Image: St. Flannan's College Space Settlement design team

Contents

Executive summary

"Ideas have consequences and the worst idea we have ever had as a civilisation, is that we have access to limited resources. The correct thing to say, is that we have access to limited resources on Earth…. because the moment you lift your gaze up from the surface of the Earth and out into space, to the asteroid belt and beyond, then, you see that there are effectively unlimited resources out there"

Prof. Brian Cox paraphrasing Dr. Robert Zubrin[1]

For the occupants of our off-world space settlement to thrive, a supply of food, water and air is essential. By constructing and placing our rotating space settlement in the asteroid belt and in orbit around Ceres. The water and minerals required to grow food and make nitrogen rich air on our settlement can be sourced form Ceres itself and from selected asteroids in the asteroid belt. Further, all the materials for fabricating our space settlement are at hand in this region of the solar system, as the asteroid belt is abundantly rich in mineral resources and chemical volatiles.

We have an opportunity to make an off-world space habitat, that is a desirable and exciting place, for up to 10,000 people to live, for children to be born and grow up, for scientific research to be carried out, for television and cinema films to be shot, for new industries, materials and space technologies to be developed, for people from Earth to visit and a place where for the sheer fun of it, zero-gravity can be experienced, and to assist industrial manufacturing processes. *Our Space Settlement will be people centred, incorporating the design concepts of Toyota's 'woven city'*[4]*. Mall Meg "will serve as a test site for new technologies*[4]*" and is an opportunity to create new possibilities for a collective future*[6].

Given the fragility of human existence on our planet, we have an obligation to optimise the survival chances for our species and to develop space settlements in our solar system and ultimately in other solar systems. The threats to our survival on Earth from asteroid impacts, nuclear weapons, anthropogenic global warming, and scarcity of resources compels us to spread out as a species, into the solar system. We must learn and adapt as a species to living in new and challenging environments.

Naming The Settlement

We have called our Settlement **Mag Mell**[2]. Mag Mell was a mythical land in Irish mythology and translates from the Irish as a delightful or pleasant plain. Something akin to Elysium in Greek mythology. We want our Space Settlement to be a great place to live. Residents of Mag Mell should be able to enjoy a very good quality of life as per the United Nations human Development Index[5]. Health, Education, and Income will be prioritised.

Stand Out Features of Our Space Settlement

Our Space Settlement has been partly inspired by Dr. Pekka Janhunen's paper [3] "Interconnected and growable Ceres mega satellite world" (2021), the work of Jason Dunn of Made in Space inc. and Toyota's Smart City[4] (called the Woven City). The woven city is intricately designed with autonomous technologies, smart homes, mobility, and robotics technologies being central to the functioning of the city.

- Our Space settlement will be constructed robotically in-situ, in high Ceres orbit (r = 100,000 km, equatorial orbit)[3] using materials mined from Ceres and nearby transported asteroids
- A space elevator will be constructed on Ceres (elevator cable, 1024km in length)[3]
- Ceres' rotation period is 9.02 hours
- Our Space Settlement structure will be 3-d printed in-situ
- Our Space Settlement will be a rotating half-cut Torus with different angular rotation rates for the central hub and outer rim
- Our Space Settlement will have artificial 1g gravity and an Earth like atmosphere
- The Central Hub is split into zero gravity and micro gravity areas
- We will use asteroid/Ceres regolith for radiation shielding and to make soil to allow us to grow trees and shrubs as we landscape our Space Settlement
- The central hub of the settlement will contain our industrial and docking areas
- Residential areas will be constructed on the 1g outer rim at the termination of each spoke
- Each of the six residential areas (villages) will have different layouts and designs
- We will begin controlled research of genetic modifications, to allow humans to cope better with space radiation
- Our Space Settlement will be a test site for new technologies, "A living laboratory"[4]
- The state of health of each resident will be monitored continuously via smart body sensors
- Our Space Settlement will contain its own film studio
- Ease of mobility around our Space Settlement has been prioritised[4]

Meet the team

Cian Pyne *I am a 5th year student attending St Flannan's College. I am captivated by all things related to Space. I'm fascinated by sci-fi films and the idea of humans travelling beyond Earth. I find great enjoyment in physics as it helps me to understand the science behind ideas I come across in everyday life. My hobbies include basketball and swimming, and I would love to experience space travel one day.*

Jack O’Connor

I like playing rugby and Gaelic football. I spend my free time listening to music and playing the guitar/ banjo. I like watching videos about interstellar space and I think physics helps me to imagine a future interplanetary species and also understand phenomena in everyday life.

Adam Downes

I am a 5th year student in St Flannan’s College Co. Clare. My hobbies are playing sport and music (piano). I enjoy physics and maths and hope to be an engineer.

*I’m **Garbhán Monahan** from Ennis, Co Clare and I study physics in school. Ever since I was young, I always found the laws and theories of physics fascinating, especially the ones about space. I also love music, reading and Teakwon-Do.*

Naem Haq

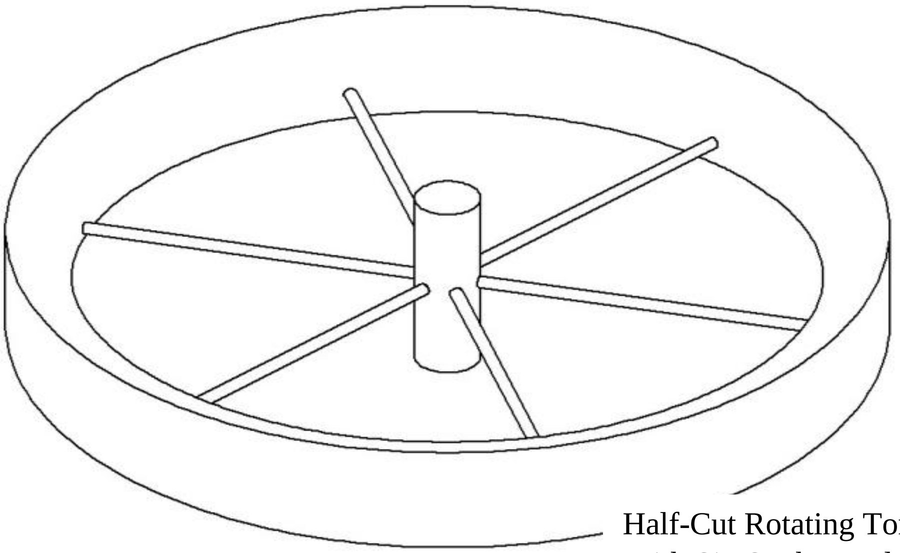
I am a 5th year student in St. Flannan's College, Ennis, Co. Clare. My hobbies include soccer, badminton and reading astronomy discoveries. I am interested in Medical Sciences and Space related developments. I am extremely enthusiastic about Physics and maths, and I love problem solving especially with my classmates.

Structure of the Settlement

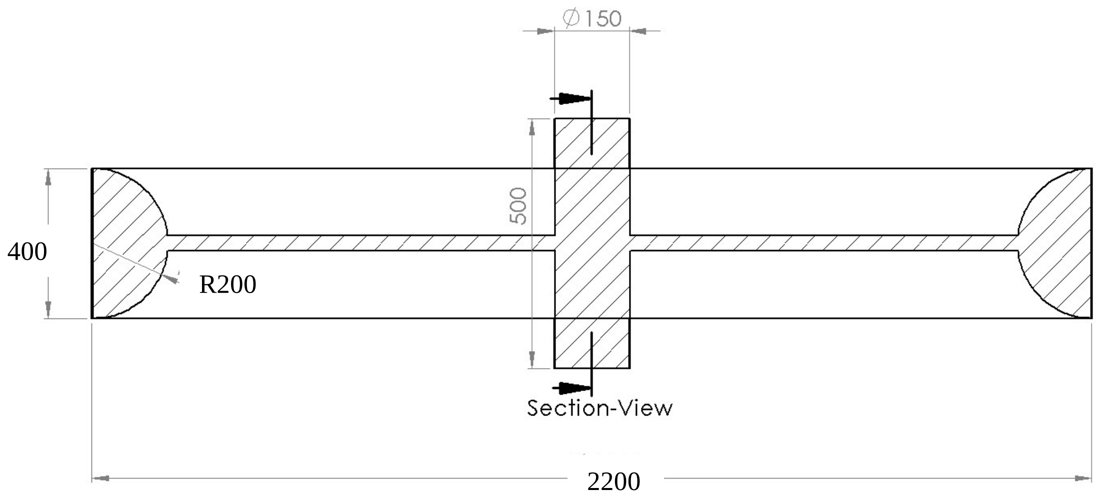
Basic Shape and Dimensions of Mag Mell

A half-cut rotating torus with six spokes and a central hub that can rotate at a different rate of rotation to the outer rim

Image: St. Flannan's College Space Settlement design team



Half-Cut Rotating Torus. With Six Spokes and inner central hub



The Outer Shell

Ultra-pure iron nickel steel will provide the material for the internal frame and outer ‘skin’ of the settlement. The outer shell of the station will be approximately ~2m thick and will be formed from a honeycomb framework of iron nickel steel.
The settlement will be 3d printed in high Ceres orbit. Iron nickel ore will be sourced from nearby metallic asteroids. Asteroids will be transported to Ceres High orbit and processed there using the gaseous ‘Mond process’. The space settlement will be 3-d printed in sections, using the ultra-pure iron nickel (*from the Mond Process*) as the feedstock, and the sections will be assembled and welded together
Ground up silicates from asteroids will provide radiation shielding, the silicates will be incorporated between shell layers and into the honeycomb reinforcing structure. Floors will be made of a similar iron-nickel steel honeycomb structure iron and will be up to 1m thick, interior walls will be ~ 0 .5m thick.

Image: St. Flannan’s College Space Settlement design team

Empire State building

Size comparison of Mag Mell with the Empire State building (436m)

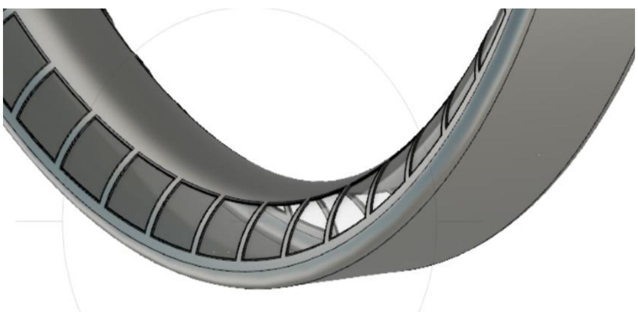
Space Settlement (2200m diameter)

Windows

The windows of the torus are designed to maximise the amount of light that can enter the torus. They also allow the residents to get an unobstructed view of Ceres and beyond.
The glass in the windows will be constructed from aluminium oxynitride[7] otherwise known as transparent aluminium.
Shutters can be operated to create an artificial night inside the settlement and to protect the settlement from the impacts of larger objects.

Image: St. Flannan’s College Space Settlement design team

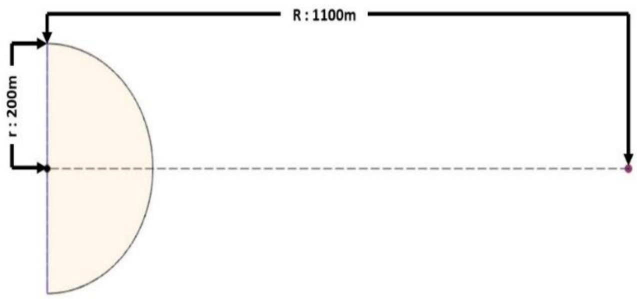
Windows ‘artificial night’ or protection mode



Windows ‘artificial day’

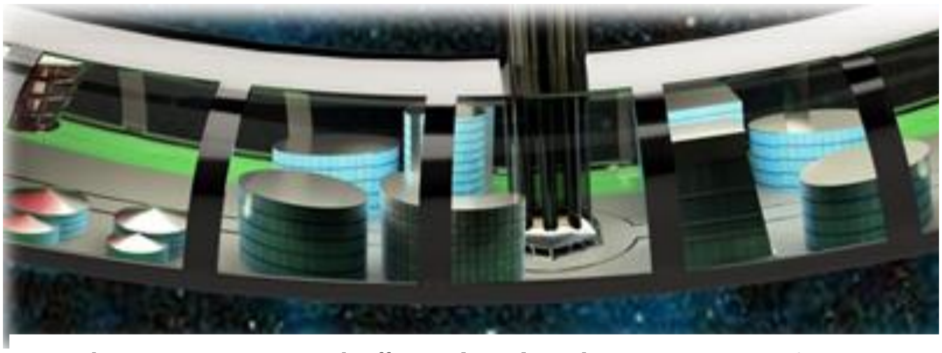
Torus Dimensions

The torus is a half-cut rotating torus with a radius R =1100 m and a minor radius, r =200 m. As it is a truncated torus the "floor" relative to the inhabitants will be 2 times (r) or 400m across while the ceiling will be 200m high.



