Stanford Torus Cutaway

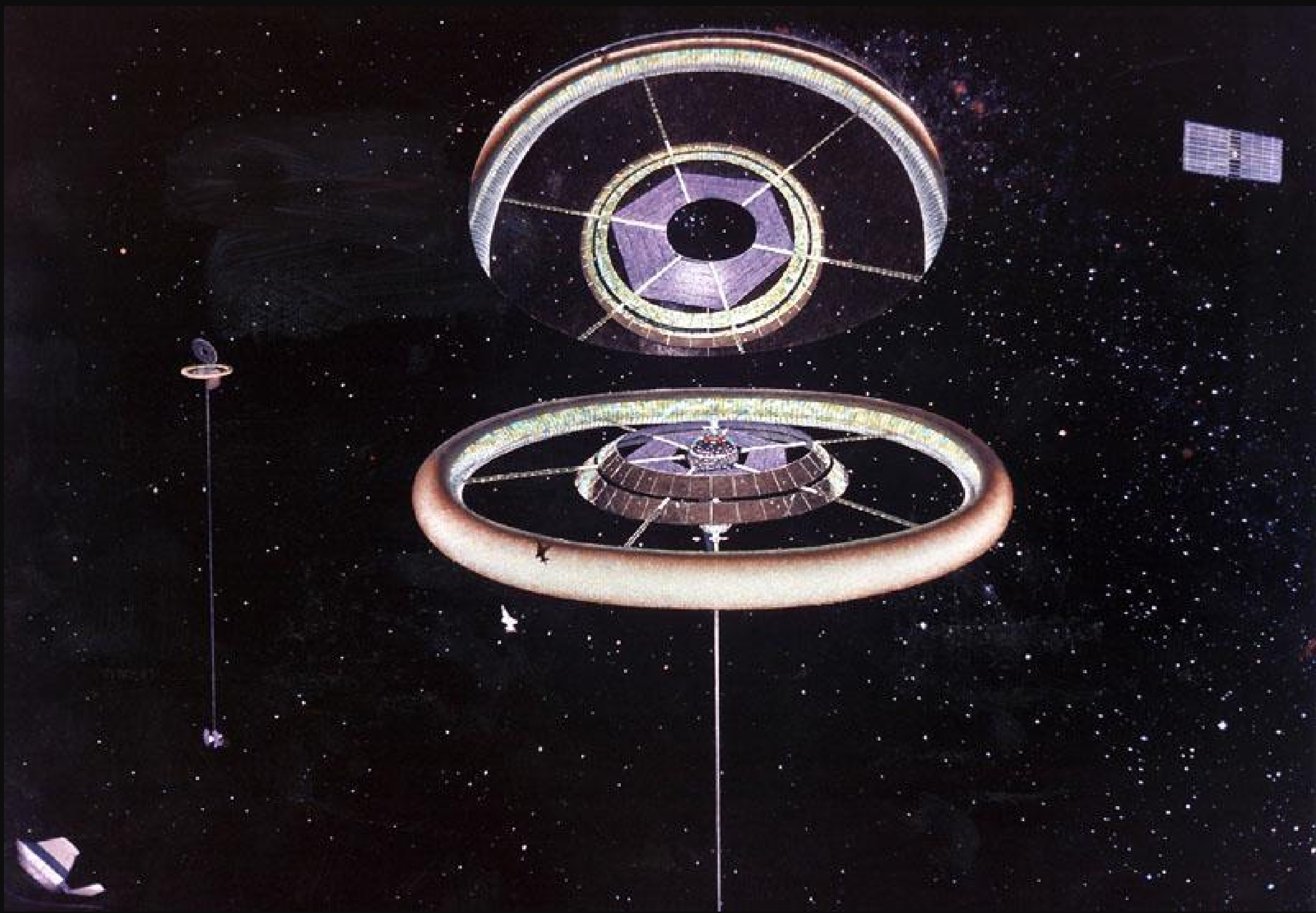

Figure 1_ Stanford Torus external view_© Don Davis courtesy of NASA
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General characteristics

