StellarDynamics Colony

Category: Space Colony Design Challenge 2025
Team Name: StellarDynamics
Team Members:
– Polina Kishko (Project Lead)
Institution: Ziyatker School, Shymkent, Kazakhstan
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Abstract

StellarDynamics Colony is a design of an autonomous space colony located within the Kuiper Belt. The project represents a sustainable habitat for 200,000 people that can live independently for over a century without resupply from Earth. The station's structure provides 20% of Earth's gravity through controlled rotation. It has comfortable living conditions. Life support systems are based on closed ecological cycles that recycle air, water, and organic waste. It is made by advanced technologies such as the Urine Processor Assembly 2.0, Algae Air Recycling Units, and BioSolar Purification Systems. The colony uses an electric sail propulsion system to travel efficiently through deep space. Although the design is hypothetical. It is grounded in scientific principles and technologies by NASA, ESA, and other space agencies. This project demonstrates how future human settlements beyond Neptune might achieve true autonomy and sustainability.

Project Structure

1. Colony Specifications

1.1 **Size and Shape:** Detailed design of your colony
1.2 **Population:** Between 100,000 and 300,000 people
1.3 **Location:** Within the Kuiper Belt
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2. Life Support Systems

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1. Colony Specifications

1.1 Size and Shape: Detailed design of your colony

The StellarDynamics Colony is designed as a rotating cylindrical station. It is located in the Kuiper Belt. The station's elongated shape provides structural stability during rotation, which generates artificial gravity for long-term human living..
The length of the colony is approximately 3 kilometers with a diameter of 500 meters. This proportion allows efficient internal zoning — separating residential, agricultural, and technical modules.

The cylindrical shape was chosen because it provides:

- ➢ Even distribution of rotational forces.
- ➢ Efficient use of internal volume.
- ➢ Possibility to create a stable artificial gravity environment by rotating around its longitudinal axis.

The outer shell consists of multiple protective layers made from aluminum alloys, carbon composites, and regolith shielding collected from asteroids. These layers protect inhabitants from micrometeorites and cosmic radiation.

Inside the colony, the design follows a multi-ring structure:

- ➢ The middle ring contains residential areas and green zones.
- ➢ The outer ring holds storage, docking ports, and external maintenance facilities.

To visualize the overall configuration, a schematic 3D model was created.
In the model: (Figure 1, Figure 2)

- ➢ The orange cylinder represents the main structural body of the station.
- ➢ The smaller blue cylinder inside indicates the residential module, where living quarters and public zones are located.
- ➢ The green cross-shaped lines illustrate the support framework connecting both cylinders and maintaining internal stability.

