SPACE STATION DESIGN: IN ROTATION

Queen Mary University of London

EMS690U- Integrated Design Project

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Front End Report

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DECLARATION

This report entitled

Space Station Design: In Rotation

Was composed by me and is based on my own work. Where the work of the others has been used, it is fully acknowledged in the text and in captions to table illustrations. This report has not been submitted for any other qualification.

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Signed:

Date: *07-12-2024*

Abstract

This project outlines the process in which the Structural Design Systems (SDS) of a rotating space station is designed to reduce the effects of long-term habitation in microgravity has on the human body. As the ISS's life span slowly ends and countries such as Russia start to investigate launching their own stations for human occupation for both government and commercial uses, design concepts such as a rotation space station become more feasible as time goes on. With this new motivation the design concept for a rotating space station is proposed by research group Ad Astra Per Aspera (ASPA). This paper goes into detail of the initial structural design systems for a 446m diameter, 4 rings design that generates earth-like gravity through centrifugal force. Comprehensive background data, CAD models and plans for future work are used demonstrate the potential for creating advanced space habitats for humans for prolonged periods of time.

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1. Introduction

The human body faces immense physiological challenges when exposed to microgravity for prolonged periods of time, such as muscle atrophy, bone density loss and cardiovascular de-conditioning.(1) To reduce these effects research group, Ad Astra Per Aspera (ASPA), proposes the idea of a space station that would generate centrifugal force by rotating around its central axis. When looking into creating a design for a space station there are several components that must taking into consideration.

ASPA are currently researching into the following systems:

- Attitude and Orbital Determination (AOD) (Emmanuel E Airiofolo)
- Shielding and Protection Systems (SPS) (Abaas Nunow)
- Life Support Systems (LSS) (Ilanthiraiyan Sivagnanamoorthy)
- Electrical and Power Systems (EPS) (Yesung Baek)
- Structural Design System (SDS) (Wania Farooq)

This paper focuses on the structural design concept and the feasibility of such designs.

ASPA's station design concept is a rotating space station that has multiple modules under gravity where astronauts can take a break from the microgravity conditions essential for experiments and in-space missions. The main aim of this station is to provide astronauts earth equivalent living conditions to reduce the effects that long term habitation in microgravity can cause. To do so this paper proposes a design with four rings:

1. The innermost ring that is under microgravity conditions (stationary)
2. The second ring that acts as a support system and bridge between the innermost ring and the two outer rings (stationary).
3. The upper outer ring will rotate clockwise.
4. The bottom outer ring will rotate anti clockwise.

The rotation of the two outer rings will produce the gyroscopic stability affect and makes sure that the rotation does not cause disturbance to the microgravity(stationary) central rings. See to Figure 11 for reference.

Some of the factors that the design must include are a large enough radius to generate the desired artificial gravity while also having enough structural integrity to withstand the stress es caused by rotation. This report outlines the initial process in which structural integrity, material selection and operation feasibility through research and design development.

2. Background

There have been multiple rotating space station concepts proposed throughout the years. One of the first designs, in 1929, was proposed by a German rocket scientist in his spaceflight dissertation.(2) The Von Braun space station concept was proposed in 1952 in a magazine as a 76m wheel made of nylon that would house 80 people.(3) The Stanford Torus in 1975, a study by Stanford university led by NASA, had the aim of housing 10,000 people on the station. (4) A proposal in the 1980’s for a wheel shaped station by Hughes Aircraft was referenced by NASA in their research that led to the development of the International Space Station (ISS). (5)

Current ‘long-term habitation’ occurs is stations such as the Intenational Space Station (ISS) and China's Tiangong Space Station (TSS). Both stations have hosted humans for just over a year with record holders Mark Vande Hei (USA) and Pyotr Dubrov (RUS) staying on the ISS from April 9, 2021, to March 30, 2022.(354 days, 14 hours, and 56 minutes).(6) And Oleg Kononenko (RUS) and Nikolai Chub (RUS) stayed on the TSS from September 2023 to September 2024 (374 days).(7)

With the ISS slowly coming to its end of life there are multiple new station in the plans to launch in the future. VAST’s Haven-1 is set to launch in 2025 with the crew capacity of four (8) while some are still in the pans. Examples include the Axiom Space Station, Blue Origin's Orbital Reef, Nanoracks' Starlab, and Northrop Grumman's HALO. (9) With the interest in sending humans to space for longer missions and experiments the issues with long term exposure to microgravity becomes a major factor to consider when developing space station designs. Reports such as ‘Review of space habitat designs for long term space explorations’ by Texas A&M University students U. Chen, R. Goyal, M. Majji, R. E. Skelton support the idea having rotating space stations as a reasonable solution to long term habitation if ‘the five fundamental problems in long term space exploration’ are addressed in the design.(10)

3. Design Considerations

3.1. Centrifugal Force Facts and Figures

For the station to generate an earth like gravity, AOD (Emannuel E Airlofolo) discovered that the diameter of the outermost ring would have to be 446 meters (about four times the height of the Statue of Liberty). With a radius of 223 metres, the outer rings will have to rotate 0.2094 rads per second at 42.2 m/s to generate the desired gravitational pull.