- **Location**: Earth–Moon L5 Lagrangian point
- **Total mass**: 10 million tons (including radiation shield (95%), habitat, and atmosphere)
- **Outer ring diameter**: 1,790 m
- **Circumference**: 5,623.45 m
- **Habitation tube diameter**: 130 m (430 ft)
- **Spokes**: 6 spokes of 15 m (49 ft) diameter
- **Rotation**: 1 revolution per minute
- **Radiation shield**: 1.7 meters (5.6 feet) thick raw lunar soil

Background

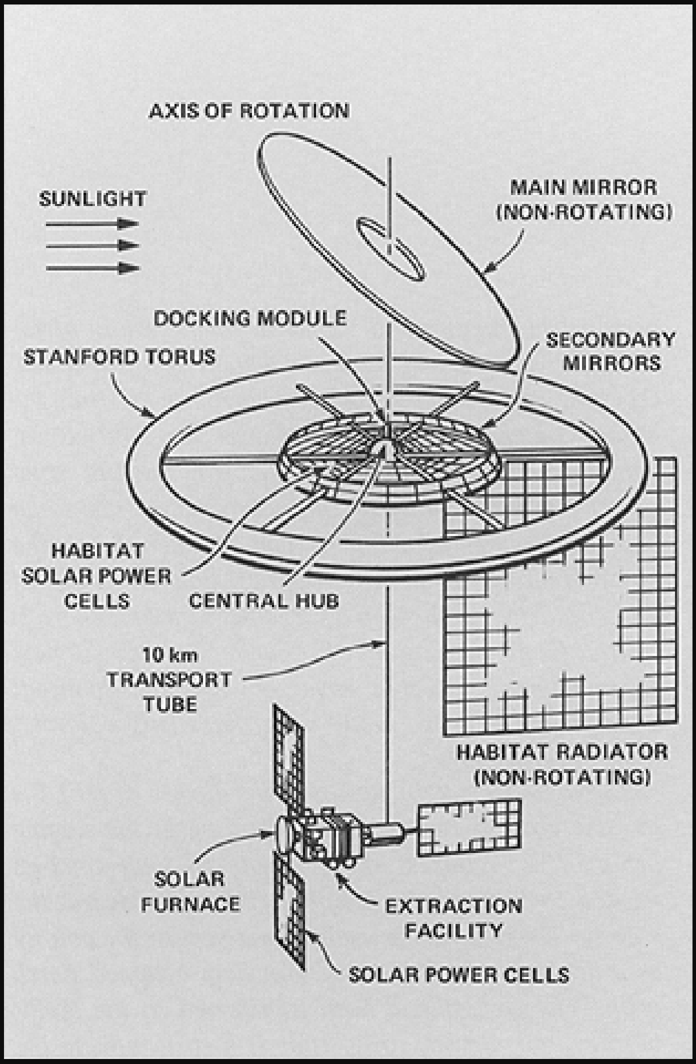

Figure 2_ Colony Configuration_© Courtesy of NASA. Source: Wikimedia Commons http://large.stanford.edu/courses/2016/ph240/martelaro2/

The Stanford Torus was a visionary concept space colony that captured the imagination of researchers, scientists, and educators during the summer of 1975. At its core, the project was a response to the growing concerns around the energy requirements needed to sustain human life and activities.

To address this challenge, the architects of the Stanford Torus drew on ground breaking research from experts like Gaucher, who predicted that human energy consumption would grow exponentially through to the year 2200. This led to a focus on developing technologies that could harness new forms of energy, with a heavy emphasis on solar energy production.

In 1968, Glaser proposed solar power stations as a means to tap into the vast potential of solar energy. The idea was to collect solar energy in space and beam it back to Earth, enabling the creation of space power companies that could sell energy to residents on Earth. Space colonies were created as the living quarters for the personnel who would construct and maintain these solar power plants.

The Stanford Torus was a groundbreaking example of such a space colony, featuring a ring-shaped design that rotated to simulate gravity and provide a comfortable living environment for humans. Its cylindrical shape also provided a large interior space that could accommodate up to 10,000 people, with a mix of residential, commercial, and recreational areas.

The Stanford Torus and other comparable initiatives offer a daring and inventive endeavour to comprehend the viability of building sizable homes to sustain human life in space, even though the idea of space colonies may still sound like science fiction. As humankind continue to confront the challenges of climate change and finite resources on Earth, the vision of space colonies may become an increasingly relevant and important concept for the future of human civilization.

