PROJECT NOVA 2

'Per aspera ad astra'

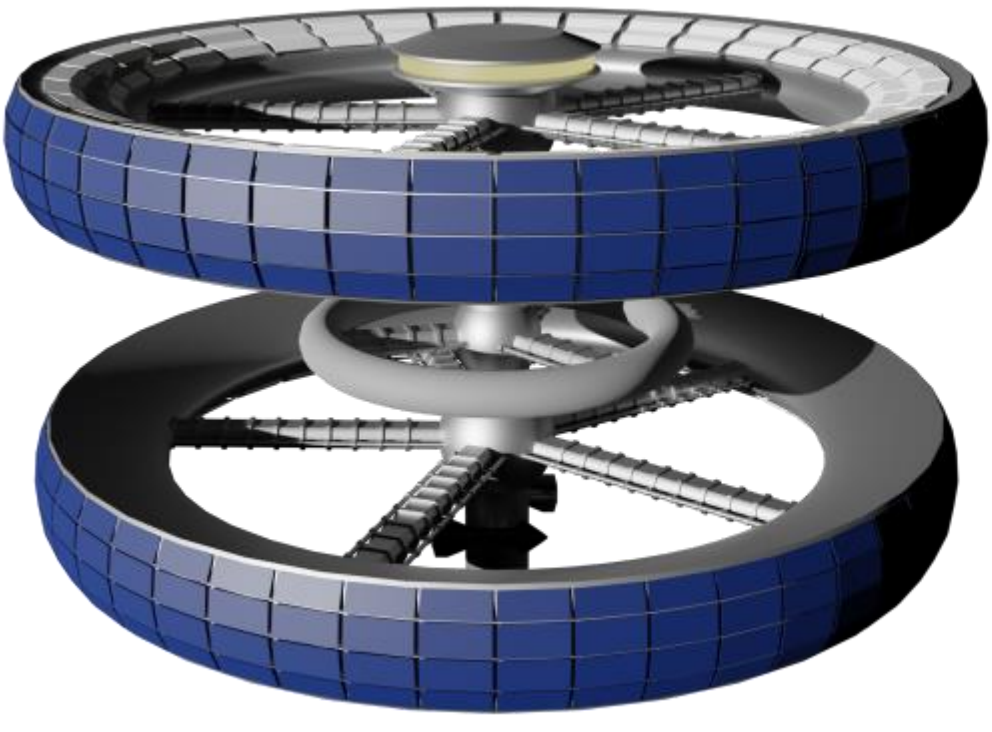
A settlement designed at Vianu School Research Centre, Grades 11-12

By Maria Neagoie [3,4], Medeea Marinescu [3,4], Luxin Matasaru [1,3], Mihai Priboi [2,6], Vlad Carasel [2,6], Tudor Nicorescu [1,3], Andrei Ciobanu [4,6], Hristoforos Koutsioukis [5], Eliza Radu [1], Vlad Dimulescu [5], Alex Paun [5], Luca Teodorescu [1]

[1]Design
[2]Engineering
[3]Infrastructure & Operations
[4]Life Support
[5]Social
[6]Research & Finance

Coordinating Teacher: Ioana Stoica

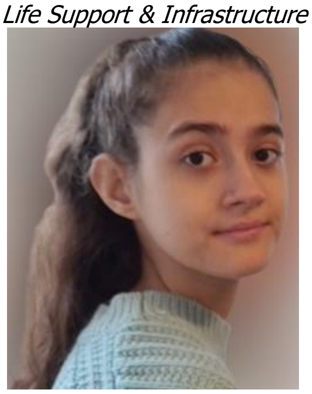
Tudor Vianu National High School of Computer Science, Bucharest Romania



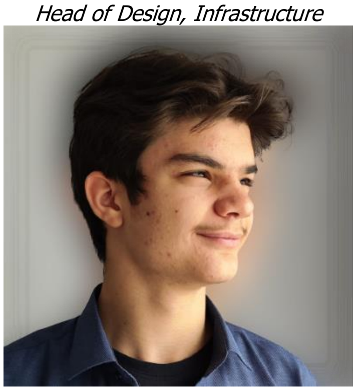
PROJECT NOVA 2: THE VIANU RESEARCH CENTRE TEAM

Maria Neagoie
Head of Life Support; Infrastructure; Project Manager

Medeea Marinescu
Life Support & Infrastructure



Luxin Matasaru
Head of Design, Infrastructure



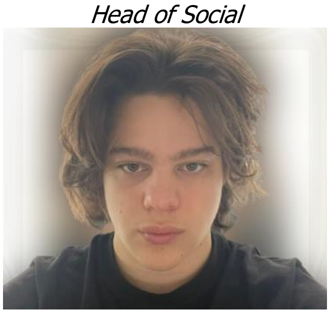
Mihai Priboi
Head of Engineering; Research & Finance

Vlad Carasel
Engineering, Research & Finance

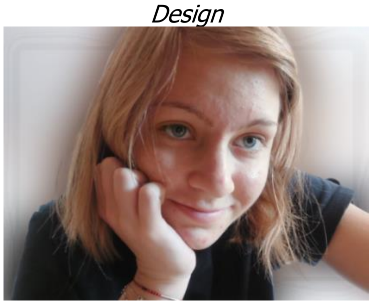
Tudor Nicorescu
Design & Infrastructure

Andrei Ciobanu
Life Support, Research & Finance

Hristoforos Koutsioukis
Head of Social



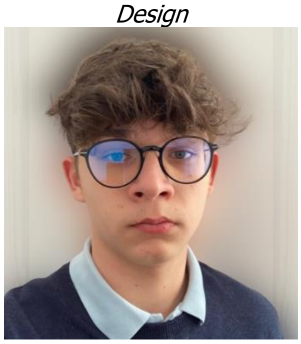
Eliza Radu
Design



Vlad Dimulescu
Social

Alex Paun
Social

Luca Teodorescu
Design



PROJECT NOVA: EXECUTIVE SUMMARY

Notes: Each chapter has been treated as a scientific article and thus contains all the respective references.
Please click on the chapter title/page number to go to the respective part of the project.

1. INTRODUCTION

1.a. NAME CHOICE

We have chosen the unique name *Project Nova* for our Space settlement because it represents the birth of a new era in Space exploration and habitation. To be clearer, the term "nova" refers to a star that suddenly increases in brightness and energy, signifying a transformation and a new beginning, just like Project Nova serves as a stepping-stone towards establishing permanent habitats beyond our planet.

Moreover, *Project Nova* symbolizes the limitless potential and opportunities that exist in Space. Just as a nova is a source of light and energy in the universe, *Project Nova* represents a beacon of hope and a source of innovation in Space. With its cutting-edge technology and innovative design, our novel settlement concept will pave the way for future generations to explore and settle in Space, unlocking the full potential of our galaxy and beyond.

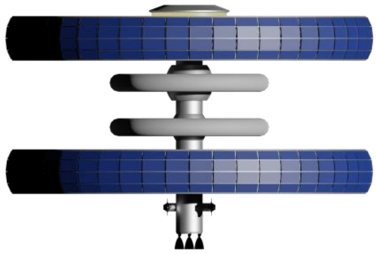


Figure 1.a.1. Design of our Settlement – Front View

When talking about our motto, we have chosen ‘Per aspera ad astra’, the well-known Latin saying, meaning ‘Through hardships to the stars’. In a nutshell, we opted for this slogan in order to express our continuous work and determination to put effort into making novel discoveries connected to Space exploration.

1.b. GENERAL PRESENTATION OF THE BASE

Nova station will be a permanent toroidal space colony located in Mars’ orbit, sustaining over 2000 tourists, scientists, and permanent settlers. Much thought was put by our team into deciding every aspect of the space settlement. Starting with the location, after careful consideration of multiple candidates, Mars’ orbit was chosen for its scientific importance, as well as its proximity to the asteroid belt and its resources.

As for the shape, it was picked considering the requirements for population capacity, artificial gravity, and rotational stability. The two main habitation modules will consist of tori, with a catenary arch cross-section. A secondary moon base was also proposed and designed to provide raw materials for the station’s construction.

To demonstrate the self-sustainability of the settlement, life support, waste management and agricultural systems have been laid out. What’s more, an experiment has been carried out by our team demonstrating the efficiency of hydroponics systems using magenta light for plant growth. Lastly, the social aspects of the space colony have also been investigated, from social structures and organization to individual’s mental health and entertainment.

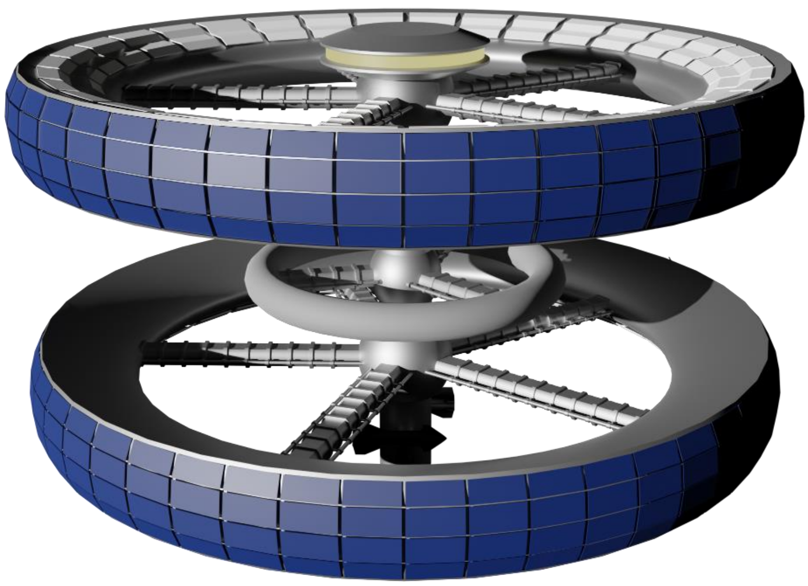


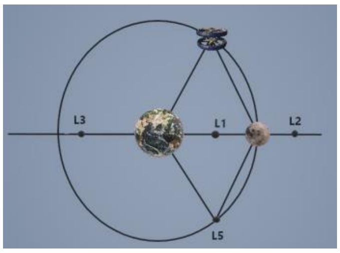
Figure 1.b.1 Space Station Nova

2. DESIGN

2.a. LOCATION

Vlad Carasel [2], Mihai Priboi [2]
[2] Engineering, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

Headings:



ABSTRACT

Selecting the right location for our space settlement is vital to the success of the project. A poor choice in this regard could severely hinder our progress, even if all other aspects of the settlement are well planned.

Firstly, we chose a couple of significant criteria that should be taken into consideration: distance and costs, radiation, resources, solar energy, space debris, and scientific importance.

Based on these factors, we started comparing potential locations: Earth orbit, Moon orbit, Mars orbit, and Lagrange points for the Earth-Sun and Earth-Moon systems and asteroids.

After undergoing an in-depth analysis, we narrowed our potential location list to the following two finalists: polar LEO and Mars' orbit.

Finally, we chose Mars' orbit as the best location choice for our settlement.

INTRODUCTION

To ensure the best possible outcome, we have established a set of criteria that must be considered when determining the most appropriate location.

- **<u>Distance and costs</u>**

Firstly, when planning for a space settlement, it is crucial to consider the distance from Earth. This distance has a significant impact on both the cost and duration of travel for the rocket, as well as the speed of communication. For instance, the time it takes for radio waves to travel from the Moon to Earth is just over a second, whereas the same journey from Mars takes about 5 to 20 minutes. The speed of communication is vital as it determines the level of autonomy required for the station. If communication is too slow, remote control from Earth may not be feasible, and the station must be able to operate independently.

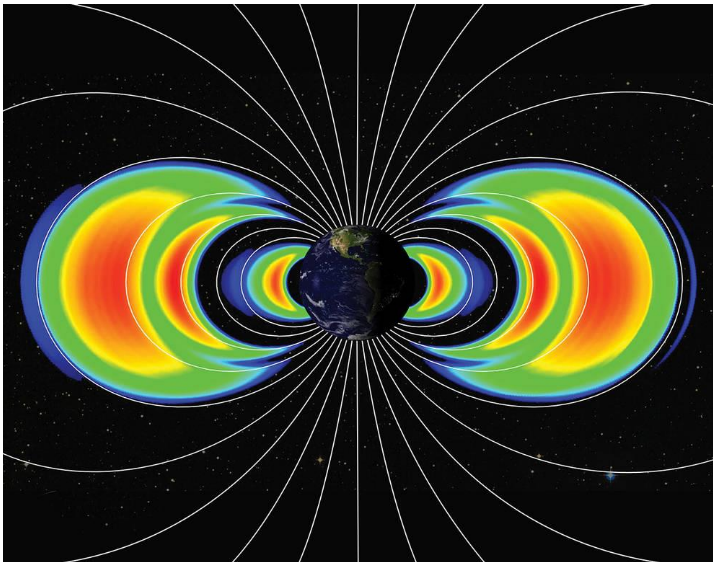


Figure 2.a.1. Van Allen belts, image credits: NASA's Goddard Space Flight Center/Johns Hopkins University, Applied Physics Laboratory

- **<u>Radiation</u>**

Furthermore, a critical safety concern for our population is the effect of cosmic rays. In outer space, without the protection of Earth's magnetic field, radiation is more intense and harmful. To mitigate these effects, a large amount of materials and shielding is required, adding extra weight, necessary fuel, and exorbitant costs. Therefore, when choosing a location for our settlement, it would be ideal to select a place that is somewhat protected from cosmic rays. For example, placing our space colony somewhere affected by the Van Allen radiation belt would not be favorable.

- **Resources**

Procuring resources more efficiently than from Earth is another important factor to consider when choosing a location for our settlement. This would greatly ease the construction and reduce the cost of building a larger station. To achieve this, the settlement should ideally be situated near another planet or asteroid, where landing, taking off, and resource extraction is less arduous than on Earth. Additionally, the celestial object must possess the necessary resources and we have to be able to process them.

- **Solar energy**

One of the most cost-effective methods for obtaining energy for our settlement is through the use of solar power. With this in mind, our goal should be to maximize the benefits of this renewable energy source. As solar energy will likely be our primary power generator, it would be beneficial to locate our station in an area with consistent sunlight exposure and optimal solar radiation.

- **Space debris**

Space debris and micrometeoroids present a significant risk to our space station. Although they may be small in size and mass, their high speeds can cause significant damage. While it is virtually impossible to completely avoid collisions, carefully selecting the location of the settlement can significantly reduce the likelihood of impact. Micrometeoroids are present throughout the solar system, but their density and distribution can vary depending on the location. For example, areas closer to the sun have a lower density of micrometeoroids compared to those further away, and regions such as the asteroid belt between Mars and Jupiter have higher concentrations due to the presence of many small bodies. On the other hand, space debris is man-made, so the more explored regions of space, particularly the vicinity of Earth, have a higher density of debris.

- **Scientific Importance**

Even as we work towards establishing a colony, we must not forget one of our fundamental objectives as human beings: advancement and progress. Choosing a location that offers opportunities for scientific research and development would be beneficial in this regard. Additionally, our settlement could serve as an intermediate step, such as a refueling station, for future space missions, enabling humanity to undertake longer expeditions to more distant destinations. In this light, locations near asteroids rich in minerals and materials, or near exciting satellites would be particularly advantageous for our settlement.

POTENTIAL LOCATIONS

Taking into consideration all of the above criteria, we had to narrow our potential location search to the following:

2.1. Earth orbits

Firstly, we had to consider the Earth's orbits. Due to its proximity to Terra, costs are on the lower side and communication is almost instant.

Also, restocking resources and any kind of assistance could be done regularly, as in the case of the ISS. The main drawback to these locations is that there is little scientific importance, due to the numerous past and present missions that took place here. We took into consideration the most common orbits: LEO, MEO, HEO, and GEO.

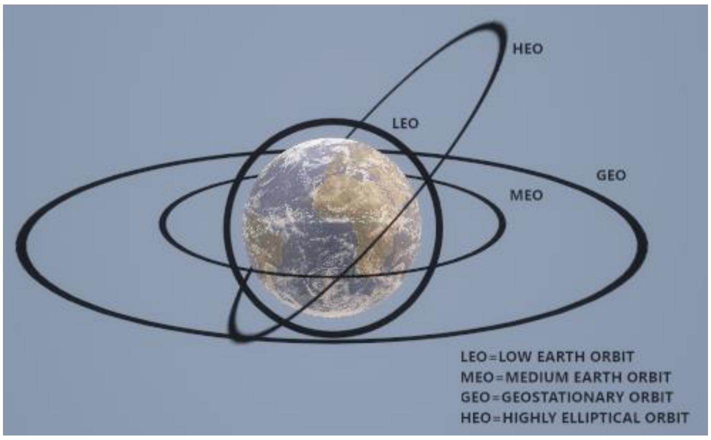


Figure 2.a.2. Earth orbits

- **LEO (Low Earth orbit)**

The lower Earth orbit (LEO) is a popular destination for space missions because it is the closest orbit to Earth, ranging from an altitude of around 150 km to 1,500 km. LEO is also considered a safe location for radiation, as it is not just located outside both Van Allen

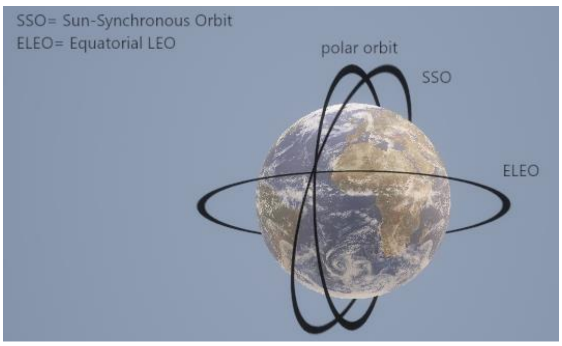


Figure 2.a.3. Lower Earth orbits

radiation belts, but also below them, and is therefore protected from dangerous radiation storms. However, LEO also has a high concentration of space debris, as many human-made objects are launched into this orbit.

There are different types of LEO orbits with different characteristics, such as equatorial LEO (ELEO) and polar LEO. A concern with a polar LEO placement is that it may experience increased radiation due to the Atlantic Anomaly. On the other hand, a polar orbit has the benefit of constant sunlight, unlike an equatorial orbit which has a lower exposure to solar energy.

- **MEO (Medium Earth orbit)**

The medium Earth orbit (MEO) is situated between low Earth orbit (LEO) and high Earth orbit (HEO) and is primarily used for telecommunication satellites as it offers coverage of a larger area of Earth because of its higher altitude. The GPS satellite constellation is also situated in MEO. Potential settlement locations in MEO would be between 12,000 km and 13,000 km, where orbits do not intersect with the Van Allen radiation belts and the amount of space debris is lower compared to LEO and GEO.

- **HEO (High Earth orbit)**

High Earth Orbits (HEO) start at an altitude of 35,786 km, making it possible to have an orbit that is protected from radiation belts. Additionally, selecting an HEO would result in very low exposure to space debris, as there have been few missions conducted in this orbit.

- **GEO (Geostationary orbit)**

Objects placed in a geosynchronous equatorial orbit (GEO) maintain a fixed position relative to a specific point on Earth. This makes GEO ideal for satellite and telecommunications purposes, as it allows for consistent communication using a single antenna. Additionally, GEO's relatively high altitude above Earth means that solar energy is not a concern in this location. However, it is important to note that GEO has a high amount of space debris, second only to LEO. GEO orbits at an altitude of approximately 35,786 km above the equator, which also passes through the Outer van Allen radiation belt.

2.2. Moon orbit

The lower lunar orbit (LLO) is located at an altitude of approximately 100 km from the lunar surface. Its proximity to the lunar surface makes it an attractive location for research and exploration opportunities. Additionally, this placement enables the possibility of constructing a lunar base for extracting and refining resources such as lunar regolith which can be used for construction, Helium-3 for rocket fuel, or ice in order to procure water.

However, this location also has a drawback, as when the station reaches the far side of the Moon, communication would be lost for a significant amount of time in each orbit due to the Moon being between the station and Earth.

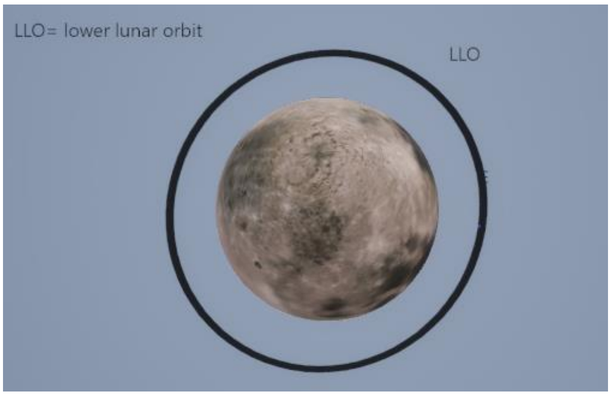


Figure 2.a.4. Lower Moon orbit

Another negative aspect is that lunar orbits suffer from gravitational perturbations that lead to instability, making it rather hard to achieve a frozen orbit. There are just a couple of possible orbital inclinations (27, 50, 76, and 86 degrees) that can assure long-term stay in an LLO.