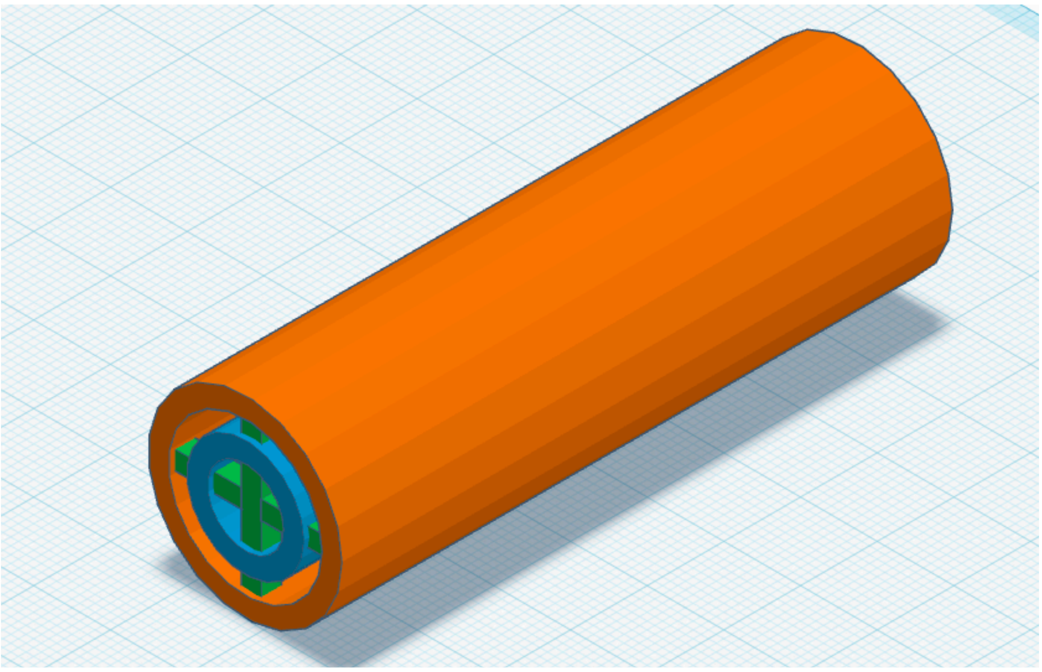

Figure 1. *Schematic 3D design of the StellarDynamics cylindrical colony.*

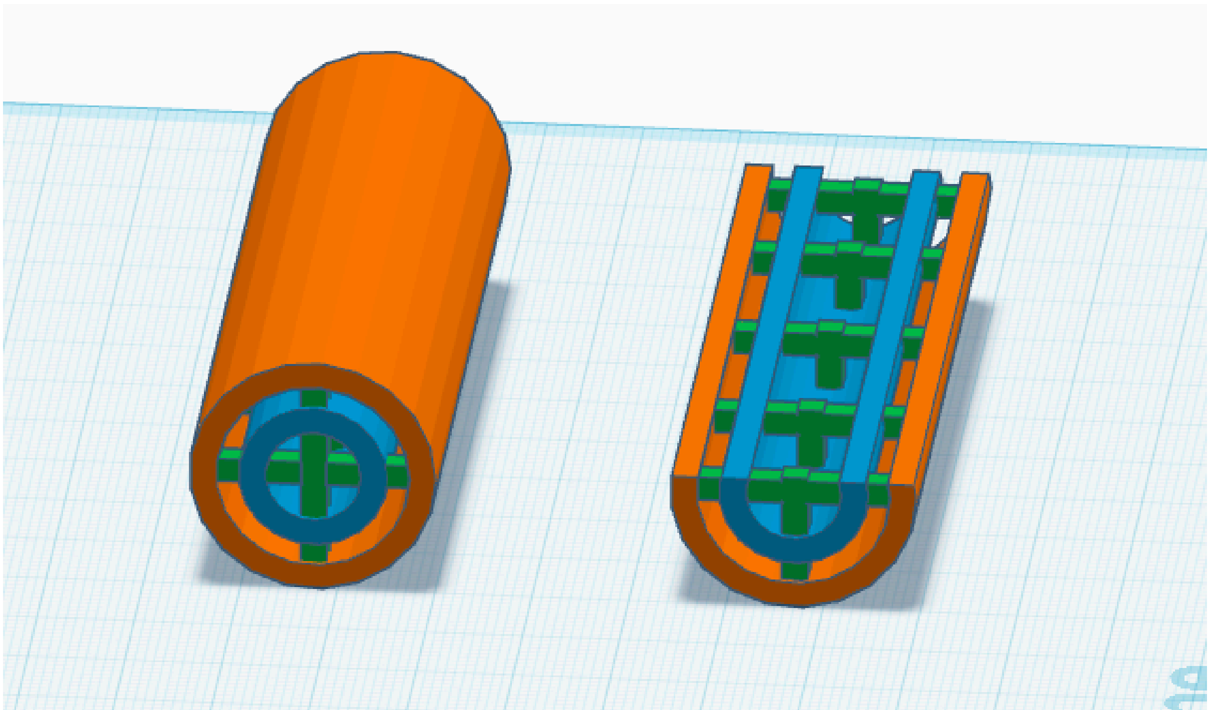

Figure 2. *Schematic 3D design in section, showing internal residential and support structures.*

This simplified colorful design allows a clear understanding of the colony's internal layout and its parts.