Introduction

The Stanford Torus is a stunning example of visionary architecture that captures the imagination of space enthusiasts even today. Originally conceptualized as a space habitat that could house up to 140,000 permanent residents, the Stanford Torus was part of a larger project to explore and speculate on designs for future space colonies.

NASA scientists in the 1970s embarked on a mission to develop innovative designs for space colonies, and the Stanford Torus was one of the remarkable results of this effort. As part of this project, two other space colony form factors were also developed - the Bernal Sphere and the O'Neill Cylinders. However, it was the Stanford Torus that stood out for its unique doughnut-shaped ring structure that offered a spacious and comfortable living environment for humans.

The name "Torus" derives from the Greek or Latin word for "doughnut" or "bagel," reflecting the unique circular design of the Stanford Torus. This concept was born out of a NASA-backed study that sought to explore the possibilities of building large-scale habitats in space.

The Stanford Torus was designed to simulate gravity by rotating, providing a comfortable and habitable environment for its residents. It featured a mix of residential, commercial, and recreational areas, and its cylindrical shape allowed for maximum use of interior space.

Despite being a conceptual design, the Stanford Torus remains a testament to human ingenuity and the spirit of exploration. Its innovative design and futuristic vision continue to inspire architects, scientists, and space enthusiasts around the world.

Design description

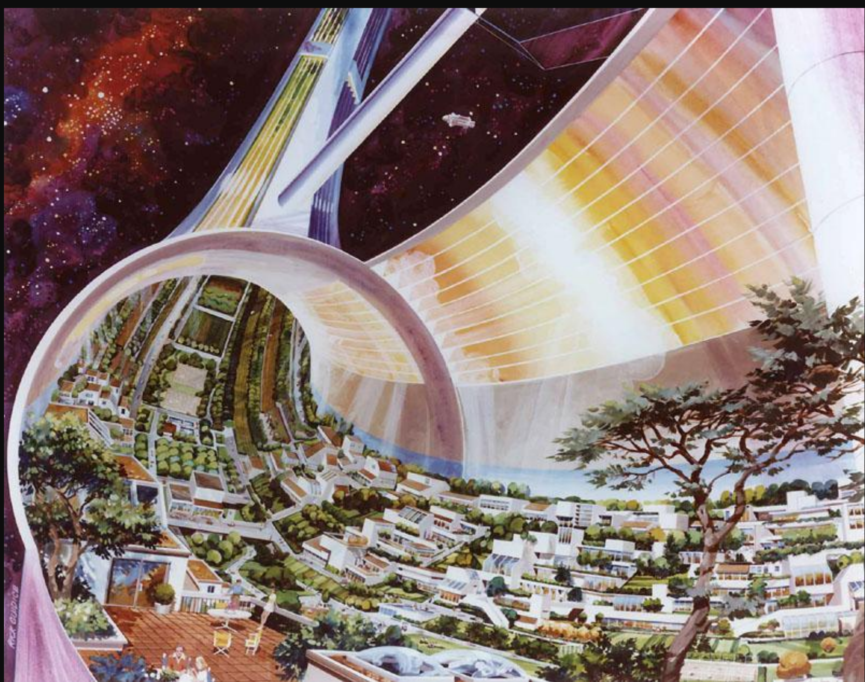

Figure 3_ Stanford Torus cutaway view_© by Rick Guidice courtesy of NASA
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The basic structure of the Stanford Torus can be seen in a cutaway view, revealing two concentric rings rotating around a central hub. The larger outer ring measures 1.8 kilometers in diameter and serves as the living area of the habitat, providing approximately 8.3 square kilometers of total surface area. It can accommodate up to 10,000 people, with each individual having around 800 square feet of living space. The smaller inner ring, which is 130 meters in diameter, rotates at a slower rate and creates a simulated gravity that is about one-third that of Earth's. This inner ring is where the agricultural and support systems are located, as the lower gravity is sufficient to support plant growth and other biological processes. The two rings are connected by spokes that run through the hub, serving as conduits for people and materials traveling to and from the hub. Through the use of centrifugal force, the inner ring rotates once every minute and produces 0.9 to 1.0g to 1.0g of artificial gravity inside the outer ring.

The Stanford Torus' central hub is home to the power generation and other support systems, as well as serving as the docking area for incoming spacecraft. A non-rotating module is affixed to the hub's axis for use in zero-gravity industry.