Also, radiation levels near the moon are significantly higher than ones measured on an LEO. In order to have as much exposure to solar energy, we would have to use a high inclination, but because of the way the Moon orbits around Earth, constant sunlight is not a possibility. While not in an orbit around Earth, the problem of space debris isn't completely gone. Multiple missions to the Moon, from the past and that are going to come in the future, are causing a rise in the density of space junk. To add to that, unlike on Earth, where by entering the atmosphere, debris burns and dissipates, because of the absence of an atmosphere on the Moon, such junk can collide with the surface, and potentially with our lunar base.

2.3. Mars orbit

One of the more popular destinations for space missions in recent times is Mars, as it is considered the best candidate in our

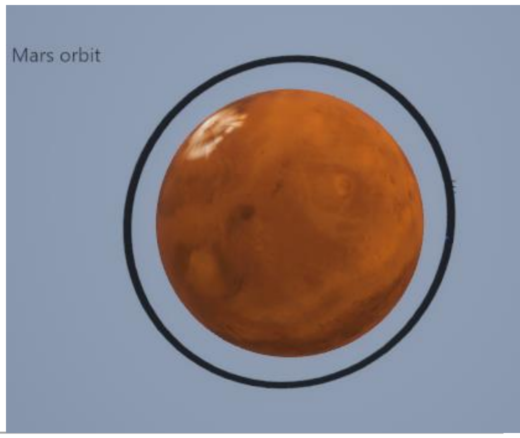


Figure 2.a.5. Mars orbit

solar system for potential colonization. This is due to a number of factors, such as its proximity to Earth, the presence of a thin atmosphere, and the potential to find evidence of past or present microbial life. Having this in mind, from a scientific point of view a location closer to Mars would be incredibly useful. Moreover, the idea of developing an outpost on the surface of Mars, or its two natural satellites, Phobos and Deimos, for resource-gathering purposes might as well be possible.

Nevertheless, placing our settlement here implies some minor issues. Sunlight cannot be effectively used as an energy source because of the great distances and also communication would be harder with Earth. The duration of communication between Earth and Mars ranges from 5 to 20 minutes.

Also, a direct line of sight with Earth might not be always possible, so the station will sometimes be out of contact. Communication is crucial, as it impacts the level of autonomy needed for a station on Mars. While space debris is present around and on Mars, the density is significantly lower than near Earth, and thus, should not pose a significant problem. Regarding radiation levels, we will obviously have a harder time stopping them here than in an LEO, but we can overcome this difference with additional shielding.

Some of the biggest advantages of choosing an orbit around Mars as our settlement's location are the overwhelming research opportunities. Mars allows us to be closer to the asteroid belt, which is home to several celestial bodies that are full of vital, precious resources. Moreover, our base could make use of our lunar settlement.

2.4. **Lagrange points**

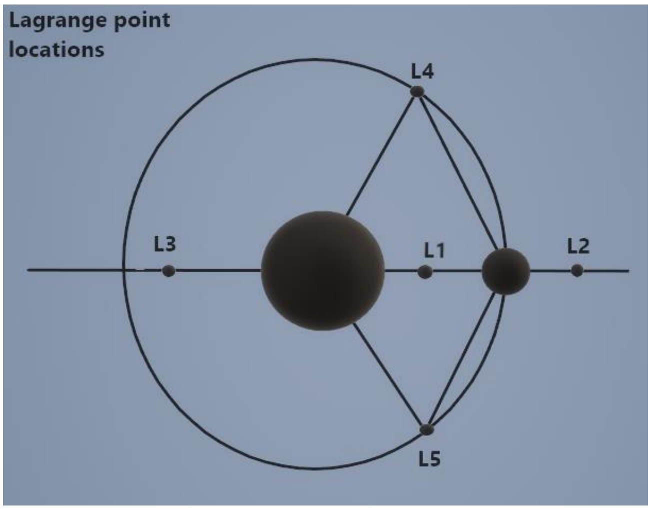


Figure 2.a.6. Lagrange points locations

Another possible location for our settlement is a Lagrange point or an orbit around one.

"*There are five special points where a small mass can orbit in a constant pattern with two larger masses. The Lagrange Points are positions where the gravitational pull of two large masses precisely equals the centripetal force required for a small object to move with them.*"

(Essai sur le Problème des Trois Corps, 1772).

Out of these five points, L4 and L5 are known to offer stable equilibrium, while L1, L2, and L3 could only be used by maintaining a small orbit around them, due to their instability. Further, we will conduct an analysis of the Lagrange points of two possible systems:

- **Earth-Sun system**

Starting with L1, due to radio interference generated by the Sun, a relatively higher orbit is necessary to maintain communications with Earth. Additionally, for L2, because of its placement behind Earth, a higher orbit is also required to ensure constant exposure to sunlight. Both of these placements, being relatively close to Earth, are contenders for our final location choice. This is further highlighted by the fact that they are the only Lagrange points between Earth and the Sun that have satellites in their orbit. Furthermore, L3 is not a viable option due to its great distance from Earth and communication issues. On the other hand, L4 and L5, while being the most stable, are also quite distant from Earth and are overall not as favorable as L1 or L2.

- **Earth-Moon system**

A great advantage of establishing our settlement at one of these points is the proximity to both Earth and the Moon. This allows us to once again consider building a moon base, as we previously did in the Moon orbits analysis section.

Establishing a lunar camp would be highly convenient for the delivery of resources to our settlement. The reduced gravitational pull and lack of an atmosphere would greatly lower the costs of travel between our settlement and our lunar base. Sun exposure would be nearly constant, with only brief periods of darkness when directly behind either Earth or the Moon. In terms of radiation, the Lagrange points are not protected by the Van Allen radiation belts, but since they are all far enough from Earth, they are not affected by them either. Additionally, proximity to the Moon, which does not have a magnetic field, should not affect radiation levels. The risk of space debris is minimal, as only a few space missions have been near these locations. However, they should not be completely ignored, as they along with micrometeoroids still pose a threat to the settlement. The moon base could also serve as a research center for the Moon, and the settlement itself could host a variety of sensors and research devices. Furthermore, the station could be used as a launch platform for other space missions, as the delta-v required would be minimal. Communication would not be a problem, as transmission times would be only slightly longer than one second. All points would have a direct line of sight with both Earth and the moon base, but L2 and L3 would need to be in a high orbit to avoid transmissions being blocked by Earth or the Moon.

The L1 and L2 points offer similar potential as locations, as they are both at the same closest distance to the Moon of all the Lagrange points. However, their main drawback is their lack of stability. In practice, we could maintain long-term stability by orbiting around them, but this still carries some risk. In contrast, we consider L3 as the worst potential Lagrange point in the Earth-Moon system due to its long distance from both Earth and the Moon and its lower stability compared to L4 and L5. Using a lunar outpost would still be less costly than regularly transporting all resources from Earth, but the trip would take longer. L4 and L5 are by far the best contenders as locations. These two points are theoretically proven to be stable equilibrium points. Placing our settlement in one of these two orbits would not only greatly reduce the costs of maintaining orbit, but the restoring forces would actually keep our settlement in position.

2.5. **Asteroids**

Another potential location option would be orbiting a mineable asteroid, whose resources could be utilized for construction and scientific purposes. One class of asteroids that is particularly promising is Near-Earth asteroids (NEAs), as they are located relatively close to Earth, making them more accessible and cost-effective to reach. This is demonstrated by the fact that there have already been missions to study some of them. Some NEAs that were taken into consideration include 162173 Ryugu, 101955 Bennu, and 25143 Itokawa.

The other main class of asteroids is called Main Belt asteroids, which are located in the asteroid belt between the orbits of Jupiter and Mars. They can also be classified based on their composition, with 3 main types. C-Type (Carbon) asteroids include a large number of organic materials and can also be rich in water. They are the most common type, accounting for about 75% of all known asteroids. M-Types (Metallic) asteroids have a high concentration of metals, primarily iron-nickel. S-Type (Stony) asteroids consist mainly of iron and magnesium silicates. The most suitable of the belt asteroids are Ceres (a dwarf planet that comprises 25% of the total mass of the asteroid belt, which is a C-Type asteroid and thought to be rich in water and other volatile elements) and 16 Psyche, an M-Type asteroid that is mostly composed of iron-nickel. While we would orbit only one asteroid, it would be possible to use other nearby ones from the asteroid belt to extract resources.

The downside of Main Belt asteroids compared to Near-Earth asteroids is that they are much more distant from Earth, which raises issues for travel, costs, communication, and solar energy. However, we consider Ceres, the dwarf planet, the most promising.

DELTA V

A crucial aspect of our complete potential location analysis is the transfer time and costs from an LEO to our chosen placement. In the table below, we conducted a comparison between all of the possible locations. Full physics calculus regarding Earth-Moon Lagrange points distances can be found in the annex.

Orbit	Delta-v from LEO (km/s)	Distance from Earth (km)
LEO	-	150 - 1,500
MEO	2.3	12,000 - 13,000
GEO	3.9	35,786
LLO	4.04	356,500 - 406,700
Mars orbit	4.3	54.6 - 401 million
Earth-Sun L1	7.4	1.5 million
Earth-Sun L2	7.4	1.5 million
Earth-Moon L1	3.77	322,540
Earth-Moon L2	3.43	445,460
Earth-Moon L4/5	3.99	384,000
Ceres orbit	4.7	277 - 789 million

The values from the table are approximations used for orientation purposes only.

CONCLUSION

Taking into account all of the above, we once again narrowed down our search to two possible locations that really stand out from the rest. The first finalist is one of Earth's orbits, the polar LEO. We chose this placement due to the following characteristics: constant sunlight, good radiation protection (shielded by the Van Allen radiation belts), proximity to Earth, lowest delta-v out of all the contenders, and great communication with Terra.

The next finalist is Mars' orbit. The main highlight of this potential location is its scientific value. Out of all the rival locations, this location offers incredibly useful resource extracting opportunities due to its proximity to the asteroid belt, such as metals and minerals, and also water. For instance, the scientific and research potential Mars has is outstanding, knowing that scientists believe life could be possible on its surface. It is believed that larger conducted studies regarding Mars habitability could lead to great discoveries.

Based on these factors, we have decided to establish our space settlement on Mars' orbit, with the potential to expand to the asteroid belt in the future.

REFERENCES

[1] Garcia, M. (2015, April 14). Space debris and human spacecraft. NASA.
[2] The deadly van Allen belts? - NASA. (n.d.).
[3] Canadian Space Agency. (2006, August 18). How does radiation affect the human body in space? Canadian Space Agency. Low Earth orbit. ESA. (n.d.).
[4] Elburn, D. (2019, May 31). FAQs. NASA.
[5] Wikimedia Foundation. (2022, November 3). Medium earth orbit. Wikipedia.
[6] Wikimedia Foundation. (2022, November 13). High Earth orbit. Wikipedia.
[7] Types of orbits. ESA. (n.d.).
[8] Wikimedia Foundation. (2023, January 24). Lunar Orbit. Wikipedia.
[9] The Moon could soon have a space junk problem. Science. (n.d.).
[10] ExoMars 2016 arriving at Mars. ESA. (n.d.).
[11] TGO's orbit around Mars. ESA. (n.d.).
[12] Greicius, T. (2015, May 4). Diverse orbits around Mars. NASA.
[13] NASA. (n.d.). What is a Lagrange point? NASA.
[14] NASA. (2022, December 15). Asteroids. NASA.
[15] Bartlett, R. J. (2022, February 25). Different types of asteroids (C, S, and M) - the definitive guide. Astronomy Source.
[16] Wikimedia Foundation. (2023, February 8). Ceres (dwarf planet). Wikipedia.
[17] Wikimedia Foundation. (2023, January 1). Delta-v budget. Wikipedia.
[18] Lecture D30 - orbit transfers - Massachusetts Institute of Technology. (n.d.).
[19] Lagrange and the Interplanetary Superhighway. Plus Maths. (1970, September 1).

2.b. CONSTRUCTION PHASES

Tudor Nicorescu [1]
[1] Design, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

The Nova spacecraft will be built in 3 phases which take place after the construction of the Moon Camp.

Figure 2.b.1. Phase I

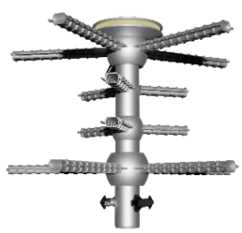


Figure 2.b.2. Phase II

Figure 3.b.3. Phase III

<u>Phase I</u>

The first phase of construction will consist of the launch of four spacecraft from the moon base which will make up the material for the center cylinder of the base as well as the docking station. These parts will be put together in space and will create the anchoring point for the rest of the parts of the base which will be added later. This phase also ensures that the base is positioned in the LLO (Lower Lunar Orbit) which will provide easy access for following missions. Thus, this phase constitutes the beginning of the base's building, the center cylinder being assembled and put into orbit. To ensure the transportation of the 250-meter cylinder, we will make use of a vehicle similar to Starship, developed by SpaceX, which will be able to be significantly larger due to the lower gravitational pull of the Moon and the smaller air friction encountered on the satellite.

Phase II

Phase two will consist in the addition of the Control Center. This will host the entire operational crew which is interchanged every six months comparably to the ISS system. Materials will be delivered using the same type of spaceship as in the first phase of construction. These will be docked in the designated docking area of the cylinder which will be then used in building further parts of the base. When the main elevator will be functional, the crew will be then transported to the control center from where all the other part's construction will be coordinated. The next part consists of adding the magnetic supports and the elevators. These will be attached to the main cylinder by first adding the titanium alloy supporting rods. After this part has been finished, the tori will be built, first the titanium rods, and then the aluminum walls are going to be added. After this, the base should be inspected and everything should be working properly, including the life support systems.

Phase III

When the full base is operational, the entire 2000-person crew will be introduced to the base and the tori will be put in motion in order to ensure artificial gravity is applied. This will be the time the Control Center crew will be returning to Earth to recover from the time spent in low gravity. Since the rest of the base is fully functional, the Control Center will be transformed into its permanent state of storage and recreational use. Following this, the reactors will be added on the rear end of the center cylinder as well as the correction propulsion systems. This will be the end of the construction phases of the spacecraft which will then proceed to transfer to its final location to Mars.

2.c. STRUCTURAL OVERVIEW

Luxin Matasaru [1]

[1] Design, Vianu Research Center

Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

The colony will be composed of 7 parts, out of which the most important are: a central section, which we will call “the hub”, and two counter rotating outer toruses. The hub will be cylindrical in shape and will serve as a mounting point for docking ports and elevator shafts. The toruses will house most of the inhabitable area of the colony, their rotation helping to create artificial gravity. Transportation between the central section and the inhabitable area will be done through special elevators, also serving to anchor the toruses.

INTRODUCTION

The most important aspect of any future space settlement proposal is undoubtedly the design, as it will not only determine the economical and construction viability of the project but will also have to deal with most of the unsolved challenges of space travel, giving room for new and creative solutions.

STRUCTURAL DESIGN

In order to better explain the construction of the space station, we will divide the structure into 7 main components:

1. **The outer tori**

The two outer tori will contain almost all the inhabitable area of Space Station Nova. Thus, we started by settling their exact design and dimensions, as they would dictate our approach to the rest of the structure.

Given pseudo-gravity will have to be generated using rotation (as is outlined in the *Artificial Gravity* section), our design is limited to using one of 4 common arrangements: dumbbell, spherical, cylindrical and toroidal. Out of these, we found the torus to be the optimal shape, thanks to its high usable area to volume ratio and many axes of symmetry, minimizing the number of weak spots in the structure.

For the cross section, we realized a circular shape would make building on the steeply curved outermost edge difficult, while at the same time not allowing for a very efficient use of space. Ideally, the outer edge would be flat, however that may introduce weak points within the structure. Thus, in our final design, we settled for a hybrid profile, flattened on the outside, and curved on the inside. For the inner edge we will use a catenary arch (the shape a cable makes when hanging from two points and acting only by its own weight), for its ability to support itself under constant load. In order to make full use of this advantage, we will compensate for the centripetal acceleration variation with radius by linearly decreasing wall mass from the top down.

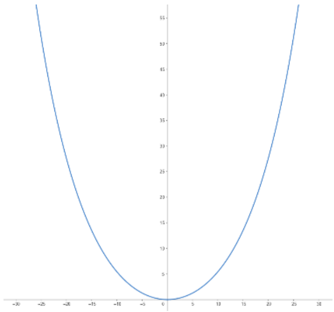


Figure 2.c.1: Plot of a catenary curve

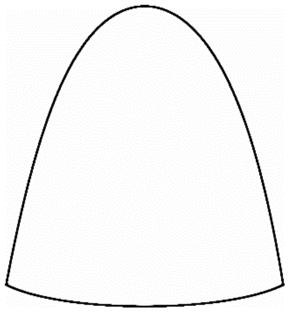


Figure 2.c.2: Cross-section of the torus

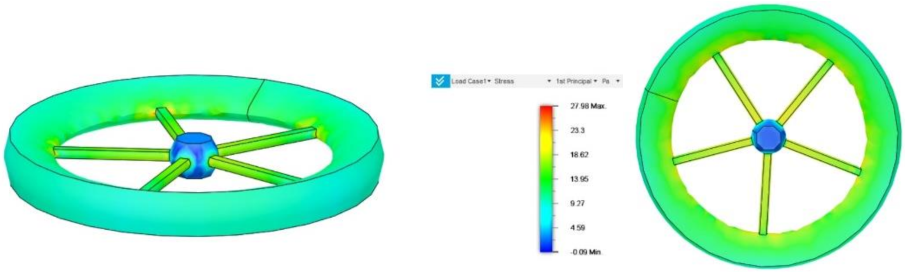


Figure 2.c.3 Structural analysis of the torus

The catenary curve is described by the following equation:

$$y = \frac{a}{2}\left(e^{\frac{x}{a}} + e^{-\frac{x}{a}}\right) \tag{1}$$

where a is the sag parameter.

The graph in *Figure 2.c.1* was obtained by plotting the equation for $a = 10$, and offsetting the lowest point of the curve to 0. Using equation (1), and approximating to a flat outer edge, the area of the profile and torus volume can be calculated as:

$$A = \int_{-\frac{l}{2}}^{\frac{l}{2}} (h - y + y_0)dy \tag{2}$$

$$V = 2\pi\left(R - \frac{h}{2}\right)A = 2\pi\left(R - \frac{h}{2}\right)\int_{-\frac{l}{2}}^{\frac{l}{2}} (h - y + y_0)dy \tag{3}$$

Where:

- A is the profile area
- $l = 50\ m$, the width at the cross-section's base
- $h = y_{\frac{l}{2}} - y_0 = 50\ m$, the height
- $R = 200\ m$, the outer radius of the torus

Numerically, using the values provided in the next paragraph, we get $V = 2\ 040\ 892\ m^3$.

Calculating the total usable area (S_ω) of a torus is somewhat trickier since the inner volume will be divided into 5 evenly spaced levels, each with slightly smaller width. In our case, an empirical formula for this would be:

$$S_\omega = 2((y_{10} - y_0)(R - 40) + (y_{20} - y_0)(R - 30) + (y_{30} - y_0)(R - 20) + (y_{40} - y_0)(R - 10) + (y_{50} - y_0)R) \tag{4}$$

Again, for the values above, this gives $S_\omega = 436\ 584\ m^2$. Assuming a minimum of 1000 people per torus, we get an average area of 436 m^2 used to sustain a colonist.

Given the radius R, in order to generate about 1G of acceleration at the outermost layer, the torus would have to rotate at an angular velocity of:

$$\omega = \sqrt{\frac{g}{R}} = 0.22\ rad/s = 2.1\ rpm \tag{5}$$

Each torus will rotate independently, in opposite directions, so as to cancel out any moments on the central hub. This is mainly done for stability reasons (which will be outlined in a further paragraph) but has the added benefits of creating a weightless environment for colonists and scientific experiments, while also making docking to the station and maneuvering much easier.

2. **The inner tori**

Between the two living modules outlined above, two smaller tori will be present. These will be used to generate different levels of microgravity, mainly for scientific research, but also for the colonists' entertainment. Here, the cross sections will be circular with a radius of 10 m while the outer radius will be 100 m. Similarly, to their larger counterparts, these tori will rotate in opposite directions, however, their speeds will be variable in order to allow for different artificial gravity levels.

3. **The central hub**

The central hub consists of a hollow cylinder 30 m in diameter and 250 m in length. It spans the length of the toruses' rotation axes, connecting them to one another. Thanks to magnetic rails within the joints between the main hub and the elevator shafts, the tori will be able to spin with zero friction and minimal loss of energy.

4. **The control center**

The control center is located at the top of the central tube; it is 20 m tall and about 100 m wide. This component will not only manage operations during the construction stages of the space station but will also serve as an area where people will be able to experience weightlessness for recreation.