1.2 Population: Between 100,000 and 300,000 people

The StellarDynamics Colony is designed to support a stable population of approximately 200,000 inhabitants. This number represents an optimal balance between sustainability, social diversity, and technological manageability within the closed ecosystem of the station.
The population is divided into several key sectors: (Figure 3)

- 60% – civilians (families, educators, service workers, and scientists)
- 25% – technical and engineering personnel
- 10% – medical and life support specialists
- 5% – administrative and command staff

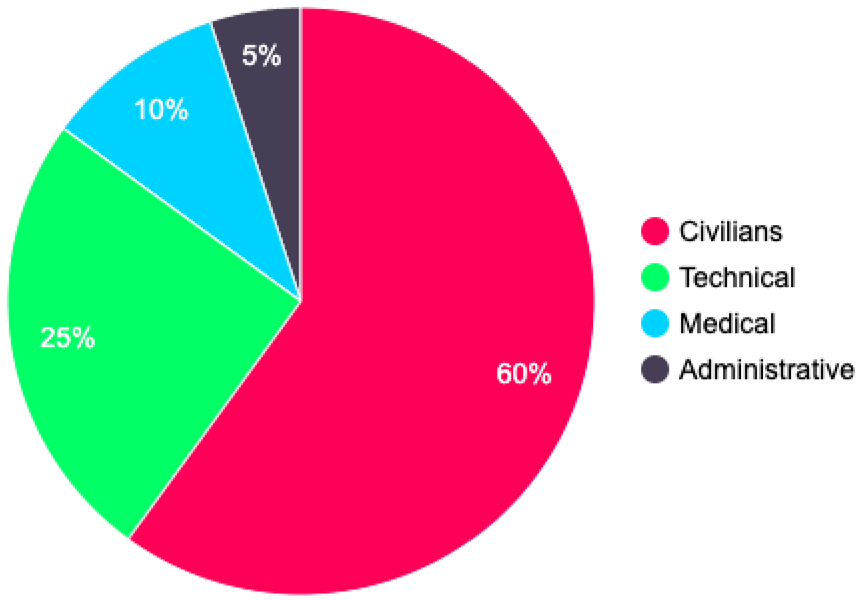

***Figure 3**. Population distribution*

Such distribution ensures that every aspect of life — from education and healthcare to maintenance and research — can function independently for centuries without external assistance from Earth.
Each resident is provided with an average of 30 square meters of living space, including shared areas, workplaces, and public facilities. This density maintains comfort while minimizing the energy required for lighting, temperature control, and oxygen circulation.
Population growth is strictly monitored through a controlled demographic policy to keep the total number of inhabitants below the ecological carrying capacity of the life support system. Artificial intelligence algorithms assist in managing population dynamics by forecasting long-term resource availability and habitat sustainability.
The colony's societal model follows a cooperative structure, encouraging collaboration, education, and scientific development as key cultural values. This approach supports long-term psychological stability and community resilience in deep-space conditions.

1.3 Location: Within the Kuiper Belt

Our colony is located in the Kuiper Belt (Figure 4). It is approximately 30–50 AU from the Sun.
This distant region after Neptune's orbit has numerous asteroids and icy bodies, which can serve as valuable resources. The ice found there can be processed into water and oxygen for life support systems.
The stable orbit within this area provides both safety from dense asteroid fields and an excellent position for future deep-space missions. Being far from major planets also reduces the risk of strong gravitational disturbances.