The Villages, their Transport Stations and Highways

There will be six residential areas/villages surrounding each lift transport station. The layout of the villages will allow a sense of local community to develop. The villages will have mixed residential and commercial development.
The village transport stations contain elevators which link to the central hub. They are also connected to the rim's transport/mobility network.



The transport station with office and residential areas Image: St. Flannan's College Space Settlement design team

As in Toyota's 'Woven City'[4], there will be three different types of mobility highway, each type catering for a different form of mobility. The first type is a highway for faster transportation, and it is tree lined to mark off its boundaries. Vehicles using this highway will be autonomous and electric[6].

The first type is for faster transportation (electric cars). Image credit: Screenshot-1, Toyota Motor Corporation presentation[6], CES Las Vegas, 6th Jan 2020, [3mins,21sec]

The second type of highway/street will be an urban street promenade[6] (for the towns) shared by pedestrians and slower personal mobility vehicles, for example electric scooters. The street promenades will be landscaped to make them more interesting looking and natural.

The Urban Street Promenade. Image Credit: Screenshot-2, Toyota Motor Corporation presentation[6], CES Las Vegas, 6th Jan 2020, [3mins,27sec]

The third type of street will be a linear park.[6] With lush green areas, extensive planting of trees and shrubs and continuous paths for pedestrians only.

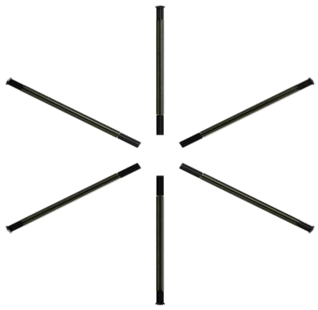
The Linear Park. Image Credit: Toyota's Woven City[6]: Screenshot-3, Toyota Motor Corporation presentation[6], CES Las Vegas, 6th Jan 2020, [3mins,35sec]

The Villages

The residents of the torus will reside in smart technology apartment blocks. The apartment blocks will be similar in style to those on Earth, these apartment blocks could be 40m high with up to 13 storeys. Each person needs a minimum of 25m^2 (according to the Tokyo, Japan building regulations[8]) A very basic calculation allowing for 600m^2 per storey habitable floor area, gives a living space for up to 310 people per block and so 33 of these apartment blocks could accommodate 10,000 people.

The Six Spokes and their Elevators

The spokes serve multiple purposes. These include linking the torus to the central hub and providing transport to the central hub and back to the torus via high-speed elevators.

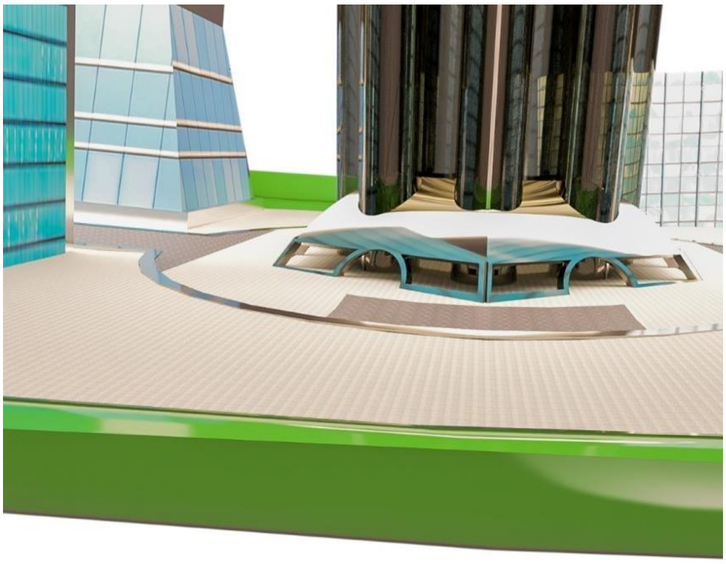


The Spokes

Cross-section of Elevators

The outer shells of the spokes have structural strength, so they can withstand the forces generated as the torus rotates and to protection the elevators against meteoroid impacts.

There are nine elevators contained within each 'Spoke', for transport between the rim and central hub. One large cargo elevator *30m in diameter (see above diagram)* and eight smaller people carrying elevators.



People and Cargo elevators at the transport station

Image: St. Flannan's College Space Settlement design team

The Agricultural Area

The multi-level Agri-Areas (farms) are suspended from the ceiling, this maximises the use of space within the torus. They will utilize both natural sunlight and led lighting. These farms have an area of 47420m^2 per level. With 6 levels per farm and a total of six farms (*see image below*) that leaves us with a total area of 1,707,120 m^2. Plants will be grown in these farms in hydroponics bays. This will enable us to maximise our food our food production.

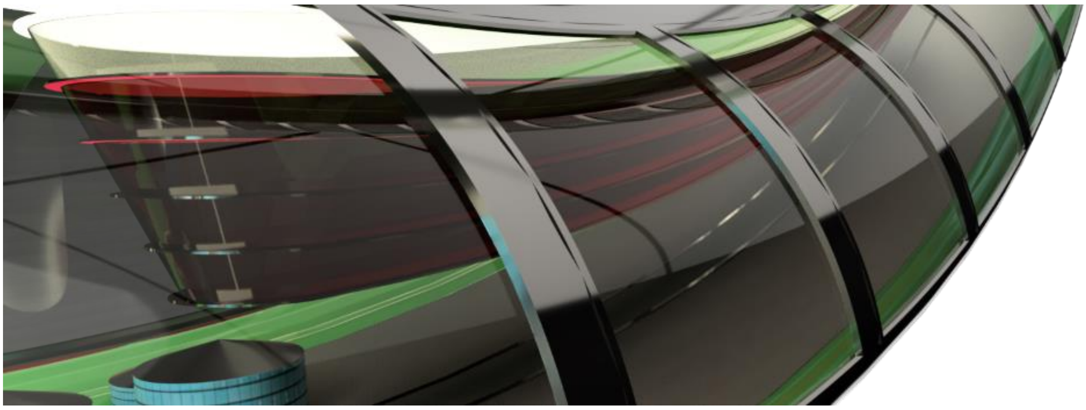


Image: St. Flannan's College Space Settlement design team

suspended farms

The Central Hub

The central hub performs many functions, heavy manufacturing, space craft docking and a place for leisure and sports amenities.
We have split the central hub into two parts. The outer section (*outer hub*) will remain connected to the spokes and rim of the station and so rotate at the same angular rate as the outer rim. It has multiple floors (*layers*). The effective value of gravity for the floors in the outer rim, will be lower than at outer rim of the torus, as their distance from the axis of rotation is lower than at the rim. The inner section of the hub will be capable of rotating at a different rate to the outer rim, thanks to the transfer ring and magnetic bearings.

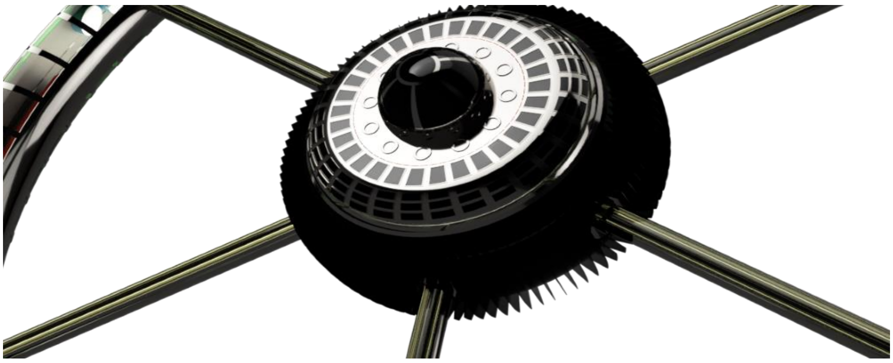
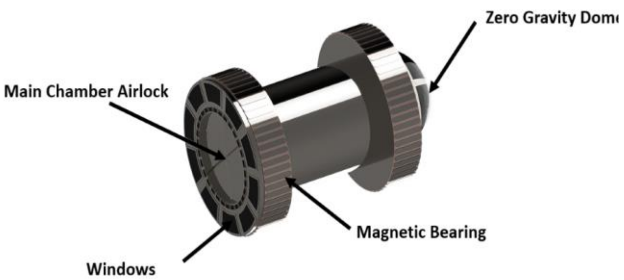


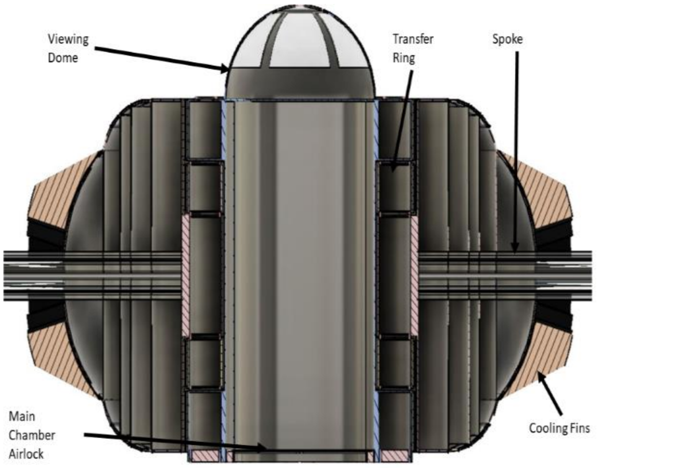
Image: St. Flannan's College Space Settlement design team

Central hub with locking ring

As mentioned above the outer hub (with four floors) rotates at the same rate as the spokes and outer rim. The outer hub values of gravity range from 0.2g to 0.1g ($a = r\omega^2$ and r, ranges from 110m to 200m, $and\ \omega\ =\ 0.0994436\ \mathrm{rad/s}$) This section for the lighter manufacturing industries. The heavy industries will be in the gravity free, non-rotating section of the central hub. The outer hub is divided into multiple floors each with progressively less gravity. Each floor will contain factories and other industrial plants which could range from electronic device production to chemical manufacturing.



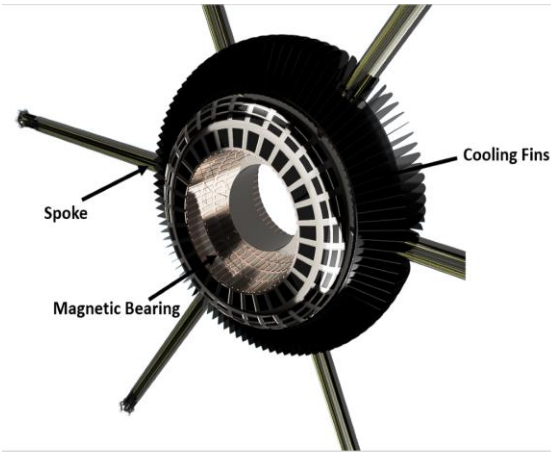
Inner hub



Images: St. Flannan's College Space Settlement design team

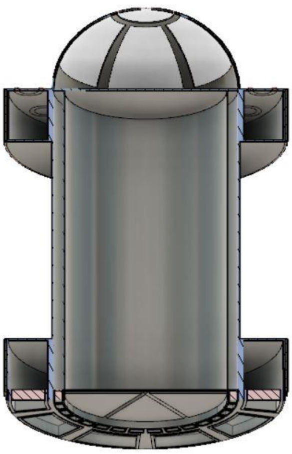
*Cross section of the outer and inner hubs with transfer ring. Note the four floors on the outer hub, with floor radii, to central axis, ranging from, 110m to 200m. **The inner dome is the zero-gravity zone as it doesn't rotate**. The outer hub values of gravity range from 0.2g to 0.1g*

Many of the settlement inhabitants will work here. However due to the reduced gravity environment in the central hub, there will be a limit to the daily time period they can spend here, due to muscle and bone degradation caused by low gravity environments.



Central Hub

Image: St. Flannan's College Space Settlement design team

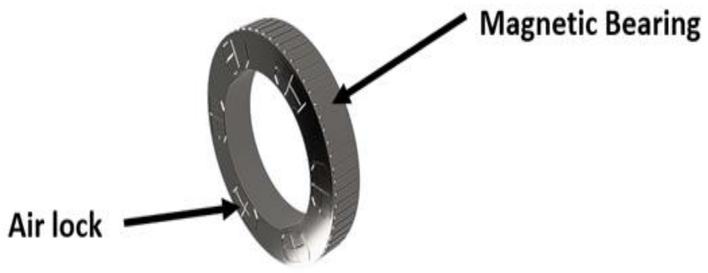


As the **inner hub** experiences zero gravity it is the perfect location for heavy industries and other zero g activities. The inner hub houses a large, pressurised area.
Space Craft repairs and industrial activities which can benefit from a zero-gravity environment, can be carried out here. **A great place to experience Zero gravity**!

The Transfer Ring

Freedom of movement will be achieved using electromagnetic bearings which will both allow the inner hub to rotate relative to the space station and allow precise control of the rotational speed through precise adjustments to the magnetic fields created by the bearings.