5. **The elevators**

These will make the connection between the central hub and the toruses, enabling the transport of people to and from the habitable areas. The main feature of the elevator shafts are the two thick wires on either side, which are meant to help relieve some of the load off the central sections while also fixing them in place. Each of the outer toruses will be connected through five evenly spaced-out elevators, while the inner tori will only have three.

6. **The docking ports**

The space settlement will benefit from two docking ports. Their 9 m diameter will enable the exchange of more people and cargo between the spaceships and our settlement. The docking ports are offset by about 15 m from the main hub.

STABILITY CONSIDERATIONS

A rotating body is stable only when rotated about the axis of maximum angular momentum. This can be easily proved as follows:

Let $I_1 < I_2$ the moments of inertia of a body about two different axes. From the conservation of angular momentum, it follows that:

$$I_1\omega_1 = I_2\omega_2 = L \tag{6}$$

Where:

- ω_1 and ω_2 are angular velocities.
- L is the angular momentum.

Since $I_1 < I_2$, from (6) it follows that:

$$\omega_2 < \omega_1 \tag{7}$$

Calculating the kinetic energies, we get:

$$E_1 = \frac{I_1\omega_1^2}{2}, \qquad E_2 = \frac{I_2\omega_2^2}{2} \tag{8}$$

$$E_1 = \frac{L\omega_1}{2}, \qquad E_2 = \frac{L\omega_2}{2} \tag{9}$$

So, from (7) and (9):

$$E_2 < E_1 \tag{10}$$

Since no real body is rigid, small flexing will cause loss of energy through heat. This means that a real rotating body will tend to settle at its lowest kinetic energy state, which corresponds, as demonstrated above, to rotation around the axis of maximum moment of inertia.

Now, considering our own space settlement, let I_x, I_y, I_z denote the moments of inertia along the main axes of rotation, with Ox along the central hub's length. Given the geometry described above, it can be shown that $I_y = I_z > I_x$. Thus, if we were to rotate the whole space settlement along the x axis, because of energy losses due to bending in the structure, the axis of rotation would eventually shift to y or z. While the use of an active stabilization system would help mitigate this problem, its failure, no matter how unlikely, would spell disaster for the colony. In the end, our solution is to rotate the tori separately from the middle cylinder since each individual torus is stable when rotated about its center. By spinning them in opposite directions we also ensure all moments upon the central hub cancel out.

REFERENCES

[1] *4.8 stability of free rotation*. PC1672: 4.8 Stability of free rotation. (n.d.).
[2] *Catenary Arch*. Wikipedia. (2022, October 16).
[3] Encyclopedia Britannica, inc. (n.d.). *Catenary*. Encyclopedia Britannica.
[4] Globus, A., & Hall, T. (2017, June). *National Space Society | Working to create a spacefaring civilization ...*
[5] Marotta, T. (2017, July). *A survey of space settlement designs - space.nss.org*.
[6] [*Space settlements: A design study (1977)*. Internet Archive. (1977, January 1).

2.d. FUNCTIONAL OVERVIEW

Tudor Nicorescu [1]
[1] Design, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

The Nova spacecraft will be composed of 7 main components:

- **The Outer Tori**

First, both the tori have the same structural and functional design. Each will be divided in 5 parts which will be located between the elevator shafts connecting with the tori. Each will have the same number of housing units, hosting a total capacity of 100 people. This ensures that in case of minor damage to a section's integrity which would lead to a section losing its cabin pressure, the area can be sealed off and that damages do not propagate throughout the entire torus. The tori will also be covered with solar panels on the exterior used for generating current as well as heat radiators on the top. Furthermore, each torus will be constructed out of 5 floors with the following purposes:

- Storage
- Habitation Modules
- Recreational Spaces Combined with Aquaculture
- Research
- Life Support System

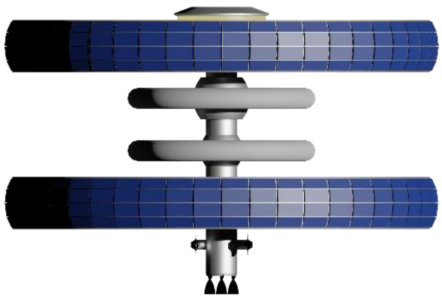


Figure 2.d.1. Lateral View of the settlement

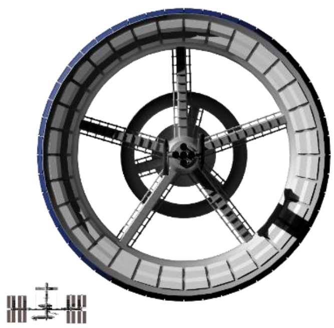


Figure 2.d.2. Top view of the settlement

- **The Inner Tori**

Second of all, the inner tori will have much less space than the other pair of tori. With a radius half the size of the outer ones, these tori will only be able to host 2 floors which will be made up of research and low-gravity entertainment. Both of them will be functionally the same, being split up into three parts in between each one of the supporting lifts. The tori will also have variable rotational speeds to help the research be conducted in all types of environments.

- **The Central Cylinder**

Third of all, the central cylinder will be the main structure supporting the base. This section will be the anchoring point of the magnetic supports which will be rotating the elevators and consequently the tori. This part will function essentially as a big elevator that connects all other parts of the base.

- **The Elevators**

The elevators act as connecting segments from the center cylinder to the tori, being the reason, the artificial gravitational force is able to be applied on the habitation areas. Thus, they act as lifts which also help transport materials and people throughout the base.

- **The Control Center**

Moreover, the control center is an integral part of the base, being located at the top of the central cylinder. This area is going to act as the center of command during the phases of construction of the base and will later on be turned in a recreational and storage area. Due to the 0g present in this zone of the base, storing heavy materials will be efficient. Moreover, residents of the spaceship will be able to take advantage of the area for recreational use in the lack of gravity environment and also for watching space from an observatory.

- **The Propulsion Systems**

The main purpose of the propulsion systems is to bring the base to Mars and also to perform the needed corrections in the trajectory and stability of the base. It will be composed of two parts: the main reactor and the correction systems.

- **Docking system**

The docking systems ensure that spacecraft coming from Earth and the Moon have a place to safely dock the spacecraft. They have similar technology to the ISS docking system, being located on the rear end of the spaceships and not spinning at any time.

2.e.i. BASE MATERIALS

Tudor Nicorescu [1]
[1] Design, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

When talking about materials, the base will be made up of the following materials with properties shown in the table 2.1:

- Central cylinder: Al 6061-T6
- Central cylinder support rods: Grade 5 Titanium (Ti 6Al-4V)
- The control center: Al 6061-T6
- Main elevator shafts: Al 6061-T6
- Elevator support rods: Grade 5 Titanium (Ti 6Al-4V)
- Tori main walls: Al 6061-T6
- Tori support rods: Grade 5 Titanium (Ti 6Al-4V)
- Docking stations: Al 6061-T6 and Grade 5 Titanium (Ti 6Al-4V)

Material	Al 6061-T6	Grade 5 Titanium (Ti 6Al-4V)
Hardness, Brinell	95	334
Ultimate tensile strength	310 MPa	1170 MPa
Tensile yield strength	276 MPa	1100 MPa
Elongation at break	12 %	10%
Fracture toughness	29 MPa*m½	84-107 MPa*m½
Thermal conductivity	167 W/m*K	7.1-7.3 W/m*K
Melting point	855-925 K	1878-1933 K

Aluminum alloys have a history of being used in the space industry due to their robustness and lightweightness. Alloys can be altered by modifying their composition and controlling the amount of each impurity. Si, Cu, and Mg are highly sought after when trying to improve the hardness and tensile strength of a material, being the main alloy elements used in altering aluminum's properties. Moreover, heat transfer is the main way of increasing the yield strength of aluminum alloys. Due to its recent increase in availability, dropping down the prices Al6061-T6 is now the preferred material for spaceship construction and the structure of satellites. The majority of the base's structure will be composed of this material, being a cost-effective way of building the structure, even though the moon lacks any known deposits of bauxite. Thus, our moon base will take advantage of the vast anorthite ($CaAl_2Si_2O_8$) deposits on the lunar surface to produce the required materials.

Ti6Al-4V is the most widely used type of titanium alloy, making up more than half of the total titanium production in the world. This material will be used in more significant high static stress parts of the base, which will be the main reinforcement of the entire structural integrity. This alloy provides strength-toughness combinations similar to aluminum and steel alloys and have the same stiffness as commercially available pure titanium but are substantially stronger. This material is highly used in the aerospace industries, its applications being favored by its resilience to fatigue and high strength-to-weight ratio.

2.e.ii. RADIATIONS PROTECTION

Eliza Radu [1]
[1] Design, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

Keywords: The effects of radiation on humans, Van Allen radiation belts, Space radiation, Tungsten, BNNTs

ABSTRACT

Unlike the Earth which is protected by the magnetosphere and the atmosphere against radiation and particles, in space the radiations are more dangerous, making it difficult to ensure the protection of the astronauts. People exposed to radiation from space can develop minor to serious injuries, depending on the level of radiation that hits them. The protective layer that we propose is made of tungsten that will be used against alpha, beta, gamma radiation and X-rays and BNNTs for the rest of cosmic radiation, including neutron radiation. As for Van Allen radiation belts, we thought about using a magnetic field. To carry out missions outside the protective space, we will also have space radiation vests for astronauts. Although the radiation protection chosen by us is not exactly the cheapest, we consider it to be the best option.

INTRODUCTION

Astronauts are exposed to many risks when sent into space. If an astronaut is exposed to the radiations between 100 and 1000 mSv, the risk of cancer increases. If the exposure is greater than 2000 mSv, acute radiation syndrome occurs. An exposure greater than 5000 mSv produces death in less than a month for half of those exposed, and if the exposure exceeds 10000 mSv, the death of the exposed person occurs in a few days.

Mars is not free of radiation. Here we find ionising and non-ionising radiations. Forms of non-ionising radiation are found on Earth as well, like ultraviolet radiation, infrared, radiofrequency or light. Ionising radiation refers to alpha and beta particles, gamma radiation and X-rays. Gamma ray is an electromagnetic radiation formed by the decay of atomic nuclei. X-rays are also a form of electromagnetic radiation. Also, because Mars does not have a magnetic field, there is no form of protection from Sun's devastating radiation.

RESEARCH METHOD

Non-ionising radiation is not a problem, because it is not so harmful and can be easily prevented by a simple layer of aluminium.

Ionising radiation, on the other hand, can cause some serious damages. Once again, we do not have to worry about alpha and beta particles because they can be prevented using only a sheet of paper, respectively a metal layer of any kind. We have to focus on gamma radiation and X-rays because they are hazardous for our spacecraft and can penetrate through a lot of heavy and strong materials.

When thinking about a suitable material for slowing down these types of radiation, lead would be the first option that comes to mind. Although it is easy to find and has a good resistance, we may want to replace it with tungsten. Tungsten is harder to find and more expensive, but we think it's the better option because tungsten holds up better at high temperatures and isn't as toxic as lead.

For the other forms of radioactive decay, hydrogenated materials like BNNTs (boron nitride nanotubes) are more suitable. This material has very high heat resistance (up to 800℃) and is chemically stable. Also, it's a good thermal conductor and is very though.

RESULTS AND DISCUSSIONS

Replacing the lead with tungsten means having a thinner layer because radiation shows an efficiency directly proportional to the density of the material and tungsten has a density greater than lead by 1.7. So, since it takes 10 cm of lead to slow down the gamma radiation by 1/1000, and since the tungsten layer is one-third as thick as the lead layer, the tungsten layer required will be about 3.5 cm. To help us protect the spacecraft from the neutron radiations, the second layer will consist of hydrogenated BNNTs.

In addition to the spacecraft's radiation shielding layers, an important idea is represented by space radiation vests. These vests ensure astronauts' mobility and protect them on missions outside the spacecraft. They are made of rigid materials to withstand and have a high density, such as High-Density Polyethylene.

Figure 2.e.ii. Radiation Shield Layers

CONCLUSION

To wrap things up, our final structure against radiations consists of two layers: the inner one is BNNTs and the outer one is Tungsten. For a better protection, the astronauts will have space radiation vests. To prevent the charged particles from the Van Allen radiation belts a magnetic field is required.

REFERENCES

[1] Mars, K. (2017, September 21). *Positive, negative or neutral, it all matters: Space radiation*. NASA.
[2] *Boron nitride nanotube: Synthesis and applications - NASA*. (n.d.).
[3] *What is ionising radiation?* ARPANSA. (n.d.).
[4] Wu, Y., Cao, Y., Wu, Y., & Li, D. (2020, October 9). *Mechanical properties and gamma-ray shielding performance of 3D-printed poly-ether-ether-ketone/tungsten composites*. MDPI.
[5] Nofit AmirWrites content for StemRad's website. (2022, October 30). *Blocking space radiation in deep space*. StemRad.
[6] Horne, R. B., Thorne, R. M., Shprits, Y. Y., Meredith, N. P., Glauert, S. A., Smith, A. J., Kanekal, S. G., Baker, D. N., Engebretson, M. J., Posch, J. L., Spasojevic, M., Inan, U. S., Pickett, J. S., & Decreau, P. M. E. (n.d.). *Wave acceleration of electrons in the Van Allen Radiation Belts*. Nature News.

2.e.iii. PASSIVE RADIATIONS PROTECTION

Eliza Radu [1]
[1] Design, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

Keywords: Space debris, Whipple shield, Aluminum layer

ABSTRACT

Space is a place where waste is in continuous movement and formation. Debris larger than 10 cm in diameter can be detected from the spacecraft. For those up to 1 cm we considered of having a Whipple shield. Debris between 1 and 10 cm can be stopped by a chaser spacecraft designed with a harpoon or a net system. From the spaceship, we thought of using an aluminum layer of resistance like steel. So, this article proposes a protective layer against cosmic debris consisting of an aluminum layer and a Whipple shield.

RESEARCH METHOD

Space is full of debris like small meteorites which at high speed, no matter how small, can cause minor to very serious damages to our spacecraft.

A Whipple shield consists of a bumper located at a certain distance from a wall. The bumper and the rear wall are usually made out of LY12 Al alloy. Using a stuffed Whipple shield, between these two plates there will be some layers of protection, usually consisting of Nextler and Kevlar.

We do not consider a big problem space debris larger than 10 cm since they are visible. The Whipple shield we thought for the small objects is slightly modified compared to the one often encountered. Instead of using LY12 Al alloy for the bumper, we'll have amorphous alloy due to the higher resistance. For the rear wall we'll keep the LY12 Al alloy.

The biggest problem now is debris between 1 and 10 cm because they are too big to be blocked by the shield and too small to be noticed. From outside the spaceship, they can be eliminated by a chaser spacecraft designed with a capturing system. From the spaceship, we'll have the aluminum layer.

RESULTS AND DISCUSSIONS

The bumper slows down or destroys the object, which then breaks into small pieces that will travel between the two metal plates. The layers of protection between these two plates will break down even more the remaining parts. The aluminum layer will also divide the waste into small parts, which in turn will be divided until they will be stopped by the Whipple shield.

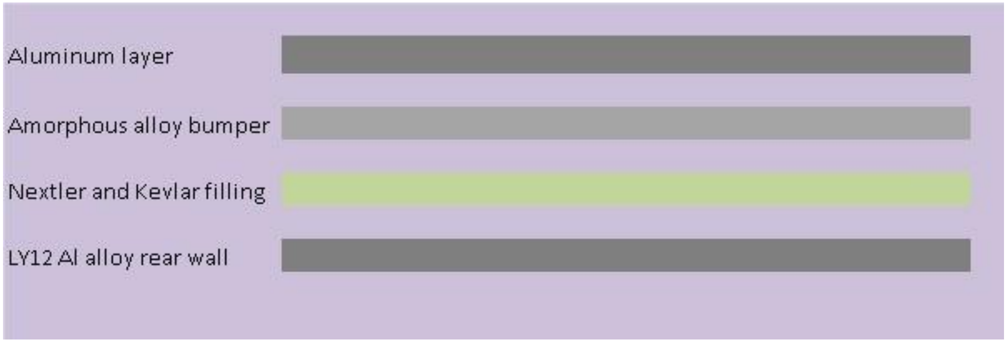


Figure 2.e.iii. Space Debris Protection Layers

CONCLUSION

Therefore, the spacecraft's protective layer against debris will be composed, from outside to the inside of an aluminum layer, an amorphous alloy bumper, a Nextler and Kevlar filling and a LY12 Al alloy rear wall.

REFERENCES

[1] Reed, J., & Barraclough, S. (1970, January 1). *Development of harpoon system for capturing Space Debris*. ESA Proceedings Database.
[2] Scharring, S., Wilken, J., & Eckel, H.-A. (n.d.). *Laser-based removal of irregularly shaped space debris*. SPIE Digital Library.
[3] Trexler, M. M., Yew, C. H., Westine, P. S., Grady, D. E., Wei, S. C., Bjork, R. L., Anderson, C. E., Wang, W. H., Inoue, A., … Cour-Palais, B. G. (2011, November 15). *Amorphous alloy reinforced Whipple Shield structure*. International Journal of Impact Engineering.
[4] Pai, A., Divakaran, R., Anand, S., & Shenoy, S. B. (2021, July 20). *Advances in the whipple shield design and development: - journal of dynamic behavior of materials*. SpringerLink.

2.e.iv. ACTIVE RADIATIONS PROTECTION

Luca Teodorescu [1]
[1] Design, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT
To have a long-lasting space station, the safety and the integrity of the construction are two vital aspects. Unfortunately, safety during the stay in space will be threatened by the existence of space waste. In this regard, we decided to use several techniques that reduce the risk of collision.

THE ORBITAL MANEUVERS

We must increase the major semiaxis by increasing velocity if we wish to move our spaceship to a higher orbit. However, to lower the spacecraft's orbit, we must reduce the minor semiaxis by lowering its velocity.

Take this spacecraft, for instance, which is now in orbit 1, a low orbit, and wants to move to orbit 2, a higher orbit, to avoid space junk. The spaceship must transit a transfer orbit, which is an intermediary orbit, to move from orbit 1 to orbit 2.

We need to complete two parts of the process to transfer the spacecraft. We modify the energy of the orbit by moving from orbit 1 to the transfer orbit, which results in a change in the spacecraft's velocity of V1, where V1 = |V transfer at orbit 1 - V orbit 1|. The spacecraft's energy must then be changed once more when it reaches orbit 2, which is done by modifying its velocity by a factor of V2, where V2 = |V orbit 2 - V transfer at orbit 2|. The spacecraft will bounce between orbits 1 and 2 if we don't alter its energy. It's crucial to realize that the velocity is lower in a higher orbit than in a lower orbit due to the bigger radius.

THE MAGNETIC SHIELD

What is the purpose of a magnetic shield? A magnetic shield is probably the ideal solution for avoiding collision between space debris and the spacecraft, being also a reason for less dodging maneuvers.

One might imagine a real-life shield, that surrounds our spacecraft and due to its magnetic system, stops any kind of space debris from getting dangerously close.

In fact, the space shield we designed is even more than that. It doesn't represent an actual shield, but a well-programmed net of satellites, that collect space debris, usually represented by medium to big-sized objects. Such a satellite has its own propulsion system, photovoltaic panels, and a command system that allows it to be controlled from our space station and communicate with all the other satellites. Last, but not least, one of the things that makes it special is its ability to connect to a wide guidance system and travel throughout orbit without the danger of a collision. Once the satellite has collected the maximum amount of space debris, it will de-orbit and burn along with the space junk.

Our idea of designing such a satellite was inspired by Astroscale's space debris removal mission, in which they are using a satellite called ELSA-d.

UNDERSTANDING THE DANGER CAUSED BY SPACE DEBRIS – THE KESSLER SYNDROME

What is Kessler syndrome? According to the Kessler Syndrome, certain regions of Earth's orbit are too densely filled with junk and objects, making it impossible to use satellites there. According to this theory, space pollution is sustained by collisions between objects in orbit because they produce more debris, which leads to additional collisions in the future. Scientist Donald J. Kessler of NASA first proposed this notion in 1978 in a study called "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt."

In conclusion, not only that this syndrome represents a major threat to our spacecraft, but it also blocks any other attempt to place a space station or a satellite in Earth's orbit. Therefore, the magnetic shield we designed has a very good reason to be put into practice.

REFERENCES

[1] Office of Aerospace Medicine. Office of Aerospace Medicine | Federal Aviation Administration. (n.d.)
[2] Wikimedia Foundation. (2023, January 28). Kessler syndrome. Wikipedia.

2.e.v. INSULATION

Eliza Radu [1]
[1]Design, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania
Keywords: Heat insulation, MLI, Silica gel-based aerogels

ABSTRACT
Due to the high temperature in space, radiation protection is not enough, therefore we will need heat insulation. The two options we came across are MLI blankets and aerogels.
In this article, we thought about replacing multi-layer insulation (MLI) blankets with silica gel-based aerogels. Both are two good options, but aerogels have some better properties that made us choose them.