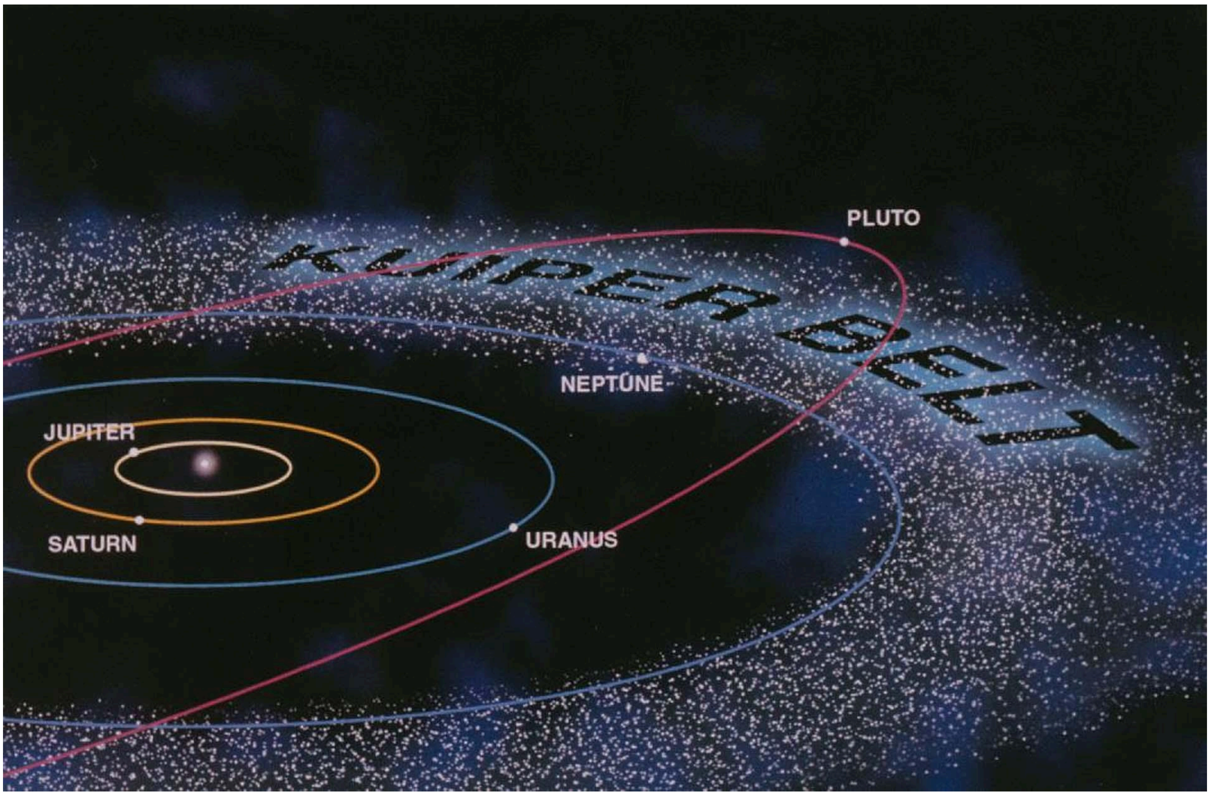

Figure 4. *The Kuiper Belt*

1.4 Technologies: Innovations with scientific evidence

1.4.1 Propulsion System

To keep our station moving for a long time, I looked at different engines like chemical, ion, and nuclear.
All of them have some problems. Chemical engines need too much fuel. Ion engines use a lot of power. And nuclear are dangerous for people because of radiation.
Because of that, I decided to use an electric sail (E-sail). (Figure 5) It works with very long wires that have an electric charge. These wires push against the solar wind, which is a stream of small particles from the Sun.
When the particles hit the charged wires, it makes a small constant force that moves the station.
This system does not need fuel and can work for many decades. So it is perfect for traveling and staying in the Kuiper Belt for a long time.