Due to the inner and outer hub sections rotating relative to each other, we have introduced an intermediate third pressurised section. This section can speed up and slow down to match the rotational speed of either hub section. The transfer ring as it is named can then lock on to the chosen hub section and airlock with it. This allows cargo and people to move from the hub section to the transfer ring and back. The ring then disconnects from the hub section and uses its electromagnets to match the speed of the other hub section with which it airlocks. In this fashion people and cargo can move between the two hub sections, while staying safely in a pressurised environment.



Transfer Ring

Image: St. Flannan's College Space Settlement design team

For a person to travel from the stationary section to the rest of the station they would have to make their way to one of the airlocks for the transfer rings. They would then wait for the transferring to match the rotation of the stationary hub and the airlocks with engage. They would then move into the transfer ring, which would then disengage and speed up to the rotational speed of the rest of the station. The other set of airlocks will then engage, and people can then make their way out and into the rest of the station.
The transfer rings will constantly be moving from the stationary hub to the rotating station and back at set intervals allowing the inhabitants to plan their journey.

Solar Power on the Settlement[9]

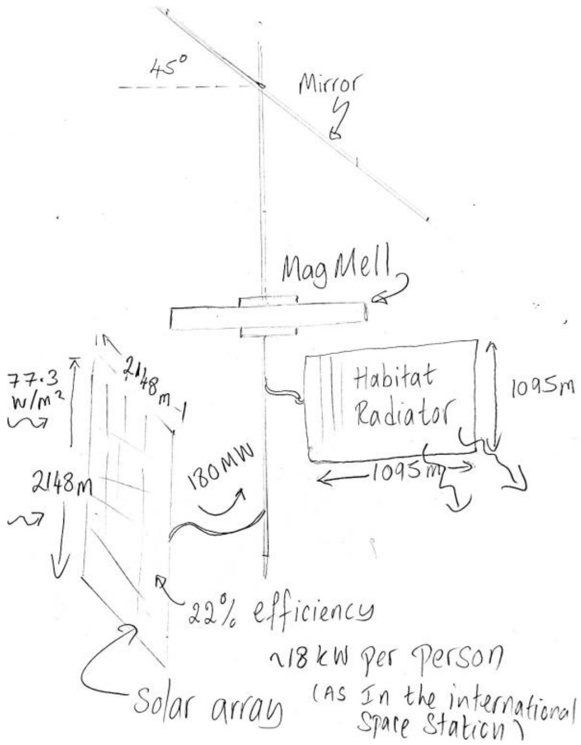
Image below: Team Drawing

Assuming 1390W/m^2 solar power at 1Au
Ceres at 2.8Au, gives 1390/(2.8)^2 W/m^2
(*Inverse square law for light intensity*)
So, 77.3 W/m^2 of Solar power, is available at Ceres high orbit.

Allowing a max of 18KW per person[9], *as on the International Space Station* and taking 22% as the efficiency of the solar cell.

77.3W/m^2 @ 22%, efficiency gives 38.98W/m^2 for the solar array (*Right Image*).

Hence, 18000W requires (18,000/38.98) m^2 or 461.8 m^2, that is 461.8 m^2 per person.
Hence 10,000 people need 4617753 m^2 of solar array area, or (2148m)^2

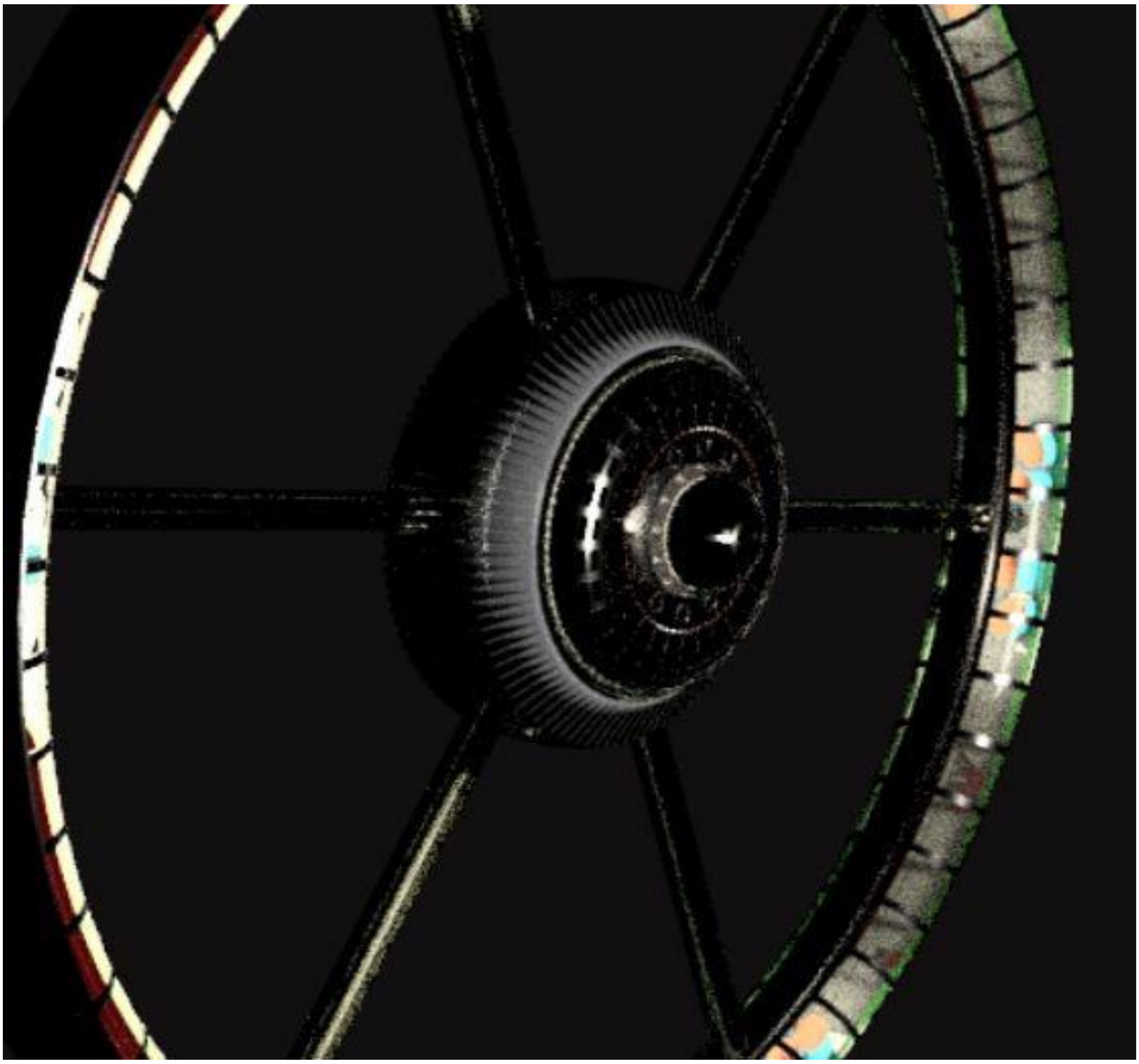


There will also be some visible light from a mirror angled at 45^o above the settlement (see diagram above). Similar in the design of the mirror in the original Stanford Torus.

Cooling requirements

Using the figures from 'Powering the Stanford Torus' by Nikolas Martelo[9] (2017), we estimate that, as our settlement is very similar in design to the original Stanford torus, it will require an area of 1199025 m^2 or (1095m)^2, for the habitat radiator. The coolant will be ammonia based. We have some cooling fins at the low gravity section of the central hub.

Additional view of Space Settlement



View of settlement

Image: St. Flannan's College Space Settlement design team

The Gaseous Mond process, to produce ultra-pure iron and nickel metal for the 3-d printing of our space settlement

In their paper *'BENEFICIATION OF ASTEROIDAL MATERIALS IN SPACE' (2012),* Richard M. Westfall and William C. Jenkin, outline how stony/iron and iron asteroids can be mined for their metals[19].

- The material from the asteroids or meteoroids is pulverised into a powder
- For stony/iron powder, metals are separated using magnets (not necessary for the iron asteroid)
- Expose to carbon monoxide gas at 100 atm. pressure and a temperature of 120 ^{0}C the iron and nickel iron pentacarbonyl gas and nickel tetracarbonyl gas[12]
- These metal carbonyls are highly toxic[18] (the carbonyl process is better suited to space than Earth for this reason)
- The nickel and iron carbonyl can be separated by fractional distillation
- The carbonyl gases can be turned into their metals by exposing them to a heated surface, Chemical Vapour Deposition (CVD)

The Chemistry of the Mond process

The gaseous 'Mond Process'[14] (named after Ludwig Mond) is the method used to produce most of the world's nickel and cobalt from their ores[12], it has been in commercial use since 1905**.** If you were to separate the metal from a stony/iron or iron asteroid, and expose it to carbon monoxide gas at 100 atmospheres pressure, and a temperature of 120 ^{0}C, the iron and nickel form iron pentacarbonyl gas and nickel tetracarbonyl gas[12]

$$Fe_{(S)} + 5CO_{(g)} \rightarrow Fe(CO)_{5\,(g)} \text{ Iron pentacarbonyl gas}$$

$$Ni_{(s)} + 4CO_{(g)} \rightarrow Ni(CO)_{4\,(g)} \text{ Nickel tetracarbonyl gas}$$

These carbonyl gases have a similar freezing and boiling point to water and a similar vapor pressure; However, their vapour pressures are sufficiently different *from each other* to allow them to be separated by fractional distillation. As these carbonyl gases have similar boiling and melting points to water, they are liquid at room temperature, allowing them to be poured into molds. Heating the metal carbonyl in the mold to 200 ^{0}C decomposes it and carbon monoxide gas (CO) is released, leaving behind ultra-pure iron or nickel.

Other Carbonyls

Carbon monoxide gas can similarly be applied to produce carbonyls of chromium, osmium, ruthenium, iridium, rhenium, cobalt and tungsten. Again, these can be decomposed into their metals. These metals can be combined with iron, to form various types of ultra-pure steel. Generally meteoric iron contains up to 30% nickel, up to 1% cobalt and platinum group concentration up to ten times better than terrestrial iron ore (*the platinum group metals tend to occur together*[12]).

Iron Carbonyl

The iron carbonyl can be made with extremely high purity[12]. After thermal decomposition analytic grade iron is produced with a purity of 99.999999 % thus ‘six nines iron’. It can also be referred to as ‘high pure iron’ or ‘high purity iron’[3]. If you make this ‘six nines iron’ into a wire its tensile strength is five times greater than piano wire. If you make a bracket or fixture or a bolt from ‘six nines iron’, and put it into a terrestrial environment, it is so pure that it has the corrosion resistance of the best stainless steel. In short it is a superb structural material[5].

The Mond process would produce a much purer grade of metal than the melting in a furnace of a ferrous metal asteroid. Smelting would produce a grade of metal containing many more impurities. Importantly the pure iron and nickel could be mixed to form nickel-steel alloy. ***The pure iron and nickel produced by the ‘Mond Process’ will be used as feedstock for our 3d printer.***

Demandite[17]

We are using the concept of ‘demandite’ to help us understand the scale of the resources contained in asteroids. ‘Demandite’ is a term used to provide a unit average of the materials required for a person’s lifetime, in this case in space. Applying this idea to asteroids allows us to extrapolate from, the amounts of all the resources they contain, the number of people they could possibly sustain. One unit of demandite includes all the materials needed for respiration, agriculture, build of Space Settlements etc. The asteroid belt contains 8×10^{18} ‘demandite’ units. Enough to support a population of 10 million billion people from now until the sun dies[17] . This means that it could sustain a population one million times that of Earth, over the same period.

Resources Contained in Asteroids[11]

Asteroid Type	***Resources***	***Extraction method / Use***
C, P and D	10% - 20 % water	*Extraction*: Vaporisation & Melting *Use*: Propellent, life support material & Space agriculture
Extinct comet	Up to 60% water ice	
M	Up to 99% ferrous metals	*Extraction*: Solar powered furnaces, The ‘Mond’ process *Use:* Making Space Settlement, Space Craft etc.
Chondrites	Up to 5%-30% ferrous metals	

Asteroids could be brought to high Ceres orbit for processing, SHEPHERD would work well for asteroids which are loosely packed

A Case Study of two Asteroids[15]

To give some idea of the scale of the resources contained in asteroids, we will look at two asteroids.

Case study one

The first named '1986 DA' is a small M-type (metallic) asteroid. It is 3.1 km in diameter. It is estimated that it contains 4×10^{10} tonnes of iron, not to mention over one million tonnes of platinum group metals, including 100,000 tonnes of platinum and 10,000 tonnes of gold. Professor John S. Lewis (University of Arizona) estimates that the total mass of the metals contained in asteroid '1986 DA' amounts to *forty times the mass of all the metals mined over human history*[3].

Case study two

In John S. Lewis' book 'Space Resources[15]' he considers a small 'run of the mill' S-type (stony) asteroid, one kilometre in diameter and ~ two billion tonnes mass. The asteroid contains 200 million tonnes of iron, 30 million tonnes of nickel, 1.5 million tonnes of cobalt and 7,500 tonnes of platinum group metals.

