Project ASTRA

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Grade 9

Category: Individual

Table of Contents

1. Introduction

1.1 Why a Space Settlement?

The human species has been wandering into every place it can get to since we first split from the apes. The next place to wander to is space. After colonizing the Earth almost entirely, we are faced with the issues of a growing population and a potential lack of resources for the people of Earth. The answer to this problem is to colonize space.

Planetary colonies show much promise, however, with the human species being fine-tuned to living on Earth, it is difficult for humans to cope with an evolutionarily bizarre environment. Orbital settlements fix this issue by allowing for the fine-tuning of the environment based on human needs.

Astra is a proposed orbital colony created to expand the human species into space.

1.2 Why Astra?

Space settlements are massive megastructures. To launch orbital settlements, several super-heavy-lift rockets must be launched. These are very expensive, complex, and could cause other potential issues like environmental damage. In addition to this, the materials used in orbital settlements are also expensive and must be launched from Earth.

The Moon is abundant in resources and has low gravity allowing rockets to easily launch from the Moon. Considering the benefits of the resources and gravity of the moon, parts of Astra will be built on the Moon and sent into orbit from the Moon. It allows for the utilization of previously untapped lunar resources and does not require the use of many super heavy-lift rockets. Compared to rockets on the Earth, lunar rockets can easily launch and achieve required high speeds with minimal fuel.

Astra will expand the human species across the final frontier – the expanses of space.

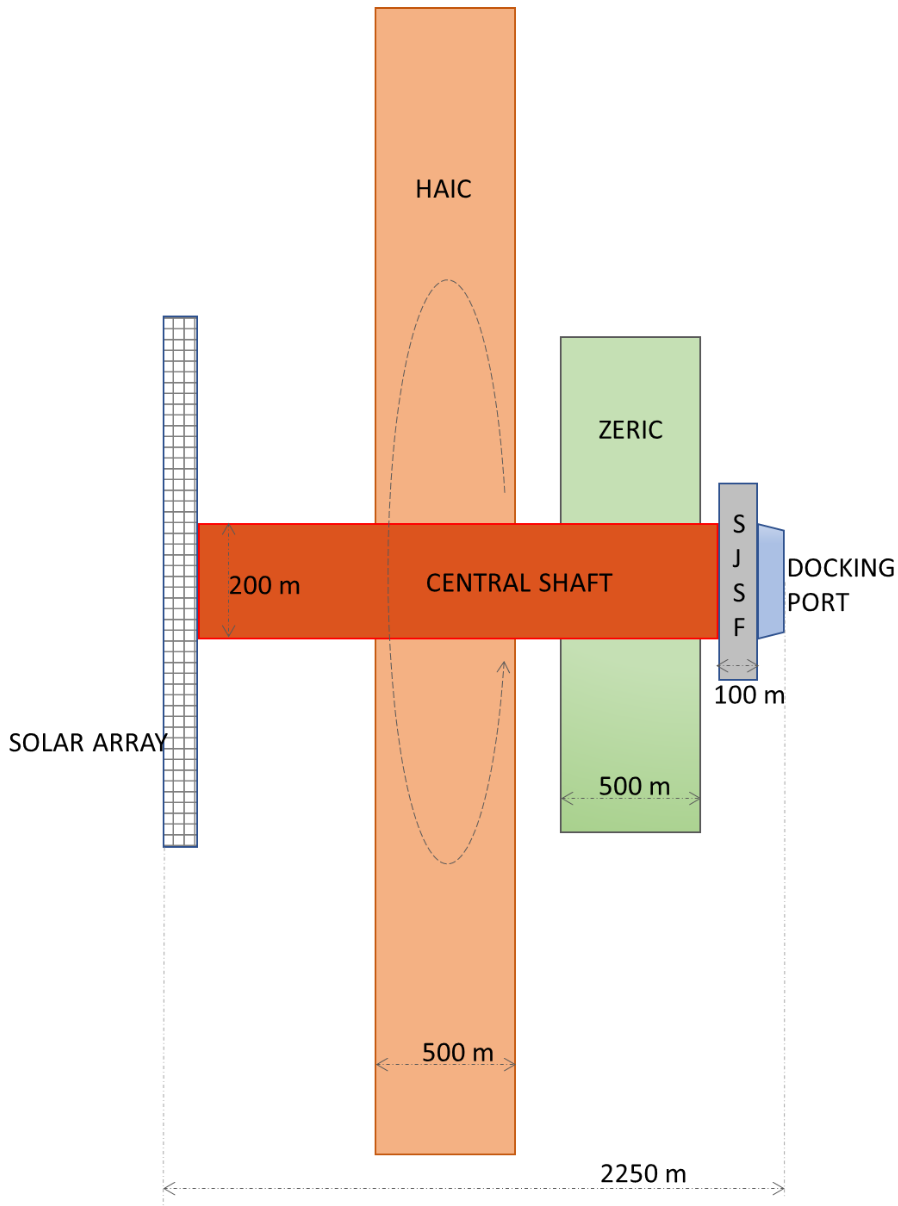
2. Settlement Design, Orbit, Costs, and Construction

This chapter describes the form and function of the settlement, the materials involved its orbit, economics involved, and how the settlement will be constructed.

It also provides a general overview of the settlement and provides an outlook on how the settlement works at a high-level, describing the most fundamental features of the settlement.

2.1 Settlement Structure

Astra will consist of 4 major parts – the Habitation and Agricultural Complex (HAC), the Zero Gravity Recreation and Industrial Complex (ZERIC), the Space Junk Storage Facility (SJSF), and the central shaft, which holds everything together.



2.1.1 Habitation and Agricultural Complex

The HAC is perhaps the most important part of Astra. All habitation will take place on the HAC. It is where people live, play, learn, get entertained, and work. In addition to this, all habitation activities will take place in the HAC, due to its constant natural sunlight.

