits of the settlement. At the time of contingency on-board OPUS, Stairs should be used for the evacuation process which leads to the emergency exits. No electronically controlled transports will be used for the evacuation process. Mandatory traction stairs provided should be used at each level leading to the emergency exits of the respective levels. Patients, old age people, and children will be given first preference for evacuation. Emergency kits will be released with an oxygen mask lasting long enough to board the escape pods and belt themselves to the seats. Each Escape pod can have 4-6 members and children must be accompanied by adults.

Once the crew is on-board the escape pods, an immediate ejection process will be initiated and the pod will eject itself from the settlement within 45 seconds of the initiation. The navigation system of these escape pods will be pre-programmed in its destination & course towards the earth. The course of the escape pods cannot be changed by the members on-board but can be directed towards the nearest water body to the rescue centre by the ground station.

At the time of crisis, the ground station on earth should immediately be intimidated so that the rescue team on the earth will be well prepared to rescue people from the pods once they come back to the earth. These escape pods will be developed for a destined reentry and splashdown to avoid unnecessary explosion and crash on the ground while touching down due to some technical issues. These escape pods will house the same concept of current splash down technology until future modifications are done.

Escape pods will have enough supply which can last long enough for at least 3 months for each passenger on-board. The number of escape pods on-board OPUS will be suf-

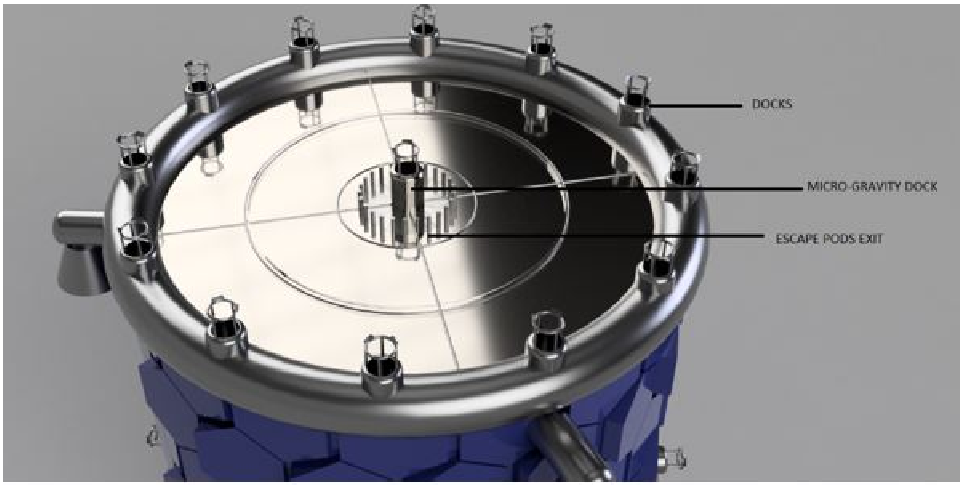

Figure 8.2: Docking ports in OPUS

ficient enough to bring all the 1000 crew members back to the earth safely. Once these pods are the detached ground station will automatically detect these pods and can command them from the ground station.

8.3 | Docking

Docking Area

There are several places for the docking area in this settlement. The torus has many numbers of docking areas and the micro-gravity also have a docking area. Each industry would have its own docking area for supply for raw materials or for exporting outside the settlement. Near the docking area of the micro-gravity cylinder, there is an exit for escape pods which leads directly to space. The emergency escape pods will always be on standby and can be used in case of emergency. There will be a docking area in the middle torus also and the middle torus can also have a place for hangers and a place where spacecraft can land. This place can be used for the maintenance of the spacecraft.

To mate the spacecraft like the space shuttle and the space settlement we need matting techniques, these techniques are namely berthing and docking, these are the methods followed by International Space Station (ISS). On the question of what is the difference between docking and berthing, NASA gave a clear explanation of it in which the following document will explain to you in detail.

Docking is defined as the process of connecting two spacecraft without external assistance. To give a lively example, docking represents the combination of a port and

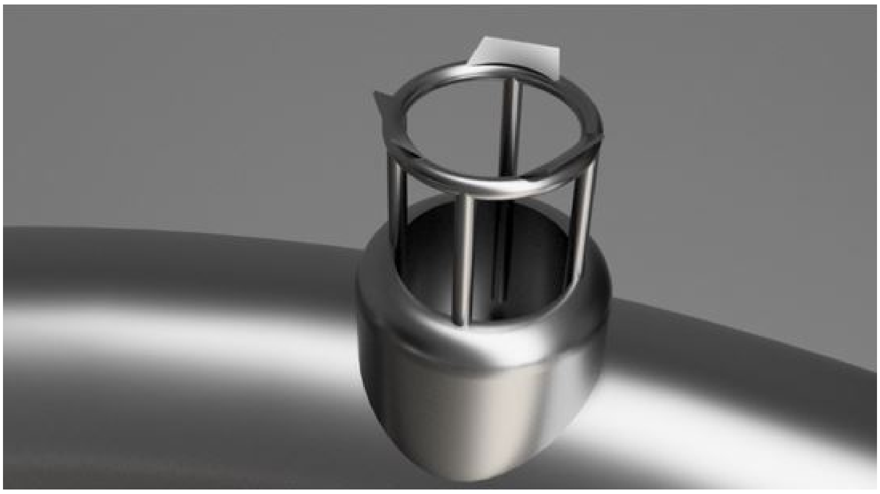

Figure 8.3: A single docking port on OPUS

a ship for which the captain in a boat can navigate, make land and tie up to the dock without external aid. Whereas berthing in this terminology, to the large ship scenario where a harbour master or pilot boat is required to aid moving the boat into the boat dock. While coming to real case scenario that is docking and berthing as per Automated rendezvous and docking of spacecraft (Wegbert Fehse) is as follows:

- In the case of docking, the guidance navigation and control (GNC) system of the chaser controls the vehicle state parameters required for entry into the docking interfaces of the target vehicle and for capture.
- In the case of berthing, the GNC system of the chaser delivers the vehicle nominally zero relative velocities and angular rates to a vehicle meeting point, where a manipulator, located either on the target or chaser vehicle, grapples it, transfers it to a final position and inserts it into the interfaces of the relevant target berthing point

In the current international Space Station (ISS) berthing operations, the pilot boat is replaced by the space station robotic arm. Visiting vehicles or other external hardware are plucked from a station-keeping position or removed from a cargo bay and placed onto the attachment mechanism on the ISS. Berthing allows for a lighter and less complex attachment mechanism than docking but requires an external robotic manipulator to present all berth and unberth events. The safe hand-off of the payload from the robotic arm to the berthing mechanism presents technical challenges as well.

Whereas in docking, the attachment mechanism includes its own robotic manipulator, known as the Soft Capture System (SCS), for manoeuvring the vehicles after soft capture into the final position for a hard mate. The SCS has a capture envelope large enough to accommodate the inaccuracies of the Guidance, Navigation, and Control (GN&C) system which was followed in the Berthing mechanism. We will get in detail about the mechanism of docking which was followed by NASA.

NASA Docking System - NDS

NDS(McFatter et al. (2018)) is a new spacecraft docking and berthing mechanism to dock with International Space Station (ISS). This docking system is developed according to the international docking system standard. NASA Docking System is a combination of ASTP, APAS, ILIDS, and SIMAC.

Working of NASA Docking System

On the ISS, the passive side of the system is existing in which it consists of 2 subsystems named the soft capture system and hard capture system. The most prominent part of the soft capture system is the alignment petal and a crucial yet not so obvious part of the soft capture system are passive strikers used in the latching process in which we will discuss further, hard capture are located around the soft capture system and this hard capture system consists of 12 pairs of latches, fine alignment pins, & fine alignment pinholes and a power and data plug.

Now on the approaching vehicle like a space shuttle, there will be an active site of the NASA docking system here also the soft capture and hard capture system will be existing. Here the soft capturing system is held by six electromechanical linear actuators. Electromechanical linear actuators is essentially a threaded rod that can be extended and retracted using an electric motor that engages with the threaded rod via a threaded sleeve, by having the active soft capture ring mounted on the six linear actuators, these have the ability to vary the extended length of each actuator to move the soft capturing with six degrees of freedom this means we can move at all 3 axes of rotation and all 3 axes of translation. On the active soft capture system, we don't have the passive striker that the passive soft capture ring does but on the rough alignment petals there will be soft capture latches. While coming to an active hard capturing system on the space shuttle is quite similar to the passive hard capturing system of the ISS. Additionally, it has an elastomeric seal, that's the general anatomy of the NASA docking system.

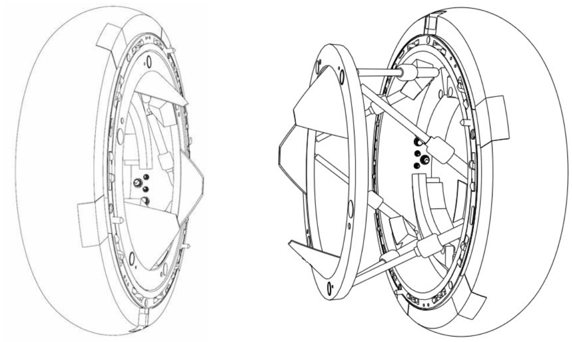

Figure 8.4: Passive (left) and Active (right) parts of the NASA Docking System, Credit: NASA

- The linear actuators of the active soft capture system are fully extended and retracted to make sure there are no mechanical issues, the actuators then position the soft capture ring in the ready to capture position.
- The approach to the docking port is made slowly and carefully and when contact occurs the active soft capture system will perform what is called lunge, where the actuators will push the active soft capturing forward into the passive one.
- The electric current flowing to each actuator is limited in order to limit the force the actuators exert, if an actuator reaches the maximum allowed force the actuator is designed to slip while maintaining the maximum force this way the active soft capturing gets pushed in all the way flush engaging with the passive soft capturing without simply just pushing off of it.
- If the lunge is successful and pushing the two soft capture rings together the soft capture latches and the petals on the active side will extend and strike the passive strikers on the passive side.
- The job of the active soft capture system now is to attenuate the relative motion between the two vehicles and align the active and passive hard capture systems this is done by driving all six the linear actuators to an equal length, then the actuators start retracting to bring the active and passive hard capturing systems together.
- Once close enough together, the hard capture latches are driven closed in two groups of six and these two groups are made up of alternating peers around the hard capture rings.

– Upon completing the hard capture, the power and data plug into their respective sockets from this point, the area between the hatch on the space shuttle and hatch on the ISS called vestibule needs to be pressurized. Once this is done the leak checks are performed the hatchways can be opened up and astronauts can move between the visiting space shuttle and space station.

8.4 | Airlocks

One of the main components of space settlement or any manned space mission is Airlock. The airlock separates the outer space from the settlement. Its job is to provide a passageway for the people to enter or exit the settlement without wasting much gas. It consists of two segments; the equipment locks and the crew lock. Equipment lock is where the spacesuits and other equipment will be kept and the crew lock is from where the astronauts can exit the settlement. Before the crew airlock hatch is opened to space, it has to be depressurized all the way down to 0 psi.