RESEARCHERS AND DISCUSSIONS

MLI consists of several thin layers and is very light. Aerogels are nanomaterials with very low density. The liquid inside them is replaced with gas so there will be a lot of air, over 90%, making them also very light.

The most used thermal insulators are multi-layer insulation (MLI) blankets. They are suitable for spacecraft due to their lightweight, but we think a better option will be silica gel-based aerogels.

An advantage is the ultralow density of aerogels, the lowest density for solid materials (about 0.001). Another advantage is the low thermal conductivity which is around. Due to their proprieties, we'll choose silica gel-based aerogels as heat insulators.

REFERENCES

[1] Multilayer insulation (MLI) blankets are extensively used in spacecraft as lightweight thermal protection systems. Heat transfer analysis of MLI is sometimes too complex to use in practical design applications. Hence. (2001, February 16). *Heat transfer correlations for multilayer insulation systems*. Cryogenics.

[2] *The future of thermal insulation in Space | AERSUS project - europa*. (n.d.).

[3] *Silica aerogel*. Aerogelorg RSS. (n.d.).

2.f. ARTIFICIAL GRAVITY CONSIDERATIONS

Eliza Radu [1]

[1] Design, Vianu Research Center

Tudor Vianu National High School of Computer Science, Bucharest, Romania

Keywords: weightlessness, artificial gravity, linear acceleration, centrifugal force

ABSTRACT

When astronauts are exposed to weightlessness for a long time, they are prone to various ailments like loss of muscle mass or weakening of the immune system. Even if trained, they sometimes return from missions less physiologically stable than when they left. Therefore, to perform missions under acceptable risk conditions, artificial gravity is required. There are several ways in which this artificial gravity can be achieved, such as linear acceleration, electromagnetism, mass or centrifugal force. This article covers the artificial gravity by rotation because it is the most affordable and we find it the best method from several points of view.

RESEARCH METHOD AND RESULTS

Weightlessness is among the many risks to which astronauts are exposed in space, and although it does not cause as serious an injury as radiation exposure, it has a significant role in the health of astronauts. Conditions that may develop include cardiovascular deconditioning as pulse and heart rate increase and cardiac chamber volume decreases, to physiological and physical deconditioning.

The linear acceleration method involves accelerating the spacecraft in one direction to impose an artificial gravity on the mission members equal to that of the engines. Due to the fact that the artificial gravity produced lasts very little, we do not consider this method suitable for our spaceship, and increasing the duration would not be a good idea because we would need more energy, which means more cost. If we consider the mass of the spaceship, another method would be to generate its own gravitational field through its own mass. But because we would need a lot of mass, we would have to use materials of very high density and that would not take up much space, which is very difficult with current resources. Although the magnetic technology is not developed enough, we also thought about the magnetism method, but the costs generated by an extremely heavy magnet and made of expensive materials to be conductive and cold at the same time put this option in last place.

We think the best option for our spaceship is the rotation which generates the centripetal acceleration from which the centrifugal force results. The force acts on all objects rotating with the centrifuge, forcing them toward the edge of it. For this circular motion we will have a radius r. This radius represents the distance from the center of gravity of the spacecraft to the edges. Knowing that ω is the angular velocity and m is the mass of the spaceship, the formula by which we can find the centrifugal force is

$$F = m * \omega^2 * r$$

But the centrifugal force is equal to the force $F = m * a_n$, where a_n is the normal acceleration and which leads to:

$$m * a_n = m * \omega^2 * r \Leftrightarrow a_n = \omega^2 * r \Rightarrow \omega = \sqrt{\frac{a_n}{r}}$$

Because we want a gravity close in value to that of the Earth, we will have $a_n = g \Rightarrow \omega = \sqrt{\frac{g}{r}}$.

CONCLUSION

The easiest way to generate artificial gravity is through rotation and so this is what we will use for our spaceship. We can achieve an acceleration equal to that on Earth and thus reduce the risk astronauts are exposed to due to weightlessness.

REFERENCES

[1] Google. (n.d.). Artificial Gravity. Google Crți.

[2] Chapter 2 Physics of Artificial Gravity - NASA. (n.d.).

2.g. PROPULSION SYSTEMS

Tudor Nicorescu [1]
[1] Design, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

MAIN BOOSTER ENGINES

The Nova project will make use of a different type of engine compared to that using liquid fuel. Our engines are going to use solid-fuel engines based on aluminum since we are going to be able to produce it in mass on the Moon Base. This type of engine works by mixing the fuel oxidizer (ammonium perchlorate) into a solid and packing it into a cylinder. We chose this type of engine due to its increased power output compared to the liquid propellant type of engine. The thrust of this type of engine is calculated using the following formula:

$$F = \dot{m}V_e + (p_e - p_0)A_e$$

where: $\dot{m}$ is the mass flow rate, p the pressure, V the velocity, A the area.

However, the mass flow rate cand be written as such:

$$\dot{m} = \rho V A$$

where: ρ is the density, V is the velocity and A is the area. When considering an ideal compressible gas, the first equation is equivalent to:

$$\dot{m} = \frac{Ap_t}{\sqrt{T}}\sqrt{\frac{\gamma}{R}}\left(\frac{\gamma+1}{2}\right)^{-\frac{\gamma+1}{2(\gamma-1)}}$$

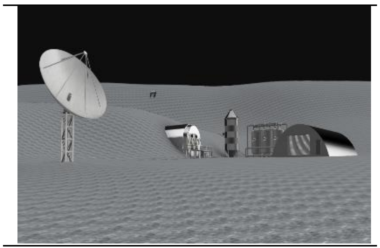
CORRECTIVE PROPULSION

When the base finalizes its journey to Mars, the only propulsion method the base will be left with is going to be a set of Ion Thrusters. Even though much weaker than other propulsion methods, their efficacy is the best of all other propulsion methods. This will ensure that a minimum amount of material transportation will be required in order to keep the Nova spacecraft in place. This type of propulsion takes advantage of the Coulomb force in order to accelerate ions. They will be located both in the rear end of the central cylinder as well as the upper part in order to also correct the bases small destabilizations if required. These will be remotely controlled using a high-performance computer which will calculate the exact angle the 8 thrusters need to direct themselves in order to make the required small rectification. Therefore, our base is ensured to keep its trajectory and to remain functional.

3. INFRASTRUCTURE & OPERATIONS

3.a. SECONDARY MOON BASE – PROJECT SELENE

Maria Neagoie [3], Medeea Marinescu [3]
[3] Infrastructure & Operations, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania



Headings:

Design and Materials
Location
Protection
Resources
Waste
Communications
Scientific Research
Space Vehicles

ABSTRACT

Even though the main base will be in the 4th Lagrange point in the Earth-Moon system, will have an additional habitat placed at the rim of the Shackleton crater on the Moon's South Pole. To be clearer, this secondary base will house 50 people at first, including computer scientists, engineers, medical staff, and others. Not only will the moon settlement be of great use when it comes to the transportation of materials, but it will also help us maximize the number of people that can live in Space, thus reaching mankind's colonization and fulfilling diverse scientific experiences.

The aim of the following paper is to further discuss and explain our team's choices regarding the design and materials used for designing our base, the chosen location - the rim of the Shackleton crater, the means of protection against the Moon's harsh environment, our plan for gathering vital resources (water, food, energy, and water), the implemented waste management, communications, and transport systems, as well as the scientific research topics to be studied inside our lunar habitat.

DESIGN AND MATERIALS

We aim to have an expandable camp, so it is important to use as many materials as possible from the Moon itself. The lunar surface contains iron, aluminum, and titanium, which will be extracted using our rovers and processed. We will use these resources to build some parts and for repairs. Also, the tubes will be made using regolith as well, since it's stronger than cement. There is still a need for some materials that we can only obtain from Earth, at least in the form that we need. The modules will be brought from Earth, but they will be covered in regolith to assure safety from radiation and possible impacts. Each one will be positioned with help from rovers and sealed to another one or an airlock. The modules are cylinder-shaped, with a length of 10 meters, and a diameter of about 5 meters, although the interior is smaller, most of the space that is not inhabitable is going to be used as storage space and for machinery.

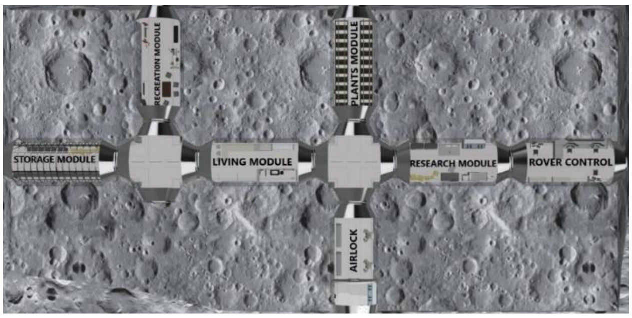


Figure 3.a.1. Top view of the base

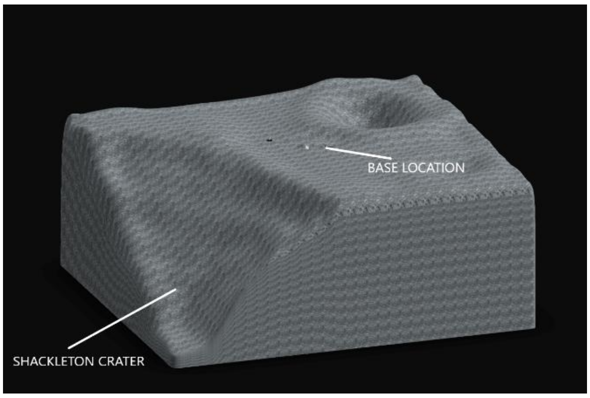


Figure 3.a.2. Location

LOCATION

After thoroughly studying the lunar environment, the most promising location for our settlement is by far the Shackleton crater, South Pole. In order to decide on our placement, we had to analyze a couple of conclusive factors such as resources, radiation coverage, inhabitants' safety and life quality, and scientific importance. The Shackleton crater exceeded by far our expectations in each of the previously listed categories, leaving us psyched for what Project Selene can achieve if placed here. The crater's rim receives almost year-round sunlight, providing our Moon camp with constant solar energy. Furthermore, in Shackleton's shadowed interior, ice can be found, which is crucial. Electrolysis can separate a water molecule into oxygen and hydrogen gases. The obtained hydrogen can be used for fuel, while oxygen is critical for residents. In addition, the walls offer protection from radiation and moon dust, which are both lethal.

PROTECTION AGAINST THE MOON'S HARSH ENVIRONMENT

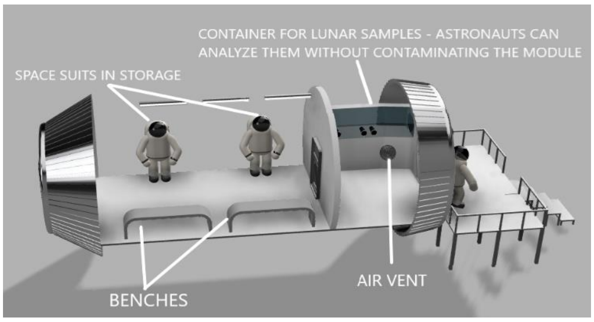


Figure 3.a.3. Airlock

Our moon camp will have to protect the astronauts against the many threats of the harsh lunar environment: radiation, micrometeorites, high-temperature fluctuations, and moon dust.

By building our base underground, we will use the regolith as a natural shield against micrometeorites. Even at shallow depths of around 1m, the lunar soil can absorb most cosmic rays as well as the lower energy solar particles, which will drastically reduce the number of materials needed for radiation protection and thus the cost of our settlement. Nevertheless, to ensure astronaut safety during high radiation events, such as solar storms, a dedicated room reinforced with thicker aluminum walls will provide more adequate shelter.

What's more, thanks to its remarkable thermal properties, the regolith will also provide a first layer of insulation reducing the energy required to maintain constant temperatures within the habitat despite the hundreds of degrees of temperature variation on the outside.

Lastly, because of its structure, composed of very fine and sharp particles, regolith is harmful to both humans and equipment, but also notoriously hard to clean, as evidenced by the early Apollo missions. To achieve minimum exposure to lunar dust, we will employ a combination of systems: Firstly, special spacesuits will be used, connecting directly to airlocks, thus minimizing astronaut contact with contaminated surfaces. Furthermore, cleaning of residue will be performed using air suction, while stray airborne particles will be captured by the air filtering system. A positive pressure differential between the settlement atmosphere and the airlocks will also ensure as little dust as possible gets inside our moon base. Secondly, all the regolith samples collected will be placed in sealed compartments and analyzed using gloveboxes, thus never encountering the clean air of the settlement.

RESOURCES

With the required special equipment due to high temperatures, astronauts can remove water ice from the poles. Furthermore, we can generate healthy drinking water by using reverse osmosis to remove most contaminants from water by pushing it under pressure through a semipermeable membrane. We intend to perform this process twice a week and collect the remaining water in a reservoir.

Our idea for producing fresh food on-site involves an essential lunar greenhouse, where we will combine hydroponics with growing plants in the lunar regolith, thus supplying our space explorers with much-needed nutrients. The astronauts would provide carbon dioxide by breathing and extracting water for the plants from their urine by using the Water Recycling System. Regarding hydroponics, we have performed an analog experiment in our Physics laboratory, studying the effects of the symbiotic relationship between legumes and the nitrogen-fixing Rhizobia bacteria on plant nodulation, varying variables such as light color & intensity, magnetic field, and Rhizobia content.

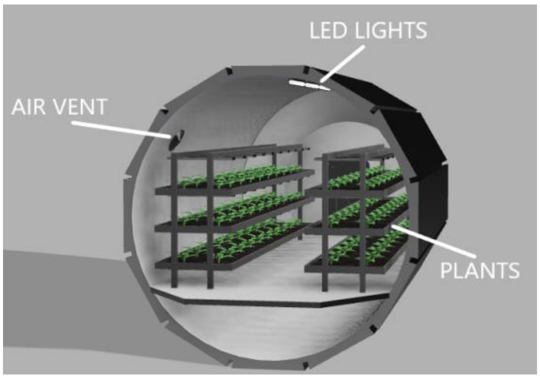


Figure 3.a.4. Greenhouse

As we have decided to place our base near the rim of the Shackleton crater on the South Pole, we will benefit from permanent sunlight. Then, we can store solar power in fuel cells, which are safer and more efficient than common batteries. These will also store extra power for use during lunar eclipses, also avoiding the problem of lunar eclipses when Earth entirely blocks sunlight.

Before we leave Earth, we are going to make some "supplies" with enough oxygen for the first few days on the moon. Then, we can process the oxygen-rich regolith: one experimentally proven method is molten salt electrolysis which involves mixing the lunar soil at high temperatures with calcium chloride, and then, by running a current through the mixture, the oxygen gathers around the anode where it is harvested.

COMMUNICATIONS

To keep in touch with Earth and our main settlement located on Mars, we will rely on an advanced satellite communication system. This system will enable two-way communication, allowing us to send and receive messages. Moreover, we will use a combination of two technologies, as each has its own unique use cases complementing the others' weaknesses. Radio waves will be used for the majority of day-to-day communications, while laser technology will be used for critical and higher data rate transmission. The camp will also use voice, video, and data transmission systems and data encryption technology to ensure secure communication. Additionally, the system will be built to function in a variety of environments, including extreme temperatures, low visibility, and long distances.

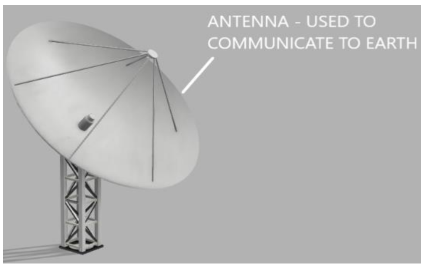


Figure 3.a.5. Antennas

SCIENTIFIC RESEARCH

At first, the purpose of our Moon Camp will be solely scientific, the analyzed topics being divided as follows: Geology, Low Gravity, Biology; Astronomy; Robotics, and Technology. To maximize efficiency, our dazzling crew will be split into smaller groups of experts: Biologists, Astronomers, Engineers, or Environmental Scientists.

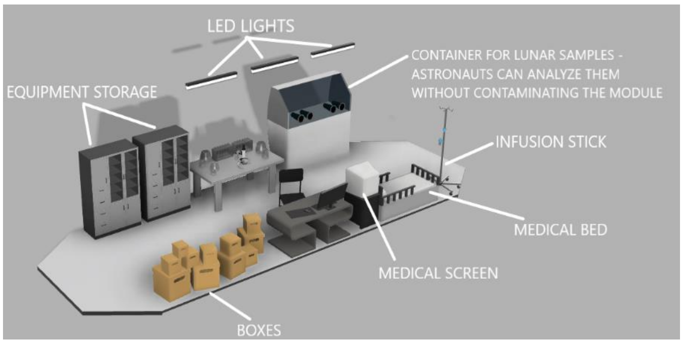


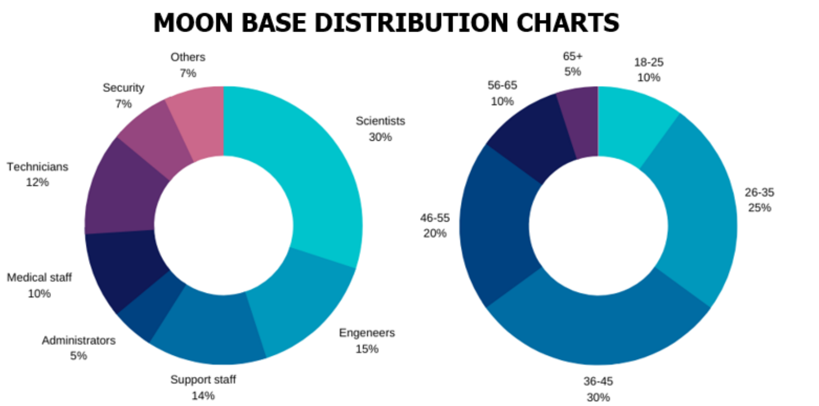
Figure 3.a.6. Research Room

First, a top purpose of our base will involve a combination of geology and biology, thus studying the possibility of growing plants in the lunar regolith. Nevertheless, our greenhouse also includes the hydroponics experiment, which will be taken one step higher by examining how plants evolve in the low gravity environment on the Moon, compared to our Earth control batches, as explained in the Food section.

It goes without saying that constructing a moon habitat directly implies studying the astronomical facet. Therefore, we aim to thoroughly explain the origin and evolution of the Moon and to exploit it to its fullest potential, thus landmarking a steppingstone for mankind.

Being the first permanent human settlement on the moon, one of its major goals will be to pave the way for humanity's colonization of other planets in our solar system, providing an accurate test bed for new technologies aimed at the exploration and settlement of new worlds. Moreover, the development of robotics systems adapted to the lunar environment is crucial, as performant rovers are necessary when it comes to transportation on the Moon.

To sum up, our motivated team is bound to come up with ground-breaking lunar discoveries in various fields, as we will doubtlessly implement an increasing number of research programs on a wide range of scientific topics, some of which have not been investigated before. For instance, we plan on further studying other key subjects (Physics, Biochemistry, Ecology, or Zoology) or even Immunology (assessing the transmissibility of COVID-19 on the Moon).



SPACE VEHICLES

To efficiently explore vast surfaces on the moon, our moon camp will have multiple types of vehicles. Thus, there will be two types of autonomous rovers: one designed for the extraction and transportation of water ice while the other used for scouting new terrain. For long-distance missions, astronauts will also make use of a crewed vehicle. This will have to be equipped with a pressurized module able to accommodate up to three people and be completely self-sufficient for multiple days at a time.

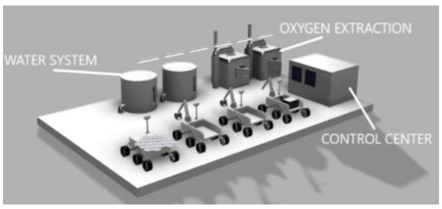


Figure 3.a.7. Rover Hangar

NOTE

This section was repurposed from our team's entry to ESA Moon Camp Challenge (see *https://mooncampchallenge.org/pioneers-gallery-2022/details/18213*).

3.b. VEHICLES

Tudor Nicorescu [3]
[3] Infrastructure & Operations, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

When it comes to the journey to and from Earth, this will be performed in two stages: First, astronauts will leave Earth on a rocket which will take them to lunar orbit. Then, the capsule will rendezvous with NASA's lunar gateway, where the crew will embark on a lander in order to arrive on the surface of the moon.

When talking about vehicles, the most widely used will be the Starship which is going to transfer needed materials to the base from both the Moon and Earth. The crew will also be transported using this vehicle, being the most economically viable option on the market. The rocket's reusability will be key in ensuring that all the needed materials and crew will be transported in an efficient way, therefore making the mission viable. However, there will also be spaceships that are permanently docked on the spacecraft which will be used to repair damage to the large spacecraft due to small collisions or other causes. These will be way smaller compared to Starship and will accommodate a crew of 3 people which will ensure restoration of the affected area is done properly.