2.1.1.1 Form

The shape of the HAC needs to allow for a large population to live in an artificial gravity area easily and safely. For a rotating pressurized structure, there are a few options which come to mind for the shape of the HAC:

Shape	Advantages	Disadvantages
Sphere	• Easy access to all parts of the HAC • Easy access to the central shaft	• Complex structure – difficult and expensive to build • Gravity varies significantly • Only a small part of the structure receives 1g • Curvature of the outer wall makes it difficult for easy habitation, as structures easy to build on flat surfaces
Torus	• Large surface area for living • Area under livable gravity is large • Unibody curved form allows for easy retention of a pressurized atmosphere	• Gravitational acceleration varies on the curved outer surface • Curvature of the outer wall makes it difficult for easy habitation, as structures easy to build on flat surfaces
Cylinder	• Surface area for living is constant at 1g • Flat outer wall for habitation	• Difficult to withstand pressure differences caused by the atmosphere on corners

	• Surface area for 1g habitation is greater than that of a sphere • High efficiency of material use	

The HAC will be a cylindrical structure which has curved edges. These curved edges allow for easier construction and easier retention of the (relatively) high-pressure of the internal atmosphere. It combines some of the advantages of tori with the advantages of cylinders.

2.1.1.2 Area and Mass Distribution

Astra will have two floors (an inner and outer floor; see 2.1.1.3), and the area distribution for them is as follows:

Purpose	Area Taken	Floor
Recreational Facilities, Shops, and Commercial Centers	1.5 square kilometers	Outer Floor
Living Area (Homes and Hotels; see 4.2.3)	0.5 square kilometers	Outer Floor
Parks, Roads, Free Space, Greenery	1 square kilometer	Outer Floor
Expansion Area and Additional Facilities (Banks, Administrative Offices, Schools, Government Buildings, etc.)	1.5 square kilometers	Outer Floor
Agriculture and Agricultural Processing	2 square kilometers	Inner Floor
Storage Facilities	0.75 square kilometers	Inner Floor
Life Support Systems (Atmospheric Cleaning Facilities, etc.)	0.75 square kilometers	Inner Floor

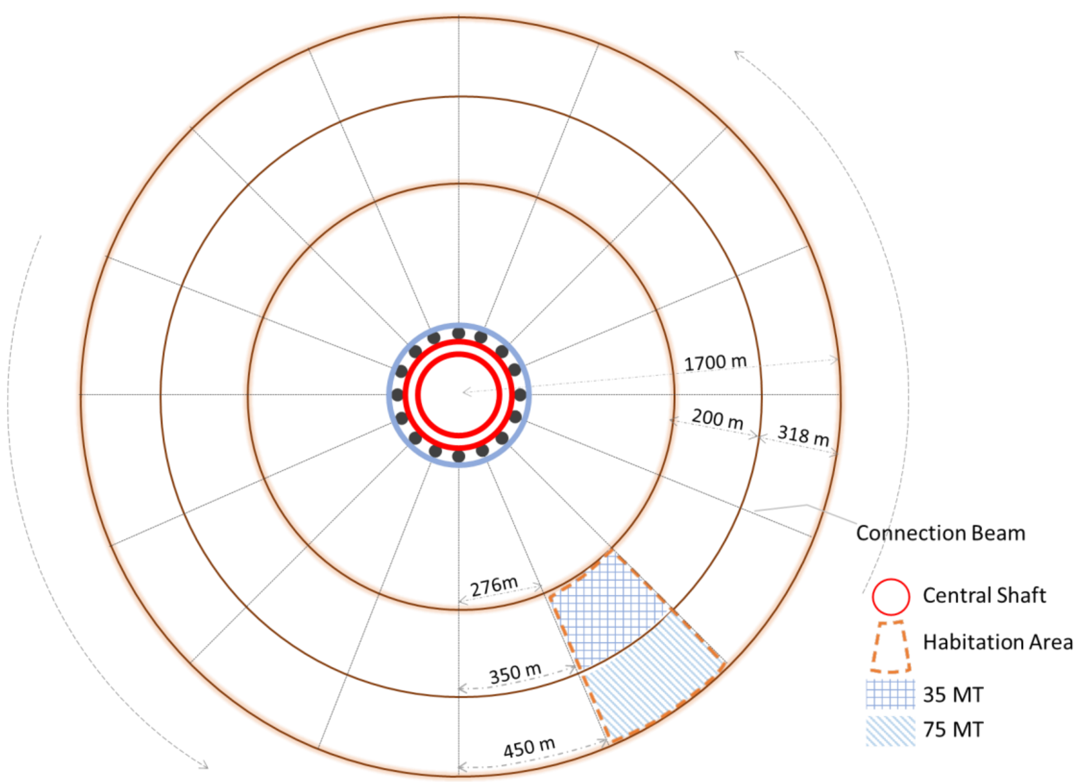
Total area for inner floor = 3 square kilometers
Total area for outer floor = 4.5 square kilometers

The mass of the HAC, excluding the hull and other supporting structures will be around 1,320 metric megatons (also see section 4.1.1 for atmospheric masses).

2.1.1.3 Structure & Dimensions

The HAC will feature two floors, a thick outer hull made of titanium and transparent material, and 50 titanium connection beams which intersect with the central shaft.

The HAC will have a total radius of 1,700 meters. The radius to the actual living area on the outer floor is 1,432 meters, and the radius to the used area in the inner floor is 1,114 meters (not including hull thickness in both cases). The radius of the inner side of the hull is 880 meters.



The HAC will be divided into 16 sectors which will be conjoined. Each of these 16 sectors has a group of 5 cylindrical beams, which transfer the ‘weight’ of the individual sector to the central support column. Four beams run through each lateral edge of the sector, and one through the middle of the inner side of the hull. All these beams are connected to the central support column, which is held to the central shaft with ball bearings.

The hull of the HAC will contain structural and insulating materials along with structural strengthening elements.