The air in the intermediate zone will have the pressure equal to the next door which we are going to use. The cross-section view is shown in the figure.

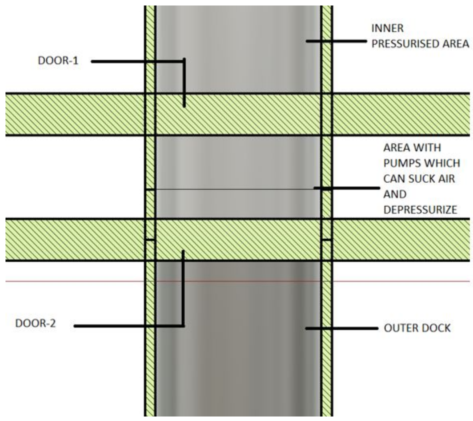

Figure 8.5: Cross sectional view of Airlocks in OPUS

8.5 | Thrusters

The thrusters will be placed on the outer cylinder where solar panels will be there. Few thrusters can be placed on the torus also. The thrusters will have thrust vectoring. There will be three thrusters on the top and three at the bottom. The thruster's components will be in the extrusion. All thrusters work on ion propulsion. It will be extruded from

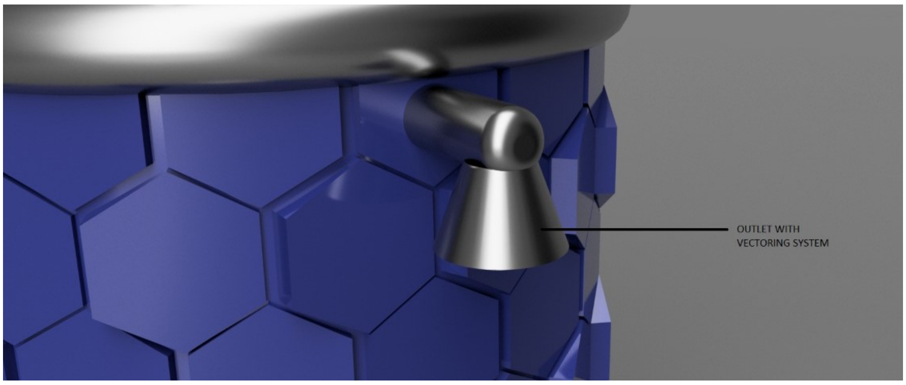

Figure 8.6: Thruster on-board OPUS

the surface as shown in the figure. For OPUS, **Electro-static Ion Thruster** would be used | (Foster et al. (2004)).

An ion thruster or ion drive is a form of electric propulsion used for spacecraft propulsion. It creates thrust by accelerating ions using electricity. It ionizes the propellant by adding or removing electrons to produce ions. Ion thrusters are being designed for a wide variety of missions from keeping communications satellites in the proper position (station-keeping) to propelling spacecraft throughout our solar system.
These thrusters have high specific impulses-ratio of thrust to the rate of propellant consumption, so they require significantly less propellant for a given mission than would be needed with chemical propulsion.

Working of Ion Thruster

An ion thruster ionizes the propellant by adding or removing electrons to produce ions. Most thrusters ionize propellant by electron bombardment: a high-energy electron (negative charge) collides with a propellant atom (neutral charge), releasing electrons from the propellant atom and resulting in a positively charged ion. The gas produced consists of positive ions and negative electrons in proportions that result in no over-all electric charge.
The most common propellant used in ion propulsion is xenon, which is easily ionized and has a high atomic mass, thus generating a desirable level of thrust when ions are accelerated. It also is inert and has a high storage density; therefore, it is well suited for storing in Spacecraft. In most ion thrusters, electrons are generated with the dis-charge hollow cathode by a process called thermionic emission.

Parts of Ion Thruster

The primary parts of an ion propulsion system are the ion thruster, power processing unit (PPU), propellant management system (PMS), and digital control and interface unit (DCIU). The PPU converts the electrical power from a power source, usually solar cells or a nuclear heat source into the voltages needed for the hollow cathodes to operate, Tobias the grids, and to provide the currents needed to produce the ion beam. The PMS may be divided into a high-pressure assembly (HPA) that reduces the xenon pressure from the higher storage pressures in the tank to a level that is then metered with accuracy for the ion thruster components by a low-pressure assembly (LPA). The DCIU controls and monitors system performance, and performs communication functions with the spacecraft computer.

Current Application of Ion Thrusters

Ion thrusters (based on a NASA design) are now being used to keep over 100 geosynchronous Earth orbit communication satellites in their desired locations, and three NSTAR ion thrusters(Polk et al. (2001)) that utilize Glenn-developed technology are enabling the Dawn spacecraft(launched in 2007) to travel deep into our solar system. Dawn is the first spacecraft to orbit two objects in the asteroid belt between Mars and Jupiter: the proto-planets Vesta and Ceres. **Note** : All images pertaining to the settlement structure design in this section was designed by OPUS design team and rendered in Fusion360.

9

Communication Systems

Considering the fact that how dependent OPUS would be on technology, it is of utmost importance to have a high-speed communication network for both Internal (inside settlement) and External connectivity (with Earth / other orbiting stations etc.). Akin to the Internet on Earth, there needs to be a network in the settlement which would connect the people of the settlement together and bring about a sense of 'digital-togetherness'.

9.1 | Internal Communication

The internal network should provide high speed data transfer with low latency. The settlement would be utilizing cutting edge technology and efficiency of the communication network is paramount. For keeping the settlement running, AI would be heavily used to keep the conditions suitable for normal life of the citizens. However, to keep the AI systems running, a constant and high-speed data input is required to keep the response time very low.

Considering this, OFC (Optical Fiber Cable) network would be the main medium of communication for internal communication network(Prucnal et al. (1986)). Since the settlement is akin to a city, a Metropolitan Area Network (MAN)[1] would be a suitable network. However, connecting every single major user using optical fiber would be a tedious, costly and space-consuming process. To circumvent that hurdle, a Municipal Wireless Network would connect citizens to the Settlement 'Internet'.

Wireless access points would be provided throughout the settlement providing all-the-round connectivity to users. The distribution would be optimized for maximizing

[1] https://en.wikipedia.org/wiki/Metropolitan_area_network

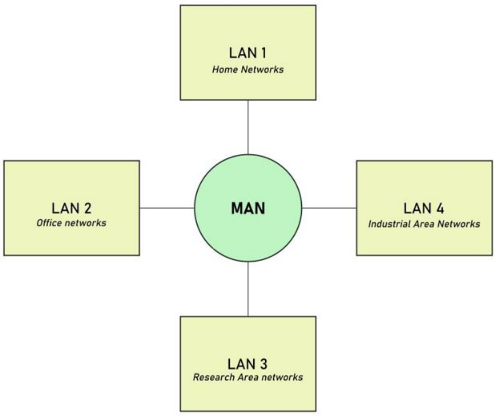

Figure 9.1: A sample MAN network for OPUS

coverage and users can hand over to the next access point without a hassle while traveling.

9.2 | External Communication

Communication with Earth based systems is also necessary for the survival of the settlement. The settlement would require updates from Earth for a multitude of reasons. With adequate space-based communication satellites around Earth, round-the-clock communication can be set up between OPUS and any ground station on Earth.

Laser based communication has already achieved encouraging results and allows very high data transfer rate, as shown by NASA's OPALS(Oaida et al. (2013)).

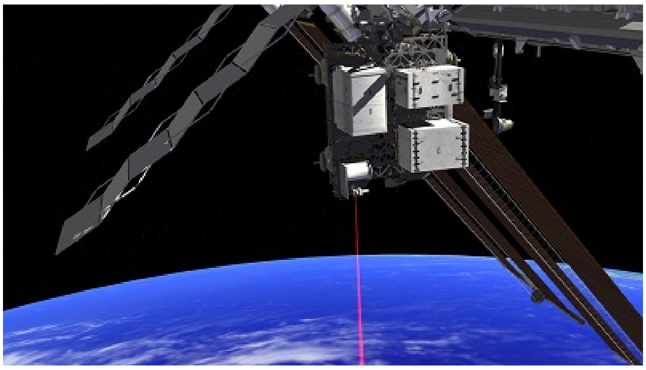

Figure 9.2: Artist rendition of NASA OPALS on ISS, Credit: NASA

10

Space Dangers and Contingency Plans

10.1 | Asteroids

1. **Small Asteroids** - For these, we can use Laser system(Vasile and Maddock (2012)). By using laser, we can change its momentum and slow down the speed of the incoming object and there was also one other option to have net as well so that we can capture any small debris. We can also use parabolic reflectors. The settlement will be provided with several sets of parabolic reflectors with a large aperture. These mirrors will be placed in an order so that they focus the sunrays to a point on the asteroid. Due to very high temperature at a point, the asteroid will melt at that point, thus forming an air-pocket. Due to this air-pocket, there are fair chances of the asteroid to change its course.

2. **Large Asteroids** - In case any asteroid with diameter of about 250km comes into the path of the settlement, the settlement would be translated from its position using thrusters. During translation of settlement, there will be not much of a difference in the net force experienced by a person and hence he will not feel much of a difference in his weight while the settlement is being accelerated for translation.

10.2 | Space Debris Management

Space debris was another topic which had to be considered to for the orbital settlement. The L5 point being the stable point does have asteroids or any space junk which has been floating around. Over the years there have been various methods that have been proposed and tested into the space to remove these active debris.

The methods we can use for our settlement for removing any debris around it is laser-based system. The reason to select this method is as the laser is ejected towards the debris it tends to slow down the incoming debris and then later deviates the path of the incoming object. The laser-based system is used for both on ground-based station as well as on board station. On L5 itself there aren't many space debris present but being a stable point there are asteroids present which might cause a problem in the future. Currently, ESA[1] has been also working on a technology to remove these asteroids using the help of satellites.

The existing ideas for removal of space debris aims to de-orbit the object from the lower Earth orbit such that it burns up in re-entry time. In laser system we can just slow down the object and control it. Being in L5 we had to select the removal technique which would just change the trajectory of the asteroid. With the momentum transfer the incoming object velocity can be slowed and then captured through a net for any debris if its trajectory can't be changed.

10.3 | Contingency Plans

Fire Accidents

Smoke detectors will be installed in the walls of the settlement. Fire alarms will alert the people and they will be evacuated from the affected area. Mono ammonium Phosphate will be sprinkled by these smoke detectors. The damages in the affected area will be repaired immediately.

Ruptures

Sensors will detect any damage occurred to the hull components. This will be directly reported by safety system to the commander. RTV- 3145 adhesive/sealant gel will create a layer on the damaged part. Specialized robots will be used to repair this part.

Power Failure

We will switch to backup power. The problems will be resolved by automated systems as early as possible. External repairs will be done by the repairs/maintenance team.