3.2. Benefits of a Large Semi-rotating Station

- Artificial gravity ideal for human comfort and health
- Expansive surface area for international collaboration
- Large docking space means higher expansion potential
- Increased research capabilities
- Operation efficiency

3.3. Challenges Faced in the Structural Design Process

- Figuring out the mechatronics of the spinning outer wheels.
- Designing transportation method to get from the rotating rings to the non-rotating rings and vice versa.
- Ensuring the structure can withstand the stress from rotation and external forces such as micrometeoroid impacts.
- Addressing the psychological and physical health of the astronauts.
- Designing modular parts for easier assembly.
- Including multiple docking port systems.

4. Initial Design Ideas

4.1. Orientation

ASPA's design concept was developed once the orientation of the station was decided on. Figure 1 shows the station as a ring facing the earth horizontally. With the station facing the earth at this angle it enables the windows that are on the modules, experiencing artificial gravity, to be found on the walls, in oppose to the floor when orbiting at the angle shown in Figure 2. With the rings parallel to the earth surface the bottom modules will have constant view of the earth while in orbit. The upper rotating ring will have constant view of space while in orbit.

The benefits of earth parallel orientation for rotating habitation modules include:

- **Reduced disorientation-**
  Parallel orientation provides stable visual reference which helps to maintain spatial orientation and reduced the risk of the Coriolis effect on astronauts. (11)
- **Psychological comfort-**
  Constant view of earth provides astronauts psychological comfort by reducing feelings of isolation and stress by reminding them of their home planet. This particularly important in long term habitation cases. (12)
- **Improved task performance-**
  With a stable visual environment astronauts are less likely to experience dizziness, allowing them to perform task efficiently. (13)

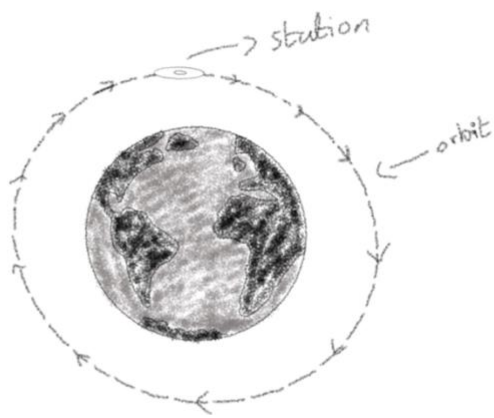

Figure 1: Parallel Station Orientation Design Sketch

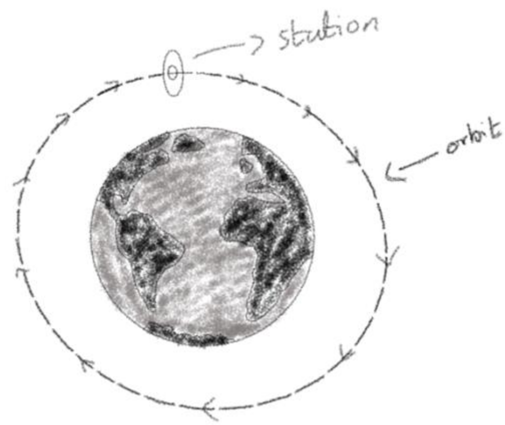

Figure 2: Perpendicular Station Orientation Design Sketch

4.2. Rotation Mechanism Selection

There are multiple ways in which the station can be rotated around its axis. As shown in Figure 3 and Figure 4 the initial idea was to use ball bearing or wheels to spin the outer ring. Table 1 depicts the pros and cons of both wheels and ball bearings. To determine which of the two options will be used in the final design of the station further experiments through Finite Elements Analysis (FEA) will be done to help analyse the contact stresses, bearing loads, and wear characteristics of wheels and ball bearings to compare the results.