2.1.1.4 Artificial Gravity

The long-term effects of exposure to microgravity are disastrous to human health. It has been shown to cause muscle degeneration, the weakening of bones, and a wide range of other health issues. To combat this, the HAC will have artificial gravity.

This artificial gravity is caused by centrifugal acceleration. The settlement will rotate, thus causing masses within it to experience an outward pull to the inner side of the outer wall of the HAC.

The HAC will have an angular velocity (ω) of 0.79 rpm, or 0.08272 radians/second.

Thus, the artificial gravitational acceleration *g* is produced for the radius *r* = 1432 m:

$$g = \omega r^2$$

$$g = 0.08272 \times 1432^2$$

$$g = 9.8\ m/s^2$$

This is identical to the gravitational acceleration on Earth. This applies to the inner side of the outer wall, i.e., the outer floor.

For the inner floor, the radius is shortened to 1114 m, so the value of *g* decreases:

$$g = \omega r^2$$

$$g = 0.08272 \times 1114^2$$

$$g = 7.6\ m/s^2$$

This value is around 77.5% of the gravitational acceleration on Earth. However, this is non-problematic. Most human habitation and activities will take place on the outer floor. The inner floor is mostly used for agriculture, storage, and life support, and humans will not spend remotely harmful durations of time in these areas. Plants have also been shown to grow perfectly well, if not better, in microgravity or variable gravity. Agriculture will not be affected due to the variation in gravity.

2.1.1.5 Supporting Beams & Central Support Column

Considering that the maximum force on a single sector is 1,375 meganewtons, the force being exerted on a single beam is 275 meganewtons. The beams will be made of titanium, so the required radius of a single beam can be calculated with the formula below:

$$Young's\ Modulus_{Titanium} = \frac{Stress}{Strain} = \frac{\frac{Force}{Area}}{\frac{Extension\ Length}{Original\ Length}}$$

$$100\ GPa = \frac{\frac{275\ MN}{\pi r^2}}{0.002}$$

$$r = 66\ centimeters$$

Hence, the radius of each of the beams will be 66 centimeters.

All this force will be transferred from the beams to the Central Support Column, which bears the entire load generated from the HAC's rotation. It will be made of Titanium and will be very thick to withstand such forces.

2.1.1.6 Glass Side Panel

To allow for the use of natural sunlight, the top surface of the HAC will be mostly glass with a few metal beams to support the glass. This side of the HAC will always face sunlight. The curved surface will be opaque, and the side of the HAC that always faces away from the sun will also be opaque.

2.1.2 Zero Gravity Entertainment and Recreational Complex (ZERIC)

The ZERIC will be used to perform all microgravity operations on Astra. This will span manufacturing, research, and recreation.

The ZERIC will feature a hull design similar to that of the HAC. Unlike the HAC, it will only need to withstand the internal pressure of the atmosphere, and not have to withstand forces that are caused by artificial gravity.

ZERIC's hull will be made of a combination of glass and titanium, much like the HAC.

2.1.3 Central Shaft

The Central Shaft connects all the parts of the settlement with each other and acts as an axle about which the HAC rotates. It will also hold the solar array in place on its sun facing side (see 4.3.2) and will have a docking port on the other side.

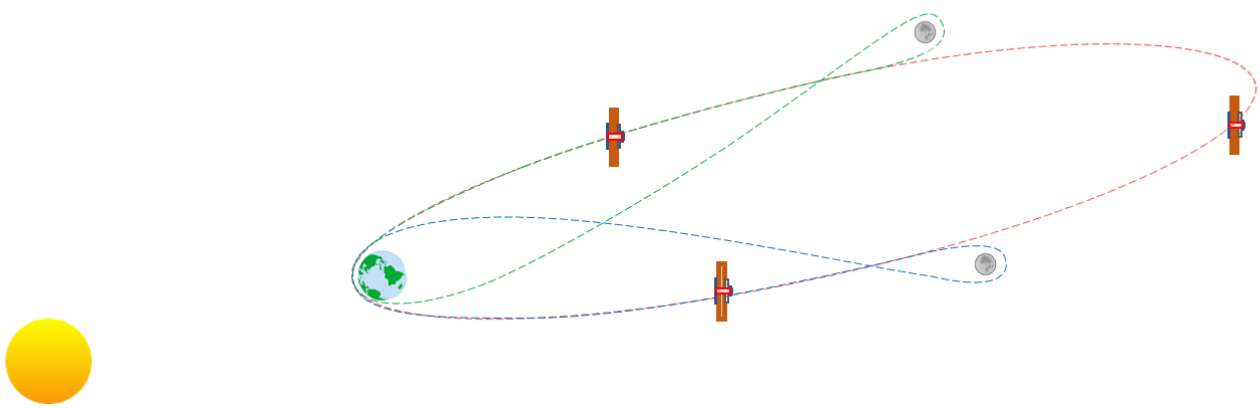
To connect the ZERIC and the SJSF, simple hollow tubes will contain elevator systems for transport to other parts of the settlement, or to the docking port where things may be transported outside the settlement.

For connection to the HAC, ball bearings will be used to connect with the rotating support column. The support column is a part of the HAC. Elevator shafts parallel and conjoined with support beams will run through until the support column. The support column then has a shaft through the ball bearings which connects with an inner rotating structure within the Central Shaft. The Central Shaft itself is stationary, but this specific part will rotate inside the central shaft with the same angular velocity as the HAC. This part will then slow down until it is no longer rotating, and then is sent to other parts of the settlement.

2.2 Orbit, Orientation, and Rotation

2.2.1 Orbit

Astra's orbit is a 'lunar cycler' orbit, which allow for periodical encounters with the Earth and Moon. This orbit is an elliptical orbit, and when it encounters the Moon it flips back to the Earth resembling a 'figure 8' and repeats the cycle. In other words, the orbit will switch between and elliptical orbit and a 'figure 8' orbit. The 'figure 8' orbit will allow for a lunar encounter. The Earth is more frequently encountered as the orbit nears Earth for every cycle.