Image: The Willamette Meteorite[28]

S.H.E.P.H.E.R.D.[21]

Secure Handling by Encapsulation of a Planetesimal Heading to Earth-moon Retrograde orbit Delivery

As a team we were inspired by Dr. Bruce Damer's TED×SantaCruz Talk[16] on how to retrieve an asteroid. This concept is a modification of the previously proposed ARM[25] (NASA's Asteroid Redirect Mission) for capturing an asteroid.

Many asteroids are likely 'loose agglomerations of rocks and regolith'[21]. These asteroids, which are basically piles of rubble need to be handled with care as drilling or sawing through them will cause them to disintegrate. Dr. Damer proposes to solve this problem by capturing the asteroid in a gas filled enclosure. The SHEPHERD method for capturing and transporting intact a weakly consolidated asteroid, complements project RAMA[26].

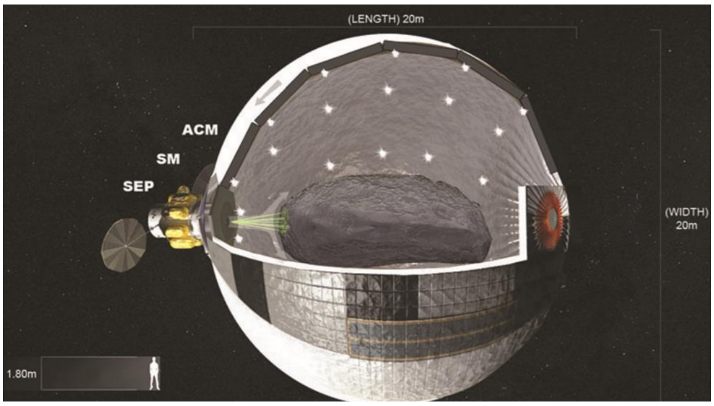


Image: courtesy of Dr Bruce Damer

As the robotic space craft approaches an asteroid (the asteroid will be spinning), it scans it with its LIDAR (laser light is bounced off the asteroid producing a 3d image of it). The balloon structure of SHEPHERD opens and encloses around the asteroid and seals it from the vacuum of space. Xenon gas at 0.1 atmospheres pressure is introduced into the enclosure. The gas slows down (force of friction) the tumbling asteroid until it stops.

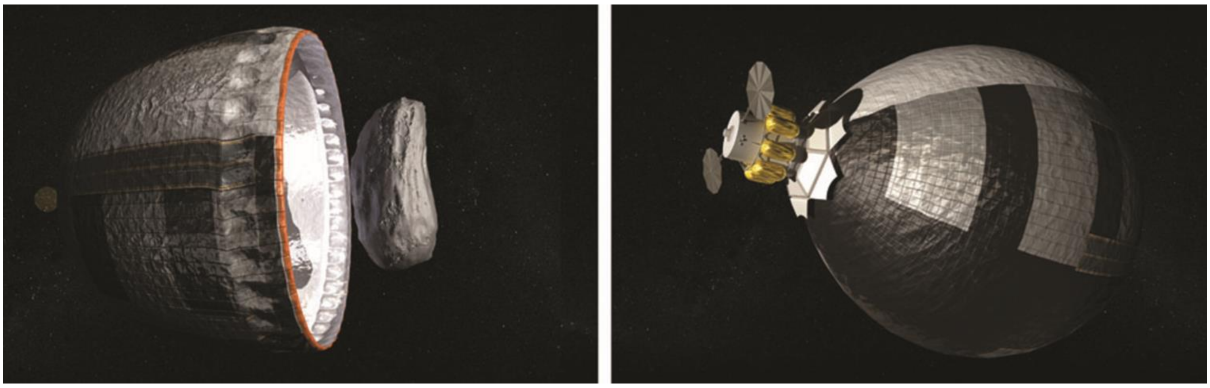
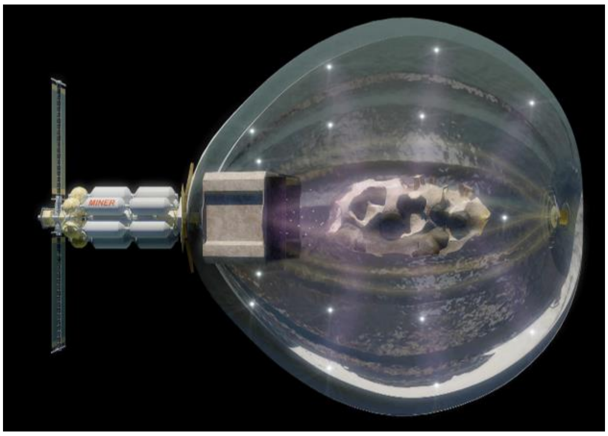


Image: courtesy of Dr Bruce Damer's slides

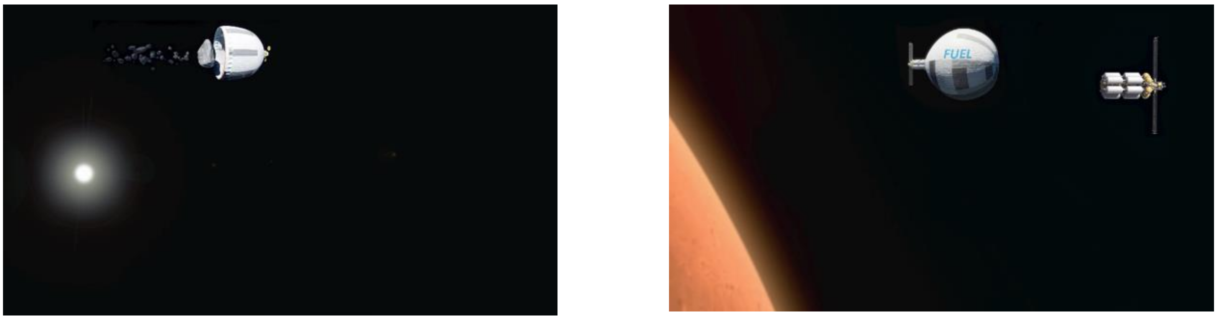
Waves of gas are now sent towards the captured asteroid, *which is still sealed in the balloon and gas envelope* . By Newton's third law of motion *that for every action there is an equal and opposite reaction*. The space craft moves in the opposite direction to the wave of gas incident on the asteroid. A propelling force of 1.5 N will be generated by the gas wave interaction, giving a delta-v of 100 ms^{-1} to the craft. This method could be used to capture weakly consolidated asteroids in the asteroid belt and move them to High Ceres Orbit for processing.

The initial proposal for SHEPHERD is for the capture of asteroids ranging in size from 100 tonnes to 1000 tonnes, it is also scalable. Having an asteroid enclosed in an envelope means that some processing of the asteroid can take place. Water can be boiled/fractioned off from an asteroid by heating its interior. This water could be stored in tanks attached to SHEPHERD. A nickel-iron asteroid could be further processed elsewhere using the 'Mond' process (mentioned earlier), carbon monoxide gas driven through the partially separated metallic asteroid producing ultra-pure nickel and 'six-nines iron'. *These metals can be further processed downstream to produce a metal feedstock for our 3D printer.*



A nickel-iron asteroid being processed in carbon monoxide gas Image: Dr Bruce Damer's, TED×SantaCruz Talk[16]. Screenshot-[6mins, 01 secs]

SHEPHERD will open a range of possibilities for space exploration. Icy objects exist beyond the solar system's snow line, these could be captured processed and brought to anywhere in the solar system. Water and other volatiles (note; H_2O can be electrolysed to produce H_2 and O_2) could be placed at various points in the solar system. Water and volatiles will likely be a valuable commodity in space.



"SHEPHERD" capturing and processing an object in outer solar system Images: Dr Bruce Damer's TED×SantaCruz[16]Screenshots [7.00mins](Left image) and [7mins 08 Secs](Right Image)

An Updated Design and a New Material for a Space Elevator Tether

Our design for a space elevator is based on Dr Bradley C Edwards' inspirational 2003 *NASA Institute for Advanced concepts Phase II Final report*. We have also incorporated the latest space elevator thinking from the *International Space Elevator Consortium (ISEC).*
In Dr Edwards' 2003 conceptualised space elevator design, carbon nanotubes were used for the tether, but *Single-Crystal Graphene* has emerged as a major new contender for a tether material. This material *Single-Crystal Graphene ('Nixene')* meets the physical tether properties target, as determined in the ISEC and IAA (*International Academy of Aeronautics*) feasibility report on space elevators[30](2013).

Single-Crystal Graphene ('Nixene') ISEC

Comparison with target : MATERIAL PROPERTIES

	CNT Target	NIXENE
Yield Strength	49.3 GPa	124 GPa
Density	1300 kg m^{-3}	2260 kg m^{-3}
Specific Strength	37.9 MYuri	54.5 MYuri
Young's Modulus	1000 GPa	1000 GPa

Sources :
CNT : ISEC studies based on "Space Elevators : An Assessment of the Technological Feasibility....", IAA 2013
Nixene : A. Nixon, July 2018 : atomic layer separation = 0.34 nm
CNT = Carbon Nanotubes

Single-Crystal Graphene ('Nixene') ISEC

Impact on Earth Space Elevator Design

No change in climber loads or safety margin (40%),
Tether dimensions : 100,000 km long x 1m wide

	CNT Target	NIXENE
Tether Thickness at Earth Port	10.5 micron	4.2 micron 12,333 atomic layers
Tether Thickness at GEO	64 micron	14.7 micron 43,167 atomic layers
Taper Ratio	6:1	3.5:1
Total Tether Mass	6540 tonnes	2740 tonnes
Apex Anchor Mass	1900 tonnes	1455 tonnes
Working Stress	35.2 GPa	88 GPa
Nominal Strain	3.5 %	8.8 %

Based on calculations by J Knapman and P Robinson

Images: With kind permission of Nixene Ltd

What is single crystal graphene ? We will first look at graphene. This material was first isolated in 2004 from graphite (material in a pencil). It is a 2-d 'super' material (it is one atom thick) and layers of graphene attach to each other by Van der Waals forces to form graphite.

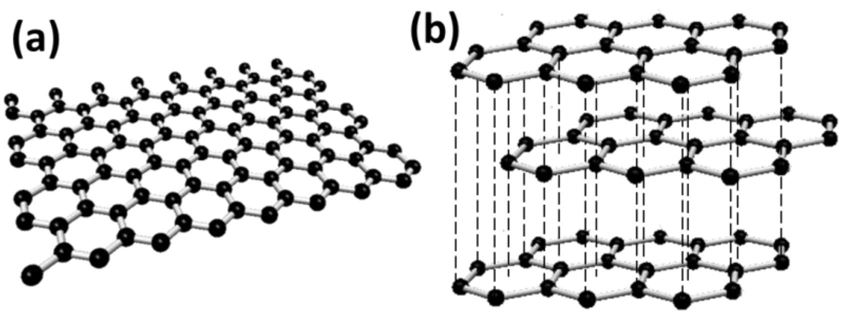
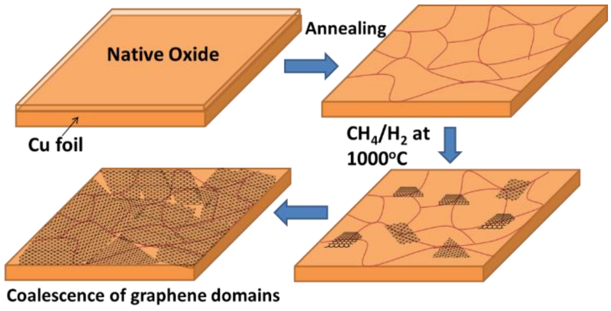


Image (a) graphene (b) graphite, layers of graphene held together by Van der Waals forces
Ref:intechopen.com/books/advances-in-graphene-science/synthesis-and-biomedical-applications-of-graphene-present-and-future-trends[23]

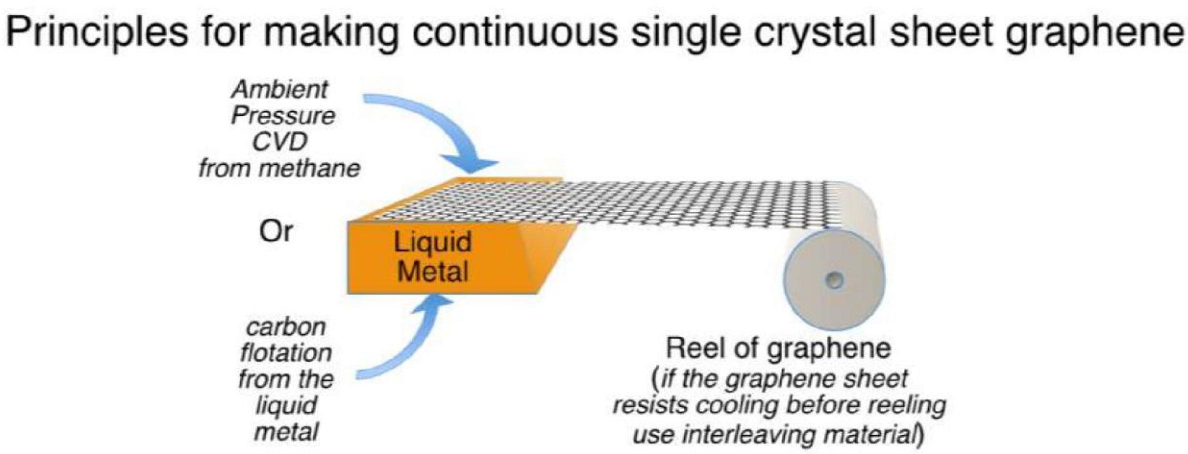
Non single crystal CVD (chemical vapour deposition) graphene can be made using the process below[23]. *'Copper oxide at the surface of the copper foil is reduced after annealing at 1000°C in a H_2 gas environment, the exposed Cu,* ***copper develops grains on its surface****. The Cu foil is then exposed to CH_4 and H_2 atmosphere at 1000 °C. The grains formed on the surface of the copper, cause imperfections to arise in the graphene so it is not a single crystal'*[23]



Ref:intechopen.com/books/advances-in-graphene-science/synthesis-and-biomedical-applications-of-graphene-present-and-future-trends

To date *Single crystal graphene* has been made in small amounts, initially in Peking[27] (*X. Xu et al, 2017)*. However, 1000 km long graphene sheets (one metre wide) are required to produce a space elevator tether. How do we modify this process to produce single crystal graphene? -A proposal for a method to produce km long sheets of this one atom thick graphene material has been made by a Manchester, UK based chemist Adrian Nixon and his company Nixene Ltd.