The station also relies on a tethered solar power generation satellite, situated 10 km away, to provide additional power to the colony. A stationary radiator positioned below the inner disk helps to dissipate waste heat from the station. To bring sunlight into the interior of the torus, a system of mirrors is utilized, including a large non-rotating primary solar mirror and a stationary mirror at 45° that redirects sunlight down to the colony. The interior space of the Torus is shaped into large "Valleys" resembling Earth-like features, and its residential complex resembles a bustling suburb with ends curving upward and eventually meeting overhead to form a complete circle.

Figure 4_ Stanford Torus interior_© by Don Davis courtesy of NASA
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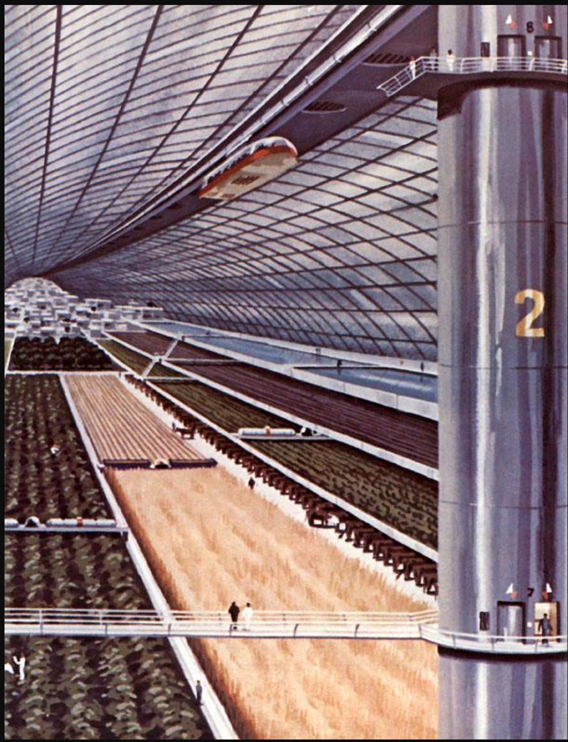

Figure 5_ Stanford Torus agriculture, conducted on multiple tiers for efficient use of space
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With a portion of the ring devoted to agricultural and housing, the population density is comparable to that of a crowded suburb. The Torus is designed to be fully self-sufficient, capable of producing food, supporting manufacturing, and providing high-quality residences for its inhabitants.

Construction

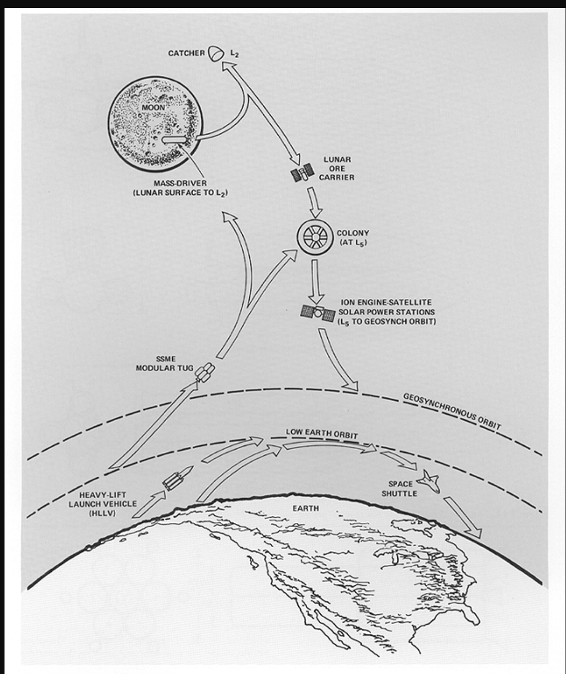

Figure 6_ Transportation system for the torus construction (1975) _© courtesy of NASA
https://en.wikipedia.org/wiki/Stanford_torus#/media/File:Figure4.13,_Baseline_transportation_system,_Space_Settlements,_A_Design_Study.NASA.gif