The Earth-Moon orbit allows for:

- Lunar resources can be transported from the Moon to the settlement when the orbit is near the Moon.
- Space junk can be captured when the orbit is near the Earth and in debris-dense areas.
- Occasional transfers of people and cargo from the Earth to the settlement can take place.
- Space junk can be sent to the Moon from Earth via the settlement for processing and recycling.
- The Moon can be used for tourism.

It ultimately allows for the full utilization of both the Moon and the Earth.

2.2.2 Orientation & Rotation

Astra uses natural sunlight, on which several things are dependent upon – ranging from agriculture to visibility. The axis of rotation of the HAC must always face the sun to allow for sunlight to pervade into it and to power the solar panels. The glass side of the HAC will always face the sun (see 2.1.1.6). Astra will have a small initial rotational velocity which perfectly synchronizes with its orbit. This allows for it to tilt itself to face the sun always. Occasional thruster firings will take place to maintain and correct this rotation.

2.3 Materials

The parts for Astra will be built on the Moon and sent into orbit from the Moon. To allow for lunar construction of Astra, materials need to be sourced from the Moon or the proposition of using the Moon for construction becomes irrelevant. The materials that can potentially be used for structural components are:

Material	Yield Strength	Young's Modulus
Iron	185 - 285 MPa	210 GPa
Magnesium	160 - 195 MPa	45 GPa
Aluminum	90 MPa	69 GPa
Titanium	275 – 690 MPa	110.3 GPa

Out of all the above materials, iron and titanium stand out for their tensile strength. Under many circumstances iron will be stronger than titanium; however, it is very dense. Other than structural integrity, the mass of these substances must be considered for a space settlement. The use of iron is not possible.

Titanium will be the primary material used in the structural components of Astra.

2.4 Construction

The construction of Astra will be one of the most complex and difficult operations in the entire project. It will require huge scales of manufacturing and launches to complete.

2.4.1 Stage 1 – Lunar Base Construction

Time Frame: 2027 - 2035

Initially, Astra will simply be a single small lunar base, with mining facilities, processing facilities, etc. The base will be launched from the Earth on modern super-heavy lift chemical rockets (most likely the SpaceX Big Falcon Rocket) and landed near the Shackleton Crater on the Moon. This small lunar base will then perform mining operations and use the materials it obtained to expand itself, building more and more facilities. Occasional resupply and materials shipping from Earth may be required. At the end of Stage 1, the lunar base is complete and ready to initiate construction of the orbital settlement.

2.4.2 Stage 2 – Construction of Central Shaft, ZERIC, and SJSF

Time Frame: 2035 - 2042

When Stage 2 begins, the lunar base begins producing massive quantities of titanium and other materials required for the settlement. Individual parts of the Central Shaft, ZERIC, and SJSF will be constructed in individual pieces (sectors for SJSF & ZERIC, cylindrical sections for the Central Shaft) and launched into **lunar orbit**. In lunar orbit, the individual parts will be assembled.

2.4.3 Stage 3 – Construction of HAC, Rotation, and Orbit Insertion

Time Frame: 2042 - 2048

At the start of Stage 3, the settlement is complete excluding the HAC. The HAC will be built on the moon in its 16 individual sectors. These sectors will further be split apart to be sent into orbit. At first, the central support column will be sent to orbit along with the ball bearings and rotation mechanism. Sectors will then individually be put together in orbit, and 5 beams will be welded to the sector and to the central support column. Eventually all the sectors will be in their correct locations and will be put together and unified. The internal environment will be pressurized, and minor cargo will be sent to the settlement. At this stage, massive rockets will dock with the settlement and fire their engines, making Astra leave its moon-only orbit and give it its Earth-Moon ‘cycler’ orbit. When in this orbit, the HAC will fire rocket engines on its circumference to give it an angular velocity of 0.79 rpm, allowing for artificial gravity to exist.

2.4.4 Stage 4 – Occupation and Completion

Time Frame: 2048 - ????

After Stage 3, Astra's construction is completed. At this stage, people will begin to occupy the settlement in large numbers. People and cargo will be sent from the Earth to the settlement. These people are now citizens of Astra.

When occupation is complete, Astra can begin its operations. It will sweep up space junk and send it back to the moon, get resources from the moon, carry tourists, perform experiments, and sell materials to the Earth.

2.5 Costs and Economics

Astra will be one of the most complex and elaborate human feats, and that all comes with large costs. The estimated cost for Astra will be 1 trillion USD for its construction. This includes the initial costs for the moon base and for the construction of the settlement.

The costs will be covered after the settlement's completion. This will be done in 3 ways:

- Transport and sale of products produced in microgravity, including perfect protein crystals.
- Tourism
- Transport and sale of lunar resources to the Earth, primarily Helium-3.

3. Settlement and Lunar Operations

This chapter deals with operations occurring on the Moon and in the orbital settlement – spanning the lunar base, space junk reprocessing, industry, raw materials harvesting, mining, etc.

3.1 Lunar vs Settlement-based operations and infrastructure

Astra has a huge dependence on the Moon. This is primarily owed to the fact that the parts for Astra will be made on the Moon, and then sent to orbit from the Moon. This offers an array of advantages:

- Launching parts of the settlement from Earth is expensive, inefficient, and difficult for a project like Astra. It will require a high launch frequency with super-heavy launch vehicles. This isn't the case with the Moon.
- Launching parts of the settlement from the Moon is simple and requires less rocket fuel and less powerful rockets due to its low gravity and lack of an atmosphere.
- The Moon has several important resources which will be used for the assembly of Astra, reducing dependence on the Earth.

Launching massive orbital structures from the Earth is extremely difficult and expensive. **The primary goal of the Moon base is to allow for cheaper and simpler assembly of Astra by reducing cost and complexity of sending parts to orbit.**

In addition to this, the Moon helps in providing resources for subsistence, export, maintenance, construction and for tourism opportunities. For this, major infrastructure on the Moon must be built along with Astra.