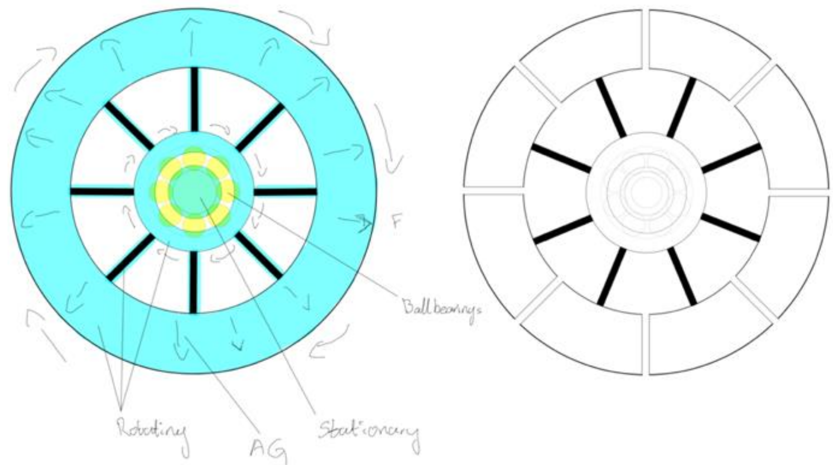

Figure 3: First Sketch of the Station Concept

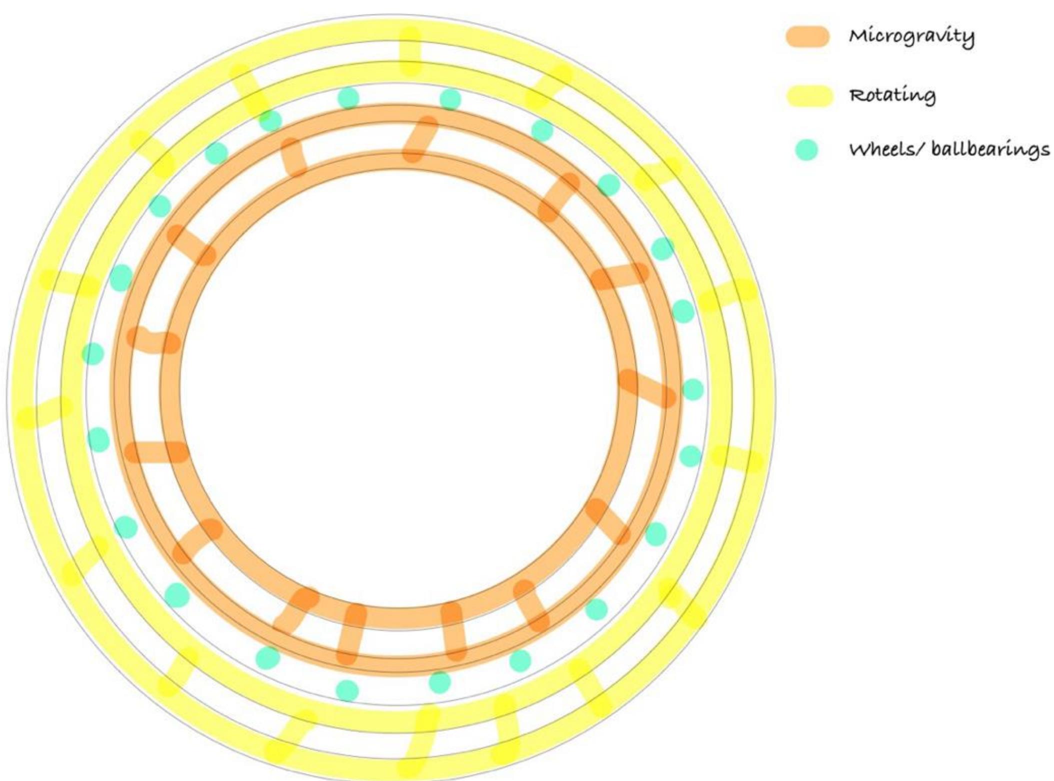

Figure 4: Second Sketch of the Station Concept

	Advantages	Disadvantages
Wheels	• Robust support • Structural integrity • Shock Absorption • Consistent rotation • Mechanical simplicity	• Higher friction • Regular maintenance due to wear and tear • Size and weight • Complex instillation
Ball bearings	• Low friction • High speed capacity • Compact design • Ease of replacements	• Lower load capacity • Sensitivity to shock loads • Noise

Table 1: Pros And Cons of Wheels and Ball Bearings

4.3. Habitation Modules Under Artificial Gravity

The Net Habitation Volume (NHV) required for long term habitation in space was researched into by NASA's Chief Scientist C. Stromgren, Lead of the Mars Integration Group M. Rucker, Senior Analyst C. Burke, Aerospace Engineer J. Cho, and Junior Operation Research Analyst R. Calderon. Outlined in their report "Defining the Required Net Habitable Volume for Long-Duration Exploration Missions" it was concluded that in microgravity conditions that the minimum NHV needed per astronaut is $37m^{3}$. (14)

Given that the outer rings of the station will be experiencing earth like gravity, less wall space is used than when experiencing microgravity, it was assumed that the NHV would be greater in this station. When designing the habitation modules and calculating the circumference by diameter ratio it was concluded that the habitation modules could have enough space to fit a three-story house and not affect the space needed for microgravity labs on the station. Figure 6 shows the initial sketch of a habitation module, Figure 7 depicts having a cuboid living space within the habitation module to provide flat surfaces to build the habitat in and the space between the outer walls to act as a buffer in case of collision as the vacuum provides extra protection. (15) Figure 8 depicts the measurements of each level if split into three floors. With these measurements the overall habitable volume of a single module is $8{,}550m^{3}$.

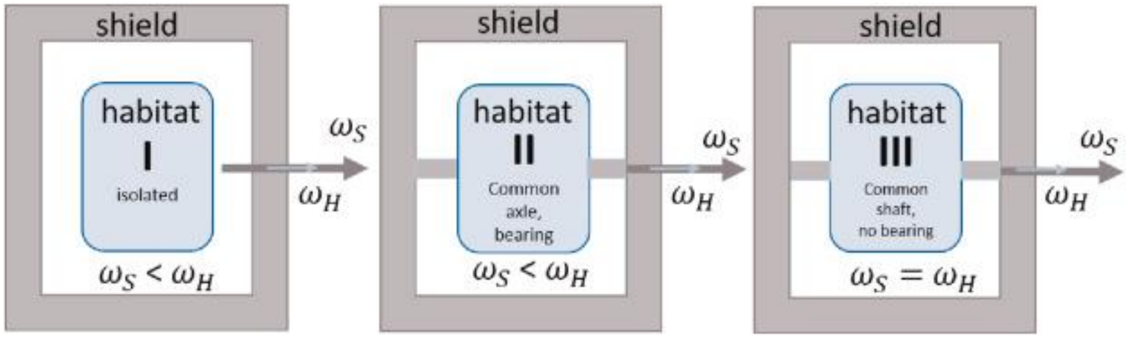

Figure 5: The space between the shield and the habitat is a vacuum working as a buffer in case of collision. (15)