3.c. COMMUNICATIONS

Luxin Matasaru [3]
[3] Infrastructure & Operations, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

Even for a self-sustaining colony such as our own, communication with earth and even other future settlements will be vital, both from an economic standpoint, for trade, and an individual point of view, for communication with friends or family. While, given current technologies and infrastructure, there should be no issue communicating with a station on Mars, the real problem arises when we consider the data rates necessary for wide scale, daily use by a colony of over 2000 people. Thus, the implementation of a dedicated communication satellite constellation will be needed in order to ensure adequate data rates all the way to lunar orbit.

COMMUNICATION TECHNOLOGIES

1. **Radio waves**

Maintaining basic radio communications between Earth and objects at or beyond the Moon would be very much possible with current technologies, a capability which has been proven time and again by multiple space agencies, ever since the first Moon landing in 1969 and even before. What's more, this can be achieved even by some amateur radio stations, though with significant interference, evidenced by the EME (Earth-Moon-Earth) communication technique, consisting of reflecting radio signals off the Moon. The one major downside of radio communication is the lack of infrastructure enabling high data rate connections beyond low Earth orbit. While on Earth multiple satellite constellations ensure a steady connection almost anywhere and at all times, those constellations do not listen nor emit signals beyond LEO. Furthermore, direct communication from the settlement with existing infrastructure would be almost impossible since consumer technologies are not sensitive enough to pick up signals from space. Thus, a dedicated satellite system would be needed to integrate Station Nova into Earth's communication ecosystem.

2. **Laser Communication**

Another promising up and coming technology is laser communication. Similar to radio, it uses electromagnetic spectrum to transmit data, however, it promises to solve many of its predecessor's shortcomings by using short wavelengths, well into the infrared spectrum. This way, laser communication will enable the use of less crowded frequencies, increase data rates and signal power, while at the same time requiring lighter and more compact equipment. This technology has already made it past the theoretical stage and is currently being tested as part of multiple programs within NASA. Most notably for our purposes, Earth-Moon laser communication is set to be established as part of the Artemis II mission in the coming years.

3. **Quantum Teleportation**

Probably the most novel, yet extremely exciting, communication technology is quantum teleportation which uses entangled particles to communicate almost instantly over long distances. The promise of this method is immense, having the potential to spark a second information revolution, where latency times would become a thing of the past. There are, however, many obstacles which still need overcoming: the need for better ways of generating and distributing entangled particles over long distances to increase data rates and very high costs associated with specialized equipment, just to name a few. Thus, while today, this technology is far from viable for widespread use, it isn't unlikely to play an important role by the time our space settlement would be built, given the rapid rate of development of the quantum information theory field.

CONCLUSIONS

A combination of the three technologies outlined above should be used, as each has its own unique use cases complementing the others' weaknesses. Radio waves will be used for the majority of day-to-day communications, while laser technology will be used for critical and higher data rate transmission. Finally, quantum teleportation could find uses for top priority and maximum-security applications, as well as for research into the further development of this technology.

REFERENCES

[1] Globus, A. (n.d.). *Communication*. Orbital Space Colonies.
[2] (n.d.). *NASA's First Space Laser Communication System Demonstration*.
[3] Schauer, K. (2022, August 10). *What's next: The future of NASA's Laser Communications*. NASA. Retrieved from
[4] Cacciapuoti, A. S., Caleffi, M., Van Meter, R., & Hanzo, L. (2020). When entanglement meets classical communications: Quantum teleportation for the Quantum internet. *IEEE Transactions on Communications*, *68*(6), 3808–3833.

4. LIFE SUPPORT

4.a. RESOURCE GATHERING

Mihai Priboi [2], Vlad Carasel [2]
[2] Engineering, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

Headings:

Introduction
Moon Resources
Resource Locating
Extraction
References

In order to build and maintain the space settlement, a steady source of materials is vital. For gathering and processing resources, we will be using the moon base and other stations. Due to our settlement's proximity to both the lunar surface and the asteroid belt, all the valuable resources extracted from these two will be quickly and continuously transported to the settlement.

As previously studied the costs and travel specifications from the settlement's location, Mars to the lunar surface, the delta-v required for transportation is low (7.8 m/s). Moreover, the time duration of the expedition is rather small. With both these factors in our favour, we will be able to launch numerous resource-gathering missions to the abundant environment of the moon, while keeping costs on the lower side.

The aim of this study is to present the process of locating, extracting, and refining resources supplied especially by the lunar environment and other celestial bodies as well.

INTRODUCTION

The process of mining, extracting, and processing resources are expected to consume significantly more power than the lunar outpost itself. While life support and scientific activities are estimated to require a few hundred kilowatts, the resource extraction process will require several megawatts. Consequently, a nuclear reactor will be necessary to support material gathering, unlike the moon base, which can be powered by solar panels alone.

We will also undergo space missions to a lot of NEOs (near-Earth objects) because the amount of resources requested by a settlement this big is enormous. In order to balance out the incredibly high costs of obtaining and processing extraterrestrial resources some of the gathered assets that are less common can be transported back to Earth and traded economically.

MOON RESOURCES

Knowing what elements can be found on the moon is crucial because the lunar habitat is our main resource supplier. Rocks, minerals, regolith, fumaroles, and vapor deposits are the main categories of natural resources that can be found on the Moon. A high percentage of the lunar surface crust contains minerals that could be used as nuclear fuel and or construction materials.

Regarding elements in the lunar soil, most of them can be commonly found combined with oxygen. Thus, further processing is required if we want to acquire the corresponding pure element. Some of the most dominant elements found are SiO_2 (mostly found in basalt rocks), Al_2O_3 and CaO (mostly found in anorthosite rocks), FeO, and MgO.

- **Water**

Water is a necessity for any human habitat, being used for drinking, watering plants and electrolysis, and making oxygen and hydrogen. In the form of ice, it can be found on the surface at the Moon poles, in more abundance at the south pole, where our lunar outpost will be located. In order to ensure the constant functioning of our water extraction and processing system, an increased amount of energy is required. Studies have shown that approximately 3 MWs are needed for an electrolysis-based system to function. That being said, nuclear power is the recommended energy generation method.

- **Regolith**

A great material for construction and radiation protection is the lunar regolith, so it is important to spot possible elements on the moon that fulfill these purposes. The development of concrete using local resources from the moon is a great idea. In order to obtain this concrete, lunar rocks should undergo high-temperature processing. The lunar environment houses large amounts of SiO2, Al2O3, and CaO that can be really useful for the creation of cement. A valuable characteristic of concrete is that it can be introduced into any structure offering increased durability. However, concrete has low thermal conductivity, making it an efficient heat-resistant material, but its high specific heat capacity can be problematic, as it retains heat for a prolonged period of time.

RESOURCE LOCATING

Several missions have been launched to examine the resources on the moon, and as a result, there is available information that points to potential mining sites. A map depicting the weight percentage of iron in the soil was created by the Clementine and Lunar Prospector missions.

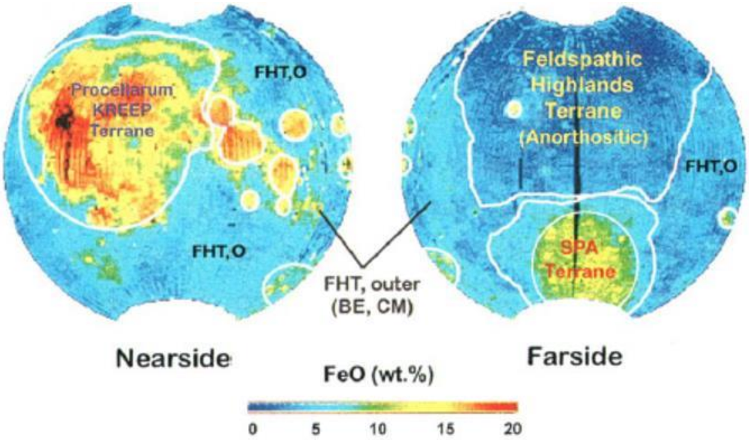


Figure 4.a.1. FeO Concentration Maps on the Moon. Image credit: Power Generation on the Moon for Future In-Situ Resource Utilization, May 2022

In terms of obtaining fuel for the nuclear reactor, the Gamma Ray Spectrometer (GRS) on the Lunar Prospector spacecraft has uncovered high concentrations of thorium, potassium, phosphorous, and rare-earth elements.

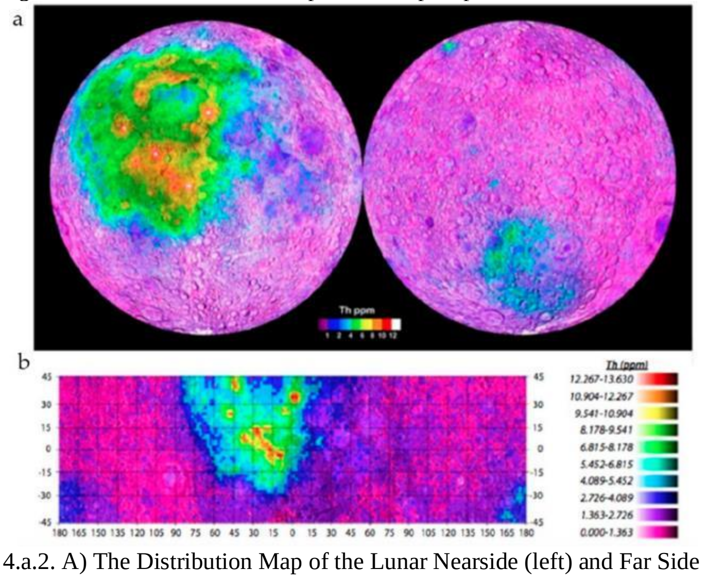


Figure 4.a.2. A) The Distribution Map of the Lunar Nearside (left) and Far Side (right).
B) Gamma Ray Spectrometer Generated Map of The Abundances. Image credit: Power Generation on the Moon for Future In-Situ Resource Utilization, May 2022

Additionally, the Japanese Kaguya Global Resource Survey (GRS) investigated the abundance of uranium and thorium in the region. The results showed that thorium is a more suitable fuel choice due to its higher abundance and because only ^{238}U was found, while ^{235}U is the best for fission.

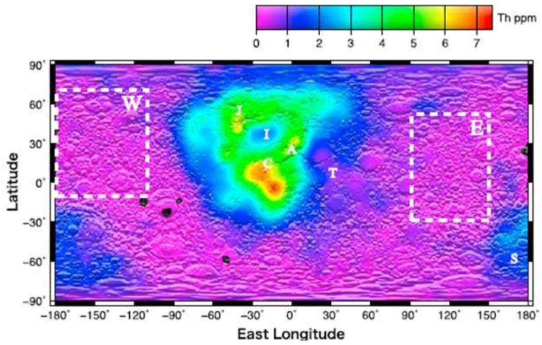


Figure 4.a.3. Distribution of Th on the Lunar Surface by Kaguya GRS. Image credit: Power Generation on the Moon for Future In-Situ Resource Utilization, May 2022

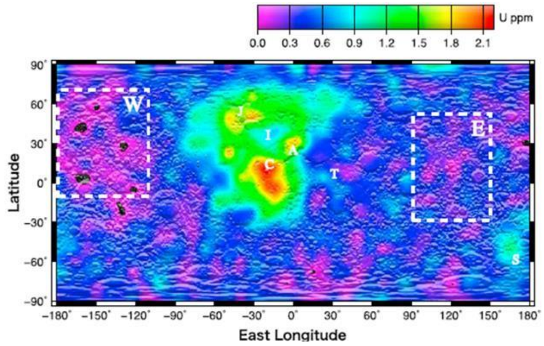


Figure 4.a.4. Distribution of U on the Lunar Surface by Kaguya GRS. Image credit: Power Generation on the Moon for Future In-Situ Resource Utilization, May 2022

We have created a Python program to determine the ideal site for mining. It utilizes a density map, such as the one mentioned above, along with the scale and desired area, to give the optimal location for maximizing resource acquisition.

```
import numpy as np
import matplotlib.pyplot as plt

def find_best_mining_location(density_map, scale, area_size=15):
    # convert the density map to a numpy array
    density_map = np.array(density_map)
    n, m = density_map.shape[:2]
    best_density = 0
    best_area = None
    best_coords = None
    for i in range(n - area_size + 1):
        for j in range(m - area_size + 1):
            area = density_map[i:i + area_size, j:j + area_size, 0] # extract
the red channel
            avg_density = np.mean(area)
            if avg_density > best_density:
                best_density = avg_density
                best_area = area
                best_coords = (i, j)
    i, j = best_coords
    area_center = np.array([i + area_size / 2, j + area_size / 2])
    return area_center * scale

def main():
    # read the density map image
    density_map = plt.imread("density_map.jpg")
    # get the scale of the image (pixels to km) from the user
    scale = float(input("Enter the scale of the image (pixels to km): "))
    # get the area size (square km) from the user
    area_size = int(input("Enter the area size (square km): "))
    # find the best location for mining
    best_location = find_best_mining_location(density_map, scale, area_size)
    # display the density map image
    plt.imshow(density_map)
    # plot an arrow at the best location for mining
    x = best_location[1] / scale
    y = best_location[0] / scale
    plt.annotate("", xy=(x, y), xytext=(x, y-density_map.shape[0]/12),
                 arrowprops=dict(arrowstyle="->", lw=1.5))
    plt.show()
    # print the best location for mining
    print("The best location for mining is at ({0:.2f}, {1:.2f})
km".format(*best_location))

if __name__ == '__main__':
    main()
```

EXTRACTION

The carbonyl extraction of metals is an efficient and cheap (energetically wise) method for obtaining high-purity Fe, Ni, Cr, Mn, and Co from lunar or asteroidal surfaces. Again, thermal power obtained from nuclear reactors is the most suitable for obtaining water from ice. Knowing that water has one of the lowest vaporization temperatures out of all the elements found in our selected extraction area and since the ice on the moon comes in relatively small crystals, we plan to collect water vapors by applying a heat big enough to evaporate water, but not other elements with a higher vaporization point. Afterward, a purification process will take place in order to separate water vapors from other substances extracted. For extracting minerals from asteroids, systems including powerful claws and drills will be used.

In addition, smelters can be used to break down the lunar maria (the large dark plains on the Moon, created by asteroid impacts, which are more abundant in resources) into the pure elements that compose it. For this, large volumes of soil will need to be processed, so we will use a system of excavators and conveyor belts to feed the smelters.

REFERENCES

[1] Encyclopædia Britannica, inc. (n.d.). Lunar Resources. Encyclopædia Britannica.
[2] Power generation on the moon for future in-situ resource utilization. (n.d.).
[3] Wikimedia Foundation. (2023, February 4). Lunar Resources. Wikipedia.

4.b. WATER

Andrei Ciobanu [4]
[4] Life Support, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

The purpose of this article is to describe the processes underwent by water on our space colony.

To start with, it is that clean, mineralized water is one of the most important human needs. Besides this, water is required for cleaning operations, plant irrigation, sewer systems, electrolysis, as well as cooling the nuclear reactor.

The water-gathering process has been fully described in the Resource Gathering chapter. Despite the sufficient exploited quantities, a water recycling system is needed.

The main sources of water recollection will be urine, drainages situated all around the colony (which collect water used for cleaning, irrigation, sewers). The water will be subject to a series of purification mechanisms, which will be discussed in the next paragraph. The purified water will then be recirculated into every system.

REVERSE OSMOSIS

Reverse osmosis is a generally used method for separating unwanted particles and bacteria in water, and so far, it has shown the best results on large scales (an approximation of 10 tons of water shall be treated every day).

As its name affirms, reverse osmosis conceptually consists in applying a high enough pressure in order to overcome the osmotic force between two adjacent colloidal mixtures.

The structure will consist of a series of filters: sand, and coal, which will remove insoluble particles. Then, the water will move to a pressurized chamber with a semi-permeable membrane at one side, which will only allow water to pass.

The next two processes are only meant for drinkable water, as other activities do not require a high-water quality.

UV TREATMENT

The environment of our colony shall remain as sterile as possible, which is why infections represent a serious concern. UV stations will be used for treating drinkable water, eliminating potentially harmful bacteria.

MINERALISATION

Even though water is already potable at this stage, enriching it with minerals would determine a better nutritious result for humans. Therefore, filtered water will be treated with salts (bicarbonate or fluoride) of calcium, magnesium, sodium, and copper.

ELECTROLYSIS STATION

The electrolysis consists in a simple reaction, in which water is subject to a direct electric current, which decomposes it in hydrogen and oxygen.

$$2H_2O \rightarrow O_2 + 2H_2$$

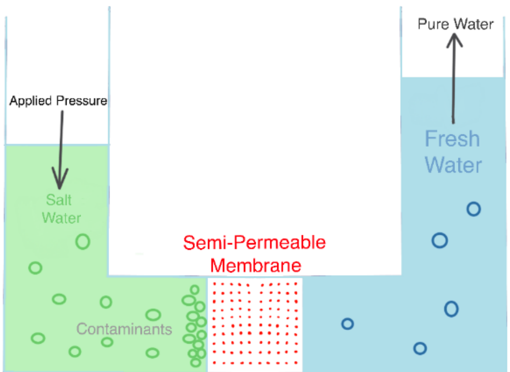


Figure 4.b.1. Reverse Osmosis Process Illustration [1]

The reason this station is needed is the production of oxygen which, even though it is partially stabilized by the artificial ecosystem (humans and plants), will require additional adjustments. In normal conditions, a litre of water will produce a yield of 90% about 0.62 litres of molecular oxygen, so daily electrolysis of 100-1000 litres of water should satisfy the needs.

REFERENCES

[1] Helles, Dr-Zakaria & Habib, Azzam. (2020). Coping Challenges of RO Technology in Water Desalination. 10.13140/RG.2.2.20367.25768.

4.c. FOOD. SIMULATED EXPERIMENT.

Maria Neagoie *[4]*
[4] Life Support, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

Keywords:
Space Colonization
Trifolium Pratense (red clover)
Magenta / Blue LED Light Root Nodulation
Rhizobia Bacteria
Chlorophyll Level

ABSTRACT

As we strive to send humans on further and longer space missions, finding ways of sustaining an entire crew with fresh food produced on-site will substantially reduce resupply costs and bring the concept of self-sustaining colonies one step closer to reality.

In this paper, we examined the possibility of growing plants (we chose clover due to its compact size) under magenta and blue LED light compared to natural sunlight.

Firstly, we monitored root systems and nodules development under magenta light, blue light, and natural sunlight respectively, the growth media being agar-agar due to its transparency that enabled us to better observe the roots. A key part in achieving root nodulation was played by the nitrogen-fixing Rhizobia bacteria.

Subsequently, we narrowed our analysis to the best LED light color (that proved to be magenta) in comparison to natural sunlight, also replacing agar with potting soil. We then studied plant health by examining chlorophyll levels with the help of near-infrared imagery, as well as the overall growth by programming a Raspberry Pi computer to take pictures periodically.

Finally, magenta light proved to be the best choice in terms of root development & chlorophyll level, as this paper further aims to present.

INTRODUCTION

The feasibility of growing plants in space for human consumption has been proven thanks to multiple experiments performed on the ISS over the past decade. [1,2,3] Thus, there are already some cultivation methods, such as hydroponics [4], which have already been adapted to accommodate plants in a microgravity environment. [5,6]

Figure 4.c.1. Setting up our experiment.

We aimed to improve upon these methods by finding light conditions which would favor faster growth. It is widely known that light is one of the most important factors in the proper development of plants, being a crucial resource for photosynthesis. [7]

However, research shows that plants mainly absorb the blue and red parts of the electromagnetic spectrum, while light from other sections proves less important [8].

This begs the following questions: what are the effects upon the development of plants when exposed solely to red and blue light and is the energy provided by these narrower parts of the electromagnetic spectrum enough to ensure satisfactory growth in a controlled environment? [9] Answering these questions could help scientists build plant growth modules for use in space which would be both more efficient from an energy consumption point of view while also providing better yearly production.

Figure 4.c.2. Root nodules

Our experiment was designed with these inquiries in mind and a specific focus on the influence of continuous exposure to magenta light on growth rate. This was achieved by comparing clovers grown by us in a controlled environment under magenta light to control samples placed in sunlight, and blue light respectively. Note that in the Munsell color system, magenta is called red-purple. The additive secondary color magenta, as noted before, is made by combining violet and red light at equal intensity; it is not present in the spectrum itself. [10]

RESEARCH METHOD

1.1. <u>Root development. Nodulation.</u>

The first stage of our experiment consisted in **assessing the effect of light on root nodulation**. For this purpose, we have set up 3 trials: one under **magenta light**, one under **blue light**, and another one exposed solely to **sunlight**.