Astra (orbiting settlement) offers the following benefits over a purely lunar surface-based habitat:

- Ability to easily allow for artificial gravity to used, allowing for a healthier habitation environment. People will not be subjected to the unhealthy low gravities of the Moon.
- For Astra, the 'figure-8' orbit around both the Moon and the Earth allows for effective resource sharing between the two planetary bodies. The settlement can secondarily act as a transport craft between the Moon and the Earth. While this is not the main purpose of the settlement (to act as a mere cargo craft), it can derive huge incomes from exports to the Earth.
- At times when the portion of Astra's orbit near the Earth is accessible, it allows for the capture of space junk which can be recycled.

- Surface bases are subject to day/night cycles. Astra, with its specific orbit will have constant sunlight, which can allow for 24x7 photosynthesis.

Most operations that do not come under the above categories needn't take place or exist in an orbit-based settlement. It is more practical and easier for most other operations to take place on the Moon.

In addition to this, it will not be significantly difficult to transport things off the Moon, because of a lack of a lunar atmosphere and low gravity. This will allow for massive transport capabilities from the Moon to the settlement when the settlement is near the Moon in its orbit.

Manufacturing and industry will be primarily concentrated on the Moon, as raw materials sifted or mined from the Moon can directly be converted into usable materials or products. It is far easier to transport the final products than all the raw materials to the settlement, as raw materials typically take up more volume (in the requirements for Astra), and may require significant purification and processing.

Most manufacturing will not require a large team of humans and will mostly be automated. On the Moon, shifts of small teams will be required for industrial and transport supervision. These small teams will cycle members, preventing health issues related to low-gravity.

With the above factors in mind, the distribution of activities and operations are as follows:

Lunar Surface Based Activities	Orbit Based Activities
Mining Operations	Habitation
Raw material refineries and processing plants	Agriculture and Food Processing
Parts manufacturing for construction and maintenance of the settlement	Stores, entertainment complexes, hotels, malls, etc.
Surface-based tourism	Settlement-based tourism
Launching operations to transport cargo and materials to the settlement during intercepts	Earth interactions and trade with Earth
Space junk recycling	Space junk collection
Fuel production	Perfect Crystal Synthesis
Lunar research	Microgravity research

3.2 Lunar Resources

The Moon is a rich source of valuable resources that will be used in the construction of Astra and for its sustainability. Lunar resources can provide important chemicals and materials that also have huge demand on Earth but were formerly never able to be harnessed.

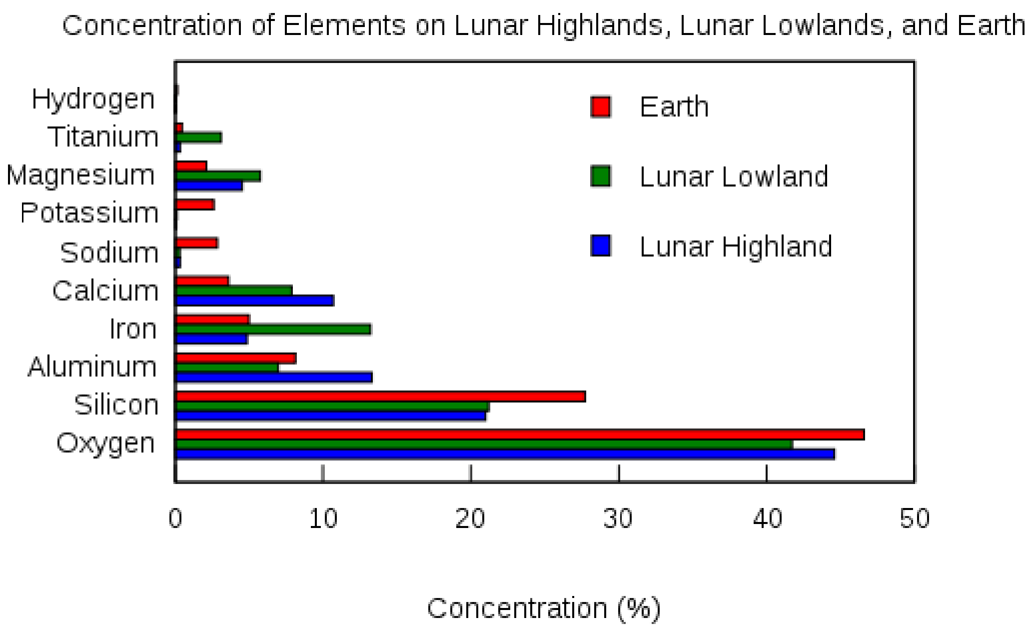


Image Credit: Roger wilco
Image Source: Wikipedia Commons

Fig 2.1 Lunar Elements Concentration

3.2.1 Oxygen

Oxygen is an essential resource for the settlement, being the second most concentrated constituent in Astra's atmosphere and a vital element for raw materials processing applications.

The Moon has abundant oxygen concentration (Fig. 2.1), which is primarily found in Moon rocks as metal oxides.

Oxygen can be separated from oxides via electrochemical processes. The most promising currently developed method is to use an electrolyte solution of molten calcium chloride and two electrodes made of a combination of calcium titanate and calcium ruthenate. This will allow for huge scales of oxygen production.

Oxygen will also be obtained from water electrolysis (see section 2.2.3).

3.2.2 Titanium

Titanium on the Moon is primarily found as ilmenite ($FeTiO_3$), which will account for all titanium production on the Moon for Astra. On Earth, 47% of titanium oxide is derived from ilmenite. By using a chloride acid process, ilmenite will be converted into titanium oxide on the Moon. This titanium oxide can easily be split into metallic Titanium, which will be used for the settlement.

3.2.3 Water & Hydrogen

Water-ice is present in abundant quantities in the polar lunar craters. Astra will have a lunar base located in the Shackleton Crater, which is estimated to have 20% water-ice. This is sufficient water supply for settlement operations for a huge duration.