Figure 7_ Stanford Torus construction. Depicted is the final stages of installation of the radiation shielding. _© by Don Davis courtesy of NASA
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The construction of the Stanford Torus would require a massive amount of materials, almost 10 million tons to be exact. However, extracting that amount of material from Earth would be a daunting task. Instead, futurists suggest mining the moon, which is rich in materials like aluminum, and using a mass driver to transport them to space. These materials could also be smelted using solar furnaces powered by the sun, which is a simple and nearly limitless energy source. To generate the necessary heat for the colony, radiators as large as 900,000m2 would be required, capable of producing heat up to 280 K. The Torus is connected to a hub via a series of "spokes" for people and material transport. Materials collected by a mass catcher at L2 would be transported to L5 for processing in an industrial facility to construct the Torus, with only materials unavailable on the moon needing to be imported from Earth. Another option for material acquisition is asteroid mining. However, the challenge of manufacturing the Torus remains due to the immense weight of the required mass, which could exceed 10 million tonnes.

Estimating Electrical Energy Requirements

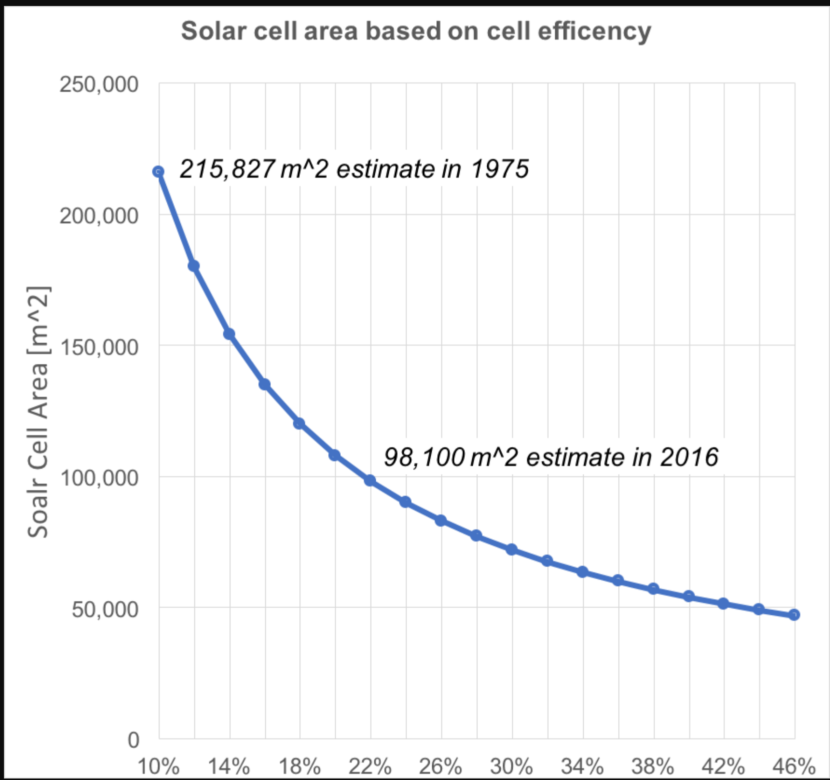

Figure 8_ Solar panel area vs. cell efficiency.
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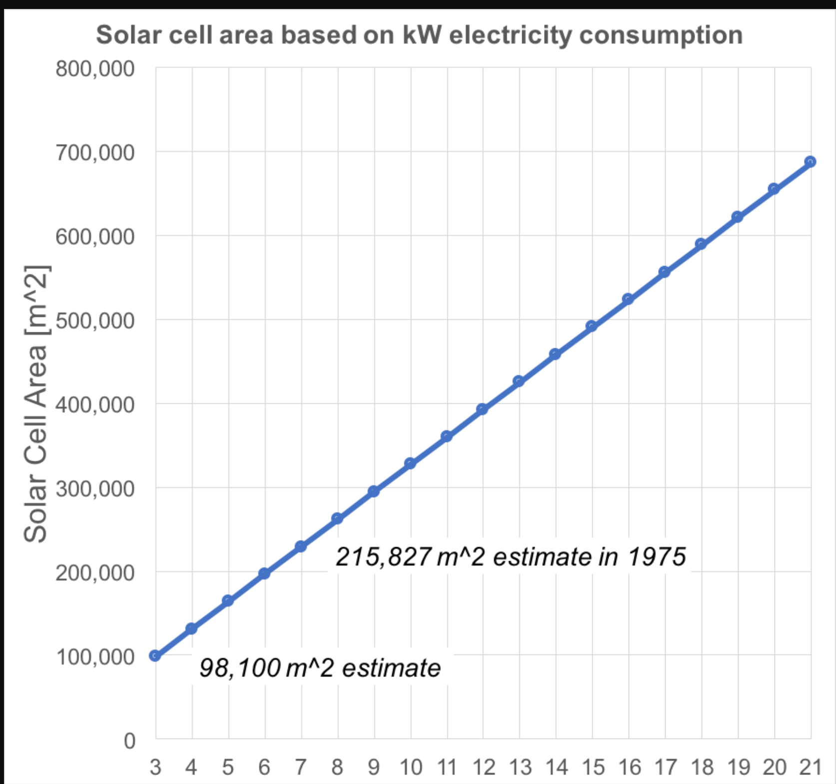