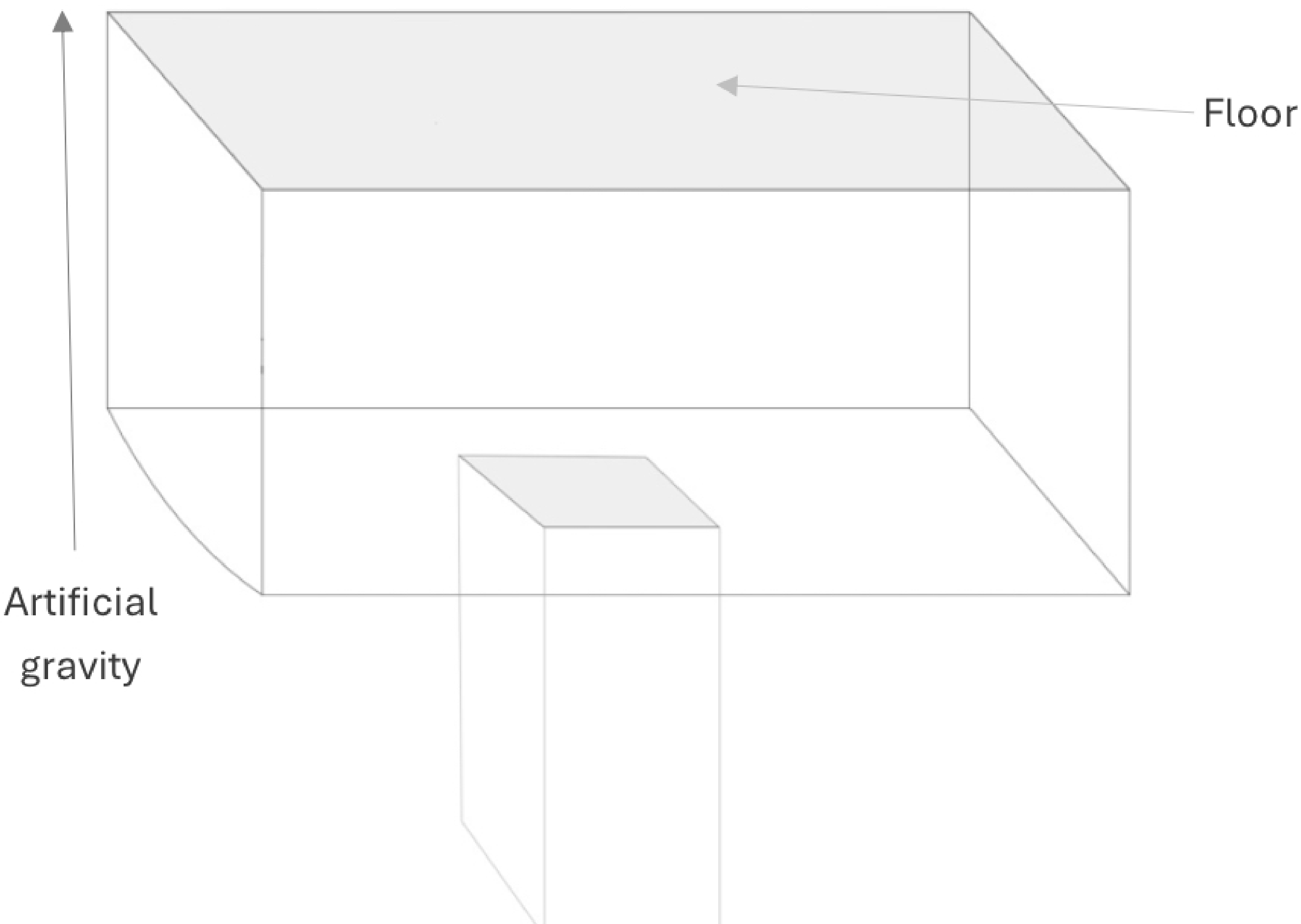

Figure 6: Habitation Module Sketch

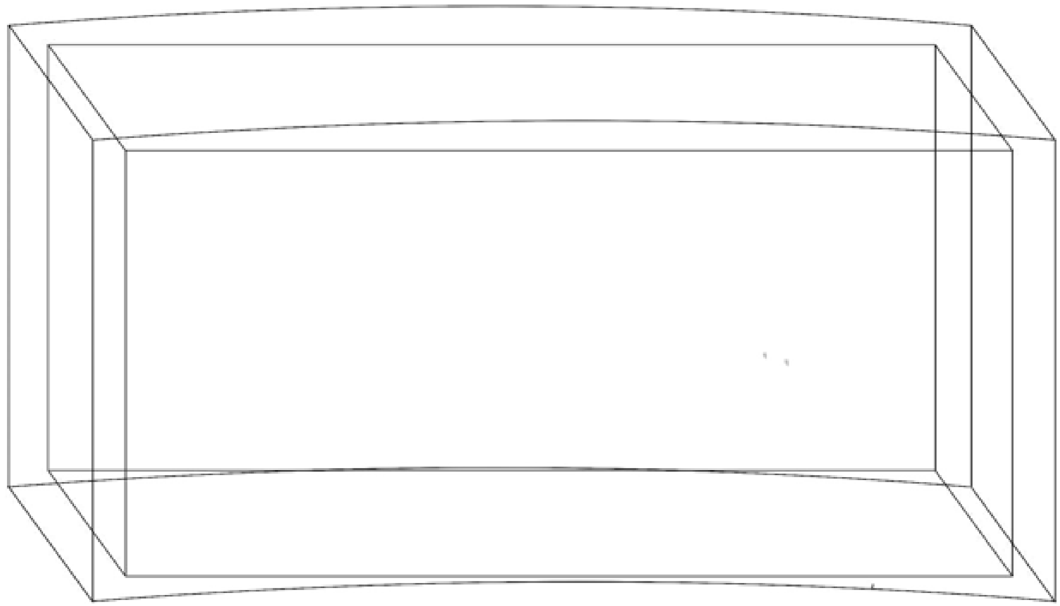

Figure 7: Sketch of the Pressurised Habitat and Shielding Space within the Habitation Module