The water is to be processed in lunar-based purification facilities and then shipped to the settlement.

Water can also be electrolyzed to generate hydrogen, which will be used for rocket fuel, and oxygen, which will be used for settlement operations such as atmospheric regulation and as an oxidizer.

3.2.4 Helium-3

Helium-3, an isotope of helium, has massive potential use in the future. Its capabilities to help provide cheap, efficient, and clean energy through nuclear fusion. With just 25 tonnes of it, the United States could be powered for an entire year! However, this resource has no current demand as fusion power generation is not yet capable of delivering actual power output. However, future innovations may make this resource have huge economic value, allowing for Astra to thrive even more.

3.2.5 Silicon

Silicon will be used to manufacture solar panels for Astra and its associated lunar base. In the lunar crust, large amounts of silicon are found in the form of SiO_4^{4+} which can be processed in the lunar base.

3.3 Space Junk Collection & Recycling

Space junk is a massive hurdle for the future use of space. Currently, there are 500,000 pieces of space junk in Earth orbit that can orbit at up to 28,000 km/h. At current rates, this number will go even higher. Even if we stop sending spacecraft to orbit, the situation will still be dire and worsen – full-sized satellites have a chance of colliding and scattering tiny debris across Earth orbit.

If we wish to continue the exploration and use of space, we must clean up space junk.

Current cleanup programs have a wide array of disadvantages and can be expensive. They may pollute the atmosphere or simply be too expensive.

Astra solves this problem by capturing vast amounts of space junk for recycling and reuse to make parts and products for Astra. Recycled space junk could also be used to help assist in making more Astras.

Previous propositions for using space settlements for recycling and reusing space junk have already been proposed, however, they require large orbital processing facilities to recycle space junk which may be difficult to send into orbit. These large facilities also may not be able to solitarily provide for settlements.

Astra integrates space junk processing with its lunar manufacturing and refinery facilities to improve efficiency. Production facilities will already exist on the Moon from the refinery of lunar resources. Space junk will be recycled and processed in parallel or in unison with lunar resource processing and refinery facilities.

3.3.1 Space Junk Collection

Space junk orbiting Earth will be captured by different sizes of Astra's space junk collection robot, SCR (Space Cleaning Robot), which is highly versatile and can collect nearly every type of space junk with ease.

The SCR will feature a large metal-threaded net to capture space junk of all sizes. It can sweep through a cluster of small pieces of space junk or capture a large whole satellite. It will have 5 thruster blocks, each having thrusters for orientation and translation.

When encountering debris, 4 corner thrusters will move apart to increase capture area. When the debris is collected on the net, the four corner thruster blocks will dock with each other.

To secure the space junk, the gaps are tightened, and the thruster blocks will reorient and move the robot back to the settlement.

3.3.2 Space Junk Transport and Recycling

After entering the settlement, the space junk will remain dormant until Astra's orbit is close to the Moon. During this time, a resupply craft for Astra will launch from the Moon. After unloading the supplies, the resupply craft will have all the space junk brought into it. The resupply craft will then undock from Astra and begin its deorbit burn and land back at the lunar base on the Shackleton Crater.

On the Moon, the space junk will be segregated, purified, and melted. The end results of this process are pellets of refined compounds or elements from space debris. These pellets are then sent to manufacturing facilities, where they will be used alongside lunar resources for making parts and products for the settlement.

3.4 Lunar Base

Astra has a huge dependence on the Moon for resources and manufacturing. For this, a permanent Moon base must exist on the Moon for mining, manufacturing, and launch operations.

3.4.1 Location

Astra's lunar base will be located around the Shackleton Crater in the lunar south pole. This location has been selected for a number of reasons:

- The interior of the crater is in perpetual night. This has allowed for water-ice to exist in the crater, which can be easily mined. The lunar prospector probe has detected large amounts of hydrogen in the crater, which implies huge amounts of water is present in the crater. Some estimates put the number at 20% water-ice.

- The rims of the crater are almost always lit by sunlight. This will allow for power generation (solar) around the rims of the crater.
- Including the rims, there are nearby areas outside the crater which are also exposed to long durations of sunlight. Such areas will likely contain huge deposits of Helium-3 for mining.
- The Shackleton Crater is in the lunar south pole, allowing for easy launches to dock to the orbital settlement.

3.4.2 Infrastructure

The lunar base will feature launch & landing complexes, mining & production facilities, and a small habitation area for the small lunar crew.

The base will occupy an area of 1 square kilometer, which is sufficient for all necessary stationary operations.

Industrial and habitation complexes will be pressurized or non-pressurized domes, depending on requirements. The base will have several of these interconnected domes.

Launch complexes will be simple, with mere support structures and a sufficient distance from other infrastructure. Landing zones will have circular, smooth, solid surfaces for landing transport and resupply craft. Landing zones will exist to allow for smooth landing surfaces and prevention of the kicking off of too much lunar dust.

4. Settlement Factors

This chapter will delve into the inner fabrications and workings of the settlement, ranging from human factors, such as population and governance, to material choices for the settlement.

4.1 Atmosphere

The atmosphere on Earth gives rise to all complex life. After 4 billion years of evolution, the human species along with the species it is dependent upon have perfectly been designed to work with the atmospheric conditions of the Earth. Astra will try to mimic the atmospheric conditions on Earth, as small changes may be disastrous.

4.1.1 Atmospheric Composition & Mass

In the atmosphere, humans are directly most dependent on oxygen. However, a pure oxygen atmosphere will not be optimal, as fires may be extremely frequent and dangerous. Nitrogen helps reduce the likelihood and destructive strength of fires. Plants and Humans will share a common atmosphere within the HAC, so a stable percentage of carbon dioxide will also be present. The oxygen and nitrogen in the atmosphere will be diatomic.