Nixene Ltd, who are based in the Graphene Innovation Centre in Manchester (GEIC) propose using a fast process method to produce graphene **without grain boundaries** (*single crystal*). This new process concept which is currently under development is outlined in the diagram below.



Graphene: A new continuous process. Image: With kind permission of Nixene Ltd

The single sheets of graphene will be layered to form a super strong synthetic version of graphite called ‘Nixene’. It is proposed that the elevator tether could be constructed from ‘ Nixene’.

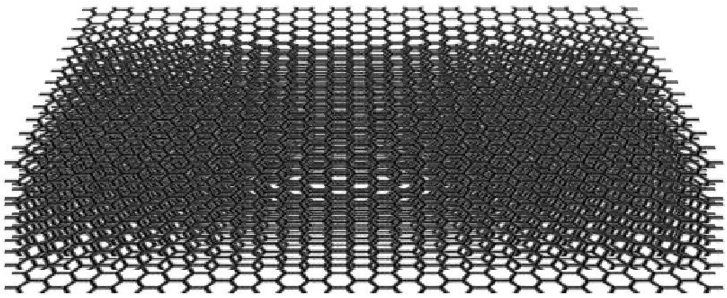
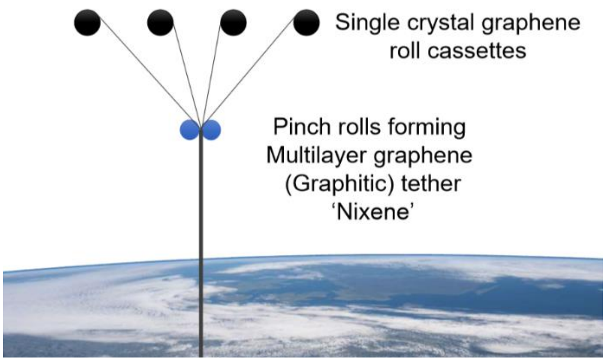


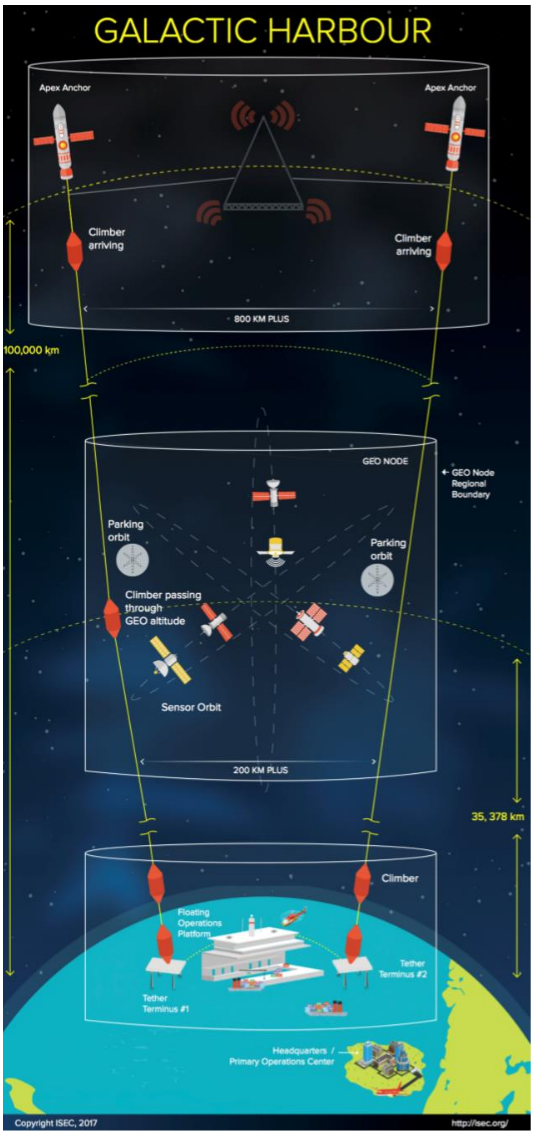
Image: multi layered single sheets of graphene forming ‘artificial graphite’, ‘Nixene’ Nixene Ltd

The deployment of a space elevator cable begins with the launching, by conventional rockets, of a space craft (in modular form) containing spindles of a ribbon made from *Single -Crystal Graphene*. The mass of the elevator system launched would be in the order of 140 tonnes (using figures from Dr Edwards’ paper[29]). Launching could be done by employing three Falcon Heavy rockets with a payload of ~ 64 tonnes each. The modules would initially be launched to LEO. The required configuration of the ribbon deploying space craft could then be completed by connected the launched modules together. The ribbon deploying craft can then be powered to GEO by rockets attached to the modules.



Above image: Nixene Ltd

Right image: isec.org



A cable wound on motorised spindles, would first be lowered from a space craft orbiting at 35,000 km above the Earth, in other words in a parking orbit. So that it would be continuously in orbit above the same spot-on Earth, thus rotating around the Earth at the exact same rate as the Earth is spinning, that is, at a geostationary point. The cable is lowered until it reaches the surface of the Earth (~ two weeks to lower [29]). When at the surface it is caught and attached to a platform floating in the sea. At the same time as this cable is lowered, another is extended away from the Earth’s surface, *to maintain centre of mass at GEO*.

Comparison of Bradley Edwards' NIAC 2003[29] plan and ISEC's

<table>
<tr><td>Bradley C Edwards, NIAC 2003 proposal</td><td>ISEC suggested refinements of NIAC 2003[30]</td></tr>
<tr><td>

Deployment:

On Earth a 91,000 km long (minimal thickness) carbon nanotube ribbon is wound onto a spindle
It is launched together with self-propelled modules, the cable unit and modules combine at Low-Earth Orbit (LEO) to form a cable deployment system
The assembled unit then uses rockets to move up to (GEO)
As the cable is deployed towards the Earth the deployment system moves itself above GEO in the opposite direction (to maintain cable centre of mass at GEO)
The Earthward end of the cable is anchored to a movable platform, which is itself anchored to the seabed (Marine Node)
Platform located in the Indian Ocean and west of Perth, Australia.

</td><td>

As in NIAC 2013 but a more strategic approach:

Tether cable made from 'Nixene'

The Marine node/Earth Port to:

Support two tethers, each with their own apex anchor (A powered satellite which can monitor and adjust the tension and dynamics of the tether)
The transportation subsystem to be operated from the GEO node
Be located adjacent to a conventional harbour close to the equator and an airport
Concept of a cylindrical region around it, 'The Galactic Harbour'

</td></tr>
</table>

The initial cable is strong enough (capable of carrying one tonne) to allow motorised climbers to ascend the cable from Earth, the climbers powered by light, emitted from lasers on earth and directed at solar cells attached to the climbers. The climbers reinforce the original cable by laying further cables behind them and attaching these cables to the original. The original cable will be thickened by a factor of twenty (Capable of carrying a load of twenty tonnes).

If single crystal graphene can be developed it will allow the space elevator to be developed. The galactic harbour idea means that resources are concentrated, and the elevator port isn't in the middle of nowhere.

We will use the Galactic harbour Space Elevator, initially to send robots to Ceres, in order to begin mining and building the Space Settlement. Eventually to send people to Ceres. Chemical rockets can launch from the fast-moving Apex anchor at the tip of the elevator ribbon, thus requiring less energy to get to CERES, as they will already have a large velocity.

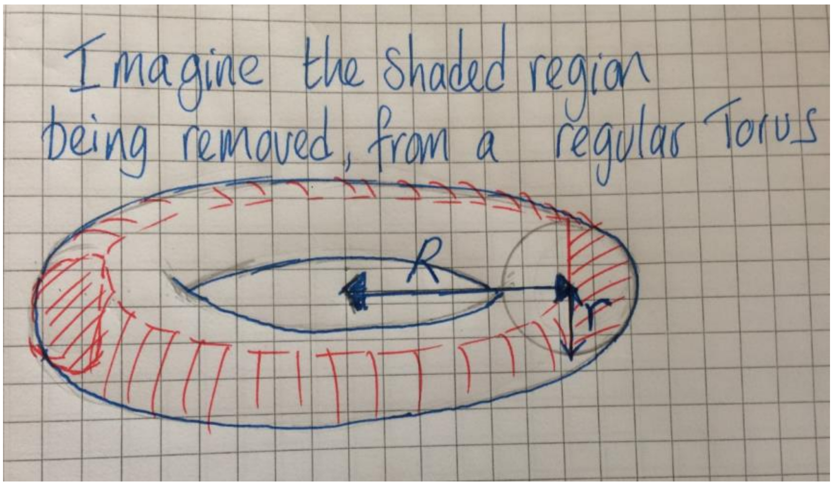
Volume and Rim area of Mag Mell

How we found the Volume of a half-Cut truncated torus

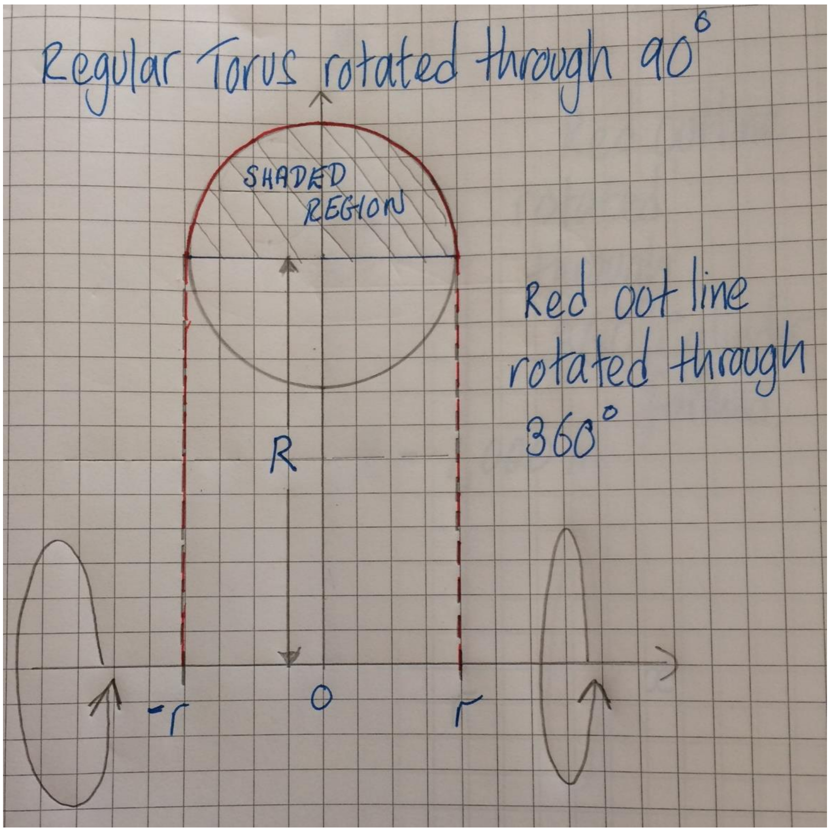
We are using a slightly unorthodox method to find the volume of a half-cut torus. First, we look at a regular torus and find the volume of the half that would need to be removed to make it into a half-cut torus. We do this in two stages and call the volume removed the shaded region.

Next, we subtract the shaded region from the volume of a regular torus and this gives us the volume of the half-cut Torus.