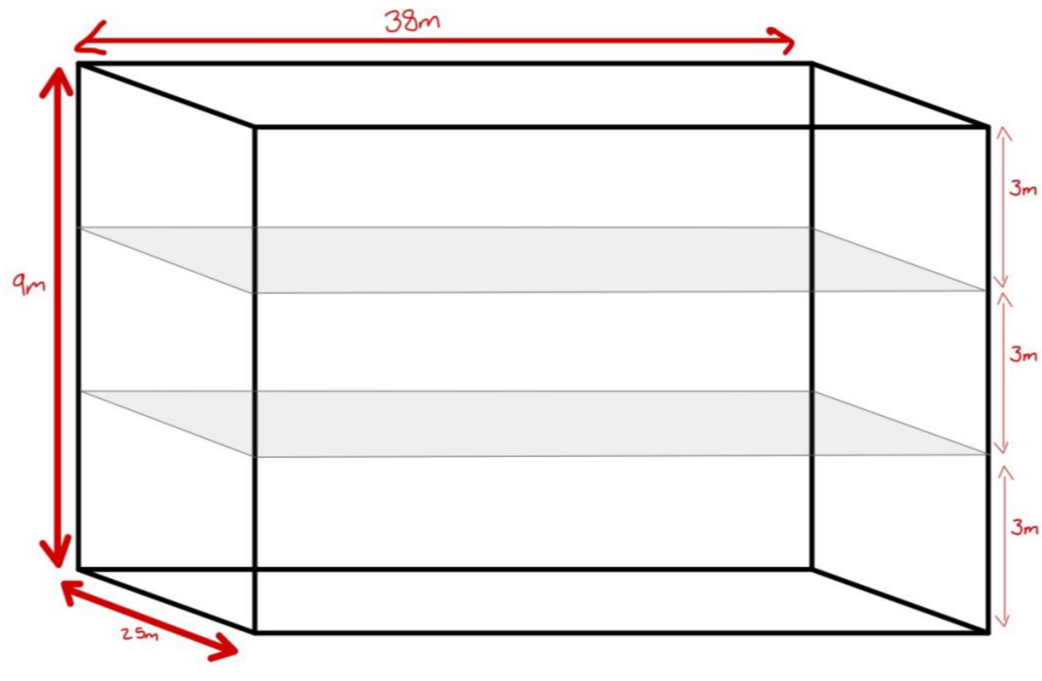

Figure 8: Example Sketch of Pressurised Floors in Habitation Modules

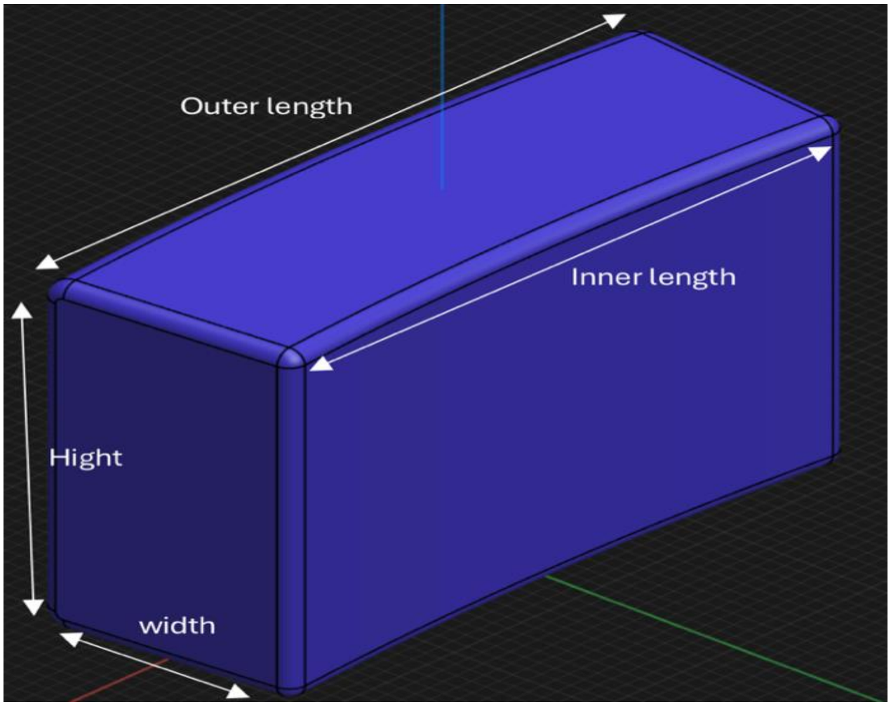

Figure 9: CAD Design of Habitation Module Shell

Habitation Module Shell Under AG	
Hight (m)	27
Width (m)	16
Inner Length	40.6444
Outer Length	43.7859
Surface Area (m^2)	4,327.5469
Volume (m^3)	18,141.8729

Table 2: Dimensions Habitation Module Shell Under Artificial Gravity

Future work for the development of the habitation modules include:

- Incorporating the Shielding and Protection Systems to the design
- Developing an example floor plan
- Adding airlocks
- Adding the lift mechanisms for easier exit/entry
- Adding storage space
- Selecting materials for optimal structural integrity.