The number of moles of gas molecules in the atmosphere can be calculated with the ideal gas law:

$$PV = nRT$$

Substituting for the volume of the HAC, setting the pressure to be 1 atm, and setting the temperature to be room temperature, we get:

$$n = \frac{PV}{RT}$$

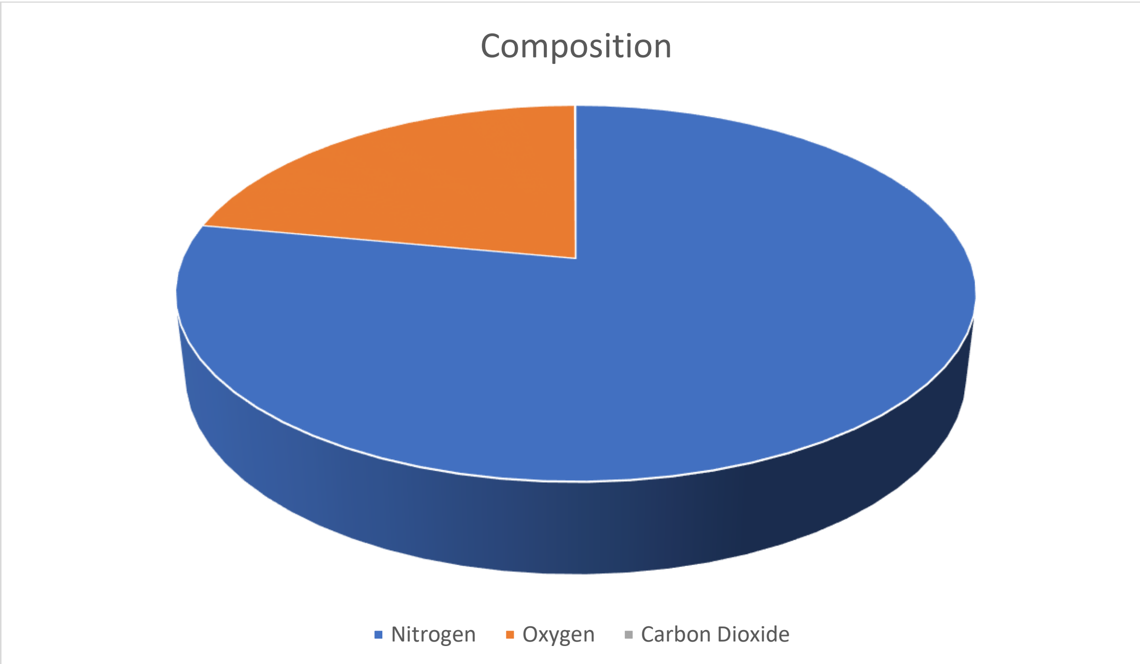
$$n = \frac{101325\, pascals \ \times 1.65 \times 10^{9}}{8.3145 \times 296\, K}$$

$$n = 6.79 \times 10^{10}\, moles$$

A specific amount of carbon dioxide must also be present in the atmosphere to allow for plants to photosynthesize. Plants grown with aquaponics and trees will intake a median limit of approximately 1000 kilos of carbon dioxide. Hence, a minimum of 22700 moles of carbon dioxide must be present in the atmosphere of Astra. This is an extremely small amount of carbon dioxide in terms of concentration, which may increase to higher levels due to carbon dioxide generation within the settlement.

Given the carbon dioxide requirements, oxygen and nitrogen can be estimated and ratioed like the atmosphere of the Earth.

With all factors, the atmospheric composition of Astra is as given below:



The carbon dioxide concentration is not visible in the pie chart, as it will make up only 0.05% of the atmosphere (which is an increase from 0.00003% as per calculations). Oxygen makes up 21.95% of the atmosphere, while nitrogen takes up the remaining 79%.

The mass of the constituents are as follows:

- Carbon Dioxide: 1,494 metric tonnes
- Oxygen: 476,911 metric tonnes
- Nitrogen: 1,483,645 metric tonnes

This yields a total atmospheric mass of 1,533,050 metric tonnes within the HAC. Similar atmospheric ratios are applied to the central shaft and ZERIC.

4.1.2 Cleaning & Stability

Carbon dioxide level must be maintained at regular low concentration levels to maintain a clean and stable atmosphere.

The plants used for agriculture and other uses will not be able to scrub sufficient amount of carbon dioxide to maintain it at stable and safe levels. Hence, a significant portion of carbon dioxide filtering must be done artificially.

A portion of the ZERIC and HAC will have an air filtration unit that will also feature liquid amine, absorbents, adsorbents, and permeable membranes, which are currently used on the International Space Station to maintain clean air. These will be periodically maintained.

This technology is well developed and would not require any new innovations or changes for its use on Astra.

4.2 Human Factors

4.2.1 Population

The population of Astra will consist of 10,000 permanent residents (10+ years residency) and 3,000 transient residents (few months).