[1] https://www.esa.int/Safety_Security/Space_Debris/First_laser_detection_of_space_debris_in_daylight

Solar Flare

We will determine the occurrence of solar flares by using the technology onboard. Few parts of the settlement will be constructed to act as faradic cage. Polyethylene foam will be used as seal to reduce the effect of radiation of solar flare.

Biological Threats

Nano-detectors are used to detect biological infections. People will be evacuated from the affected area. Infected people will be quarantined. Source of contamination will be fixed by using automatic systems. If the infection is a new outbreak Bio scientist's team will work to discover anti dotes as soon as possible.

Data Storage Failure

Backup storage devices would be employed to backup critical data of the settlement. Main storage device will be repaired and replaced.

11

Selection of Colonists

11.1 | Selection Criteria

People from a large variety of background would be needed to create a rich and diverse culture inside the settlement. While creating this filter, everyone will have an equal opportunity to participate in the selection process. The equal opportunity does not necessarily mean that everyone would be selected, but that the selection process would be fair within the specified biases.

The selection process will be divided into 8 steps, called levels. For an individual to be eligible to go to OPUS, they must pass on all 8 of these levels. The details of the levels will be discussed in the following sections.

11.1.1 | Filters of the Selection Process

After the biases have been implemented, the group of people under consideration will be screened through various filters. These filters have been derived from references of standard astronaut candidates of various space agencies, with tweaks catering to the unique nature of OPUS.

These filters, in no particular order of priority, are as follows:

- **Standard astronaut candidate requirements**
- **Country filtering**
- **Personal habits filtering**
- **Social circle filtering**
- **Psychological filtering**

Standard Astronaut Candidate Requirements

For Astronaut selection campaigns, OPUS Mission Scouts for people with a desire to become next gen Space Explorers. The criterion is heavily influenced by NASA Astronaut Requirements[1] and is modified to suit the needs of a settlement. Then desirable candidates are selected for OPUS Mission. Particular applicant with outstanding fitness (health) & university education in science, engineering or medicine (preferably masters); and extensive knowledge and experience are chosen for Stage 1 selection.

Selection of Astronaut candidates for OPUS Mission will be different for civilians and defense personnel. Candidates from every genre is required on OPUS Settlement. But Stage 1 Selection will comprise of only Professional Candidates.

Astronaut Candidate Selection procedure, training and requirements are subjected to modifications on later stages of the OPUS Mission. This is carried out by OPUS Inc.

Skills and Qualities Required

To be a part of the Opus Astronaut Corps., one must possess:

1. Judgment
2. Integrity
3. Reasoning
4. Team Work
5. Motivation
6. Public Speaking
7. Ability to communicate using plain language

Who can Apply?

– The candidate should be a citizen to a UN member country and produce its passport at the time of selections

– The candidate must not have any kinds of criminal records. Must receive a security clearance from their particular government space program partners.

[1] https://www.nasa.gov/audience/forstudents/postsecondary/features/F_Astronaut_Requirements.html

- The candidate must have at least two years of experience in relevant profession or 1,000 hours of pilot-in-command time in jet aircraft which is usually acquired through military. Experience with regards to flying, any type will be useful, military or private. (For Stage 1 selections).

Language Proficiency

Proficiency in English language is a must. Should have a valid score in either TOEFL or IELTS test.

Age Group

Between 29yrs - 46yrs. (receptive to changes on-board OPUS settlement). This clause will be wavered of in later stages subjected to modifications.

Education (Civilian Applicants)

- Recruitment and selection of candidates will be carried out according to the requirement & distribution of People on-board Settlement.
- Candidates who have completed 12th/Diploma/Graduation in any field, candidates who have passed 12th or other equivalent education and have experience of minimum 3 years in merchandiser is eligible (must be registered to their respective government).
- Must have a Bachelor's degree from a deemed university in one of the following areas - Engineering, Science Ex., physics, chemistry, biology, mathematics, biology, geology, computer science. (Applicable only for candidates of STAGE 1 selection & Technical Team on-board OPUS for later stages).
- Candidates who have completed Master's/Doctorate degree from a deemed university in any of the following fields
    1. Two years of work toward a Ph.D. program (must have 36 semester hours or 54 quarter hours) which should be related to science, technology, engineering or maths field
    2. Or completion of any nationally recognized test pilot school program.(This clause is applicable to those candidates who wish to apply for pilot/commander of space flight).

Education (Military Applicants)

- Should have Pilot session training.
- Active duty military personnel can submit applications for the Astronaut Candidate Program through their respective government.
- After preliminary screening by the military will be carried out and a small number of applications are submitted to OPUS Mission for further considerations.
- Education qualifications for military/defense personnel will remain same as that of respective nation's military requirements.

Other Qualifications Required

- Astronauts are called to perform a variety of scientific and technical work. Hence candidates need to provide information on their: (i)Educational Qualification (ii) Experience (iii) Expertise (iv) Supporting Documents
- As part of the Astronaut Candidate training program, OPUS Astronaut Candidates need to complete military water survival prior to the commencement of their flying curriculum, and become scuba qualified to get ready for spacewalk training. All Astronaut Candidates will be expected to pass a swimming test on their first month of training

Physical and Medical Requirements

- Candidates are expected to have strict medical requirements and must be in excellent health. Must have healthy medical history. Must not have any Personal Habits hindering health like Smoking, drinking (Alcohol) or any other drugs. (True for last one year).
- All crew-members will be expected to fly aboard spacecraft and perform space walks, hence all applicants must meet the anthropometric requirements for both the spacecraft and the spacesuit. Applicants brought in for an interview will be evaluated to ensure they meet the anthropometric requirements
- Height – Should be between 149.5cm to 190.5cm.
- Weight – Should be between 50kgs to 95kgs.
- Blood Pressure – Not higher than 140/90 mm Hg, measure in sitting position.

- Auditory acuity – Normal hearing (should not suffer from chronic or recurring auditory conditions)
- Visual Activity – 20/20 (6/6) or better, with or without correction
  - Should not be Colour Blind.
  - The refractive surgical procedures of the eye, PRK and LASIK, are accepted providing at least 1 year has passed since the date of the procedure with no permanent adverse after effects. For those applicants under final consideration, an operative report on the surgical procedure will be requested.
- Vaccination against communicable diseases according to requirements

General Information on Selection Criteria

- Training and evaluation sessions will be based on various aspects according to the mission requirements spread for 2 years or more.
- Once candidates are chosen for training and evaluation process, they must be aware that selection as an astronaut candidate does not guarantee selection as an astronaut.
- Final selection as an astronaut will depend on satisfactory completion of evaluation & training sessions.
- If required Candidates should be capable of relocating to places of training according to their training sessions.

Graduate from OPUS Astronaut Candidate Program will be provided to those candidates on successful completion in following programs:

- Space Settlement System Training
- Spacewalk skill training (working in micro-gravity environments)
- Language Skill training
- Aircraft/Flight readiness training (Sustaining and working under multiple G's)
- Robotics skill training
- Scuba diving (for expertise to work under micro-gravity and stressful environments)

Each candidate selected as OPUS Astronaut will be having expertise in:

- Spacewalks
- Self-Sustenance in adverse conditions on-board OPUS
- Pilot training (for technical team candidates)
- Advanced technology used on-board OPUS
- Securing fellow members during unfavourable conditions
- Detecting faults on-board OPUS

Selected Military Candidates will be given with special training regarding the defence system of OPUS, Security breaches, isolation & quarantine at the time of contamination.

Country Filtering

This is the first stage in the selection process. To pass one must be a citizen to a UN member country and hold its passport at the time of filtering. This process will be carried out through the official *OPUS.inc* website by creating a short account for the sign-up process. All communications and further processes will be done through this OPUS account.

To avoid misuse of the OPUS infrastructure, a processing fee of Rs.2500 for India, and the buying power equivalent of 2500 INR in other countries, will be charged to the individual while signing up. The revenue from this will also help in offsetting the cost for setting up the website infrastructure and offices all over the world. At level 1, only the website will be set up along with the IT headquarters in a country where it is the most tax efficient to do so.

Personal Habits Filtering

In this section, people will be filtered out on the basis of personal habits and addictions. This is so that the healthiest of people are selected for the settlement, and to filter out people who have physical dependencies on controlled substances. The minimum criteria for selection are:

1. Smoking
    a) Delivery device of 'chemicals' using smoke like nicotine, cannabis, salvia, etc.

   b) Chemicals include controlled substances
   c) Minimum acceptable frequency: equivalent smoking effects of 1 cigarette per week
   d) Cigarette, vape pen, joint, bong, cigar, etc.
   e) True for the last 6 months

2. Tobacco
   a) Minimum ingestion criteria 1 gm of pure tobacco
   b) Frequency of once per week

3. Alochol
   a) Alcoholic drink defined as having at least of 14 gm of alcohol per drink
   b) Frequency of consumption being 1 drink per week
   c) True for the last 6 months

4. Usage of Opiates (for medical purposes)
   a) Any kind of prescription opiate
   b) Used for pain relief or emotional management
   c) Benzodiazepines, amphetamines, etc.
   d) Minimum acceptable: not used at all
   e) True for the last 2 years

5. Usage of Opiates (illegal abuse)
   a) Any kind of generalized opiate
   b) Heroin, meth, fentanyl, etc.
   c) Minimum acceptable: not used at all
   d) True for the last 10 years

6. Lack of physical exercise
   a) Exercise is counted as 30 mins per workout day of workout, done at least 4 times a week
   b) Cardio and weight-training must be part of workouts
   c) True for the last 2 years

Social Circle Filtering

In the words of Dan Pena: *"Show me your friends, and I will show you your future,"* it is easy to understand that an individual's friends have a tremendous effect on what kind of person they are. In Jim Rohn's words, *"you are the average of the five people you spend the most time with."* The level 3 filtering is based on this philosophy that an 'individual' truly is the average of the 5 people that they spend the most time with.

In this filter, the candidate's family will be interviewed in multiple sessions so that it is known what kind of person the candidate is. Here, family includes immediate family (spouse, children) and then close family (parents, siblings). All candidates will be asked to submit contact details of these people. With these details, Opus will schedule in-depth meetings with these 5 people to find out the following things about the candidate in question:

– The validity of the claim that these truly are the 5 people that the candidate spends the most time with

– Once validated, what kind of person the candidate is

– This refers to the person's way of thinking, philosophy in life, how they treat the people closest to them

– Are they a kind and generous person?

– Are they respected by the people they spend time with?

– Are they respected by the people they spend time with?

– Do they treat their colleagues professionally with courtesy, respect and dignity?

– Do they treat their immediate family (spouse and/or children) with courtesy, respect and dignity?

Along with the interviewers, trained psychologists will conduct the meetings with the family to get an accurate rating of the candidate. To quantify the 'general nature' of the candidate, a complex grading model will be created by the top psychologists of the world. This grading model will be filled in by the psychologists (3× per candidate) in presence with the interviewers, and will be assessed by the creators of the model using human knowledge and a compilation of data using machine learning.