Figure 9_ Solar cell area vs. energy consumption.
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All power needs on the Stanford Torus were planned to be met by solar power. Sunlight would be utilized for heating, agriculture, and illumination within the habitat. Photovoltaic solar panels would be used for electricity generation, which would power daily activities such as personal transportation, interior lighting, and household appliances, as well as industrial processes such as agriculture, sanitation, and manufacturing. According to the original report, the team estimated that the Torus would generate 3kW of electricity per person. This estimate was based on doubling the per capita electricity consumption of Americans in 1975. With this estimate, the total energy requirement would be 30 MW. To meet this requirement, the Torus would need a minimum solar panel area of 215,827 m2, assuming an average of 1390 W per square meter of solar energy available in space and a 10% solar cell efficiency.

The energy requirements per capita have remained consistent since 1975, currently at around 1.5kW. However, advancements in solar panel technology have resulted in commercial solar cells achieving around 22% efficiency. This increase in efficiency means that the required solar cell area for the Stanford Torus is now approximately 98,100m2, a 54% reduction from the area required at 10% efficiency. Fig. 8 illustrates how area requirements decrease with increasing cell efficiency. It's important to note that these energy calculations don't account for the energy required for manufacturing, which will be needed for space construction. The proposed metal of choice for space construction is aluminum, which can be mined from the moon. To smelt aluminum, the original designers suggested using solar furnaces. These furnaces concentrate sunlight using parabolic mirrors, enabling the smelting of aluminum with a smaller energy input. The solar furnaces could be connected to the main torus, but it's also possible that they will be separate satellites and not part of the overall system.

The feasibility of solar energy for the colony is contingent upon the accuracy of the 3kW per capita estimate of electrical energy usage. Although this estimate is based on a doubling of current US electricity consumption, it may not fully account for the energy requirements of life support within the colony. While the Torus is designed to be biologically stable with agriculture aiding in air purification and oxygen production, the use of external scrubbers to remove carbon dioxide and other pollutants may still be necessary. In 1975, the energy requirements for life support in space were largely unknown. However, with the International Space Station having been in operation for many years, its energy requirements can provide insight into whether or not the 3kW per capita estimate is reasonable.

According to a 2011 NASA report, the power systems of the ISS generate around 110kW for up to six astronauts, which amounts to a per capita electricity use of 18kW. This is six times higher than the estimate we previously mentioned. However, it's important to note that the electricity generated powers all the life support systems and experiments on the ship. As the ISS requires active life support, a significant portion of the electricity is used for managing air and water systems as well as on board controls. Around 30kW is available for experiments, leaving 80kW for general ship operations and life support. Moreover, it's worth mentioning that the ISS has room for only six astronauts, and adding more people could lead to increased energy consumption. Based on these real-world numbers, it may be necessary to update our estimate for solar cell area if the energy requirements exceed 3kW per capita. Fig. 9 illustrates the relationship between energy consumption and solar cell area, assuming a 22% solar cell efficiency. As the consumption increases, we reach our original estimate of 215,000m2 at approximately 7kW per capita. However, if the energy requirements were to reach around 18kW per person, we would need more than 589,000m2 of solar cell area.