The growth media was **agar** [11], a nutrient-rich gelatin, thus the tubes were sealed throughout the **7-week** experiment period, and the plants in agar not needing additional water. The growth media and seedlings were inoculated with **Rhizobia** [12,13], a nitrogen-fixing bacteria that forms a symbiotic relationship with legumes. As a result, nodules are formed on the plant root, within which the bacteria can convert atmospheric nitrogen into ammonia that can be used by the plant. [14]

1.2. Chlorophyll analysis. Growth process.

Figure 4.c.3. Magnifying Glass Inspection

In the second stage, we designed a simple experiment that allowed us to examine the development of clover plants in a controlled environment. After planting in **potting soil**, two tubes were chosen as the control group and set next to a window, where we made sure they could receive **sunlight** through the whole day (approximately 14 hours), while the other two tubes were set in a cardboard box illuminated by a **magenta LED lamp**. Note that the box was well sealed from any outside light and was only opened for inspection at night, so as to minimize any contamination of our data. Additionally, whenever we watered the plants, we made use of lab equipment such as disposable gloves in order to keep the ideal conditions.

Throughout the experiment, data were autonomously gathered by two **Raspberry Pi computers equipped with cameras** [15] carefully aligned to get the best view of the seedlings within the tubes. These were programmed to take photos daily, giving us a complete picture of our plants' evolution all throughout the runtime of our experiment.

To be sure any differences observed in the growth of the clovers from each of the two groups have been determined solely by the color light they were exposed to, we eliminated all potential uncertainty from other variables by exposing both groups to the same environment, where temperature and humidity were tightly controlled and provided both trials with the same amount of water daily. [16] What's more, during nighttime, the LED lamp was turned off, thus ensuring both clover batches received equal light exposure. With this setup, the clover seedlings were left to grow for **7 days**, after which the data was analyzed.

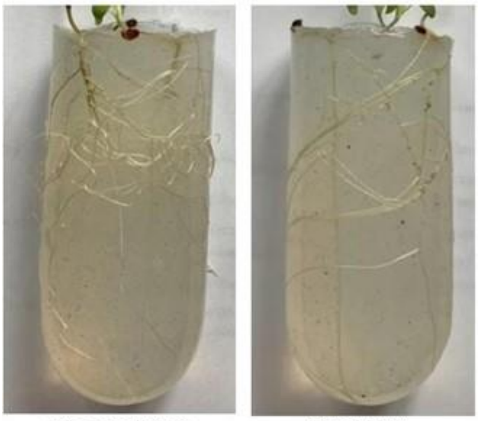
RESULTS AND DISCUSSION

1.3. Root development. Nodulation.

During this first stage of the experiment, the magenta and blue light tubes were under close monitoring, as the three figures below suggest. [17]

Figure 4.c.4. Tubes in Blue/Magenta Light

Figure 4.c.5. Emergence of first nodules (14 days after planting)



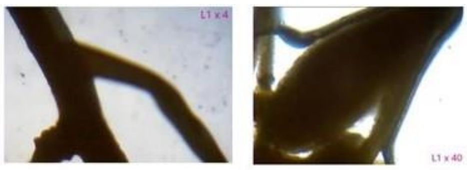
Magenta Light **Blue Light**

Figure 4.c.6. Root System Comparison (after removing the plants from the tubes)

At the end of this first stage of the experiment, the plants were removed from the tubes in order to begin the analysis of the root systems, which, as the image comparison below shows, are clearly more developed for the plants that had access to magenta light.

What is more, we counted the **root nodules** and came to a result of **26 in blue light** and **32 in magenta light**, which were also larger in size (See figure 4.c.7. for a better view of the nodules, as seen through a microscope).

On the other hand, the plants exposed exclusively to sunlight did not achieve root nodulation.



Magenta Light Root Nodule Magnified x4 **Magenta Light Root Nodule Magnified x40**

Figure 4.c.7. Nodules through Microscope

Additional work hypotheses:

- ***No Rhizobia:***

  This hypothesis fully lived up to our expectations. By starting it, we wanted to prove that Rhizobia directly impacts the appearance of root nodules and therefore did not add Rhizobia to these plants. As a result, none of the seedlings has achieved root nodulation.

- ***Double magnetic field:***

In the tube with a larger magnetic field B, one of the plants has not grown vertically upwards, the stem actually made a loop. Another interesting aspect is that one of the seeds germinated only around week 6, but, unfortunately, remained at that germination stage up to the end of the project.

When looking carefully at our plants through the magnifying glass we saw that there were actually a lot of small points protruding from the root. These points protruding from the root could have turned into real-size nodules if they would have been allowed to grow for a bit more than our 55-day experiment window.

Figure 4.c.8. Double magnetic field

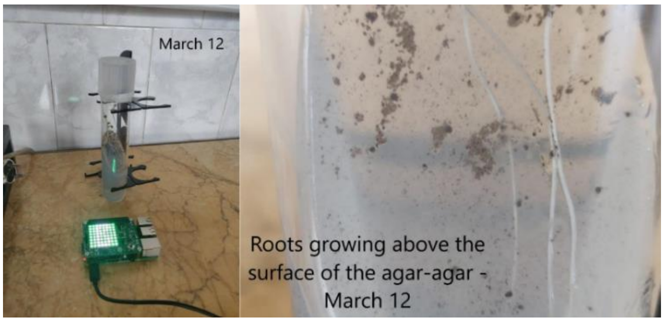


Figure 4.c.9. Double Rhizobia

- ***Double Rhizobia:***

Although we initially thought that a double content of Rhizobia would lead to the appearance of several nodules, still the plants with this double amount have had the roots on the air-agar separation surface, not inside the growth medium, during the whole period of our ground trial. That is probably why the plants did not achieve serious root nodules. Also, another possible factor could have been the dimmer light.

Seeing as the magenta light clearly surpassed the other candidates, as we originally expected, we then proceeded with the second part of our analysis in order to study clover in magenta light from a different perspective, that of growth and overall health based on the plant's pigment.

1.4. Chlorophyll analysis. Growth process.

Coming from the Greek words "chloros" (green) and "phyllon" (leaf), **chlorophyll** is a pigment that can be found in plants and that, together with light, contributes to the process of photosynthesis. [18,19] Therefore, the chlorophyll level is an indicator that can accurately assess plant health. In order to apply this theory, we used the Raspberry Pi **near-infrared camera** [20] in order to take pictures of the clovers at the end of the experiment.

We then processed the resulting images with the help of the infragram.org platform and concluded that **the plants that were exposed to magenta light had a higher chlorophyll level**. [21] See Figure 4.c.10. below for the comparison between the chlorophyll level of the plants that have been exposed to **magenta light (left)** and those exposed to **sunlight (right)**.

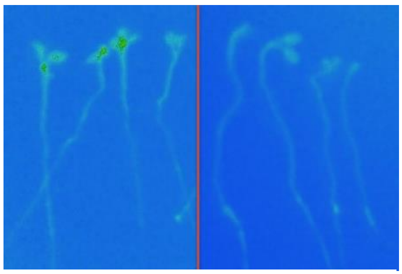


Figure 4.c.10. Plant Health. Chlorophyll Analysis. (Magenta vs. Sunlight)

The health was also studied by analyzing **raw images** (See figure 4.c.11.). In this way, we can clearly state that the plants in magenta light are stronger, having such a sustainable root just one week after planting. Examining the figure, we find that **the root of the plant that had magenta lighting is 7 cm longer than the other**, which has a 1.5 cm longer stem. Still, without support from a strong root, the plants that had access to sunlight were bound to wither. That is because, of course, roots keep a plant in place, but more importantly they take up the air, water, and nutrients from the soil and move them up into the leaves, where they can interact with sunlight to produce sugars, flavors, and energy for the plant, thus being the lifeline of the plant. Moreover, the subject on the left (natural sunlight) has a white-light green frail stem whilst the one on the right has a **dark green pigment, which is a sign of healthier growth**.

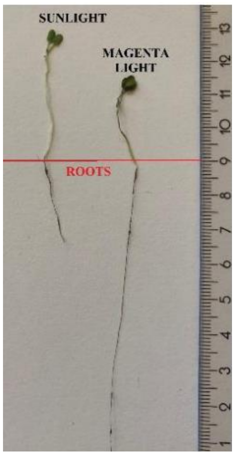


Figure 4.c.11. Growth Comparison

It should not be forgotten to mention that our second experiment ran for a 7-day window, which is why the plants were yet to achieve root nodulation in this case. From our first experiment, we noticed that the plants generally started forming nodules two weeks after planting, so longer than our second time window. Still, we decided to end our trial since root nodulation was not the purpose of our second experiment, already discussed in the first section.


Figure 4.c.12. Watering the plants

CONCLUSION

Finally, we came to the end of our research project which started with just an equation in mind: **W - G = R + B = M (Magenta)** [22]. In the end, our idea proved to be successful, with **magenta light clearly surpassing all its combatants in terms of root nodulation and healthy growth**, as is evident from Section 3: Results and

Discussions. Still, in order to rigorously confirm our findings, we will be sure to repeat the experiments in the near future. Moreover, we plan on **further extending our analysis** by not only studying chlorophyll, but also the **flowers** that the seedlings are bound to produce if the experiment time window is bigger. [23]

On a practical level, the application prospects of our research are notable, especially in terms of **future space missions**, where the astronauts will no longer be able to operate mainly with pre-packaged food and the need of producing **fresh nourishment** will be imperative. [24]

REFERENCES

[1] Heiney, A. (2019, April 9). Growing plants in space. NASA.
[2] Cawley, J. (2021, April 27). NASA astronaut paints a picture of success growing plants in space. NASA.
[3] Astrocrops - growing plants for future space missions: Teach with space PR43. ESA. (n.d.).
[4] What are hydroponic systems and how do they work? Fresh Water Systems. (n.d.).
[5] U.S. National Library of Medicine. (n.d.). National Center for Biotechnology Information.
[6] Brabaw, K. (2017, June 26). Gardening in microgravity: How space plants are adapting (video). Space.com.
[7] Photosynthesis under artificial light: The shift in primary and ... (n.d.).
[8] The electromagnetic spectrum and a typical spectral reflectance curve ... (n.d.).
[9] Baessler, L. (2021, April 19). Red light or blue light for plants - effects of red and blue light on plants. Gardening Know How.
[10] Understanding the munsell color system - owlcation. (n.d.).
[11] Macadamia cultivar evaluation in Natal. Taylor; Francis. (n.d.).
[12] Jaiswal, S. K., Mohammed, M., Ibny, F. Y. I.; Dakora, F. D. (2020, December 31). Rhizobia as a source of plant growth-promoting molecules: Potential applications and possible operational mechanisms. Frontiers.
[13] Mabrouk, Y., Hemissi, I., Salem, I. B., Mejri, S., Saidi, M.; Belhadj, O. (2018, May 30). Potential of rhizobia in improving nitrogen fixation and yields of legumes. IntechOpen.
[14] Nature Publishing Group. (n.d.). Nature news.
[15] Raspberry pi documentation. Camera. (n.d.).
[16] Understanding primary factors driving plant growth - Ohio AG NET: Ohio's Country Journal. Ohio Ag Net | Ohio's Country Journal. (2021, July 15).
[17] Magnitude.io classroom - powered by curiosity. (n.d.).
[18] Chlorophyll. National Geographic Society. (n.d.).
[19] Nature Publishing Group. (n.d.). Nature news.
[20] An introduction to near infrared (NIR) spectroscopy. An introduction to near infrared (NIR) spectroscopy | IM Publications Open. (n.d.).
[21] Infragram by Public Lab. Infragram. (n.d.).
[22] Physics tutorial: Color subtraction. The Physics Classroom. (n.d.).
[23] Bean Flowers - backyardnature.net. (n.d.).
[24] Dunbar, B. (n.d.). Fresh ideas for Space Food. NASA.
[25] **Experiment idea:** Tak Lee, Martina Orvosova, Morgane Batzenschlager, Marcelo Bueno Batista, Paul C. Bailey, Nadia A. Mohd-Radzman, Aram Gurzadyan, Naomi Stuer, Kirankumar S. Mysore, Jiangqi Wen, Thomas Ott, Giles E.D. Oldroyd, Katharina Schiessl, Light-sensitive short hypocotyl genes confer symbiotic nodule identity in the legume Medicago truncatula, Current Biology, Volume 34, Issue 4, 2024, Pages 825-840.e7, ISSN 0960-9822

4.d. ATMOSPHERE

Andrei Ciobanu [4]

[4] Life Support, Vianu Research Center

Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

This article will cover the main aspects of the atmosphere in our space settlement, from composition all the way to temperature and filtration.

HUMAN NEEDS

First, human biological needs should be taken into consideration. A study carried out by EHSS shows that a drop in atmospheric oxygen below a 19% concentration can lead to noticeable adverse effects:

- for 16% oxygen, cardiovascular effects (increased heart rate), as well as neurological ones (impaired thinking, lack of coordination) are already shown;

- for 14% oxygen, these symptoms tend to aggravate: neurological effects, significantly more noticeable at this level, may lead to emotional damage and a total absence of judgment;
- if the level drops below 10%, the outcome is loss of consciousness and, eventually, death.

The described effects are easily explained by how our body depends on oxygen. Humans have evolved to breathe the necessary amount corresponding to Earth's atmosphere, which consists of 20.9% oxygen. The influx of respiratory gas is usually measured by SpO2(oxygen saturation in the blood), which in clinical conditions varies between 95% and 100%. A sudden drop in atmospheric oxygen concentration would definitely lead to a drop in SpO2, which would in turn result in the symptoms from above.

This being said, it is important to maintain an oxygen level of at least 21%. Besides this, it is also crucial for other gases to remain between certain amounts. Carbon dioxide (CO2) is a gas naturally produced through human metabolism, as well as other activities such as fuel combustion or several industrial processes. By itself, CO2 doesn't present as a biochemical pathologic agent, as it only acts as an asphyxiation agent, reducing the volumetric oxygen percentage. The OSHA permissible limit for labor environments is 0.5%, therefore this will represent the superior limit in our colony.

Carbon monoxide (CO), on the other hand, presents serious toxic effects on the human body even in low air concentrations. Hemoglobin, the substance through which oxygen and carbon dioxide are transported through our body, forms labile chemical bonds with these gases. However, once present in our lungs, CO strongly binds to hemoglobin, not allowing it to transport respiratory gases and, finally, leading to asphyxiation. The concentration should be kept at a percentage of under 0.005% in respirable air, according to OSHA.

Humidity is also an important atmospheric factor. According to Mayo Clinic, the air should remain between values of 30 and 50 percent water vapor saturation. A humidity outside these given parameters would have a negative effect on dermal health (causing flaking of the skin) or respiratory health (irritating the respiratory system's mucous).

The ideal atmospheric pressure for a human habitat should oscillate around 30mmHg, whereas the temperature must be at around 22ºC, or 299K.

ADJUSTMENT MECHANISMS

First of all, the atmosphere in the colony will be homogenous: a complex ventilation system will vehiculate air through every zone, assuring an ideal distribution of all the needed components.

There will be 6 sensors continuously monitoring the air composition: oxygen, carbon dioxide, carbon monoxide, humidity, pressure, and temperature. In case of a destabilization, alerts will be sent to local and global administrators, which will issue the adjustment procedures. They consist in activating the specific adjustment mechanism.

OXYGEN

Once the oxygen concentration drops below the needed value, the gas is released into the atmosphere from our reservoirs, where electrolysis-produced oxygen is deposited, through the ventilation system. Once consumed, the oxygen is immediately replaced by additional quantities generated by electrolysis.

CARBON MONOXIDE

There are numerous ways of diminishing carbon monoxide concentration in air (consisting of methods based on thermal treatment, absorption, or catalytic conversion). We have found the last one most reliable for autonomous colonies since it requires low maintenance and gives good results. Magnetite, an accessible and malleable compound, is known for converting CO into CO2, through the following reaction:

$$Fe_3O_4 + 4\ CO \rightarrow 3\ Fe + 4\ CO_2$$

Therefore, if the carbon monoxide adjustment mechanism is issued, parts of the atmosphere will be contained one by one in a hyperbaric chamber containing magnetite in which, after being heated, carbon monoxide will be detoxified and released in the ventilation system.

CARBON DIOXIDE

As in oxygen, carbon dioxide quantities are also naturally regulated by the plants on our space settlement. Even in this situation, the atmospheric percentages may exceed the discussed limit. There is no efficient way of filtering it out, so the only way of regulating its levels will be to release some of the air in outer space through designated valves, while the other adjustment mechanisms are issued in order to maintain wanted parameters.

PRESSURE

In the case of low pressure, the oxygen adjustment mechanism will be issued, releasing enough oxygen to meet the required standards. For high pressure, air will be released in outer space through the same valves as in the CO2 mechanism.

HUMIDITY

- **<u>DEHUMIDIFICATION</u>**

Dehumidifiers will be placed behind every main vent. They will be no different from the ones currently used on earth, which are based on pressure-assisted condensation.

- **<u>HUMIDIFICATION</u>**

In this case, a humidification station is needed. Water from the main storage is transported to it, where it is vaporized through heat and released into the ventilation system.

REFERENCES
[1] Mayo Foundation for Medical Education and Research. (n.d.). Mayo Clinic.
[2] Carbon dioxide health hazard information sheet - food safety and ... (n.d.).
[3] Carbon monoxide poisoning - occupational safety and health administration. (n.d.).
[4] Ivanenko, O., Radovenchyk, V., Radovenchyk, I. (2021, January 20). Neutralization of carbon monoxide by magnetite-based catalysts. SSRN.

4.e. ENERGY

Medeea Marinescu [4]
[4] Life Support, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

Energy is important in space because it is what drives exploration and discovery. Space travel and exploration require a tremendous amount of energy in order to be successful. All space missions use a significant amount of fuel and power in order to achieve their goals so without energy, space exploration would be impossible. Energy is also crucial for having functioning satellites, and for powering the communication systems and other equipment necessary for space exploration. Therefore, the settlement's electrical system is essential for us because it allows the crew to live comfortably, operate the station safely, and conduct scientific experiments.

INTRODUCTION

The settlement will utilize a dual-strategy approach to generate energy. Solar panels located on both toruses will serve as the primary source. Additionally, the use of small satellites orbiting the settlement that are always pointed towards the sun and transmit energy through laser technology is also being considered. [1]

METHOD

Because of the high temperature, we will use gallium arsenide solar panels instead of the normal ones for better results. Based on our research gallium arsenide improves the properties of the panels (studies show that this type of solar panel has 40% efficiency versus the normal ones which have around 20%). Although these types of panels are more expensive, we think that the additional cost is legitimate. We will have 300,000 solar cells covering around 3000 m² of space. The panels will be placed on both toruses. We calculated the total yearly energy consumption using this formula:

$$E = A \cdot r \cdot H \cdot PR$$ [2], where:

- E = Energy (kWh)
- A = Total solar panel area (3000 m²)
- r = solar panel yield or efficiency (%) (approximately 40%)
- H = Annual average solar radiation on tilted panels (approximately 1,412 W/m²)
- PR = Performance ratio, the coefficient for losses (approximately 0.5)

Figure 4.e.1. Solar Panels

CONCLUSION

So, based on our measurements, our space settlement will use 8 MWh and 120000 kW per day. Using our solar panels, we will gather almost 122000 kW daily.

We plan to store the rest of the energy in reusable fuel cells, so in this case, if we have an emergency or we have some issues with the solar panels we will be able to continue to live on the settlement with no problems. Of course, in case of emergencies, we will lower the energy consumption to the bare minimum.

REFERENCES
[1] IAC-04-R-3-06 Solar Power Satellites for Space Applications. (n.d.).
[2] How to calculate solar panel output? CRM Software for Sales & Installation Companies. (n.d.).

4.f. HEALTHCARE

Maria Neagoie [4]
[4] Life Support, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

It goes without saying that a society cannot function properly without a well-equipped medical system and trained professionals in this field. Therefore, Project Nova is sure to be a safe host for its inhabitants, their health being our number one priority.

For this purpose, we have carefully analysed the situation and made an on-point approximation of the required number of physicians on our base. Our idea is for the settlers to benefit of regular check-ups, also making use of robots for mild injuries and certified doctors for severe illnesses.

This paper further develops on this topic, thoroughly examining the key factors that are bound to cause medical problems in Space, as well as presenting solutions for large-scale emergencies, including epidemics.

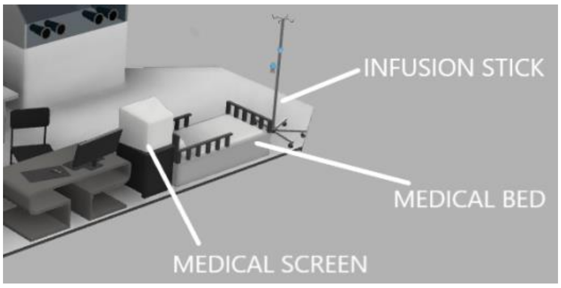


Figure 4.f.1. Medical Area 1

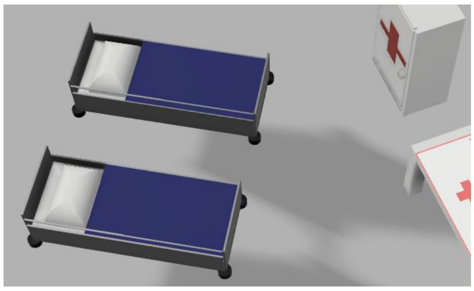


Figure 4.f.2. Medical Area 2

NUMBER OF PHYSICIANS PER 1000 PEOPLE:

To begin with, our first and foremost concern was the number of qualified physicians to accommodate n our base. For this purpose, we have read pertinent studies from data.worldbank.org that assess the number of medics per 1000 people was less than 2. Still, as we wish to ensure that there will always be enough doctors even for a large scale emergency on our base with a relatively small population, we came to the conclusion that an average of a doctor per 40 colonists will be sufficient. That brings us to a total of 25 medics per 1000 people, thus a lot better than the current situation on Earth, also noting that the more doctors there are, the easiest it will be for our settlers to train future ones and as the ratio of medical professionals per colonists is large, we will be capable of doing regular check-ups.