In case of family members, beyond the words of the people being interviewed, the psychologists will be looking for signs of withdrawal, denial, fear and lying – common characteristics of candidates that emotionally abuse/neglect their family/colleagues (especially so in the case of children). This is to ensure that the candidate has dignity, integrity and self-esteem, and are able to handle their emotions in a healthy manner in times of stress.

The comprehensiveness ties into the next level of filtering - **Psychological Filtering**.

Psychological Filtering

The most bare-minimum criteria to advance through this level of filtering in having at least 50 hours of therapy with a single authorized and recognized therapist, with the therapist certifying that the candidate has undergone significant improvement (yes/no affidavit) throughout their therapy sessions. Higher number of hours will be preferred, but are not necessary.

At this level, the complexity of analysis of an individual's psyche, emotions and sense of self gets even deeper, reaching the level of conventional psychotherapy. Here, Opus' in-house team of therapists will be analyzing and probing each candidate for weak points and blind spots in their psyche and sense of self. All such sessions will be held under doctor-patient confidentiality, with consent from the candidate, with the only usage of the data/knowledge of the analysis sessions being used to develop and assess candidates for further steps/filtering.

The panel of psychologists that will be studying each candidate (who has made it so far) for psychological robustness in terms of projection, denial, repressed emotions (anger, hatred, jealousy, joy, happiness), ability to handle stressful emotions effectively, and the ability to have and sustain self-esteem.

The panel will take reference from the Diagnostic and Statistical Manual of Mental Disorders, 5^{th} Edition (DSM-5) for checking up on the presence of any unhealthy/toxic mental habits and practices. The panel will then suggest reparative steps for the candidate to improve on. Further, candidates are trained to build strong and healthy mentality which is one of a major requirement for the OPUS mission.

For the candidate to be selected, they must show continuous improvement over the course of the entire analysis sessions. This shows that the candidate is capable of adapting to new situations and challenges, has the introspection abilities and can take criticism to the face. Further, it shows that the candidate can effectively handle any emotional conflicts that may come up, either within themselves as emotional conflicts, or with other people through conflicts of opinions, interests, actions or decisions. This ability to effectively handle conflicts is crucial for people to have effective and enjoyable lives on the settlement.

The candidates that have shown the most improvement will be selected for the further rounds of filtering.

11.2 | Execution of Selection Process

The selection process would be carried out by incorporating a company called OPUS Inc. that manages the entire selection process. This global company would be funded by publicly listing shares and direct private/sovereign investments. These shares can be purchased by a nation-state, HNWI, for-profit organization (companies, PSUs).

The shareholders must either be a member of the UN (for nation-states) or must have their companies headquartered in a UN member country (for companies) or must be residents of a UN member country (for HNWIs and individuals).

The process will be executed by OPUS Inc. in collaboration with the shareholding private companies and local governments. Since it is the parent company, OPUS Inc. will manage the selection process and handle relations between the settlement and the earth. There will be further subsidiaries and holding companies under OPUS Inc. to manage trade, transport, communication and other aspects of the settlement.

12

Society

12.1 | Time Zones

Just like the Earth twenty-four hours are considered as a day. There are three divisions in our settlement according to the time. Each division will have a time difference of eight hours. Every person on the settlement works for eight hours a day and gets sleep for eight hours a day. Remaining eight hours are allotted as their personal time. With this kind of division of time we can have three batches of people who can contribute their work throughout the day.

12.2 | Citizens' Rights on the Settlement

A nation-state is created by the founders through defining what the nation stands for and the future vision of the nation. For this, the best leadership must be in place for the people of this nation to survive and thrive in this world. As our 'nation' is out of this world, some other unique criteria do apply. The rights of various citizens are as follows:

- Right to privacy
- Right to basic amenities of life
- Right to fair and equal treatment
- Right to free speech and expression
- Right to information
- Right to constitutional remedies

12.2.1 | Right to Privacy

The right to privacy allows all of the citizens/settlers of Opus to have a sense of individuality, and gives them mental space away from each other. For Opus to be at least a spiral dynamics stage blue settlement, this is necessary.

In legal terms, privacy refers to having one's individual identity and personal data protected. Here, as mentioned, identity and personal data refer to an individual's online/electronic identity and data.

Unique Government ID on Opus

Every citizen will have a unique government electronic ID in the form of a unique pin, similar to a SHA256[1] hash code. This unique pin will be called OpusID. This will be generated at the time of signing up for the website Opus in the selection process, and will be tied to the legal passport of the individual.

The pin will be generated by a complex randomizing function created by the best of data scientists, that holds the private key for an individual's identity. This key, combined with bio-metric (fingerprint, face-scanning) will provide very secure identity protection to the individual.

Legal Framework for Individual Privacy

There will be legal regulations for individual privacy on the settlement. In the various domains where an individual's and organization's privacy can be breached, legal protection in the form of regulations and laws, along with legally-mandated cyber-security assurance checks, will ensure that the handling of data is done is a secure manner that always has user-privacy in consideration.

The best form of privacy can be achieved only if all of the possible entities that can be harmed by a privacy violation are considered in the privacy regulations. These include, but are not limited to, individual citizens, families, communities/localities, companies, organizations, various government ministries and offices, etc.

[1] https://docs.microsoft.com/en-us/dotnet/api/system.security.cryptography.sha256?view=netcore-3.1

Ministry of Information Technology

Opus will have a ministry of information technology that handles all of these aspects. It is responsible for maintaining and upgrading the physical IT infrastructure of the settlement, which includes but is not limited to:

- Communication Infrastructure
  - Communication within the settlement in the form of cellular towers, free and secure Wi-Fi to all residents of Opus, public broadcasting software
  - Communication with external spaceships in the form of local 'Space Traffic Control' (STC) equipment of antennas, transponders and signal processors with highly CPU-efficient, energy efficient and secure computers
- Cybersecurity Infrastructure
  - Maintaining and upgrading the physical communications infrastructure of fiber-optic cables, cellular towers, public Wi-Fi routers
  - Maintenance of the IT infrastructure of the government offices of OPUS
- IT research and development
  - Public funds devoted to the research and development of IT infrastructure and technology at the university on Opus, and published in the official government/university research journal associated with this
  - Research also encouraged to be done by private organizations, under tenders, and funding may be given to research organizations if they satisfy a rigorous and market-rate profits selection criterion

12.2.2 | Right to Basic Amenities of Life

12.2.2.1 | RIght to Air

This is the most fundamental right that all living beings will be provided with. Air will be controlled and regulated through the Ministry of Atmosphere and Climate (MoAC) of the government on Opus. This government department will be responsible for maintaining the climate / HVAC systems inside the settlement, and maintaining/upgrading the equipment needed for this. The air quality and composition data will be taken from the Department of Meteorology from the government university on Opus. This department would be responsible for the study and development of the HVAC systems on Opus, and is answerable to the MoAC.

The air in the 'public' spaces on Opus will be kept in a composition similar to that on earth. The air will be monitored for pollutants, SPM, and other unhealthy contaminants under regulations of the as suggested by the MoAC and ratified by the parliament of Opus. The MoAC will be responsible for maintaining this standard of air for all citizens in the public spaces. With constant monitoring probes being placed throughout the settlement, live-tracking of air quality throughout the settlement can be done.

For non-public zones of the settlement, different air-quality regulations will apply.

- In the agricultural sections, a higher oxygen content can be provided as studied and recommended to the Ministry of Agriculture and the Ministry of Food and Nutrition of by the Department of Agriculture and the Department of Nutrition and Food Technology of the university on Opus.
- In the storage sections of the settlement, there is no need for air. These sections will be under vacuum of space, and can be accessed using robots and a pressure chamber transfer bay

This air will be provided through all citizens through the centralized HVAC system that creates the atmosphere inside the settlement. Citizens and organizations are free to handle/process this air through various HVAC systems inside buildings as well, depending on the building regulation codes of the settlement.

12.2.2.2 | Right to Water

Citizens will be provided water in multiple ways depending on their usage of it. The citizens can use water domestically, industrially or publicly in the following ways.

- Domestic Use
  - For these, two pipelines (inlet and outlet) will be provided to each building as per the building regulation codes of the settlement
  - In the inlet, fresh potable water will be supplied to each building
  - All taps inside the building (including sinks and bathroom flushes) will be provided with this potable water
  - This water will be used for the primary uses like cooking, cleaning, bathing, etc.
  - Installation of plumbing inside the building is the responsibility of the citizen/builder

  - The government will provide 20% over minimum necessary daily requirement of each individual (per-capital daily water requirement) for free
  - Additional use will be billed to the citizen at market rates
  - Also, there will be public water fountains where citizens can fill up their water bottles/tanks outside their homes/buildings in 1L increments at a time

- Industrial Use
  - For this, a setup similar to that of domestic use will be provided
  - The capacity of this system will be higher than that of the domestic one
  - The capacity of this system will be higher than that of the domestic one
  - For industries, all fresh water use will be billed to the government at market rates
    - This means that companies are free to extract and sell water at cheaper rates, thereby promoting competition and lowering the cost to the end-user
    - This also means that industries are free to extract their own water from space and use it for industrial purposes
  - Industries will be encouraged, through regulations, to recycle water and to minimize water usage as it is a precious commodity in space

- Public Use
  - Besides these, water will be used publicly in the form of the Opus river, lakes across the settlement and simulated rainfall
  - In the case of simulated rainfall, humidity would also be controlled with the actual precipitation of rain

12.2.2.3 | Right to Food

Citizens who have very-low or no-income will be provided with assistance to get health--y and nourishing food. This assistance will be in the form of reduced cost (for low-income individuals / households) and free-of-cost under certain conditions (for no-income individuals / households)[2].

These provisions will be provided through coupons for local grocery stores / supermarkets at a limited budget, and only limited to groceries. The amount available to

[2] https://en.wikipedia.org/wiki/Supplemental_Nutrition_Assistance_Program

the individual / household in such coupons will depend on the number of people in the household, and the cost of living in the particular area. The amount shall cover a healthy and nourishing diet as recommended by the Ministry of Food and Nutrition on Opus.

The coupons shall be applicable only for groceries like fruits, vegetables, dairy, grains and protein. Anything other than these items will be not be available for redemption through the coupon system.

To be eligible for the coupon system, other than income, net-worth of the individual / household will also be considered (except for the current residence if owned by the individual). The individual / household's net worth includes their tangible assets like houses, other property (offices, shops, etc.), financial assets (stocks, bonds, commodities, etc.) and any appreciating and income-generating assets. Only if the net worth of the individual / household is below a certain minimum threshold, to be determined based on the cost of living by the Ministry of Economics on Opus.

12.2.3 | Right to Fair and Equal Treatment

In the eyes of the government on Opus, all citizens are equal and have the legally enforceable right to fair and equal treatment.

Incentives & Compensation

For people to be motivated to go onto Opus and settle there, people need incentives and motivations to do so. While the exciting idea of settling in space is sufficient for many space enthusiasts, a large majority of people in this world would look for something more than this.

This is where the compensation for individuals comes in. In this section, compensation will be discussed for the first 1000 settlers of Opus. These 1000 people will be specialists who would be working towards getting the settlement up and running, and will include young/mid-aged professionals.