Estimating Cooling Requirements

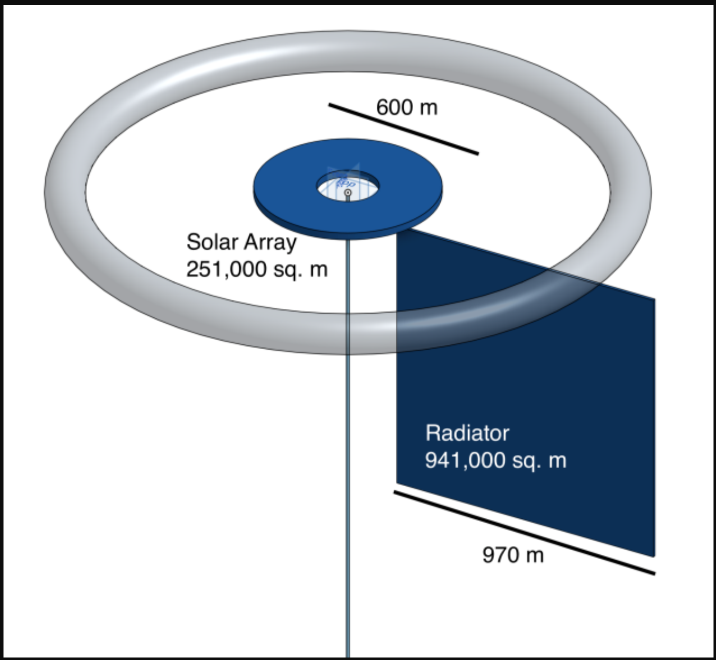

Figure 10_ Stanford Torus solar array and radiator sized to scale.
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The production of energy inevitably generates waste heat that needs to be managed. A radiator is required to expel the waste heat into space. In the original plans for the Stanford Torus, it was estimated that the colony would need to radiate 131 MW of power. This value was based on 30 MW of electricity use, 66 MW of raw solar power for agriculture, and 35 MW for illumination and heating. The radiator was designed to have a temperature of 280 K, emitting 348.5 W/m2, and an efficiency of 60%. This translates to a radiator area of 628,000 m2. To manage peak loads, the design study suggested an additional 50% in area, which would bring the radiator to 941,000 m2. Assuming that the estimated heat from environmental sources is reasonable, increasing the electric load from 30 MW to 70 MW would require an area increase to 1.2 × 106 m2, or about a 27% increase in area.

Estimating Size

Although the estimates for the necessary size of solar cell and radiator arrays for the Stanford Torus have been provided, it can be difficult to visualize their actual scale as the area increases exponentially with each panel side length. Looking at the original drawings of the Torus, one can see that the main ring has a diameter of 1800 m, while the inner ring, which features solar panels, is around 600 m in diameter, with a 200 m spaceport. If the entire disk area were covered in solar panels, there would be 251,000 m2 of solar panels. This would cover the estimated 215,000 m2 required in 1975 and provide double the capacity required with modern solar cell efficiency. Even with electric energy requirements of 70MW or more, the panels would be sufficient. However, it is important to note that having double the capacity is prudent, as any loss or degradation of power could be catastrophic for the colony. Additionally, this extra capacity allows for future growth in energy usage within reasonable limits, as the radiator can only handle so much load.

Conclusion

The viability of constructing and maintaining the Stanford Torus remains a topic of debate, but according to this analysis using modern solar technology, the massive space structure could potentially generate sufficient electricity through onboard solar power generation. Assuming a stable mirror system can be implemented, the solar array on the inner disk could generate around twice the required electrical energy for a 3kW per capita consumption rate. However, the size of the radiator poses a greater obstacle as it would require an immense amount of material, almost 1 sq. km in size. Nevertheless, the energy needed for the Torus is attainable, provided that we can construct the necessary infrastructure and manage it effectively.

Design flaws

There were a few limitations of the design and they were as follows:
The shielding coverage in the Stanford design was insufficient, as it only included a static regolith shield positioned at the sides and beneath the aluminum hull, with no protection provided overhead.
The chevron mirror system, intended to admit light and impede the passage of ionizing particle radiation, had minimal 1-inch aluminum shielding and was inadequate for the task.
Although the system's geometric principles were correct, its implementation in terms of scale and materials was inappropriate, rendering it incapable of providing adequate shielding.
This lack of overhead shielding would have exposed the occupants to GCR over time, resulting in negative health consequences for the population.
Additionally, the Stanford torus did not have any growth capability, and the study was based on the assumption of large investments of time and capital for the development of industrial infrastructure on the lunar surface as a precondition for commencing construction activities for the habitat.
Once completed, the habitat would have approached a mass of 10 million tons.

Reference

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