4.5. Truss Structures

Truss structures provide structural integrity and are used to connect the rings together as well as attach the habitation modules to the station. Using truss structures are beneficial as they use up less material compared to other structures and allow for a more modular design. Having a modular structure means that both the construction and maintenance processes are easier. The flexibility of truss structures is an especially important factor when designing the rings of this station.

Figure 10 shows the triangular shaped truss structure sketch proposed for the station. The use of triangular shapes promote stability, efficient load distribution, strength and rigidity al while simplifying the structural design. (16) Figure 11 depicts the initial CAD of the truss structure of an outer ring. The design is not yet complete but with the final truss CAD a Finite Element Analysis (FEA) will be done do compare the potential or other shaped trusses in comparison to triangular truss. FEA will also be used to determine the best material depending on the stress, strain and displacement results.

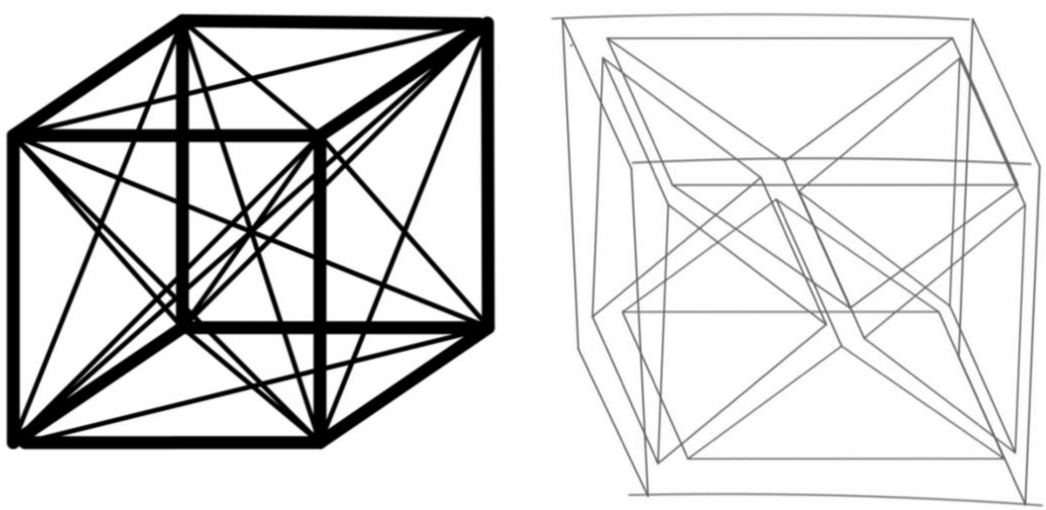

Figure 10: Initial Sketches of the Truss Structure

Figure 11: Initial CAD Design of the Truss Structure of Outer Ring

4.4. Initial CAD Designs of Rings and Habitation Modules

Once the parameters of the habitation modules were calculated, a CAD sketch was produced to show how big each module could be and provide a visual representation of the scale of the station and the four rings. Figure 13 models the 4 rings as well as the modules using the parameters outlined in Table 2 and Table 3.

	Innermost ring	Second ring	Upper Outer ring	Bottom Outer ring
Hight(m)	100	70	27	27
Width (m)	20	15	10	10
Inner Wall Diameter (m)	284	344	364	364
Outer Wall Diameter (m)	304	359	374	374
Inner Wall Circumference (m)	892.2123	1,080.7079	1,143.5397	1,143.5397
Outer Wall Circumference (m)	955.0442	1,127.8318	1,174.9557	1,174.9557
Volume (m^3)	923,423.5871	579,741.6543	156,498.438	156,498.438
Surface area (m^2)	202,787.8595	171,161.8217	74,191.9521	74,191.9521