The settler's compensation consists of salary and benefits. Salary includes the direct monetary pay to the settler, and benefits include compensation other than direct monetary pay. While the salary of individuals on Opus would vary depending on their skill-set and the labor market at the time of creating Opus, a large part of the benefits given to the settlers will be the same.

Work Experience (Years)	**Base Pay** (INR)
0 years	Rs. 60,000
3 Years	Rs. 75,000
6 Years	Rs. 90,000
9 Years	Rs. 1,35,000
12 Years	Rs. 150,000
15 Years	Rs. 165,000
18 Years	Rs. 180,000
21 Years	Rs. 210,000
24 Years	Rs. 240,000

Table 12.1: OPUS scientists pay scale

Settler's Salary

Once it has been confirmed that the candidate will be going to Opus, a multi-year training process would begin. In this training process, the settler would be trained in the ins-and-outs of becoming an astronaut and the specific job that they'll be doing on OPUS.

Civilians would be expected to leave their ongoing employment to become an Opus Astronaut Candidate (Opus AsCan). The compensation of an Opus AsCan would depend on the country in which the training is occurring, and not the citizenship of the Opus AsCan. It would be derived from the salaries of government employees and soldiers.

In this section, salary for Opus AsCans training in India will be considered. A similar compensation model would be applied for training happening in various countries.

For Opus AsCans training in India, the salary equivalent of DRDO scientists will be taken. Here, compensation is higher on the basis of seniority. This seniority will be established on the basis of work experience for civilians and military rank for active military personnel. In the case of retired military personnel, a combination of military rank before retirement and work experience after retirement (if any) will be considered. For simplicity, here only work experience (in years) will be shown. This compensation scheme, based on DRDO scientists' compensation , is as follows: This compensation structure is for the training sessions happening on earth, before going away to Opus, exclusive of the non-monetary compensation. This salary varies on the basis of cost of living in individual countries and the compensation structure of government employees in that country. For example, if candidate 'X' has to get training for 12 months in India, 12 months in Russia and 12 months in Canada, the compensation structure would be for the particular time that they have spent in each country including the previous work experience/military rank that they have had.

Settler's Benefits

Apart from monetary compensation, all Opus AsCans will be provided benefits along with their monetary pay. In this section, the monetary equivalents of these benefits will be considered for Opus AsCans in India, and will vary depending on which country the Opus AsCan is working/training in. These benefits include:

– **Health Insurance** : Any and all medical expenses of the Opus AsCan will be covered under insurance by the government of Opus, including the training that the Opus AsCan goes through on earth before ever going to Opus. This includes mental health services like therapy, and life coaching up to a certain amount every year. This health insurance is applicable for the individual and all immediate family. These include parents, children and current legal (married) spouse.

– **Personal Travel Allowance** : Every year, the Opus AsCan will get a personal travel allowance of Rs.15,000 that they can use for travel in flights, trains, buses, public transport excluding personal commute to and from their residence and the Opus training facility. This allowance, if not spent, will expire every year

– **Personal Computer Allowance** : Every 3 years, the Opus AsCan will get a personal computer allowance of Rs.80,000 that they can spend on a personal computer. This can be availed on a laptop, tablet, desktop or all-in-one. This allowance, if not spent, will expire at the end of every 3 years

– **Personal Residence** : All Opus AsCans will be entitled to staying in residences while under Opus payroll. These residences will be free of charge to all Opus AsCans. If the Opus AsCan wishes to rent a place outside of the allotted residences, they will be given an allowance depending on the median house rent on the area that they choose to live in. This rental property must be within 8 km of the Opus training facility that they will be working in. If there are multiple training facilities in a city, the nearest one will be considered.

– **Opus Provident Fund** : All Opus AsCans, from the start of their payroll, can invest in the Opus Provident Fund (OPF). The OPF will give each candidate a return of at least 9% compounded annually, and higher if the economic index of Opus performs higher than that. Opus AsCans can invest up to 40% of their annual pay in OPF, and the returns as availed through OPF will be available for redemption after at least 5 years of the first investment. If the candidate chooses to not redeem after 5 years, their account will be given an additional 5% after these 5 years.

- **Personal Phone Allowance** : All Opus AsCans get Rs.40,000 every two years to purchase a new phone. If the Opus AsCan doesn't claim this, this amount gets added up for up to two two-year terms. On top of this, all Opus AsCans will get Rs1,500 per month for their phone bill.
- **Personal Internet Allowance** : All Opus AsCans will get Rs.2,000 per month for their personal internet, through either ISP broadband, fibre, or cellular hotspot.

12.2.4 | Right to Free Speech and Expression

All citizens of Opus hold the right to speak freely about their thoughts, feelings and opinions. Citizens can assemble in groups to form companies, organizations, unions, parties, clubs and associations of any kind as per their wishes. They are totally free to do so.

Any blockage on this can be prosecuted by law. For example, if a journalist has information that compromises the credibility of a politician, any action taken by the politician against such a journalist to stop them from sharing this information (bribes, threats, lynching) will be prosecuted.

But, this does not mean that every citizen is entitled to a platform for expression. A citizen has the right to express, but not the right to have access to any platform to express. They cannot expect privately/publicly held expression media (TV, radio, podcasts, advertising companies) to cater to their wishes just because they have the right to do so. They may start/create their own platform for sharing to do so. Also, if any kind of organization is found to break the laws of Opus, they can and will be prosecuted as per the decision of the court of Opus.

12.2.5 | Right to Information

All of the government processes will be available online in a simple and easy-to-use website. To design this website, some of the best web-designers / website-building companies will be consulted to ensure that the official government website is simple and easy to use. This allows citizens to directly interact with the government through the website, instead of having to stand in long lines in a government office. A comprehensive tutorial series will also be developed so that it is very clear on how to use the website, with the provision of a moderated discussion forum to address any disputes.

A large portion of the accounting documentation of the finances of the government will be made available publicly on this website. Along with independent (non-government) auditing, bounties will be placed for reporting any disputes/gaps in the accounting of funds, to ensure that all of the documents have been properly audited.

A large portion of the decisions of the government will be publicly made available through the official Opus news website, which is run by the government. This, along with private news websites/companies, will ensure that there is true transparency and accountability in the government.

12.2.6 | Right to Constitutional Remedies

All citizens of Opus hold the right to constitutional remedies. This means that if any single citizen, or a group of citizens, feels that the constitution must be updated, they are free to submit an update request on the official government website and the local government offices of Opus. Through this facility, citizens have the ability to directly influence the laws on Opus.

All remedy requests will be made publicly available so that anyone can comment and critique on any particular request, and these will be anonymized so that the author of any controversial remedies would not be doxed.

This system will be made so that even a 10th-pass person is capable of submitting a remedy request to the government. This is so that the criteria of education would be eliminated, and any intelligent citizen can directly influence the law, similar to the open-source software community. This does not necessarily mean that their remedy would be implemented, but that their remedy would be considered.

While citizens are free to do so, there will be a particular template in which citizens must submit their request. This template will have a minimum criterion of comprehensiveness, so that one-liner and very simplistic remedies will be discarded and only the high-quality and properly thought-through remedies will be considered. The template would be designed so that a person with any background of education, not just lawyers, will be able to effectively make suggestions on influencing the law.

12.3 | Public Health

Along with the selection criteria and rights given to the selected candidates for OPUS mission, there some other major factors are to be considered for a supportive society provided on-board OPUS. The considerations are discussed below. These are subjected to modifications in future depending on the mission requirements and in supportive to the crew members.

12.3.1 | Vaccination

Vaccinations are to be administered to the selected candidates based on the guidelines provided by the World Health Organization (WHO) before the commencement of OPUS space settlement program. These vaccines are administered according to the individual medical reports under close supervision of the respective medical practitioner only. Below are a list of vaccines that can be considered.

1. Adenovirus	2. Diphtheria	3. Rabies
4. Pertussis	5. Hepatitis A,b	6. Smallpox
7. Anthrax	8. Tetanus	9. Typhoid Fever
10. AVA(BioThrax)	11. Yellow Fever	12. Mumps
13. Pneumococcal	14. Tuberculosis	15. Measles
16. CHolera	17. Varicella	18. Vaxchora
19. Japanese Encephalitis	20. Human Papillomavirus(HPV)	21. Polio
22. Seasonal Influenza	23. Shingles	

Table 12.2: List of vaccinations to be taken by an OPUS settler

12.3.2 | Organ and Medical Insurance

- Travel from Earth to Opus of every individual will be covered under insurance, pertaining to earth. Organ replacement like: heart, lungs, liver, kidney will be carried out on-board OPUS Medical team.
- Candidates with Health Insurance (on earth), can be recovered on Opus, where the insurance company pays Opus for the candidate's healthcare and medical bills for the covered amount.
- Every organ of the OPUSian will have their organs insured to the Opus Society Health Care with respect to the Rules and regulations laid down by WHO on the earth.
- In the event of death of the OPUSian, the insured amount can be obtained by the nominee. (Spouse/Children/Parents).
- At the time of any causalities, the organs of the person will be retrieved by the Opus Society and stored in the Organ Bank only if its retrievable according the

rules and regulations followed on the earth which is laid down by WHO. There will be no further modifications done on this part until the settlement has completed its Gen 1 of experimentation.

12.3.3 | Chemical dissolution of Corpse

The decomposition of the body will be carried out through Chemical Dissolution or electrical cremation. Electrical cremation would mostly be avoided to reduce Carbon and CO2 emission to the Opus Atmosphere.

The Process of chemical dissolution can be carried out in the device - Resomator, through the process of alkaline hydrolysis of bodies.

13

Space Research

Space research is a vast field embodying scientific research and experiments that are carried out ranging from space technology to astronomical observations. It is an integral part for any settlement we plan, it takes the future prospect of the settlement and answers to the question what next has to be done. Artificial satellites, physiological responses of living organisms, physical science, diagnostics, Earth Science, communications, medicine, physics etc. constitutes to space research domain. OPUS Settlement will have a separate hub for Space research to be carried out using stimulated gravity and microgravity depending on the multiple mission objectives.

Major part of the research would be carried out using robotics like the earth science, medicine and diagnostics etc. while some of which would require human interventions. Space research will be bifurcated in the research hub as departments to carry out the work. Opus will also have provision for future expansion as explained in the design structure.

Topics currently considered for OPUS Space Research are as follows:

13.1 | Effects of Space Travel on Humans

Physiological Aspects of Space Travel

A journey to Mars would require, at a minimum, two 6-8-month segments of travel in "deep space" before and after a nominally 18-month stay on the surface of Mars. On the trips to and from Mars, the crew will be exposed to micro-gravity and to radiation levels much more severe than that experienced at the ISS in low Earth orbit. During her trip to Mars, for example, the rover Curiosity experienced radiation levels beyond NASA's career limit for astronauts. On the surface of Mars, moreover, gravity is 38%

that of Earth's and radiation is still very dangerous(Paris (2014), but reduced by more than 5% from levels in deep space. Furthermore, the surface of Mars is generally coated with dust containing toxic chemicals such as perchlorates(Davila et al. (2013)). The key information that we do not have is whether the reduced gravity on the Martian surface is strong enough to afford recovery from the physiological effects of zero-g, or at least to reduce the deleterious effects discussed in the sections below. Installing a centrifuge on the ISS could provide some valuable data — at least on mice or other animal subjects.