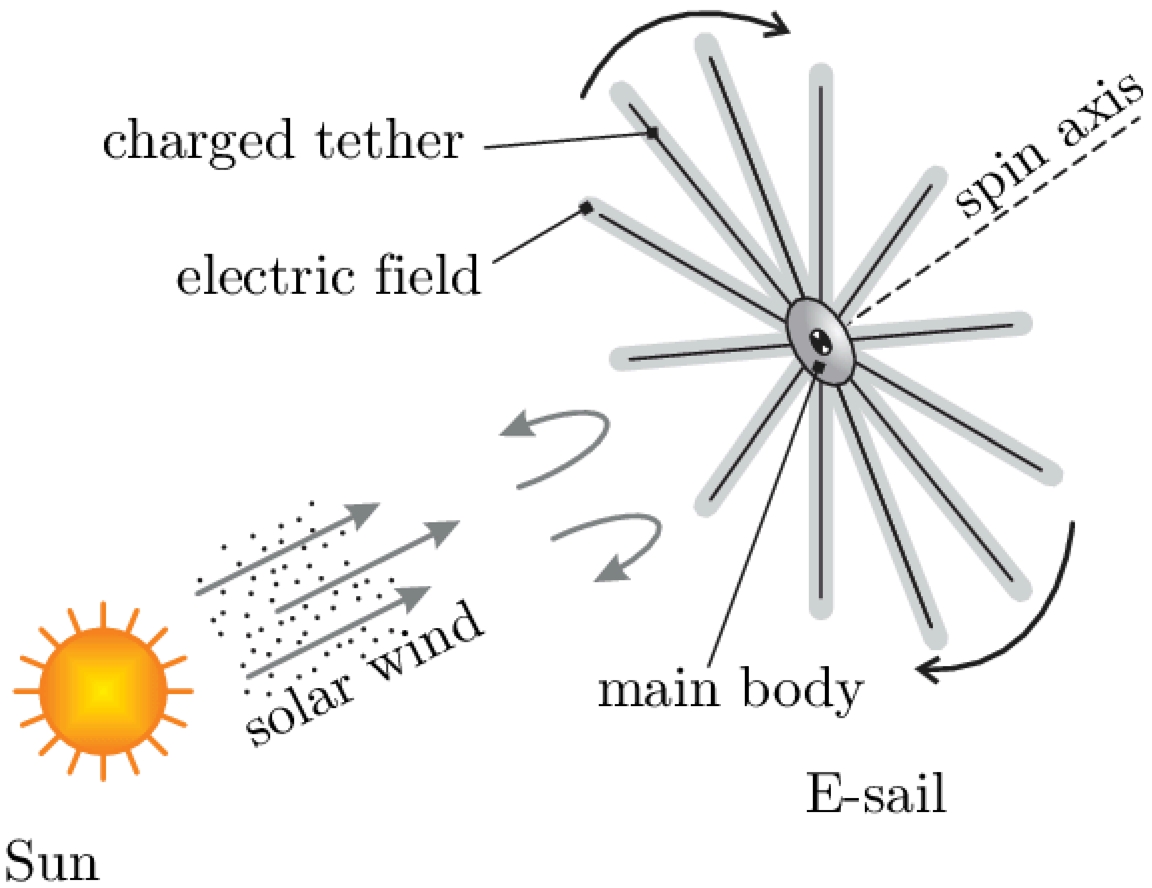

Figure 5. *Electric Sail Propulsion Concept*

1.4.2 Energy System

To keep all systems of the station working for more than 100 years, I need a reliable and long-lasting source of energy. Using solar panels is not a good option in our case. The station is located in a region with many asteroids, and because of that, the panels would often stay in shadow or get damaged by micrometeorites and small debris. This would make the power unstable and unsafe for a long-term mission.

Because of this, I chose nuclear reactors as the main energy source. They can produce a constant amount of power and do not depend on sunlight or other external conditions. The reactors use thorium or uranium fuel with a slow decay rate, which allows each of them to work for many years without refueling. The heat that comes from the reactor is also reused in the thermal system of the station — for heating water and living areas.

According to our calculations (Figure 5), the station needs nine reactors with a power of 150 MW each, and one extra reactor will be kept as a backup (total = 10). This number gives enough energy for all life support systems, engines, laboratories, and emergency situations. The system works in rotation — some reactors stay active, while others can be serviced or turned off to reduce wear and overheating.