Table 3: Station Ring Dimensions

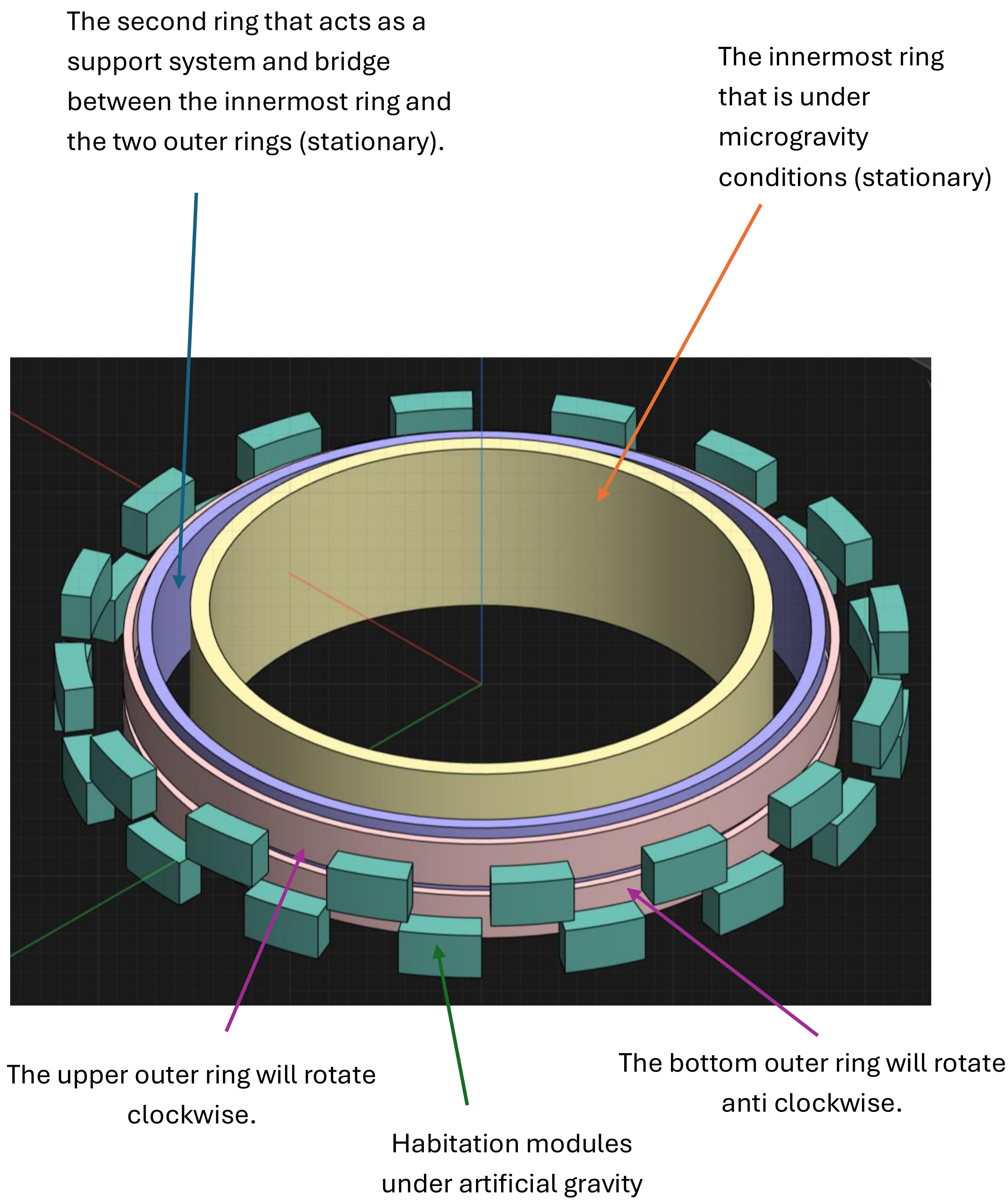

Figure 12: Initial CAD Design of Rings and Habitation Module Shells at Scale

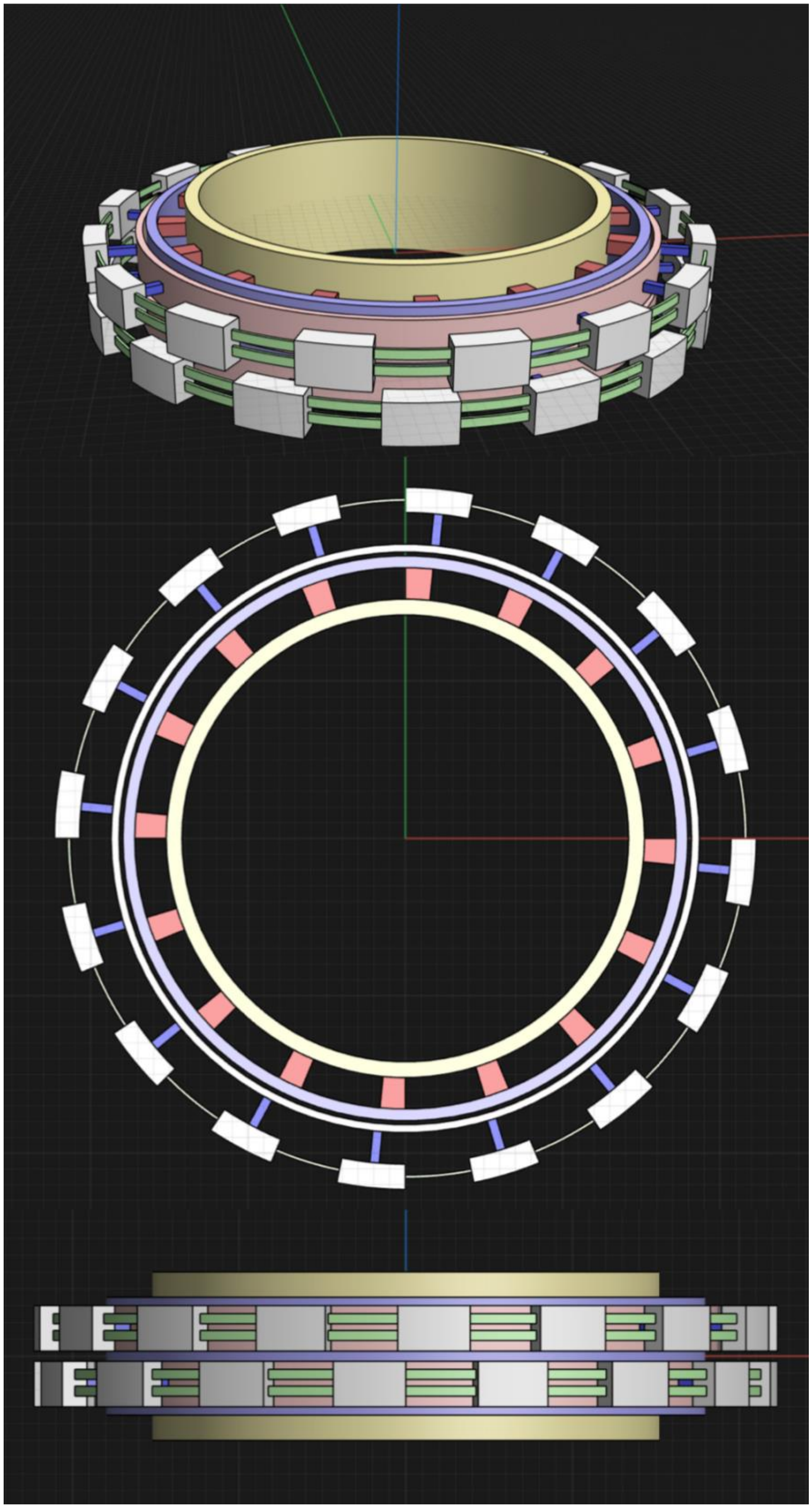

Figure 13: CAD of the 4 Rings, Habitation Module Shells and Support Trusses at Scale

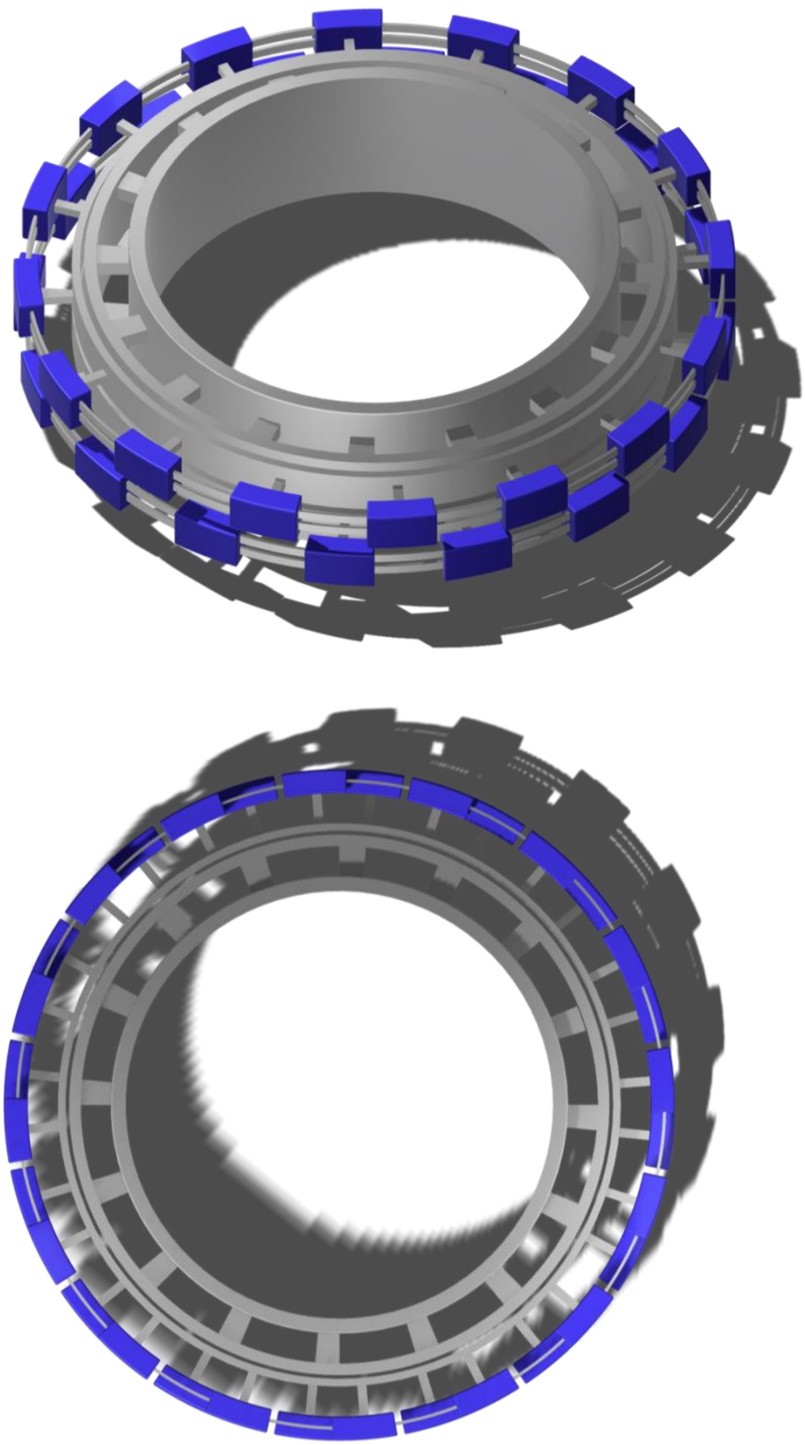

Figure 14: CAD Sketch of the Final to Scale Station Prototype with Aluminium Rings and Trusses

5. References

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CERTIFICATE of ACHIEVEMENT

This is to certify that

Wania Farooq

has completed the course

Academic Integrity at Queen Mary 2024/25