FACTORS THAT INFLUENCE THE FUNCTIONALITY OF A PERSON'S BODY IN SPACE:

Those check-ups are especially important in Space as the following three factors can drastically influence the functionality of a person's body are:

- **artificial gravity** which has negative effects on the person's skeletal resistance and muscle effectiveness;
- **artificial atmosphere** which cannot be the same as that on Earth;
- **unvaried alimentation** despite the diet providing settlers with all needed nutrients.

PLAN FOR EMERGENCY:

Nowadays, we are living in a society that is continuously evolving, so our top-notch space settlement will ensure to make use of robots for common and mild injuries, but we still need well-trained medical personnel for severe cases of illness. What is more, as recent years have been marked by the COVID-19 pandemic, we have made sure to be prepared in case such an outbreak of an extremely contagious disease will seize our Space habitat. Thus, in a similar situation, we will establish a general quarantine regime, our autonomous structure being of great aid, limiting when needed the interaction between people from different areas.

4.g. WASTE MANAGEMENT

Medeea Marinescu [4]
[4] Life Support, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

Not being the case of short-term space exploration missions, in which waste is stored on the ship until arriving back on Earth, waste management can be a complex process. Our idea revolving around waste management has its roots in recycling. On our settlement, recycling is one factor we constantly encounter throughout the overall design, and in this category, it becomes an increasingly important element in assuring the success of the Project Nova.

One of the main challenges of planning a waste management system was the limited space available for storage. This means that waste must be minimized, reused, and recycled as much as possible to prevent it from accumulating and creating health and safety hazards. Furthermore, the limited resources in space also make it important to recycle waste as much as possible in order to conserve resources and avoid having to transport them from Earth.

INTRODUCTION

Before we start looking for solutions regarding the waste that will be generated in our space settlement, we need to figure out how much there will be. The average human produces about 2 kg of waste a day, either recyclable or not. Also having ducks on the Nova project will produce some waste, mostly faeces, feathers, eggshells, and bones. So, with 1000 people on project Nova, we will have approximately 2100 kg of waste daily.

METHOD

In order to get rid of all the waste produced we decided to go through 4 main steps.

1. **Incineration**

To address the disposal of waste, incineration is the primary method used. Some types of waste, such as medical waste, cannot be reused or recycled and must be handled with caution. For these types of waste, we will use an incinerator to safely and effectively burn it and also reducing its volume by as much as 95%. The ashes resulted from the incineration will be stored securely to prevent any harm to the community. To store the produced oxygen, we will utilize membrane separation. The membranes are acting as a semi permeable barrier and the separation is made by the membrane which is controlling the rate of movement of various molecules. The captured oxygen will be stored for later use in stacks. The process is explained in the photo below.

Figure 4.g.1 Oxygen tanks

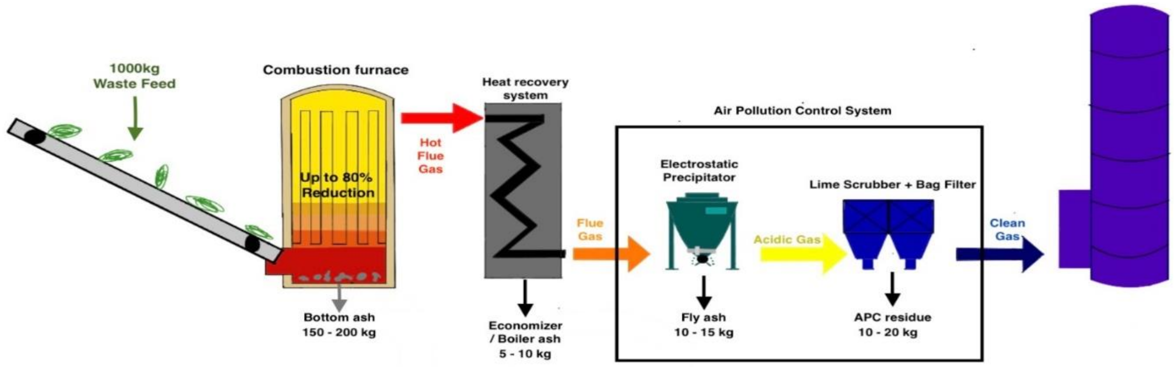


Figure 4.g.2. Incineration Process [1]

2. **Reduce, Reuse, and Recycle**

Another important detail about the waste management system is to think about how you can reduce it to the minimum. This being said, the education play an important role in this step. In order to kick off the initiative of reducing, reusing and recycling we want to educate the community on the importance of reducing the wastes while also giving them directions and suggestions on how to accomplish this goal. For example, we will promote the use of reusable items such as water bottles, food containers and much more. Additionally, we will create a recycling system for materials such as paper, plastic, glass, and metal, and place recycling bins in convenient places throughout the settlement.

3. **Composting**

For biodegradable waste, including food leftovers and human and animal faeces, we want to use the composting method. In this way all from the above can be transformed into fertile soil for our gardens. This method not only lowers the amount of waste produced but also offers a sustainable solution for fertilizing our plants. To facilitate this process, composting containers will be distributed throughout the settlement and the composting will be carried out on a weekly basis.

4. **Monitoring and Evaluation**

The last step and maybe the most important one is monitoring the outcome of this waste management system. This will involve tracking the waste generated regularly, evaluating the success of our reduction, reusing, and recycling programs. At the end of every month, based on the results of our monitoring and evaluation, we will make any necessary modifications in order to continue to lower waste within our community.

REFERENCES

[1] Phua, Zhenghui & Giannis, Apostolos & Dong, Zhi-Li & Lisak, Grzegorz & Ng, Jern. (2019). Characteristics of incineration ash for sustainable treatment and reutilization. Environmental Science and Pollution Research. 26.

4.h. THERMAL SYSTEM

Medeea Marinescu [4]
[4] Life Support, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

Finding the most efficient heat conservation and generation methods was a challenging step in planning our settlement. This process differs significantly from its earthly homologous, with Nova being exposed to the exponentially lower temperatures of space while also bathing in the much stronger unfiltered sunbeams.

One of the most universally accepted methods of passive thermal control is Multilayer Insulation, also known as MLI, which is known to work better in more enormous spaceships, such as this one.

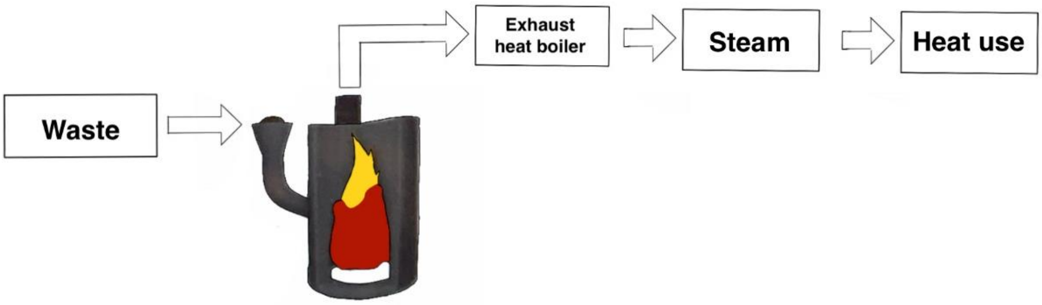


Figure 4.h.1. Heat obtained from the incineration process

METHOD

MLI blankets will be applied to the toruses and the main body to maintain a constant operating temperature, regardless of Nova's position in space. This technology works by limiting the amount of radiative heat transfer with multiple reflective layers, with low IR emissivity layers further disabling heat transport. In the end, the coating helps control the temperature at which different components operate and helps protect the spacecraft from undesired solar radiation or IR flux. By reducing the amount of heat lost to the harsh environment of space, the MLI layers help maintain a constant, comfortable operating temperature within the settlement. Besides this, the heat produced from the incineration process will be used to keep a stable temperature on the settlement.

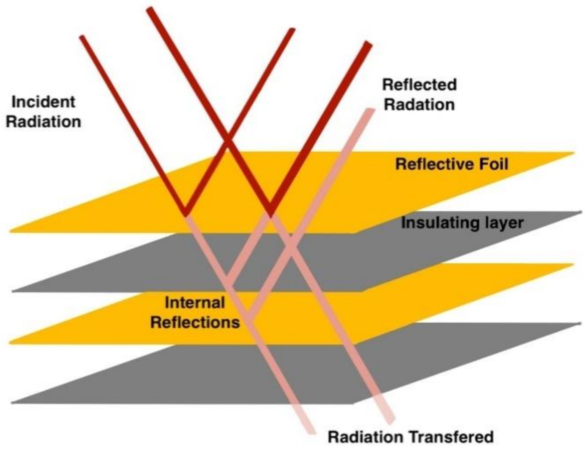


Figure 4.h.2. How MLI prevent radiation heat transfer [1]

REFERENCES

[1] Singh, D., Singh, M.K., Chaubey, A. et al. Thermal performance improvement of multilayer insulation technique. Heat Mass Transfer 59, 1365–1378 (2023)

5. SOCIAL ASPECTS

5.a. SURVEY ANALYSIS

Hristoforos Koutsioukis[5]
[5]Social, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

As our goal is to create a manned space settlement, public opinion is crucial when it comes to taking decisions. Therefore, our team assessed that the most efficient way to put this into practice would be to distribute a survey regarding life inside our base to people of all ages and further analyze their views by plotting the data into charts.

The survey consisted of 8 questions, which enabled us to take critical decisions regarding our project design, especially when it came to the Education & Medical Systems, as well as Population Distribution, where we have included the survey analysis in the respective section of our project.

QUESTIONS AND ANSWERS EXPLAINED

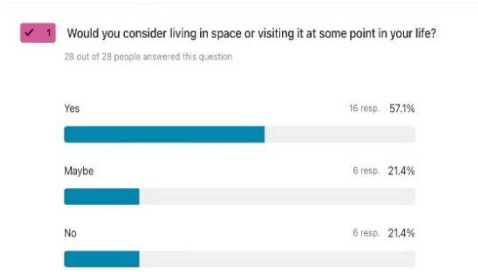


Figure 5.a.1. Survey Question 1

To begin with, the first defining question that came to mind was the intention to live or at least visit Space. The responses clearly show a general trend of acceptance, with only 21.4% of interviewees that would not like to go to Space. On the other hand, over 57.1% were not even skeptical and picked a sure "Yes!".

When it comes to the length of their stay in Space, almost 50% opted for tourism only, whilst only 14.8% chose long-term/lifetime living. Thus, this question enabled us to notice that having facilities for tourists would be crucial when we want to expand our base to the general population, not just scientists or engineers.

Figure 5.a.2. Survey Question 2

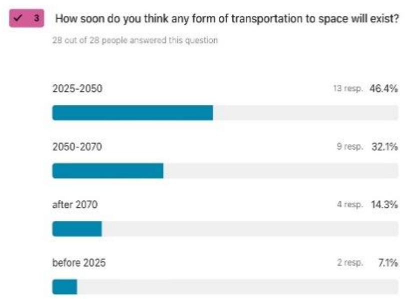


Figure 5.a.3. Survey Question 3

Analyzing the results, we conclude that, despite SpaceX's recent contribution to Space tourism, only 7.15% of the votes were expressed for the possibility of living in a space settlement before 2025. On the contrary, almost 15% believe that this would still be impossible in 50 years. Still, most of our respondents say that some of us will be living in Space in less than 30 years.

Also, the size of our space colony directly impacts the social structure, design, and costs. Studying our interviewees' answers, we note that more people would prefer a small town/city instead of a metropolis. Still, opinions diverge, almost 18% chose to leave among less than 1.000 people, whereas 32.1% opted for a colony size of 10.000-100.000 people and 28.6% for a size of 1000-10000 people.

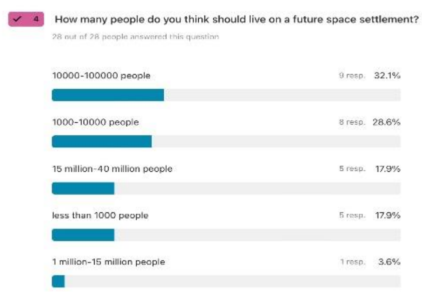


Figure 5.a.4. Survey Question 4

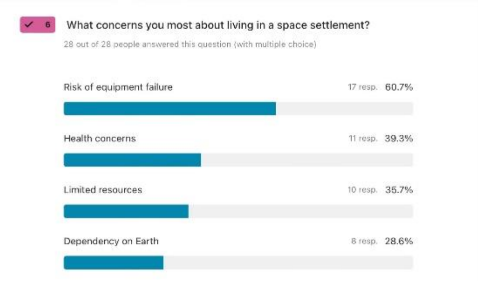


Figure 5.a.5. Survey Question 5

The concerns surrounding the construction of a space settlement are important to consider as they can have far-reaching and long-lasting consequences for both the people living in the settlement and the future of space exploration and development. For example, issues such as the sustainability of life support systems, and risk of equipment failure (60.7%), and the psychological effects of living in an isolated environment (39.3 %) must be thoroughly evaluated to ensure the safety and well-being of the residents. Additionally, the settlement must be designed in a way that is economically feasible and sustainable (35.7 %), so that it can continue to function and grow over time.

The public's opinion regarding the private ownership or international convention ownership of a future space settlement is important because it can significantly impact the perception and success of the settlement. If the public perceives the settlement as being controlled by a private corporation (27% of the country), it may result in distrust and a lack of support, as well as concerns about exploitation and the unequal distribution of resources. On the other hand, if the public views the settlement as being owned by an international convention(73%), there may be concerns about bureaucracy, lack of innovation, and a lack of private investment. A positive public perception is crucial for the long-term success of a space settlement, as it can influence funding, public support, and overall political stability.

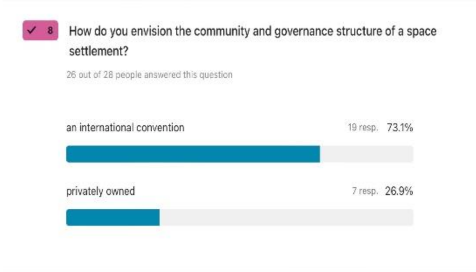


Figure 5.a.6. Survey Question 1

5.b. POPULATION DISTRIBUTION

Vlad Dimulescu [5], Alex Paun [5]
[5] Social, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

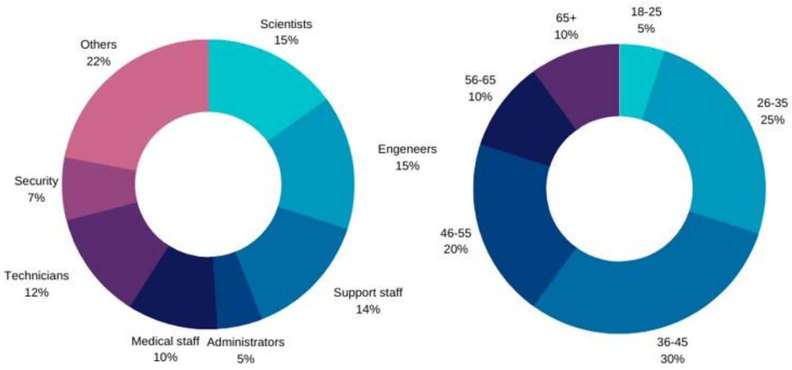
Scientific researchers aren't the only personnel needed on our settlement in order for it to be self-sustainable. There are many essential jobs that need fulfillment, on both the main base and the lunar base. Furthermore, not all age ranges might be suitable for all jobs in the settlement, taking into consideration the harsh conditions that may appear in space.

In this paper we aim to present our team's choices for the personnel and age range distribution, respectively and explain why we think that such a classification would be optimal for the progress of our settlement, helping it become as efficient and as easily sustainable as possible.

INTRODUCTION

In the beginning, our space settlement will house 1050 people. More exactly, 1000 people will live on the main base and 50 on the lunar base.

MAIN BASE DISTRIBUTION CHARTS



PERSONNEL DISTRIBUTION

The personnel distribution is based on the main purpose of the settlement, scientific research, but also takes into consideration the self-sustainability of the settlement, so there will be a fair number of other jobs that aren't related to research, such as teachers, reporters, and entertainers.

AGE RANGE DISTRIBUTION

The age range distribution is based on a mix of experienced personnel and young trainees. Even though older individuals may be of use because of their experience and skills, most people on the settlement are between 36 and 45 years old, because space missions require a certain level of physical and mental fitness. Young people are also necessary, as in a few years, with their acquired experience, they'll be great leaders of the settlement, guiding it to great success and progress.

5.c. EDUCATION SYSTEM

Vlad Dimulescu [5], Alex Paun [5]
[5] Social, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

An efficient education system is essential for the functionality and sustainability of the settlement, as the youth represents the future of our space colony. We believe that a well-rounded education system gives pupils the opportunity to find the field they are most capable in, while still having a good general knowledge that can be used in different situations on the base.

We developed an education system that's similar to the one in our country, Romania, teaching students subjects from all fields, while also focusing on the activity spheres most needed in our settlement.

INTRODUCTION

Our education system will be organized into the following age-based groups: Kindergarten for ages 3-6, primary school for ages 7-12, high school for ages 13-18, and university for ages 19-21 (which is mandatory).

In kindergarten and primary school, pupils will learn all subjects, helping them form a basic general knowledge and understand the key concepts of what they'll learn in high school.

In high school, students will have to choose a main field of study, such as Mathematics, Computer Science, Science, English, or Social Studies. However, they'll still learn a little from all subjects, to ensure a good understanding of every aspect of life.

University will be mandatory, assuring the expertise of our personnel in all fields of work.

TEACHING METHODS

The teaching methods are a mix between theory and practical experiments that'll help students understand theoretical concepts better. The academic year will have 2 semesters: the first semester begins in September and ends in February and the second semester starts in February and ends in June. A grading system with marks from 1 to 10 will be used to accurately establish a student's knowledge in a certain subject. Extracurricular activities are also encouraged, with academic and sports competitions taking place every year, rewarding the best students, and promoting excellence.

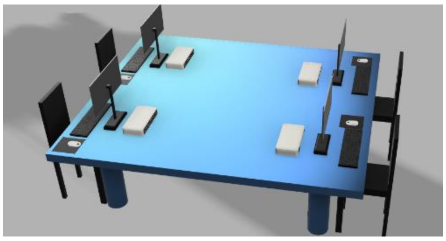


Figure 5.c.1. Lab Computers

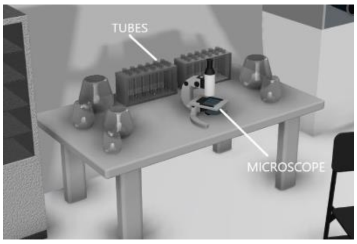


Figure 5.c.2. Lab Microscope

5.d. LEGISLATION

Hristoforos Koutsioukis [5]
[5] Social, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

- Project Nova is a space settlement with a governance structure divided into three branches: the Legislative Congress, the Executive Congress, and the Judicial Power.
- The Legislative Congress consists of two chambers, Space Legislative and Earth Legislative, elected by the members of the association living in space and on earth respectively.
- The Executive Congress is based in space and composed of three members elected by the members of the association living in space.
- The Judicial Power consists of judges, lawyers, and defenders responsible for interpreting and enforcing laws and defending the interests of the population.
- This separation of power is designed to provide a safe and balanced life for the citizens of Project Nova.

EXECUTIVE, LEGISLATIVE, AND JUDICIAL BODIES

An association named *Project Nova* will be formed before the departure of the settlement, composed of all the population (civils and professionals) in space and the members (only professionals) on Earth.

THE CART AND POWER SEPARATION

The constitution of the Space Settlement *Project Nova*, named 'The Cart', divides the government bodies into three branches which separate the power to provide safe and balanced life for the civils.

1. The Legislative Congress initializes, discusses, and approves laws according to the needs of civils.
2. The Executive Congress is mandated to ensure the administration activities, according to the laws.
3. The Judicial Power is mandated to enforce the laws approved by the Legislative Congress.

THE LEGISLATIVE CONGRESS

The members of the *Project Nova* Association, representatives of all participating countries, elect a Legislative Congress, consisting of two chambers, Space Legislative, and Earth Legislative. Each legislative chamber has 11 members. The members of the Space Legislative, based on the *Project Nova* Space Settlement, are elected by the members of the association who live in space. The members of the Earth Legislative are elected by the members of the association, who live on earth.