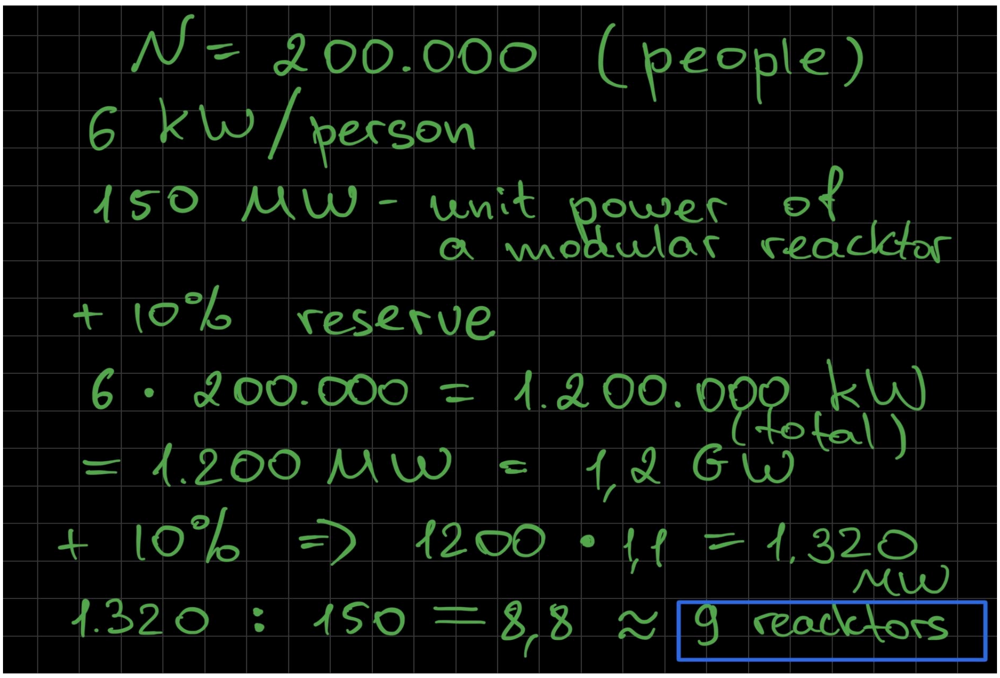

Figure 6. *Handwritten power calculations for StellarDynamics Station (author: Polina Kishko)*

All produced electricity goes to the main distribution network of the station. From there, it is sent to different modules depending on their needs. Extra energy is stored in capacitor units and ion batteries to provide power when the reactors are off or during short-term malfunctions. This design makes the system safe, independent, and ready for very long missions far from Earth.

2. Life Support Systems

2.1 Life Support: Air, water, and other necessities systems

Read descriptions below the table.

Technology Name	Purpose	How It Works	Source
Urine Processor Assembly (UPA) 2.0	Recycles urine and humidity condensate on the space station, returning clean water into the system.	Uses vacuum distillation, vapor compression, and filtration to extract water from urine and other liquid waste. (ntrs.nasa.gov)	https://ntrs.nasa.gov/api/citations/20205005454/downloads/ICES%202020-391%20--%20UPA%20Upgrades%20-%20FINAL.pdf
BioSolar Purification Systems	Purifies water (and/or air) using solar energy combined with biological or photocatalytic processes — suitable for closed-loop systems.	Uses sunlight with photocatalysis (e.g., TiO_2) or microalgae/biomembranes to break down pollutants and clean the water.	https://research.princeton.edu/news/low-cost-solar-powered-water-filter-removes-lead-other-contaminants
Closed Ecological Systems (CES) (e.g., MELiSSA Project)	Creates a nearly closed life-support system: recycling water, air, and waste, while producing food.	Modular combination of bioreactors, photosynthetic plants, and microorganisms to filter, oxidize, and recycle waste into clean water, oxygen, and food. (ESA)	https://webs.uab.cat/melissapilotplant/wp-content/uploads/sites/397/2023/11/Melissa_The_European_project_of_a_closed_life_supp-1.pdf
Algae Air Recycling Units	Air purification — reducing CO_2 and increasing O_2 to maintain breathable atmosphere inside the colony.	Uses photobioreactors filled with microalgae (e.g., *Chlorella*), through which air is circulated. The algae absorb CO_2 and release O_2. (University of Kentucky Research)	https://ntrs.nasa.gov/api/citations/19980218872/downloads/19980218872.pdf
Anaerobic Bioreactors	Processes organic waste (solid or liquid) into methane, water, and useful minerals in a closed environment.	Anaerobic digestion of organic matter (human waste, plants) produces methane, biogas, water, and minerals. Membrane bioreactors (AnMBR) are used. (syborgs.mae.ufl.edu)	https://syborgs.mae.ufl.edu/media/syborgsmaeufledu/syborgs-papers/ICES-2020-498.pdf