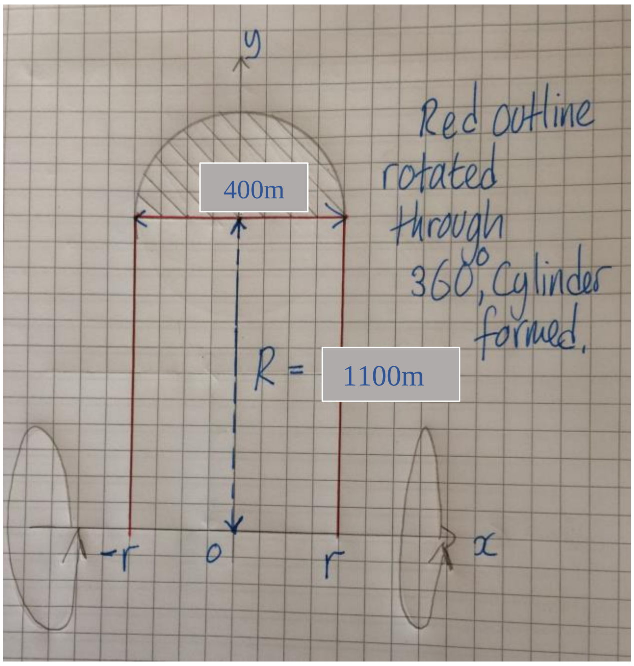
Sketch of a Torus with outer half shaded …the shaded region.



In order to find the shaded region, we first orientated the torus as shown and found the formula for the volume of a shape formed by rotating the area outlined in red through 360°. We call this volume, $\mathbf{V_1}$



we rotate the region marked in red through 360°, a cylinder is formed, we can use the formula for a cylinder $V=\pi r^2h$. We call this volume, V_2



Derivation of formula used in order to find, V_1

First imagine a 360º rotation between, $-r$ and r

R is the major radius. We will first rotate through 360 degrees the y-values between (x = -r) and (x = r) , the radius R is treated as a constant, and r is the minor radius

Starting with circle: $x^2 + (y - R)^2 = r^2$

Rearranging gives: $y = \sqrt{r^2 - x^2} + R$

Then for a Volume of Revolution from x = 0, to x = r (easier to do this)

$$\pi \int y^2 dx = \pi \int_0^r (\sqrt{r^2 - x^2} + R)^2 dx$$

$$= \pi \int_0^r ((r^2 - x^2) + 2R\sqrt{r^2 - x^2} + R^2) dx$$

Now taking each of parts A, B, and C individually,

Integrating **A** gives: A $= \left[r^2 x - \frac{1}{3} x^3 \right]_0^r$

$$= r^2(r) - \frac{1}{3}(r)^3$$

$$= r^3 - \frac{1}{3} r^3$$

$$= \frac{2}{3} r^3$$

To integrate **B**: B $= \int 2R\sqrt{r^2 - x^2} dx$

This is a circular integral, thus letting $x = rSin\theta$, we get:

$$\frac{dx}{d\theta} = r\cos\theta$$

$$dx = r\cos\theta d\theta$$

And so taking the constants 2 R outside the integral, we get:

$$B = 2R\int \sqrt{r^2 - r^2\sin^2\theta}\, r\cos\theta d\theta$$

$$= 2R\int r\sqrt{1-\sin^2\theta}\, r\cos\theta d\theta$$

$$= 2R\int r^2\sqrt{\cos^2\theta}\cos\theta d\theta$$

$$= 2Rr^2\int \cos^2\theta d\theta$$

Now to express the limits, originally in *x*, to limits in θ, where $x = r\sin\theta$:

$$\theta = \sin^{-1}\frac{x}{r}$$

Which for, $x = r$: $\theta = \sin^{-1}1 = \frac{\pi}{2}$

for, $x = 0$: $\theta = \sin^{-1}0 = 0$

Hence B becomes:

$$B = 2Rr^2\int_0^{\frac{\pi}{2}} \cos^2\theta d\theta$$

$$= 2Rr^2\left[\frac{1}{2}\theta + \frac{1}{4}\sin 2\theta\right]_0^{\frac{\pi}{2}}$$

$$= 2Rr^2\left[\frac{\pi}{4} + \frac{1}{4}\sin\frac{\pi}{1}\right] - 0$$

$$= 2Rr^2\left[\frac{\pi}{4} + 0\right] = \frac{\pi}{2}Rr^2$$

Integrating **C** gives: $C = \int_0^r R^2 dx = \left[R^2 x\right]_0^r$

$$= R^2 r$$

Hence recombining the results from A, B and C, we get

$$\pi\int y^2dx = \pi\left[\frac{2}{3}r^3 + \frac{\pi}{2}Rr^2 + R^2r\right] \text{... This is for} \quad 0 \to r$$

For volume between $x = -r$ and $x = r$

If, r = 200 m and R = 1100 m, this gives a Volume, V_1 = 1,988,303,760 m³ (1)

Volume of the cylinder, $V_2 = \pi r^2 h$ $\quad V_2 = \pi\,(1100)^2(400)$ = 1,520,530,544 m³ (2)

The volume of a non-truncated torus $\quad V_3 = 2\pi R\pi r^2 =$ 868,525,187.3m³ (3)

Volume of shaded region (1) - (2) = 4,677,729,15.7 m³ (4)

Volume of the truncated Torus,

is the volume of the non truncated torus minus the shaded region.

(3)-(4) = 868,525,187.3 − 467,772,915.7 = 400,752,271.6 m³ ,Volume of **Mag Mell**

Circumference and Surface area of rim

Outer rim radius, Let r = 1100m,

Circumference, $2\pi r = 2\pi(1100) =$ 6911.5m

The surface area of the rim is simply the curved surface area of a cylinder formula, $2\pi rh$,

Surface area of rim = $2\pi rh$, Outer rim radius, Let r = 1100m,

as, h=400 m, Surface area of rim, $2\pi rh = 2{,}764{,}602\ m^2$, floor area of **Mag Mell**

This gives an area of 2,766 m^2, per person on the settlement

Artificial Gravity on our Settlement

As **Mag Mell** rotates the outer rim, acts as a floor, the outer rim has to apply a radial centripetal force to the occupants or any objects inside to keep them moving in a circle. From Newton's Third law of motion (For every action there is an equal and opposite reaction), the equal and opposite reactions to this centripetal force, which any person or object exerts on the floor would act as an artificial weight. The value of this weight would be made equal to or less than the normal Earth weight by adjustment to the speed of rotation.

Thus, if the centripetal force, $F = mr\omega^2$ and artificial weight, $W = mg$

Then as $F = W$ $\quad mr\omega^2 = ma$

Cancelling the masses, m $\quad r\omega^2 = a$

Distance of axis of rotation to the inner rim is 1100 m

Thus, using this radius to calculate the rotations per minute necessary to produce

$a = g = 9.81 \text{ m/s}^2$

Using $T = \frac{2\pi}{\omega}$ where T, is the time for one revolution

Thus, using this radius to calculate the rotations per minute necessary to produce

$a = g = 9.81 \text{ m/s}^2$

Using $T = \frac{2\pi}{\omega}$ where T, is the time for one revolution per second

And where ω, is the angular velocity in radians per second.

Thus $\quad a = r\omega^2, \Longrightarrow \frac{a}{r} = \omega^2$

$\Longrightarrow \frac{9.81}{1100} = \omega^2$

$\Longrightarrow \frac{\sqrt{9.81}}{\sqrt{1100}} = \omega = 0.0994436$ rad/ s

$\therefore T = \frac{1}{f}$ and $\quad f = \frac{\omega}{2\pi}$ where f, is the frequency in Hertz

$f = \frac{0.0994436}{2\pi} = 0.015030$ Hz or cycles per second

The rotation rate in rpm = f × 60

rpm = $\frac{0.09904544412}{2\pi} \times 60 = 0.902$ rpm, **Rotation rate of Mag Mell**

Placing our Space Settlement in High Orbit around Ceres

- High Ceres Orbit, with circular equatorial orbit[31], r = 100,000km for stability, very little attitude control propulsion required
- High Ceres orbit has a period les than the rotation period of Ceres
- The micro gravity environment of high orbit means that mirrors attached to the settlement (*as in the Stanford torus*[34])
- The micro gravity environment of high orbit means that solar cell arrays can be linked to the space settlement in the same way as the mirrors
- Ceres rotates at a high rate (T = 9h 4m) and a has a low surface gravity value, $g = 0.28 m/s^2$
- Ceres is an ideal place to build a Space Elevator (*low-g and fast rotation rate*)
- The sub-surface of Ceres[32] is believed to contain huge volumes of water (*saline oceans*) and volatiles including large amounts of nitrogen (needed to make an Earth like atmosphere)
- The inhabitants of Mag Mell will be close to a large celestial body. That is ~100,000km or 0.26 times the Earth-Moon[33] distance. Useful in an emergency
- Ceres is in the asteroid belt, where the most accessible resources in the solar system are concentrated

The Ceres Space Elevator and robotic mining

- The elevator tether will be fixed to the equator of Ceres
- Length of ribbon[31] will be 1024km
- Stationary orbit at Ceres is some 722km
- The ribbon will be 5 cm wide and 25 micro-metres thick
- The ribbon is made from a polythene fibre, called dyneema[35] and can lift 500kg
- The elevator will be powered by solar panels, placed on the surface of Ceres
- Elevator tip speed $v = r\omega$, as $r_{ceres} = 470$km, l_{tether}=1024km and $\omega_{ceres} = 1.923\times10^{-4}$
  Hence, $v = (1{,}024{,}000+470{,}000)(1.923\times10^{-4}) = 287$ m/s
- Material mined from Ceres can be lifted towards Mag Mell using the elevator

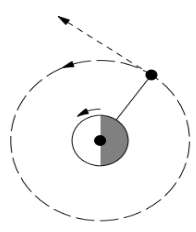


Image: *Ceres mega-satellite world* [31]

Super-Powers for Space

Introduction

If we put all moral, ethical, political, economic, social, technological, legal, and religious aspects aside for the moment, could we genetically engineer humans for survival in space? This is an interesting question and something that we need to explore if humans are to consider colonising, living, and surviving outside the environment we know as planet Earth.

To first investigate what 'super-powers' we would need, we need to understand what barriers and issues we face currently. There are the obvious ones like being able to breathe in an oxygen depleted vacuum, keeping body temperature stable in extreme cold temperatures, preventing lungs from rupture because of the different atmospheric pressure. Threats like radiation from the sun and the rest of the universe make this environment challenging too and long-term issues such as sustaining a regular supply of food and clean water seem difficult to imagine.

So basically, we know that we need to adapt in a huge way to sustain life outside of planet Earth and much work has gone into engineering spacecrafts, suitable spacesuits and even designing suitable foods for our current existence in space, but what if we were to acquire 'superpowers' that made it possible to adapt to this challenging environment?

Effects of the human body in space

In an amazing study carried out by NASA in 2015, identical twins Scott and Mark Kelly, both astronauts, were comparably studied when Scott spent a year in space aboard the International Space Station (ISS) and Mark remained on Earth[36, 37]. The aim of this research was to investigate and understand how space flight can affect the human body. This NASA Twins Study was the first of its kind where scientists examined physiological and psychological factors of both twins over a period of 340 days.

Samples of Scott's blood, urine and faeces were taken before, during and after being in space to ascertain any changes which occurred from the change of environment and also compared to Mark's samples.

It was found that Scott's genes showed many chemical markers known as epigenetic tags because of his duration in space[37]. These epigenetic tags affect how genes work and can be added or removed due to environmental factors. They can influence gene activity to turn off or on. It was found that some of Scott's genes changed more than others, and this also helped regulate his DNA, for example in the repair of DNA.

Also, telomeres, which are the tips of chromosomes, had changed in length. This was significant because it is believed that telomeres can protect against aging and health risks, such as cancer and heart disease. However, once Scott was back to earth those telomeres had quickly returned to normal and in some cases even shortening, indicating that he may be more at risk now from health issues.

Also, as a result of the change in environment, his immune-system genes switched into active mode as a response to try to understand and adapt. Other structural changes to his chromosomes were also noted and is it thought that these were natural and essential stress responses possibly caused by high-energy particles and cosmic rays in space.

Most of these changes reversed when Scott returned to earth, like his microbiome (bacteria in the gut), but some did not even after 6 months. These included factors such as his immune-system which remained at high alert and DNA repair genes being over active. One of the largest dangers in space is radiation and samples taken from Scott's urine showed signs of damaged DNA believed to be caused by radiation exposure.

While other physical changes in Scott were noted like muscle strength and bone density in space, his mental ability and cognitive performance was tested regularly, but when he returned to earth his short-term memory and logic tests were found to be slower.

Scientists concluded that this study demonstrated the 'resilience and robustness of how a human body can adapt to a multitude of changes induced by the spaceflight environment'. However, unsurprisingly there is still so much more to learn and understand.

The Next 500 Years

Whether we like the idea of moving to space/other planets or not, scientists believe that eventually our Sun will become too big and that our beautiful planet, as we know it, is doomed anyway.