Radiation

Earth's magnetic field protects astronauts in low Earth orbit from harmful radiation(Letaw et al. (1989)). Although these astronauts are more exposed to radiation than humans on the ground, they are still protected by the Earth's magnetosphere. A manned mission to Mars, however, will introduce the spacecraft and its crew to an environment outside of this protective shield. During the Apollo program, for instance, astronauts on the moon reported seeing flashes of light, and experienced cataracts; these flashes were due to radiation from cosmic rays interacting with matter, and depositing its energy directly into the eyes of the astronaut.

The crew en-route to Mars will be outside of Earth's magnetosphere and thus will be at risk from radiation capable of critically damaging the spacecraft; absorption of fatal radiation doses from bursts of solar protons due to coronal mass ejection events, with exposures lasting a matter of hours, and/or potential damage to DNA at the cellular level (which may eventually lead to cancer).

Studies to evaluate the performance of radiation shielding materials for future missions can be studied aboard OPUS.

Effects on Cardiovascular System in Space

Although the cardiovascular and pulmonary systems (including the heart, lungs, and blood vessels) adapt well in space, they function differently in micro- or zero gravity than on Earth. An astronaut's cardiovascular system begins to adapt to weightlessness as soon as the blood and other body fluids shift from their lower extremities (feet, legs, and lower trunk) to the upper body, chest, and head(Hughson et al. (2018)).

The bigger question, however, is whether or not the crew, after a 6-month journey in deep space, would be able to function on Mars, which has 62% less gravity than Earth. When the crew arrives on Mars, they would hypothetically be stronger compared to an astronaut returning to Earth's gravity after a mission of similar length.

Astronauts immediately arriving on Mars would have trouble walking, suffer fatigue, and be in real danger of bone fracture and intermittent loss of consciousness. Moreover, according to NASA, six months in zero gravity (which is the time it will take to get to Mars) will take the astronaut 2 years of recovery time. Therefore, a mission profile which allows only 30-90 days on the surface of Mars would not give the crew enough time to recover from the 6 months in zero-gravity.

Effects on Neuro-Sensory System in Space

The most striking of all of the physiological changes astronauts experience are the changes in the neuro-vestibular system(Clément (2011)), which is the part of the nervous system largely responsible for balance mechanisms. Weightlessness during a round trip to Mars will affect an astronaut's neuro-vestibular system. His or her perception of body orientation, point of reference, and equilibrium will be severely altered during the trip to Mars. As a result, astronauts will experience severe motion sickness symptoms that include disorientation, dizziness, depressed appetite, vomiting, and, in severe cases, extreme nausea. Studies can be done to analyze these effects.

Effects on Musculo-Skeletal System in Space

The human body has about 700 muscles[1]. Many of these muscles operate as cables that pull on bones to make motion possible. Their function is contraction – that is, they all work by shortening the angle between two bones. When we don't use certain muscles, however, they can go into "hibernation" mode. In a weightless environment, where an astronaut does not use his or her muscles for a period of time, the muscles themselves begin to waste away, or atrophy(Williams et al. (2009)). The long-term result on the astronaut's load-bearing tissues will be significant reduction of bone and muscle. Thus, muscle atrophy will cause problems for astronauts on a mission to Mars.

An additional consequence of leaving gravity is that the astronauts no longer require the full strength of the skeletal and muscular systems for support of their "upright" posture. This is because the astronauts do not stand up in space. Since their muscles and bones are not used, they depreciate or "decondition" somewhat. As a consequence, their bones lose calcium and become weaker and, to a degree, waste away. Bone mineral loss in astronauts has been documented in most early human space flights. Changes in calcium balance, decreased bone density, and inhibition of bone formation have also

[1] https://www.britannica.com/science/human-muscle-system

been reported. Studies can be done to evaluate possible medical compounds which can be used to negate these effects.

Permanent Damage to Vision

The space science medical community has recently realized that long-term spaceflight can cause severe and possibly permanent vision problems in astronauts[2]. Scientists believe the eye problems stem largely from an increase in pressure inside the skull, specifically, from increased pressure from cerebro-spinal fluid which surrounds the brain, which works its way to the optic nerve and pushes on the back of the eyeball. A spacecraft equipped with artificial gravity, which would prevent an increase in pressure in the skull, would be the recommended primary countermeasure to mitigate potential permanent vision problems.

Psychological Aspects of Space Travel

Of all problems that can be encountered en-route to Mars and back, effects on the astronaut's mind may be the biggest risk factor of them all. As mentioned, a round trip to Mars would take 2-3 years. Anxiety, depression, and loneliness, along with the stress of routine tasks, tensions within the crew, and a daily battle to maintain fitness and avoiding accidents, is the ideal recipe for disturbed behavior in space. Although the psychological effects of living in space for long duration have not been clearly analyzed, similar studies on Earth do exist(Levine (1991)), such as those derived from Arctic research stations and submarines. Many of these studies confirm psychological stress could be the biggest problem for the crew. For example, unlike crews on the International Space Station, the crew en-route to Mars cannot remain in direct contact with their loved ones and are not steadily supplied with replacement crews, food, or even gifts. Isolation and confinement pose the greatest challenge for the crew – as they approach the Red Planet, communications between the spacecraft and Earth become sparser. For example, they would have to wait up to 21 minutes for a message to reach family members and another 21 minutes to receive a reply.

A variety of other psychological and physical effects have also been observed from both operational and simulated isolated and confined environments. These factors include motivational decline, fatigue, insomnia, headaches, digestive problems, and social tensions. Strained crew relations, heightened friction, and social conflict are also expected from isolation and confinement.

[2] https://www.nasa.gov/mission_pages/station/research/news/vision_changes.html

As a result, countermeasures are being developed, validated, and implemented, which seek to lessen the impact of these stresses on crews, and subsequently improve mission safety and success while lowering risk. Psychological counter-measures involve astronaut selection, training, and in-flight support. One method in development is an attempt to select-in psychologically fit crew-members, as opposed to merely selecting-out psychiatrically ill applicants. The Behavior and Performance group at NASA is currently validating a psychological select-in astronaut selection methodology. These validation studies have now discovered that several personality variables such as agreeableness, conscientiousness, empathy, sociability, and flexibility, among others, are positively correlated with astronaut performance under stressful conditions, teamwork, group living, motivation, and decision-making.

Psychological training focuses on developing skills for coping with the stresses of the spaceflight environment and for interacting with fellow crew-members as well as with ground control personnel. The training also deals with leadership styles, multicultural issues, working in an isolated and confined environment, and communicating with team members. In-flight psychological support involves ground-based monitoring by flight psychologists and psychiatrists, in-flight entertainment (such as videos, books, games, and special items), leisure activities, and opportunities to communicate with the ground (i.e. with family and loved ones); it also extends to care of the families of astronauts on the ground.

Long-term Food and Nutritional Concerns

Unlike short duration space missions or the International Space Station, which gets resupplied periodically, food supply becomes a critical issue for a manned mission to Mars. The food that an astronaut must consume must be of the highest quality to combat the effects of long-term exposure to weightlessness, primarily in order to maintain body mass and prevent disease. Once the crew leaves Earth for Mars, no other options are accessible and any further supply of additional food must be sent months or years in advance. The cost of added weight on the spacecraft is also important and another of the problems that must be overcome prior to leaving for Mars. Furthermore, unlike most food with a long shelf life, the nutritional requirements for a mission to Mars must be designed so the crew can look forward to an interesting and varied cuisine while they are away from home. On the International Space Station and Space Shuttle (recently retired), food is prepared on Earth and requires only minimal additional preparation [14]. A mission to Mars, therefore, will require a shift to a system of production, processing, preparation and recycling of nutrients in a closed loop environment. This process is currently designated as Advanced Life Support and it involves not just the production of food materials but also regeneration of oxygen and potable water.

A manned spacecraft built for Mars must have a galley, eating area, and an exercise station. Furthermore, the crew must have access to refrigerators, freezers, a microwave, an oven, and ambient temperature storage for foods. Frozen items should include entrees, vegetables, baked goods and desserts. The refrigerator, moreover, must be capable of keeping fresh fruits and vegetables. Some dairy products should be available, as well as extended shelf life produce. And, at a minimum, a 30-day repeating menu with individual choice of menu within the constraints of nutritional adequacy should be provided. Other considerations factored into the menu must be a diet high in calcium and vitamin D to maintain bone mass, as well as food low in saturated fats to prevent cardiovascular disease.

Operational Medicine and Health Care Delivery

On a mission to Mars, the crew would not have access to an emergency room. Moreover, there will not be much room for a full sick bay, and ambulatory medical care will be out of the question. More importantly, during the astronaut selection process it is unlikely that one would know if a crew-member is in the early stages of a deadly or incapacitating disease that would develop during the journey. Although the probability is low, there are several possible situations where medical or surgical care could be required during a mission to Mars. Medical situations, which have emerged during analogous situations (for example, crews in Antarctica or on submarines), include strokes, appendicitis, bone fractures, cancer, intra-cerebral hemorrhage, psychiatric Illness, and kidney stones. Decompression sickness, moreover, is another potential problem the crew could encounter, particularly during an extravehicular activity, or when moving between two different pressure environments within the spacecraft.

The first step in mitigating any potential medical problem is to thoroughly screen crew, and implement prevention and countermeasure strategies to avoid most medical emergencies during the flight. A detailed knowledge of the crew-member and his or her genetic makeup, to account for heredity conditions, will be necessary.

Prior to, and during the flight, the crew must also follow an aggressive cardiovascular and cancer prevention program (and diet) to minimize the risk of disease. The crew must have access to advanced medical kits which provide a wide range of first aid and surgical instruments. These kits must include antibiotics, allergy treatments, analgesics, stimulants, cardiovascular drugs, and other drugs for motion sickness, anxiety, depression, bone loss, and radiation protection. The crew, moreover, must be trained to conduct minimally invasive surgery, and, if needed, use advanced robotic life support such as Robonaut for trauma (Figure 3). During the flight to Mars, the crew must conduct medical refresher training and have contact with medical personnel at ground control. More importantly, it is highly recommended that at least one member of the crew is a fully trained medical doctor or physician with extensive training in space medicine to monitor the crew while on the mission.

Nevertheless, the medical system developed and integrated for any mission to Mars will be more robust and intelligent than any medical care system used on the Space Shuttle or International Space Station. For example, the spacecraft would be integrated with medical systems that will function autonomously with little or no interaction from Mission Managers back on Earth.