Table 1. *Main life-support technologies used in the Stellar Dynamics Colony*

To maintain stable living conditions inside the colony, several advanced systems are required to recycle water, air, and waste. Most of these technologies are based on real prototypes tested by NASA and ESA for long-term missions. The following table (Table 1) summarizes the main systems we plan to use on Stellar Dynamics Colony, their purpose, working principles, and scientific references.

2.2 Biodiversity: At least 7 plant species required

To create a self-sustaining ecosystem, the colony will include a variety of plants that can provide food, oxygen, and psychological comfort. At least seven species (Table 2) will be cultivated to maintain both human health and the environmental balance. These species were selected for their nutritional value, growth efficiency, and ability to recycle carbon dioxide into oxygen.

As shown in Table 2, leafy vegetables such as lettuce and spinach will provide essential vitamins, while soybeans and wheat will serve as the main sources of protein and carbohydrates. Tomatoes and strawberries will not only add nutritional diversity but also help colonists feel more connected to natural colors and tastes. Finally, microalgae like Chlorella will support oxygen production and act as a dietary supplement.

Together, these plants will form the biological foundation of the colony's life-support system, making it more independent from external supplies and ensuring long-term sustainability.

Plant Species	Function in the Colony	Growth Method	Additional Notes
Lettuce (Lactuca sativa)	Source of vitamins A and K	Hydroponics	Fast growth, used in daily meals
Spinach (Spinacia oleracea)	Iron and folic acid	Hydroponics	Helps maintain muscle and blood health
Soybean (Glycine max)	Protein and oil production	Aeroponics	Can replace meat-based protein
Wheat (Triticum aestivum)	Carbohydrates and fiber	Hydroponics	Used for bread and nutrition bars
Tomato (Solanum lycopersicum)	Vitamins C and antioxidants	Hydroponics	Adds color and improves psychological comfort
Strawberry (Fragaria × ananassa)	Natural sugars and vitamin C	Hydroponics	Supports morale and provides variety
Chlorella (microalgae)	Oxygen generation and CO_2 absorption	Photobioreactor	Also used as dietary supplement

Table 2. *Sustainable Food Systems on the Space Station*

2.3 Artificial Gravity: Within 20% of Earth's gravity

Artificial gravity is essential for maintaining the physical and mental health of crew members during long-term space missions. In microgravity, humans experience muscle atrophy, bone density loss, and fluid redistribution, all of which can severely affect health and performance. To overcome these effects, our spacecraft is designed to generate artificial gravity through controlled rotation.

The station is designed to provide approximately 0.2 g (20% of Earth gravity) by rotation. (Figure 6) Using the chosen angular velocity of ω = 0.177 rad/s, the required radius for this level of artificial gravity is about 62.6 m, which gives a rotation period of ≈ 35.5 s (≈1.69 rpm) and a tangential speed of ≈ 11.08 m/s (≈39.9 km/h) at the outer living ring. These parameters balance physiological needs (reduced bone/muscle loss) with structural and comfort considerations.

$$g = 20\% \text{ of } 9{,}8 \ (m/s^2)$$

$$g \approx 9{,}8 \cdot 0{,}2 = 1{,}9 \ (m/s^2)$$

$$\omega = 0{,}177 \ (rad/s)$$

$$\omega^2 = 0{,}031329 \ (rad^2/s^2)$$

$$r = \frac{a}{\omega^2} = \frac{1{,}96}{0{,}03} \approx 62{,}6 \ (m)$$

$$T = \frac{2\pi}{\omega} \approx \frac{6{,}3}{0{,}177} \approx 35{,}5 \ (s)$$

$$v = \omega r = 0{,}177 \cdot 62{,}6 \approx 11 \ (m/s)$$

$$rpm = \frac{\omega \cdot 60}{2\pi} = \frac{0{,}177 \cdot 60}{6{,}3} \approx 1{,}7 \ (rpm)$$