In his book 'The Next 500 Years: Engineering Life to Reach New Worlds'[38] Christopher Mason discusses his ideas on how humans could adapt as a multi-planetary species. Professor Mason is a renowned geneticist and computational biologist at Weill Cornell Medicine in New York, working on many NASA missions and projects, including the NASA Twins Study of Scott and Mark Kelly.

He argues that by doing nothing, extinction of the human-race is inevitable, so why not explore possible options and solutions. We have a duty to our species and while the risks are high, ultimately if we value life and that life will end on earth, we need to experiment in futurism. If we imagine the future around us, what will it look like in a thousand years? Our ability as humans makes us unique to imagine decay in the very long term, no other species can do this, so we need to plan and look ahead far into the future since it will take a very long period of research and experimentation to mitigate against the risks of space and sustaining life on other planets.

With the recent advances in research, from understanding genetics to the development of new drugs, learning what challenges the human body faces and using these to modify humans for space living is not as science fiction as it might seem. Christopher refers to other species such as the tardigrades, known to be able to resist ionizing radiation, extreme temperatures, and pressures. They have 'dsup' damage suppressor proteins which protect their DNA or elephants having P53 tumour-suppressor proteins, which are guardians of genome cancer prevention. Perhaps we need to consider borrowing genes from other species and making our own evolutionary journey towards adapting to new environments.

The development of a human hybrid system is not so strange if you consider that we have already evolved as hybrids naturally. Therefore, whether it happens accidentally or by careful design does it really matter? If we need to survive zero gravity then a lower cardiovascular system is better, or perhaps the concept of chloro-humans which can photosynthesis their food, or even people with disabilities as we know them on earth may have superior abilities for other environments? For example, do we need new eyes for new planets… for seeing in low light, UV or the infrared spectrum?

If we are to survive in space, then propagation is also an interesting question. Can an embryo born in space have the range of genetics to support its existence on many environments? What does it mean for the procreation of humans in the far future?

Can humans be genetically engineered with ‘pleiotropy’ – genes that can do many things and have an influence on other genes? While of course there are ‘risks’ to this kind of thinking, Christopher believes that any experimentation needs to be on an informed and consent basis, there needs to be ‘pioneers’ who are willing to take a leap for the greater good of the human race.

Tardigrades – can their DNA be adapted to humans?

Mentioned previously, tardigrades seem to have ‘super-powers’ that have enabled them to survive in the harshest environments for many years without food and water. So, what are these magical creatures and how do they do it?

First discovered in 1773 by German zoologist Johann August Ephraim Goeze, these tiny species are about 0.5mm large (size of a full stop / period stop) and are mainly found living in mosses and lichens.[39] Goeze named them ‘Waterbears’ because of their appearance.

These amazing animals have been found at extreme conditions on earth and are known to be the most resilient of all species. They are known to have survived extreme temperatures and pressures, air deprivation, radiation, dehydration, starvation and even outer space.[40]

They can stop their metabolism and become ‘immortal’, a state called cryptobiosis. They have the ability to squeeze all water from their body, retract their head and limbs and roll into a ball, effectively becoming dormant. Levels of trehalose, a disaccharide essential for surviving drying have been detected in these animals showing that they have biological mechanisms for surviving desiccation (drying). Intrinsically disordered proteins (IDPs), as found in tardigrades, are highly expressed in response to desiccation.[41] Further research work in this area continues.

More impressively are their ability to guard themselves from radiation.[42] It is believed that unique proteins in their bodies called Dsup protect their DNA from being harmed from ionizing radiation, acting as ‘damage suppressors’.

Also, while UV radiation is lethal to most organisms, a study on tardigrades showed that they exhibit natural fluorescence under UV light that protects them against this radiation.[43] This ‘photoprotection’ by fluorescence uses the fluorescent compound which forms a ‘shield' against UV radiation, protecting these tardigrades from these lethal effects.

These tiny, unsuspecting species may hold some of the science secrets that could aid human evolution either directly or indirectly by revealing their biological mechanisms and genetic armour. While their stress tolerance has been summarised in many fields, this research is still in its infancy.[44]

Genetically modifying Humans

Genetic modification has always been a very controversial subject. However, if you take it for the greater good, there are now many areas of research of huge interest and one of these is the use of CRISPR technology, which has been used in the food and farming industries from engineering probiotic cultures to enhancing crop yield, drought tolerance and nutritional value.[46, 47]

As a gene-editing tool, CRISPR allows scientists to alter DNA sequences and modify gene function. The possibilities are mind-blowing when you consider that it may be possible to fix hereditary defects, treat many diseases and also act as a prevention mechanism to these. CRISPR (or CRISPR-Cas9) are specialized stretches of DNA, where an enzyme (protein Cas9) can cut strands of DNA, like a pair of molecular scissors, effectively removing or adding in DNA in order to suit the application, hence gene editing.

First demonstrated in 2007 in yoghurt[47], to acquire resistance against viruses in Prokaryotes (single-celled organisms) and hence controlling bacterial immunity, this 'cut n paste' approach makes it possible to modify DNA. For example, as Christopher Mason[38] suggests in the reactivation of vitamin C for space adaptability. Humans have the gene to synthesis vitamin C in our genome, but it has been degraded, tweaking genes via CRISPR could be one possibility. The other being Epigenome editing – transiently turn genes on or off Prof Mason states.

Advantages versus Disadvantages of Human Genetic Engineering

While it sounds plausible the technology is not without its downside. Humans are a complex species and natural evolution has enabled us to progress to this stage. Accuracy and effectiveness of any gene editing systems need to be key, as the consequences of errors could be catastrophic.

While there is reasoning on why we should think about genetically modifying humans, unexpected changes when modifying genes in existing biological systems leading to mutations or alterations in the regulation of gene expression need to be considered carefully.

On one hand, curing and preventing diseases seems a positive advancement, but can the introduction of 'designer genes' be regulated effectively? What can we learn about our future needs from current space exploration? While our knowledge has increased there is still much of the unknown to investigate and it is only in very recent years that we have begun to study the basic effects on humans in space.

In one study carried out by Dr Larry Kramer[48], human brains have been found to get larger in space which may have detrimental impacts on vision. According to Dr Kramer at the University of Texas Health Science Center, at Houston, 'the astronauts' brain volume increased by 2 per cent on average and the increases were still present one year after they returned to Earth, which could result in higher intracranial pressure'. It is believed that that microgravity prevents the fluid in the brain moving downwards (as it would do on earth with gravity), resulting in accumulation of fluid in the brain and skull. This causes pressure on the optic nerve, worsening their vision.

One change can have multiply effects on the human body and also any effects can be unique to different individuals. Age, race, gender, health are factors that cannot be ignored.

Conclusion

It would seem that we are still at the beginning of trying to understand what ‘super-powers’ we require to be able to survive long term in space. As well as environmental stressors such as microgravity and radiation, the space environment is made challenging by factors including confinement and isolation. Social and psychological impacts are more difficult to measure and can be very individualistic, just like the impact of social media or climate change over the last few years. We are continually adapting to new ways.

Finally, it is always good to get a balanced view. We should also consider opposing comments to these rational concepts and Richard Jones[49] summarises it as follows:

‘We may be the most intellectual creatures on this planet, but are hardly a role model…

…We kill our fellow humans in wars and our self-centred attitudes have eliminated many other species. Positive human traits are countered by the infiltration of greed and crime throughout society. We are already well on the way to creating a planet that is largely unfit for us to live on. Should we really seek to transfer these attitudes more widely?’

Ceres

"*Tucked into the asteroid belt between Mars and Jupiter, the dwarf planet Ceres is a small world that holds big surprises. A slew of new research from NASA's Dawn spacecraft advances the case that—in its own cold, salty way—Ceres is a geologically active body, with ice volcanoes and surviving pockets of an ancient ocean.*''-National Geographic

3-d image of Ceres

Click & Rotate

https://solarsystem.nasa.gov/resources/2400/ceres-3d-model/ : Image credit

- Located in the asteroid belt between Mars and Jupiter lies an exciting dwarf planet named Ceres.
- Previously an asteroid, Ceres has now been labelled as a dwarf planet which has become an exciting target for human colonisation due to its interesting conditions.
- Ceres has proven to be an interesting location as unlike many other terrestrial bodies, Ceres has an interesting level of geological activity.
- During NASA's Dawn project interesting research was conducted on Ceres and thousands of photos were taken of Ceres's surface.

A comparison between Ceres and Earth[54]

	Earth	Ceres
Volume	1,083,206,916,846km^3	452,331,448km^3
Surface area	510,064,472km^2	2,849,631km^2
Orbit	365.25 days to orbit the sun	4.6 years to orbit the sun
Rotation	23h 56m	9h 4m
Temperature	≈ +15° C	≈ -73° C to ≈ -143° C
Surface Gravity	9.80665m/s^2	0.28m/s^2
Density	5.513g/cm^3	2.09g/cm^3
Mass	5,972,190,000,000,000,000,000,000kg	947,000,000,000,000,000,000kg

The significance of the NASA Dawn mission[53]

Ceres gained scientists attention when in 2015, the dawn spacecraft captured pictures of Ceres using both visible and infrared wavelengths.

These images were then combined to produce false-colour images of the surface of Ceres.

Dawn provided substantial findings as pictures from as close as 225 miles from the surface were captured.

Findings from this research indicates a number of unique aspects of Ceres' environment including:

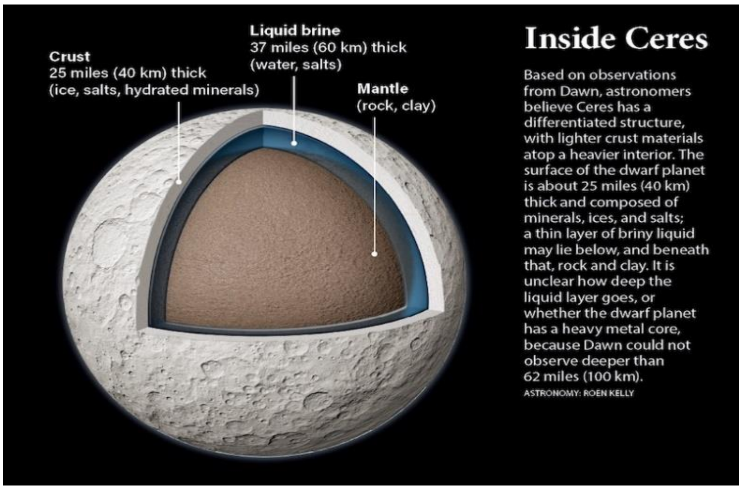
1. There are approximately 130 'bright spots' on the surface of Ceres
2. The surface of Ceres contains carbon-based compounds.
3. The atmosphere of Ceres contains water vapour
4. Ceres has a 'watery' sub surface

The strange nature of Ceres' sub-surface

Further examination of the Occator crater has given sign to the formation of these 'bright spots. The bright spots present on Ceres's surface are particularly intriguing as they can be accredited to cryo-volcanism, an indication of recent geological activity in space.

The formation of the Occator crater fractured Ceres's crust, which left deep grooves that enables salty brines to root their way up to the surface. Upon reaching the surface, the water evaporated, resulting in the formation of bright salty deposits along the surface of Ceres.

Our knowledge of Ceres is transforming each day and recent research from Italy's National Institute of Astrophysics has indicated that Occator's 'bright spots' may also contain hydrated sodium chloride[52]. This water should boil off the surface within a hundred years, yet strangely it remains hydrated. Perhaps this could be an indication of current geological activity on Ceres.



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Agriculture and Food Production

This space settlement will produce all of its food independently. A sector of the torus will be designated to food production and preparation for its 10,000 inhabitants

System of food production[56]

Hydroponics. Soil will not be used as a growing medium for the crops and instead, the roots will be suspended in a solution of richly oxygenated nutrient balanced water solution[38].

There are many advantages to this system:

Roots need oxygen to carry out respiration and grow. The hydroponics water reservoir provides more oxygen for the roots than any type of soil and leads to **faster growth**

As a plant grows, the type and amount of nutrients it needs changes dramatically. With hydroponics, the nutrients in the water can be adjusted accordingly allowing for faster growth than soil, which keeps the same nutrient balance throughout growth.

Hydroponics systems use 20% less water than soil as no water is absorbed into mineral particulates

Water can be reused, and no water is lost outside of the plant and its roots

Urine waste from the inhabitants can be processed to provide the water solution and the urea and proteins can be chemically processed into nitrate fertiliser for the plant.

There is less risk of disease to crops and to humans as the water solution is sterile. Soil of all kinds is full of pathogenic microorganisms and organisms

Hydroponics System Design[54]

- A nutrient reservoir filled with pure water and nutrient needed by the plants growing in the solution.
- A mesh made of soft plastic at the top of the nutrient solution to hold the root bundle.
- Light Emitting Diode (LED) lighting panels above the crops[39].
- Condition monitoring instruments with readings displayed on a monitor near that specific reservoir. Conditions measured include humidity, pH, nutrient composition and balance and gas composition (CO_2, O_2 etc).
- Water aeration pump and air stone.
- For most crops, the ideal pH for hydroponics is between 5.5 and 6.5. Each nutrient reservoir will hold a specific crop type at a specific stage of growth.