The station's primary goals are to enable long-term exploration of space, and provide benefits to all people on Earth. In addition to scientific research on space, additional projects that are not related to space exploration, but have expanded our understanding of the Earth's environment, have been conducted. These experiments have included learning more about the long-term effects of radiation on crews, nutritional requirements levied upon astronauts during long-term missions in space, and developing newer technology that can withstand the harsh environment of space.

Other experiments conducted over several expeditions on the ISS include:

- Clinical Nutrition Assessments of Astronauts
- Sub-regional Assessment of Bone Loss in the Axial Skeleton in Long-term Space Flight
- Crew-member and Crew-Ground Interaction During International Space Station Missions
- Effects of Altered Gravity on Spinal Cord Excitability
- Effect of Micro-gravity on the Peripheral Subcutaneous veno-arteriolar Reflex in Humans
- Renal Stone Risk During Spaceflight: Assessment and Countermeasure
- Validation Effect of Prolonged Space Flight on Human Skeletal Muscle
- Bodies in the Space Environment: Relative Contributions of Internal and External Cues to Self
- - Orientation During and After Zero Gravity Exposure

13.2 | Artificial Satellites

Artificial Satellites can be built on-board OPUS for various human & robotic space exploration missions[3]. Various tests involved at the time of development of satellites can be easily carried out using the stimulated environment available in Space Settlement. This can also be collaborated with the communication and Physiological response research fields for much favorable and supportive outputs of satellite development.

Launching of these satellites from the settlement would be of greater benefit in terms of economy and distance. Greater distances for interstellar and intergalactic space exploration can be easily carried out utilizing the advantage of the location of OPUS in Lagrange point L5. Spacecraft and Spaceships are employed to visit Lunar & Martian surface which will cut down on the cost of fuel consumption at the time of launch. Advanced technology can be employed which are developed on-board OPUS for future expansion. Advanced Artificial Intelligence will be employed in broader way so as to use at the time of human space exploration.

Miniature Satellite Development

Miniature Satellite development will be a major consideration which is compiled for the Swarm System of satellites for accurate study on given mission objective. Satellite Swarm System can be utilized for remote sensing application by providing a streamlined method to examine electromagnetic data over a region and investigate the relationship of preliminary signals to seismic events in which three or more satellites are placed in adjacent orbits. This forms a virtual structure according to the assigned mission. This topology can provide an image of the ground target from different angles at the same time while increasing the swath width. These swarm of satellites are programmed to work in different stages for efficient output of data transmission & also to detect any irregularities in the particular area at any stage. They must have uninterrupted communication facility with each other and also with the ground stations at any point in orbit. If any of the satellites malfunction the rest should be capable of performing the tasks without any interruption until the damaged satellite or part of the satellite is replaced or repaired. Few advantages of employing Swarm System of Satellites are listed below:

- Usage of small, simple & cost effective satellites can execute mission assignments and objectives

[3] https://exoplanets.nasa.gov/exep/technology/in-space-assembly/

- Unconstrained replacement of a satellite within the constellation or formation due to the relatively low costs of a single satellite.
- Soft deterioration of the system's performance caused by the malfunction of one of the satellite.
- Instant procuring of images from multiple geographical positions increases the resolution of the image.
- Increasing the coverage area that can be imaged.
- Through study of multiple areas can be carried out.
- Uninterrupted Communication can be established with MSM's from multiple Ground Stations.

13.3 | Launch Vehicles

The physical Exploration of Space is carried out by manned or unmanned robotic probes and spaceflights. Reusable spacecrafts are employed for several kinds of trips to space depending on the need and objective of the mission. These Spacecrafts can be launched into space by a launch vehicle. Launch Vehicle assembly will be carried out in the hanger. The various components of the launch vehicle are stacked starting with first stage and ending with the attachment of either spacecraft or nosecone. After assembly, the integrated parts of the launch vehicle are tested for readiness before transporting it to the launchpad of the settlement. Some of the tests are carried out in the research hub adjacent to hanger or launchpad. The manufacturing process for advanced and specialized modules for the physical space exploration mission will be carried out in the OPUS research lab.

Astronaut Training on-board OPUS

Required astronaut training sessions for future space exploration will be carried out on-board OPUS according to the aim of the mission. The training will be bifurcated according to the needs and also considering the fact that every personal on-board the settlement has already undergone the basic training required for space exploration. Additional training will be provided for the astronauts in the field of medicine and advanced technology used in upcoming human space explorations. Training on handling adverse situation and manual manoeuvring and commanding of the space ship is carried out. The training sessions are subjected to modification and upgradation based on the requirements at the time of human space program.

13.4 | Establishment of Deep Space Network

Considered as one of the most sensitive telecommunication system, radio antennas for DSN can be housed On-board communication module of Opus and the settlement can be used as communication hub between deep space communication and earth communication. Considering optical communication, the problem faced with this system is its directional characteristics. The accuracy required for effective transmission and reception would be quite difficult to achieve from millions of kilometres. Hence, the Satellites & spacecraft can communicate to the opus through radio signals and in turn these signals can be transmitted to the ground station using optical communication systems as mentioned in the external communication of OPUS system.

Depending on the purpose, radio antennas of multiple frequency can be used in both orbital and surface settlements for accurate DSN. Multiple DSN transmitter and receivers are placed at equidistant from one another. As it's risky to house people near ionizing radiation we can install radio antennas of higher frequency on the nearest lunar surface considering the upcoming lunar settlement.

These radio antennas used are vital for deep space exploration. It also serves as the major commanding module to control spacecraft and receive the images to understand the nature of universe, its contents and to expand our knowledge & research to greater heights in space technology.

13.5 | Astronomical Observations

Most of the high-energy particles and radiation emitted from objects in space are filtered out by the blanket of air around the earth(Brühl and Crutzen (1989)). The moving atmosphere also causes shimmering or twinkling, making it hard to obtain sharp images. To study these objects it is much easier to observe them from Space observatories. OPUS Settlement located at L5 have an advantage of having multiple spots from where Astronomical observations can be carried out.

Astronomical observations will be carried out on-board OPUS by a team of astrono mers using Radio telescopes and optical telescopes which encompasses Refractor, Reflector, Dobsonian and Maksutov-Cassegrain telescopes. Settlement based and orbital

Figure 13.1: 90-inch Optical Telescope at Vainu Bappu Observatory, India (Image captured by Dipti Ramesh

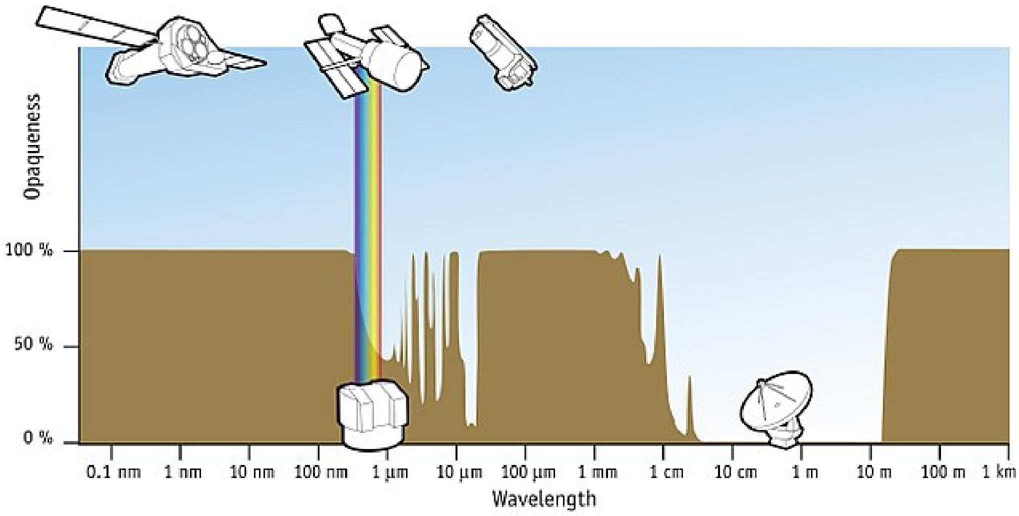

Figure 13.2: Space and ground observatories' wavelength working ranges compared against atmospheric transparency windows, Credit: F. Granato/ESA/Hubble

telescopes can also be employed for Deep space imaging. Orbital telescopes and Satellite imaging using multiple wavelengths will be carried to study the universe (e.g. Hubble Space telescope). In-house observatories can be installed on-board OPUS and also on the nearest Lunar surface.

Settlement based observations recording visible light, infrared light, radio waves will be carried out. Whereas orbital observatories can use special instruments for astronomical study which is capable of collecting data of ultraviolet radiation, X-ray and gamma-ray emissions. These astronomical observatories will partially be AI controlled used majorly for sky mapping.

Astro-photography can also be considered for astronomical observations and will also be allowed in OPUS for general public to capture images under certain terms & conditions. Armature astronomy and naked eye astronomy would be included as a major subject in academics in OPUS schooling for future generations to work upon and explore the world beyond.

13.6 | Advanced Resource Extraction Techniques

13.6.1 | Composition of Lunar, Martian and asteroid surface for resource extraction

1. **Asteroids** : These are one of the important resources for extraction of minerals and water. Using the technique of Optical mining we can capture an asteroid and then using concentrated solar energy we can have frozen water which could be used in the future. We can harvest this production from the asteroid present in LEO. Now, various research has been done on the composition of the asteroid in the Low Earth Orbit itself. So, we can study the compositions of the asteroid present in L5 in the future and use this technique as this would be a shorter distance to the settlement.

2. **Lunar Surface** : One of the biggest resource hub is the Moon, various resources are available which could be used for our settlement and even for the future industries that could be set up.
   Advantage of having Moon nearer to the settlement is that we can have vast land to set up the industries and even some habitable spots in the future. Next thing is the resources that are available on the surface of Moon. The two greatest source that are available are water and Helium-3. Both of them are an integral part to sustain life.
   Water could be used for supporting life and even generate propellants on the surface itself for missions beyond like to Mars. Using the process of thermal mining on the major areas where we can extract water from can be used for the extraction. Helium-3 being a nuclear energy can be used in industries and for power production in bulk both on surface and for settlement.

3. **Martian Surface** : Settlement on the Martian surface is also a dream which everybody had from the start. The presence of minerals and water have showed a sign to sustain life on the plant. A detailed research of the resources and possibilities further could give a much better prospect on in-situ utilization and expansion can be given.

14

Future Expansion

14.1 | Population Control

There is a chance that OPUS will face overpopulation in the future. To overcome this issue, the following methods will be enforced at the early stages of overpopulation.

Proposed population Control methods (considered at later stages of settlement)

Every Individual on-board Opus can bear a child. The following population groups can have a Child, either through sexual reproduction or Surrogacy, Test-tube baby and adoption. This clause is completely subjected to modifications considering the advancement of the OPUS Settlement in positive curve.

Population Distribution Model for Opus

- **Carrying Capacities**[1] : Defined as the maximum population size of a biological species that can be sustain in a specific environment, provided with basic fundamentals like food, habitat, water, and other resources available.
  Let us Assume, 10,000 member population, defined as the Carrying Capacity by variable K.