Figure 7. Handwritten artificial gravity calculations for StellarDynamics Station (author: Polina Kishko)

To ensure stable rotation, the system incorporates gyroscopic stabilizers and reaction wheels that maintain a constant angular velocity and prevent oscillations or unwanted wobbling. These mechanisms also allow the spacecraft to move forward through space while

continuously spinning. Once rotation is initiated, the system requires minimal additional energy input, making it both efficient and reliable.
Overall, this method provides a sustainable and low-maintenance way to simulate gravity, ensuring crew well-being and operational stability throughout long-duration missions.

2.4 Modules: Residential, power, and integration systems

The StellarDynamics space colony is divided into several main modules (Figure 7), each responsible for specific functions that ensure stable and comfortable life for 200,000 residents. Every module is designed with efficiency, safety, and accessibility in mind.
The largest section is the Residential Module, which takes up about 30% of the total area and includes personal living spaces and small community rooms. The Agricultural Module (ARGO) occupies around 18%, serving as the main zone for growing plants and producing oxygen and food. The School and Kindergarten section takes 12%, allowing children to study and grow in a normal environment even far from Earth.
Other essential zones include the Common Module (10%) for social interaction and relaxation, the Laboratory (8%) for research and development, and the Gym (6%) for maintaining physical health. Smaller but critical areas include the Command Center (4%), Kitchen (4%), Storage (6%), and Technical Section (2%) for maintenance and repair.
Such proportional design helps to keep a good balance between human needs, research goals, and the technological infrastructure required for long-term survival in space.

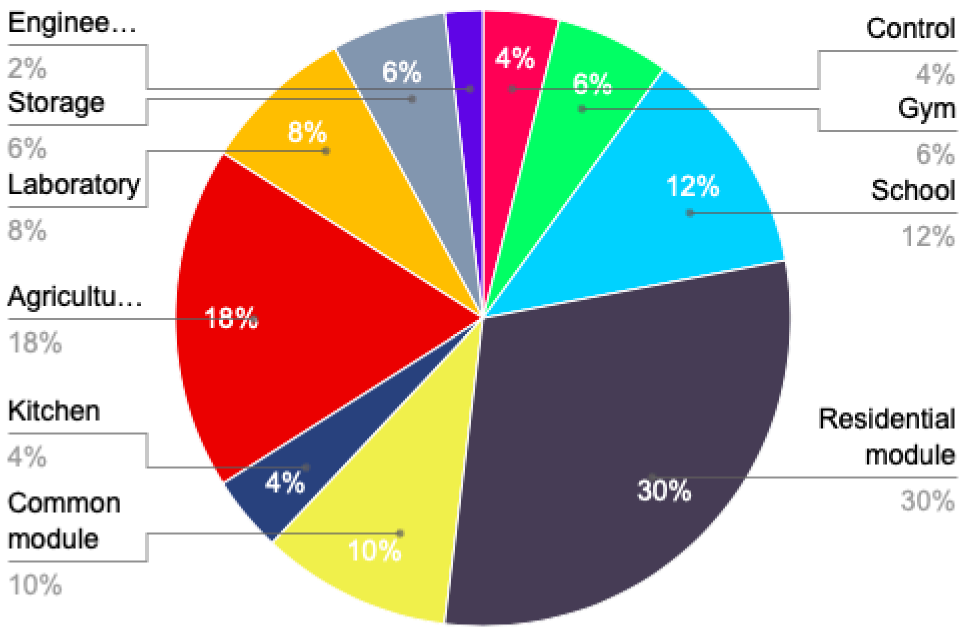

Figure 8. *Area distribution of StellarDynamics colony modules*

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3.2 Figures and Visual Sources

- **3D model (Figure 1, Figure 2)** https://www.tinkercad.com/things/3OGd1gy0Fwh-stellardynamics?sharecode=IO3fa2rC5NxX22m13yQIwA18vg3MM9s8thbNtuwokyk