- Air composition will be close to earth's atmospheric composition but with a slight increase in oxygen and higher amounts of carbon dioxide. This extra carbon dioxide may be sourced from the settlement's inhabitants.
- The nutrients used in the solution will be water soluble salts with no organic matter. The solution will contain all 17 commonly used elements by plants as in varying proportion. The main elements will be.
- Nitrogen for growth, protein production and chlorophyll production.
- Phosphorus for protein production and root health.
- Potassium, Sulphur, Calcium, Magnesium.
- Other micronutrients will be added in tiny amounts such as chelated iron, copper, molybdenum, and boron

Waste conversion to plant nutrients[55]

- Proteins are broken down in the body to urea through a process known as deamination
- Urea can later break down into ammonia gas NH3
- Bacteria called seprobiotic bacteria convert this ammonia into ammonium ion NH4
- Nitrobacter then convert this ammonium into the Nitrite ion NO2 with the use of oxygen.
- Nitrosomonas then convert this nitrite ion into nitrate NO3 which is the form of nitrogen used by almost all plants[55]
- Using this, human waste can be broken down to useable plant nitrogen through a bioreactor containing these nitrogen cycle associated bacteria.[55]
- Other nutrients can be extracted through chelation e.g. EDTA ,or isolated by chemical means from urine and faeces

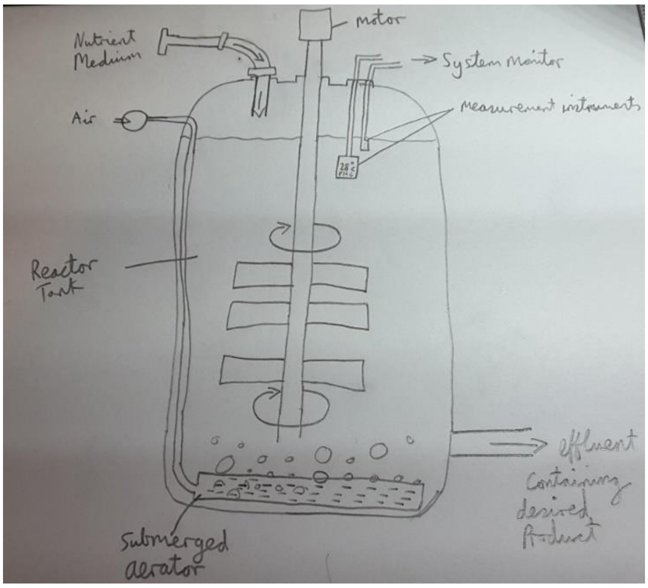

Image :Aerator of effluent. Chemistry Live textbook Dr Declan Kennedy, Folens.

- Nitrogen is the most difficult to process into a useable nutrient due to the long process. Other elements are instantly available to plants through salts (e.g Potassium Oxide, Phosphorus Pentoxide allotropes)
- Macronutrients can be taken out directly through chelation (zinc, iron, copper, boron, molybdenum)
- The result of this recycling pf nutrients is an efficient system where no useful resources are wasted

LED Lighting[58]

L.E.D lighting was chosen as a source of light for photosynthesis for many reasons. L.E.Ds convert nearly all of the received current into light energy[58] as opposed to other lightbulbs like incandescent and halogen that convert a vast majority of current into heat and infra-red (80%+). L.E.Ds also emit specific wavelengths of light. This is excellent for growing plants as chlorophyll and its secondary pigments are more efficient at absorbing light energy at certain wavelengths. With this in mind, the L.E.D lighting will consist of L.E.D chips of the following wavelengths: 430nm-520nm (blue spectrum). Blue light triggers phototropism in plants and encourages vegetative plant growth. Red spectrum light 615-620nm, 640-650nm encourages flowering and fruit growth of plants. Broad spectrum white light particularly in the blue spectrum (6000K) to provide other light waves used by plants. Ultraviolet light 380-400nm can prevent growth of microorganisms and prevent insect infestations.

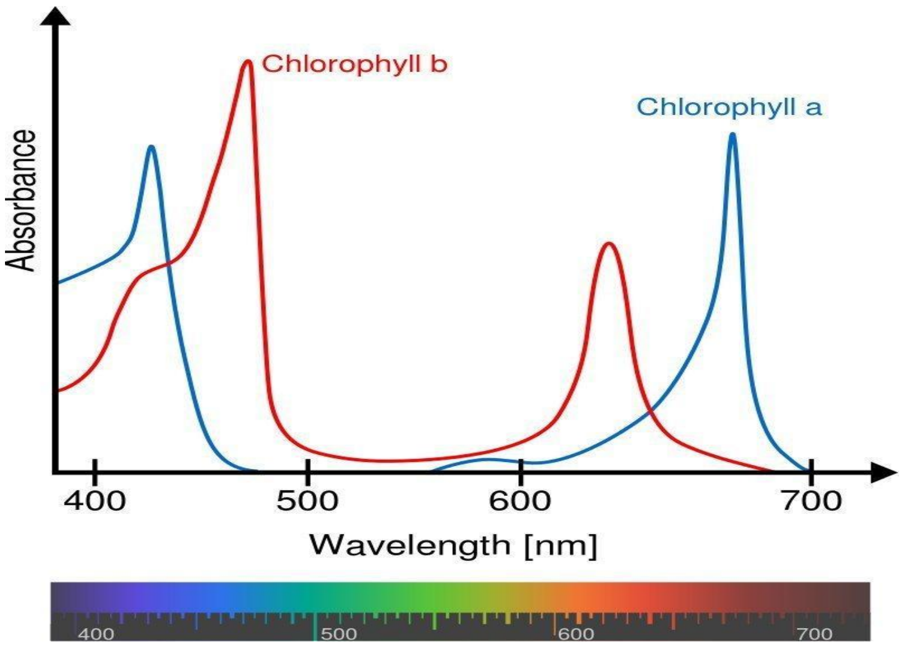

Image credit: https://sv.m.wikipedia.org/wiki/Fil:Chlorophyll_ab_spectra-en.svg

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The Woven City[59]

Woven city isa prototype city that they are currently building at the face of Mount Fuji on a 175-acre site. It will be used to test robotics, gadgets, AI, and smart homes in a real-world environment. Their aim is to create a better world for generations to come using hydrogen fuel cells and a beautiful ecosystem, and just like our station it will be **“a living laboratory.”** Think that many of their smart technology ideas would work very well on our settlement. Indeed, our settlement will be a living laboratory too.

It began construction in 2021 and will soon be launched as a full-scale inhabited city. It will have a fully connected ecosystem and will run on hydrogen fuel cells which creates and eco-friendly city and to help its environmentally conscious company they will use traditional Japanese woodwork designs, **blended with robotic production methods.** These will all be seeming weaved into place by native Japanese vegetation and hydroponic plants.

Mobility, getting around, is a priority, with three different types of roads[58]. One for faster autonomous vehicles, one for slow moving vehicles like bikes and scooters and there will be one road or “linear park” for pedestrians. This will create a grid system, where the three different types of roads are woven together. Hence ‘the Woven City’. The cars in the city are autonomous, we intend our settlement’s cars to be shared-use vehicles and autonomous also.

The Woven city’s residents’ lives will be enhanced by in-home robotics, as well as sensor-based AI, that will help around the house and with everyday tasks. This will also help boost the trust that people will have with AI and robotics. **People and robots will live and work together**.

The neighborhood parks and the large central park, as well as the central plaza will be used to encourage social interactions and human connection. Woven city is Toyotas “real world incubator” and will allow for elaborate testing and to improve the lives of everyone and everything. Toyota have really stuck to their motto “Built for a better world” with this project, as they revolutionize the lives of our generation and of generations to come.

Image: Toyota to build proto-type city of the future article[59]

The Commercial Opportunities for our Space Colony

Given the unique aura surrounding this project its entirely plausible to suspect that this project will capture major attention from the public. As a means of advertising certain firms may donate to this project in return for exposure. This concept may see the addition of corporate entities on our Torus (e.g., sponsored clothing, sponsored technology, etc.).

Image Credit: Geek wire[62]

Film Studio on the Space Settlement

As a means of promoting 'Space Culture' it may be worthwhile in considering offers from major entertainment companies. These companies may play a significant role in not only promoting the colony, but they may also result in the addition of a unique attraction to the colony (e.g., a film studio).

Benefits for the colony

- Promotes the colony to Earth
- Gains the attraction of other potential investing firms
- Would promote arts and creativity onboard the colony
- The colony could negotiate a large capital payment
- Creates employment

Benefits for the entertainment company

- Reduced CGI (*special effects)* costs
- A venture of this nature would gain major public exposure
- An opportunity exists for the company to launch into the Space-Film sector
- An opportunity exists to create a financially beneficial relationship between studio and the colonists

According to NASA over 650[61] million people watched as Neil Armstrong, Buzz Aldrin and Michael Collins became the first men to land on the moon as part of the Apollo 11 mission. ***Imagine the income the viewing numbers of this nature could generate for an opportunistic studio.***

Seemingly the concept of the entertainment industry in space is already gaining attention as by 2024 the world's first interstellar movie and entertainment studio is to launch for the International Space Station[60]. Movies filmed in space are currently quiet, however Tom Cruise is set to become the first actor to film a movie in space when he boards the ISS to film a movie over a period of 12 days.

With the addition of this new stellar movie and entertainment studio, content creators will have the ability to express themselves *from > 250miles above Earth's surface*. **A new frontier of creativity awaits!**

Zero Gravity American Football

On this space settlement, it will be important to have an outlet for its inhabitants to relieve stress and get physical activity. Sport will play an important role in this. In the centre of this space settlement, there will be an area where gravity can be manipulated. This is an area where I would like to propose that zero-gravity games of American football could take place.

Of course, to play this game in space the rules would have to manipulated to some extent. Some of the rule changes that would have to occur would be that of jetpacks being used to travel around that pitch. These would be to those used by Nasa crew while on spacewalks carrying out maintenance on the ISS.

The Story of NASA’s Jet-Propulsion Backpack | Science | Smithsonian Magazine [63]

Yards made in this game would no longer be called ‘Running Yards’. They would instead be called ‘Propulsion Yards’. This is necessary as the player would not actually be running.

Another rule change that would be necessary would be a change in the dimensions of the playing field. A standard American football field measures 100 yards long by 53 yards wide. In space, we would have to also account for a maximum height on this field. I propose that the normal ground dimensions are increased slightly to allow for the increased bulk of the propulsion aids and for a ceiling height of 80 yards to be put on the field of play. This is to account for the ball not dipping in the air once thrown to allow players to elevate themselves into the air to catch it.

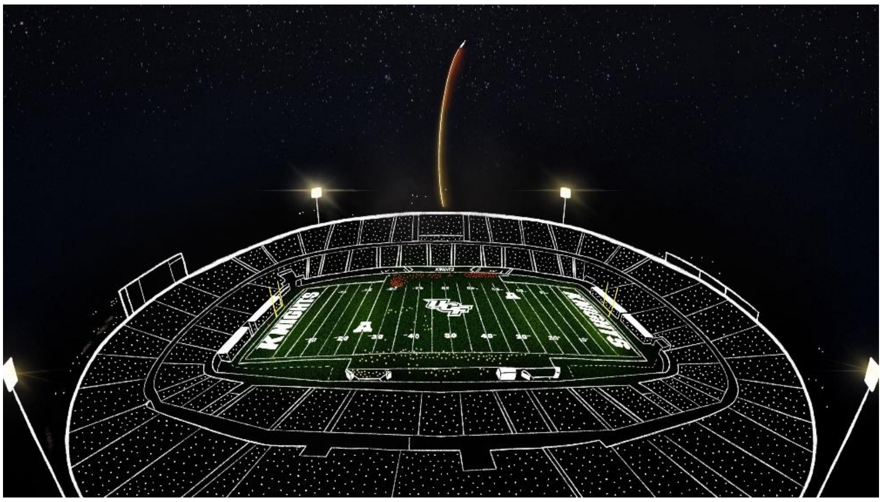

Image :UCF Knights Football Wallpapers - Wallpaper Cave

I believe that most of the other rules can remain. These games should continue to be played at full contact and punts shall remain as they are.

This shall not be the only form of sport on this settlement, however. I believe that as this will be a zero-gravity sports arena, it will be possible to recreate ‘Quidditch’ as seen in Harry Potter. This game involves flying around on broomsticks in an attempt to catch a ‘seeker’ ball witch flies around the arena. In this game it is also possible to score points by throwing a ball through the three circular rings of the opposing team. Although these space settlement inhabitants will not have broomsticks to fly around on, it is possible to make an alternative such as small metal poles with rockets attached.

For the people on the settlement who are less willing to enjoy these more extreme sports, there will be walkways and cycleways all throughout the settlement where walking, running and cycling can be enjoyed.

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