The legislative process takes place in two stages. In the case of a legislative proposal from members on Earth, Space Legislative has the final vote. The other way around, Earth Legislative has the final vote. If there is a parity of votes in one of the legislative chambers, the voting will repeat.

If following new debates, parity is repeated, the bill is removed from the discussion of the Legislative Congress. Also, if the number of abstentions in the chamber is greater than 50% of the number of members, the vote in that chamber shall be repeated. In the situation where, following new debates, the number of abstentions is maintained higher than 50%, the bill is removed from the discussion of the Legislative Congress.

THE EXECUTIVE CONGRESS

The Executive Congress is based in space. The members of the Executive Congress are elected exclusively by the members of the association who live in space. The Executive Congress has a number of 3 members, with a maximum term of 3 years.

JUDICIAL POWER

Juridical Power consists of judges, lawyers, and defenders of the Space Settlement. Judges interpret and apply the law. The lawyers represent and defend the population against the accusations brought to court. The defenders of the space settlement defend the interests of the entire population of *Project Nova*.

5.e. PSYCHOLOGY

Hristoforos Koutsioukis[5]

[5] Social, Vianu Research Center

Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

In order to keep citizens on the *Project Nova* Space settlement productive and in the best shape possible we have to take into consideration their mental health as much as their physical one. Before the departure all the soon to be citizens of the settlement will be evaluated to make sure they meet all the psychological requirements. Many studies have shown that mental state can be degraded by time in reference to changing environments, this is why mental health is a top priority for the *Project Nova*. Thus, well prepared psychologists and psychiatrists will be part of the crew on board. These professionals will be the foundation of our on-board mental health system.

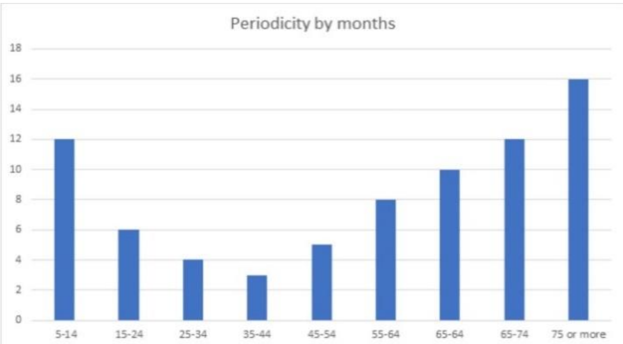
MENTAL HEALTH SYSTEM

Formed just like a normal hospital, the program will be led by 1 professional, with a term of 5 years, and chosen by all the activators in the field on the settlement. The role of the mental health system is to maintain the citizens' mental health and the best way of doing that is by periodic controls.

PROCEDURE FOR PROBLEMATIC PATIENTS

When a citizen fails to respect the laws of the settlement multiple times he or she will be introduced to a database of problematic citizens. The individual will then be monitored more closely and evaluated by a system with points.

Every mistake will be taken into consideration, given a grade of gravity (in points), and added to their point total. By the number of points, the person's mental health controls will increase and if a psychologist or a psychiatrist decides the person is a true threat to the community, the judges on board will take a decision.



PERIODIC MENTAL HEALTH CONTROL SCHEME

Periodic mental health control starts at the age of 5 and will never be skipped for the rest of the person's life, but it will vary in periodicity. The periodicity is determined by the level of stress (increased by the difficulty of the working field) and number of working hours rate for adults. School and College students' periodic mental health control periodicity is determined by study time.

5.f. ENTERTAINMENT

Hristoforos Koutsioukis[5]
[5] Social, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

Living in space shall not be only work and no fun. In order to keep our civils happy, we need to take into consideration the importance of fun activities. Out of all the ways an individual can have fun, by far the most beneficial is sport, this is why *Project Nova* will be equipped with all major sports courts and equipment. Although sports will be encouraged as a fun activity, there are many other ways to have fun.

SPORTS COURTS

The best way to maintain your health is by playing a sport, every court or field like basketball, soccer, volleyball, or American football one that doesn't take up too much space will be on the settlement, including training necessities. All the courts will be in the 2 central sections of the area.

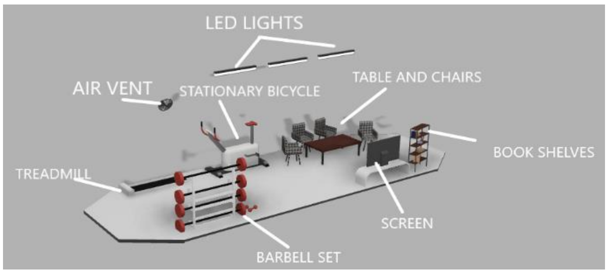


Figure 5.f.1. Recreational Module

THE CINEMA

The *Project Nova* cinema is like no other because it's not a 2D or 3D one, it's virtual reality! The cinema is equipped with high-end virtual reality headsets and motion chairs, with wind, water, and dust effects.

RECREATIONAL ACTIVITIES

There will be all sorts of recreational activities like yoga or cafés and restaurants. Residents will be encouraged to visit the artificial lakes and hills used to replicate earth in the large galleries. The outer torus will contain most of the floor area of the base, so plenty of green space is available for recreational observation.

What is more, we have designed special recreational modules in order to experience extreme sports in a low-gravity environment.

5.g. EARTH BASE COOPERATION

Vlad Dimulescu [5], **Alex Paun** [5]
[5] Social, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

ABSTRACT

Cooperating and communicating with the Earth Base is essential for our settlement, because, at least in the first phase, it will not be completely self-sustainable. Furthermore, our habitants will want to contact their family and friends back on Earth, so our base will need to provide a functional communication system.

RADIO COMMUNICATION

Our communication system will be based on X-band Radio Waves, and it will be similar to NASA's Deep Space Network. We estimate that the delay between the emitting and the receiving of the signals will be less than 2 seconds, making it almost ideal both for the scientists getting in contact with their colleagues back on Earth and for people that want to talk to their family.

6. VIABILITY

Mihai Priboi [6], Vlad Carasel [6], Andrei Ciobanu [6]
[6] Finance and Research, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

Keywords:
UN
GDP
USD/kg
Resource trading
Dark matter

ABSTRACT

Even though the goal of humanity is to evolve as a whole, discussing such a massive project is impracticable without considering its economic aspect. Hence, the necessity to secure funding arises, in order to sustain the proposed space settlement and the research missions that it will undertake.

In this paper we will discuss the total estimated cost for developing and maintaining such a project, as well as the research opportunities brought by colonizing space.

6.a. COSTS

Given that our project is of a global administration, funds will mainly come from members of the UN and private companies. This being said, each country's contribution will be proportional to its GDP. Therefore, an approximate amount around 0.05% of each country's GDP will be invested during the construction and launch phase (which, in the current economic state, reaches to a total of approximately 480 billion USD), followed by fixed annual taxes for maintenance purposes. Our aim is to build a mostly autonomous settlement, so the initial costs should represent a very high percentage of the investment.

Due to advancements in the reusability of rocket stages, the cost of sending 1kg into space has significantly decreased. The Saturn V rocket had an estimated cost of 5000 USD/kg, while newer SpaceX rockets have reached as low as 1400 USD/kg. However, it is important to note that the cost for transporting materials from Low Earth Orbit (LEO) to Mars point is estimated to be around 10 000 USD/kg. Nevertheless, the cost of materials used in building a settlement, such as aluminum and titanium, which are abundant and relatively cheap at 2.5 USD/kg and 20 USD/kg respectively, can be used to approximate the initial cost based on the settlement's mass.

Also, minerals and metals extracted by our missions will be traded for financial purposes. By doing this, we could try to balance the enormous investment done in the initial phase of our project and minimize the overall cost of sustaining such a space colony.

That being said, with the mass of the phase one settlement of 100 000 000 kg, we can estimate an initial cost of approximately 500bil USD, based on the transportation of the materials alone. This will be followed by additional costs for the next phases and maintenance, but because of the relatively lower cost and because of the resource trading, they can be overlooked.

6.b. RESEARCH OPPORTUNITIES

As we strive to establish a colony, it is crucial that we do not forget our ultimate goal as human beings: advancement and progress. Valuing and promoting scientific research and development on our settlement will be important in this endeavor. Regarding this aspect, our settlement could also serve as a stepping stone, such as a refueling station, for future space missions, enabling us to embark on longer journeys to even more remote destinations. With this in mind, traveling near asteroids abundant in minerals and materials, or close to interesting satellites, would be much easier and cheaper. The lunar base could also be utilized as a research center for the Moon, and the settlement itself could house a range of sensors and research equipment. Additionally, the station could serve as a launching pad for other space missions, as the delta v required would be minimal, due to the lack of atmosphere on the moon.

Moreover, a research subject of current and widespread interest in the science community, and especially to us, is dark matter, alongside its effects on normal matter. As more and more characteristics of black holes have already started being discovered, our remote research center will serve a great role in experimental projects. Working in outer space would mean a much-diminished impact in case of a malfunction (creating dark matter molecules, already accomplished at CERN, could at some point lead to a great implosion).

7. ANNEXES: PHYISICS CALCULUS FOR LAGRANGE POINTS DISTANCES

Vlad Carasel [2]
[2] Engineering, Vianu Research Center
Tudor Vianu National High School of Computer Science, Bucharest, Romania

Notations we use:

- M- Earth's mass
- M'-Moon's mass
- m- Our settlement's mass
- $\overrightarrow{r_M}, \overrightarrow{r_{M'}}, \overrightarrow{r_m}$ - Position vectors of the three objects relative to the center of mass between Earth and the Moon
- ω - Angular velocity, equal for each object.
- k- Newton's gravitational constant.

The center of mass condition:

$$M\overrightarrow{r_M} + M'\overrightarrow{r_{M'}} = \vec{0} \quad (1)$$

Mass M equilibrium condition:

$$-M\omega^2\overrightarrow{r_M} = \frac{-kMM'}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3}(\overrightarrow{r_M} - \overrightarrow{r_{M'}}) \quad (2)$$

Mass M' equilibrium condition:

$$-M'\omega^2\overrightarrow{r_{M'}} = \frac{-kMM'}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3}(\overrightarrow{r_M} - \overrightarrow{r_{M'}}) \quad (3)$$

Mass m equilibrium condition:

$$-m\omega^2\overrightarrow{r_m} = \frac{-kMm}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3}(\overrightarrow{r_M} - \overrightarrow{r_m}) + \frac{-kmM'}{|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|^3}(\overrightarrow{r_{M'}} - \overrightarrow{r_m}) \quad (4)$$

From (2) and (3):

$$-\omega^2\overrightarrow{r_M} = \frac{-kM'}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3}(\overrightarrow{r_M} - \overrightarrow{r_{M'}})$$

$$-\omega^2\overrightarrow{r_{M'}} = \frac{-kM}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3}(\overrightarrow{r_M} - \overrightarrow{r_{M'}})$$

By subtraction:

$$-\omega^2(\overrightarrow{r_M} - \overrightarrow{r_{M'}}) = \frac{-kM'}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3}(\overrightarrow{r_M} - \overrightarrow{r_{M'}}) - \frac{-kM}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3}(\overrightarrow{r_M} - \overrightarrow{r_{M'}})$$

By dividing on both sides:

$$\omega^2 = \frac{k(M+M')}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3} \quad (5)$$

From (4) and (5):

$$\vec{0} = \frac{kMm}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3}(\overrightarrow{r_M} - \overrightarrow{r_m}) + \frac{kM'm}{|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|^3}(\overrightarrow{r_{M'}} - \overrightarrow{r_m}) + \frac{km(M+M')}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3}\overrightarrow{r_m}$$

By dividing on both sides:

$$\vec{0} = \frac{M}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3}\overrightarrow{r_M} + \frac{M'}{|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|^3}\overrightarrow{r_{M'}} + \left[\frac{M+M'}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3} - \frac{M'}{|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|^3} - \frac{M}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3}\right]\overrightarrow{r_m}$$

There are two cases:

1. $\overrightarrow{r_M}, \overrightarrow{r_{M'}}, \overrightarrow{r_m}$ are not collinear.
2. $\overrightarrow{r_M}, \overrightarrow{r_{M'}}, \overrightarrow{r_m}$ are collinear.

- *Case 1:* The sum of two noncollinear vectors is 0, meaning that those two vectors are the null vector:

$$\frac{M}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3}\overrightarrow{r_M} + \frac{M'}{|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|^3}\overrightarrow{r_{M'}} = \vec{0} \quad (6)$$

$$\left[\frac{M+M'}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3} - \frac{M'}{|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|^3} - \frac{M}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3}\right]\overrightarrow{r_m} = \vec{0} \quad (7)$$

From (1) and (6):

$$\frac{M}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3}\overrightarrow{r_M} + \frac{M'}{|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|^3} * \frac{-M}{M'}\overrightarrow{r_M} = \vec{0}$$

$$\left[\frac{M}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3} - \frac{M}{|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|^3}\right]\overrightarrow{r_M} = \vec{0}$$

$$\frac{1}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3} - \frac{1}{|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|^3} = 0$$

$$|\overrightarrow{r_M} - \overrightarrow{r_m}| = |\overrightarrow{r_{M'}} - \overrightarrow{r_m}| = 0 \quad (8)$$

From (7):

$$\frac{M+M'}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3} - \frac{M'}{|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|^3} - \frac{M}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3} = 0$$

Considering (8):

$$\frac{M+M'}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3} = \frac{M+M'}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3}$$

$$|\overrightarrow{r_M} - \overrightarrow{r_{M'}}| = |\overrightarrow{r_M} - \overrightarrow{r_m}| = |\overrightarrow{r_{M'}} - \overrightarrow{r_m}|$$

Since $|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|$ is the distance from Earth to Moon, $|\overrightarrow{r_M} - \overrightarrow{r_m}|$ is the distance from Earth to m and $|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|$ is the distance from the Moon to m, the three masses describe an equilateral triangle. There are two positions that satisfy this condition, so we determined two of the Lagrangian points (L4 and L5).

- *Case 2:*

We will replace all the vectors with:

$$\vec{r} = \overrightarrow{r_M} - \overrightarrow{r_{M'}} \quad (9)$$
$$\overrightarrow{r_0} = \overrightarrow{r_m} - \overrightarrow{r_{M'}} \quad (10)$$

$$\vec{0} = \frac{M}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3}\overrightarrow{r_M} + \frac{M'}{|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|^3}\overrightarrow{r_{M'}} + \left[\frac{M+M'}{|\overrightarrow{r_M} - \overrightarrow{r_{M'}}|^3} - \frac{M'}{|\overrightarrow{r_{M'}} - \overrightarrow{r_m}|^3} - \frac{M}{|\overrightarrow{r_M} - \overrightarrow{r_m}|^3}\right]\overrightarrow{r_m}$$

$$\vec{0} = \frac{M}{|\vec{r} - \overrightarrow{r_0}|^3}(\vec{r} - \overrightarrow{r_0}) - \frac{M'}{|\overrightarrow{r_0}|^3}\overrightarrow{r_0} + \frac{M+M'}{|\vec{r}|^3}\overrightarrow{r_m}$$

We express $\overrightarrow{r_m}$ depending on $\vec{r}$, $\overrightarrow{r_0}$ and then we replace it in the equation. From (1) and (9):

$$\vec{r} = -\frac{M'}{M}\overrightarrow{r_{M'}} - \overrightarrow{r_{M'}}$$
$$\vec{r} = -\left(1 + \frac{M'}{M}\right)\overrightarrow{r_{M'}}$$
$$\overrightarrow{r_{M'}} = \frac{-M}{M+M'}\vec{r}$$

From (10):

$$\overrightarrow{r_m} = \overrightarrow{r_0} - \frac{M}{M+M'}\vec{r}$$

Replacing $\overrightarrow{r_m}$:

$$\vec{0} = \frac{M}{|\vec{r} - \overrightarrow{r_0}|^3}(\vec{r} - \overrightarrow{r_0}) - \frac{M'}{|\overrightarrow{r_0}|^3}\overrightarrow{r_0} + \frac{M+M'}{|\vec{r}|^3}\left(\overrightarrow{r_0} - \frac{M}{M+M'}\vec{r}\right)$$
$$\vec{0} = \frac{M}{|\vec{r} - \overrightarrow{r_0}|^3}\vec{r} - \frac{M+M'}{|\vec{r}|^3} * \frac{M}{M+M'}\vec{r} - \left(\frac{M}{|\vec{r} - \overrightarrow{r_0}|^3} + \frac{M'}{|\overrightarrow{r_0}|^3} - \frac{M+M'}{|\vec{r}|^3}\right)\overrightarrow{r_0}$$
$$\vec{0} = \left(\frac{M}{|\vec{r} - \overrightarrow{r_0}|^3} - \frac{M}{|\vec{r}|^3}\right)\vec{r} - \left(\frac{M}{|\vec{r} - \overrightarrow{r_0}|^3} + \frac{M'}{|\overrightarrow{r_0}|^3} - \frac{M+M'}{|\vec{r}|^3}\right)\overrightarrow{r_0}$$

We consider the notation:

$$e = \frac{M'}{M}$$
$$\overrightarrow{r_0} = x\vec{r}$$
$$\vec{0} = \left(\frac{1}{|\vec{r} - \overrightarrow{r_0}|^3} - \frac{1}{|\vec{r}|^3}\right)\vec{r} - \left(\frac{1}{|\vec{r} - \overrightarrow{r_0}|^3} + \frac{e}{|\overrightarrow{r_0}|^3} - \frac{1+e}{|\vec{r}|^3}\right)x\vec{r}$$

This reduces to:

$$0 = \frac{1}{|\vec{r} - x\vec{r}|^3} - \frac{1}{|\vec{r}|^3} - \left(\frac{1}{|\vec{r} - x\vec{r}|^3} + \frac{e}{|x\vec{r}|^3} - \frac{1+e}{|\vec{r}|^3}\right)x$$
$$0 = \frac{1}{|1-x|^3 r^3} - \frac{1}{r^3} - \left(\frac{1}{|1-x|^3 r^3} + \frac{e}{|x|^3 r^3} - \frac{1+e}{r^3}\right)x$$

By amplifying on both sides:

$$0 = \frac{1}{|1-x|^3} - 1 - \left(\frac{1}{|1-x|^3} + \frac{e}{|x|^3} + 1 + e\right)x$$
$$0 = x(e+1) - 1 - \frac{x-1}{|x-1|^3} - \frac{ex}{|x|^3}$$

Because of the moduli, we made a discussion about the signs:

	$-\infty$	0	1	$+\infty$
$x-1$	- - - - - - - - - - - - - -	- - - - - - - - -	0 + + + + + + + + + + + + + +	
x	- - - - - - - - - - - - - -	0 + + + + + + + +	+ + + + + + + + + + + + + +	

If $x \in (0,1)$, then:

$$|x-1| = 1 - x$$
$$|x| = x$$

So:

$$0 = x(e+1) - 1 + \frac{1}{(1-x)^2} - \frac{e}{x^2}$$
$$\frac{x^2}{(x-1)^2} = e + x^2 - x^3(1+e)$$

Since $x \in (0, 1)$, this is the equation for point L1. We continued the calculations in order to get an approximate value of the distance from Earth to L1. For this, we considered the function:

$f: \mathbb{R} \to \mathbb{R}, f(x) = \frac{x^2}{(x-1)^2}$

We also calculated:

$$f'(x) = \frac{2x(x-1)^2 - 2x^2(x-1)}{(x-1)^4} = \frac{-2x}{(x-1)^3}$$
$$f''(x) = \frac{2(1+2x)}{(x-1)^4}$$
$$f'''(x) = \frac{-12(x+1)}{(x-1)^5}$$

Using the Taylor series, we can approximate:

$$(x) \approx (0) + f'(0)x + \frac{f''(x)}{2!}x^2 + \frac{f'''(x)}{3!}x^3$$
$$(x) \approx 0 + 0 + \frac{2}{2}x^2 + 2x^3 = x^2 + 2x^3$$

But:

$$(x) = e + x^2 - x^3(1+e)$$
$$x^2 + 2x^3 = e + x^2 - x^3(1+e)$$

$$x = \sqrt[3]{\frac{e}{3-e}} \approx \sqrt[3]{\frac{e}{3}}$$

We made that approximation because λ = 0.0123. The distance from the Moon to L1 (r is the Earth – Moon distance):

$$d1 = xr = r\sqrt[3]{\frac{e}{3}} \approx 61{,}460 \text{ km}$$

The distance from the Earth:

$$D1 = 322.540\ km$$

Analogue for L2 and L3:

$$d2 \approx r\sqrt[3]{\frac{e}{3}} = 61{,}460\ km \qquad D2 = 445.460 \text{ km}$$

$$d3 \approx r\left(2 - \frac{7e}{12}\right) \approx 765{,}245\ km \qquad D3 = 381.245 \text{ km}$$

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