  For Opus, K = 10,000 members.

  Population Flux for OPUS can be defined by the following diagram (14.1):

[1] https://www.britannica.com/science/carrying-capacity

Group	Type
Heterosexual Couple	Male + Female
	Male/Female + Transgender
Homosexual Couple	Male + Female
	Female + Female
	Male/Female + Transgender
	Transgender + Transgender
Single Parent	Male
	Female
	Transgender

Table 14.1: Possible Parenting combinations

- **Birth Rate**[2] : Defined as (total number of live births given in a period of time T) / (total sample population of source, over a given period of time T); if total population is taken as 1000, it is called Crude Birth Rate
- **Mortality Rate**[3] : Defined as (total number of death in a period of time T) / (total sample population of source, over a given period of time T); if total population is taken as 1000, it is called Crude Mortality Rate
- **Emigration Rate**[4] : (Number of people entering a given location from another location at a given time period (Mi)) / (summation non migrant population (Ni) and migrant population residing in same place in the given time period (Mi+Ni); i.e.

$$(Mi)/(Mi + Ni)$$

- **Immigration Rate**[5] : (Number of People Leaving a location or Country) / (total population of the location in the given time period)

The net formula can be built as: $b + e - i - d \leqslant K$

It is important to note here that K is the maximum carrying capacity of a settlement. Thus, we should always have our population size below the K value. Thus, at time t0 our population size, should be substantially low compared to K=10,000.

[2] https://www.who.int/data/gho/data/indicators/indicator-details/GHO/crude-birth-rate-(per-1000-population)
[3] https://www.who.int/data/gho/indicator-metadata-registry/imr-details/3130
[4] https://www.oecd.org/migration/46561284.pdf
[5] https://www.un.org/sites/un2.un.org/files/wmr_2020.pdf

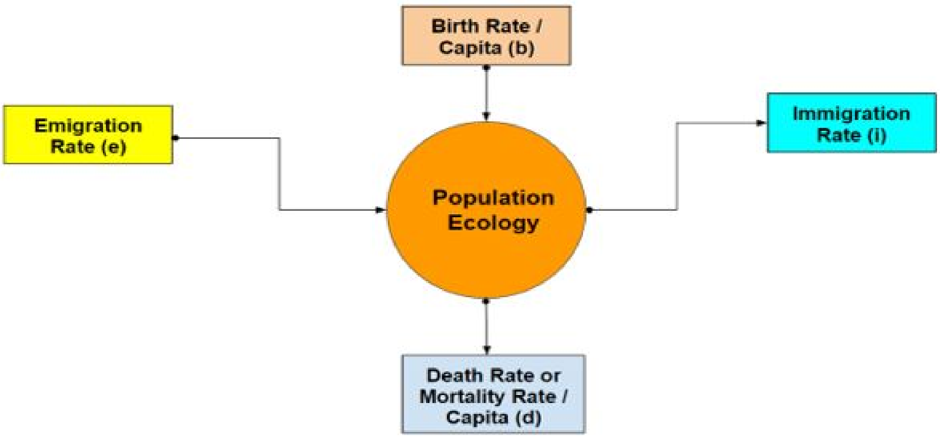

Figure 14.1: Population Ecology Design for OPUS

Also note since t_0 is the time when the settlement has just become alive, i.e. the 1st settlers are entering the settlement , at $t = t_0$, $b = 0$, $d = 0$(assuming no death occurs just after reaching the Opus settlement). Thus the net population coming in is only through e.

Let the population at time t = t_o, be p

Hence at $t = t_0$

We can't give an exact model for population distribution based on age, as it would

b	d	i	e	Total
0	0	0	p	$p < K = 10,000$

Table 14.2: at $t = t_0$

require severe experimental and observational analytical population study. A Cohort Study Design on the selected / shortlisted OPUSian population to analyse their interest or inclination towards the 3 groups may help us to understand the median age of population, during the boarding time that we should aim for at $t = t_0$. However we should make sure that our median should not be too low, as countries with lower median generally have a high population growth rate, on Earth. Another challenge that we might face during designing of such a Cohort Study is Biases. There may be cases, who initially opted for Group 2 or Group 1, but after spending time in Opus they decided to fall under Group 3 category.

However for any case , we must remember that our net population must not exceed

b	e	i	d	Total
2x	p	0	d_1	$2x + p + d_1 < K = 10,000$

Table 14.3: Fertility Control rate on opus for Sustainable Development

$p < K = 10,000$

To understand the last sentence, let us consider a Hypothesis. If let's say Group 3 from Table is available in numbers x. Each family chooses to have a maximum of 2 Children.

Over a Period of 20 Years, the net population can be estimated at $t = t_0 + 20$ as : let d_1 number of casualties(lives lost).

$$p = b + e - i - d$$

A study on population distribution and age by Hannah Ritchie and Max Roser[6], shows that following:

1. Countries with lower median age tend to have higher population growth rates
2. Lower-income countries tend to have a lower median age
3. This is because they have a 'younger' population overall: high fertility rates across these countries mean they have larger populations of young children and adolescents

Opus settlement provides equal rights and importance to all the genders. Major considerations are carried out on women empowerment, Access to better Family planning, Women's Labor period, Increasing prosperity and structural transformation of the economy, Increasing well being and status of OPUS Members, Better Knowledge About Contraception, Rising Cost of Bringing up Children, Better access to health care. Thus, it would be the duty of OPUS to take proper care of its citizens and their needs. OPUS is in fact has an advantage of having candidates who are well trained not only on the technical. physical and psychological aspects but also on Population Control Methods, Contraception Usage, Sex Education, Family Planning, Sustainable & Growth Fertility rate. Opus will house disciplined candidates which are imparted at the time of training sessions. Opus is designed to have Vertical Settlement Structure, and each Vertical Settlement will have the following in required numbers:

1. Hospitals: (Emergency, OT, General Medicare)

[6] https://ourworldindata.org/age-structure

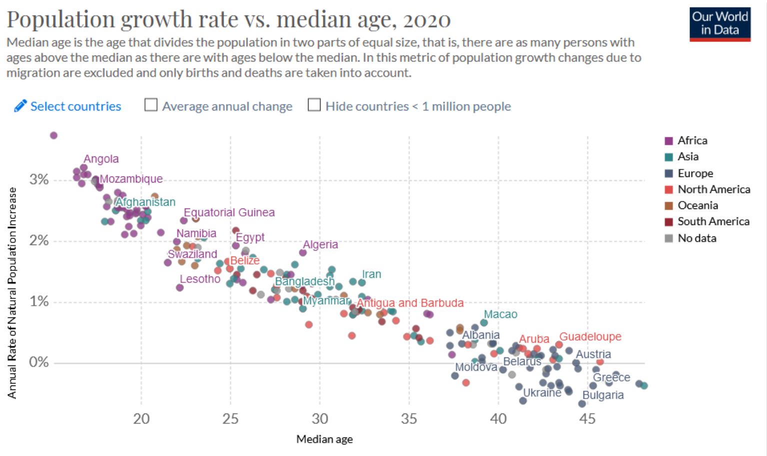

Figure 14.2: Population growth rate versus Median age, Credit:ourworldindata.org/UN (Population Division)

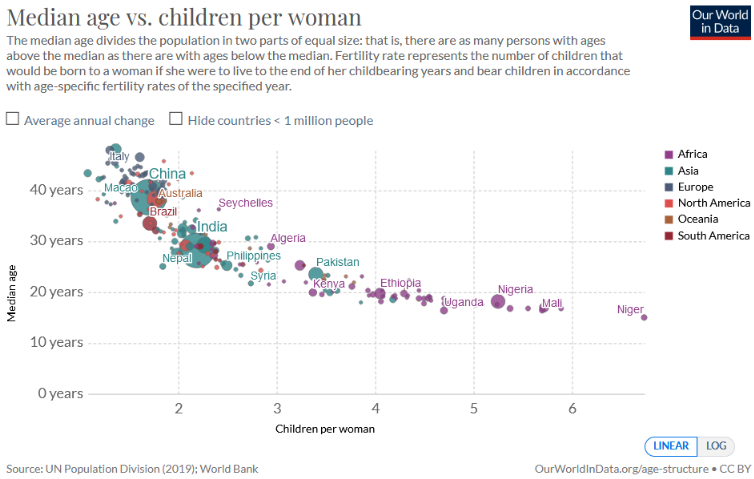

Figure 14.3: Median Age versus v/s Children per woman data, Credit: ourworldindata.org/(Population Division)/World Bank

2. SARI Treatment Facility Design

3. Containment Centers & Outbreak Management Locations (Eg: Quarantine Zones)

Since Opus is to start from a point of strong economy, strong healthcare design, education and Opus-societal trained background, along with proper health care facility, it can be fairly assumed that opus, will see a steady growing population in on an average of $p < K = 10000$, such that the fertility rate is between 0 and 2 and the population is sustainable.

Most of the ideas presented in this section are original, with reference to the previous works carried out. We have duly cited portions at places where it felt that our ideas have generated from early published literature. Other-than that each chart, diagram, picture, graph, data bank that has been extracted from other journals, has been duly cited in the literature.

14.2 | Expanding in the OPUS Universe

Figure 14.4: Future expansion of OPUS. Image created by OPUS design team in Fusion360

There is another aspect of future expansion in terms of design where we have to build few more settlements to expand our new world. There is a lot of scope for future expansion, there is an extra cylinder which can be used for increasing the living area without changing the actual volume of the whole settlement and without major construction.

Extra torus can be added on both the sides. The settlement can be attached directly through docking areas form both the end and the settlement. The extra cylinder in the settlement can be used for expansion and it can accommodate 75% of the people living in the main habitual cylinder without building anything extra and in the same volume. Both the settlement will join and become a one unit but will work independently. The docking areas will join, and transportation can be possible between the two settlement. In case of having a nuclear power plant as back up, we can add it again to the ends of the cylinder away from settlement.

Also, as we know the fact that surface offer a lot more resources. Researches will be done to find the solutions to mitigate the effects of micro-gravity. So, we can gradually decrease the gravity and give proper training to a set of colonists (say in a hundred to one-fifty years they might adapt to the micro gravity) and we will to ensure that colonists receive security, stability and perfect health through our settlement.If they can survive the conditions we can start to set up and expand colonies on the surface of the planets.

15

Conclusion

Living in space has been the dream of many, and OPUS of Armour Paradise is the first of its kind space settlement. It looks forward to exploring the world beyond the earth and discuss seemingly infinite possibilities. OPUS can be an answer to the question Are space colonies possible? It can be a better place for our endangered humanity providing the basic framework for a space settlement created by 12 people obsessed with space. The space settlement is a complex interconnected system, which will need a lot of work before it becomes operational. Team Opus has thus taken the first few steps in conceptualizing humanity's next big leap in space. We finished the project by providing the essential topics which are well thought to make a thousand people survive in a healthy and safe environment. Provisions have been provided in this report which can serve as a reference for future research and possibilities.

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