4.2.1.1 Age Structure

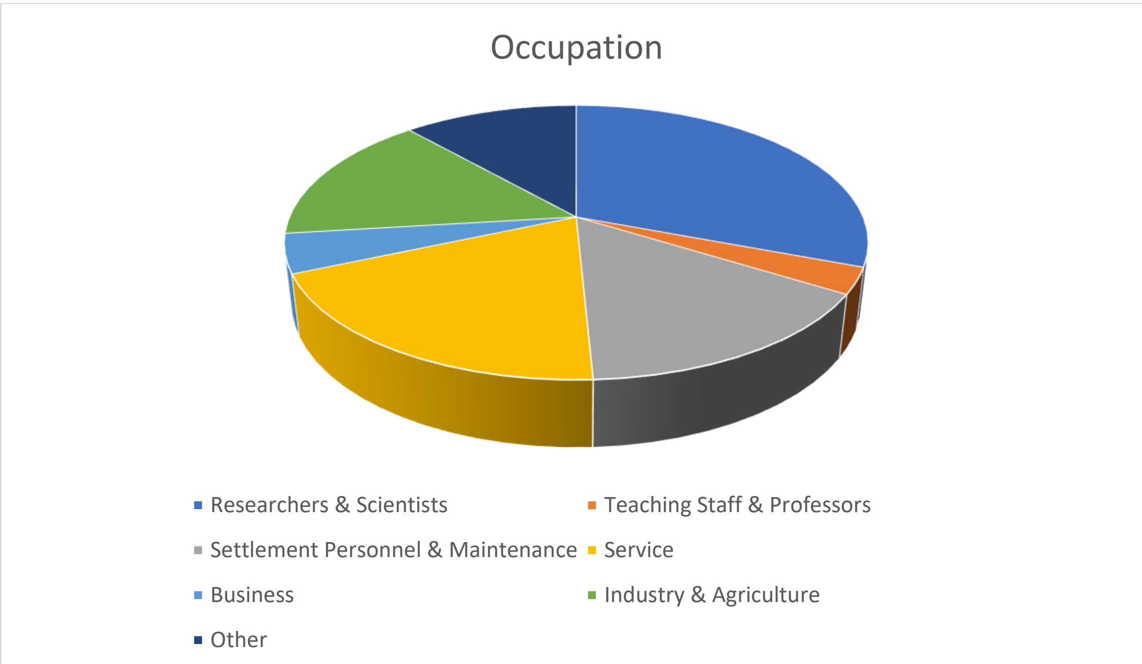
Astra's 10,000 permanent residents will mostly be researchers and professionals (see section 3.3.1.2 for occupations and use of 'professional'). Additionally, it may include families of the researchers and professionals. The age structure of Astra will likely be as follows:

Category	Age Range	Percentage Occupancy	Population
Children & Young Adults	0 – 23 years	30%	3000
Adults	23 – 65 years	65%	6500
Seniors	65+ years	5%	500

The transient population will mostly consist of adults and children, and a low likelihood of senior citizens. The percentage of children and adults will vary for tourists, but the estimation is mostly irrelevant, as the resources required for adults can also be adapted for children (who are usually less resource intensive) depending on demand. Some resources specific for children like schools do not need to be expanded for the transient population.

4.2.1.2 Occupation

Expected professional composition of permanent residents are given in the pie chart below:



- 2,000 people will be scientists and researchers working on space science and zero-gravity.
- 200 people will be teachers, professors, and educational administrators, and will work in the settlement's school and college.
- 1000 people will be part of the settlement personnel and maintenance crew. These will mostly be engineers and government heads. People who will perform government duties, such as law enforcement and administration (see section 3.3.4) fall in this category. Engineers and other personnel make up the rest of this category. They will monitor settlement stability & safety and will also conduct periodical maintenance.
- 1250 people will work in the service industry, i.e., will perform duties such as shop keeping, providing customer support, provide sanitary services, cooking as a chef, serving food, managing stores, etc.

- 300 people will businessmen/women. They are entrepreneurs who might be interested in conducting business within the settlement or selling things to Earth (such as perfect protein crystals). See section 4.2 for more details regarding economics.
- 1000 people will work in the production industries in the settlement, which helps provide resources. This includes non-lunar manufacturing and agriculture.
- 750 people will not fall in any of the above categories – they may be retired (despite being below age 65) or will have a miscellaneous job. In addition to this, there are also many students who would have graduated from school and would be studying in a university, even above the age of 23.

The transient population of 3,000 people will mostly comprise of tourists but will also include specialized personnel. These ‘specialized personnel’ perform specialized functions that require expert guidance for any in-settlement matters. They can also include advisors or people coming to the settlement for business deals or discussions. The ratio of tourists and ‘specialized personnel’ can vary depending on demand and situations.

4.2.2 Facilities

Facilities on the settlement fall into 4 primary categories – schooling, entertainment & comfort, restaurants & stores, and healthcare.

4.2.2.1 Schooling

The schooling system will be very similar to that of Finland, which outperforms every other education system in the world. Astra’s education system, much like Finland’s education system does not consist of grade levels based on age. It instead has two categories – primary and secondary. Students below the age of 16 – 17 will be part of primary education and children above that age will be in secondary education.

After the age of 20 – 21 (some students may even go below that age), students will enter college. They may choose to attend the college within Astra or leave for

Earth. Astra itself will have an excellent college/university, which will provide degrees and courses on valuable skills and occupations required to generate an appropriate next generation for the sustainability of the settlement.

There will be 200 highly trained teachers, professors, and educational administrators onboard the settlement. Some researchers and scientists onboard the settlement may also be professors or teachers, enhancing the quality of teaching.

4.2.2.2 Entertainment & Comfort

The entertainment facilities on Astra will be equivalent, if not superior to that on Earth.

On the HAC, area for recreational areas, such as parks, malls, movie theatres, stadiums, sports grounds, etc. is massive on Astra (see section 2.1.1.2).

Within the ZERIC, which has zero – gravity, an array of fun activities are available. Zero gravity sports and floating across expanses of the ZERIC will offer unparalleled experiences.

The ZERIC and the HAC both have a huge area of glass. On the HAC, most of the glass area used solely to bring sunlight within the settlement. However, when the glass is dimmed (see section 3.7), there will be large windows on the other wall of the HAC to view the beautiful cosmos and the stunning Earth & Moon. On the ZERIC, the glass exists solely for viewing, as sunlight is blocked by solar panels above it. On the ZERIC, people can view the stars, the Earth, and the Moon.

Far from the Earth, where the human species has spent all their time on, the first human settlers in space need to be able to cope with a biologically awkward environment.

On the HAC, significant area is granted for open spaces between buildings and complexes (see section 2.1.1.2). Open expanses will be truly refreshing on the settlement. Trees and plants will be scattered across the settlement, providing brilliant scenery.

In addition to open areas and natural surroundings within the settlement, VR (Virtual Reality) headsets will be provided in both the HAC and the ZERIC. VR on HAC will offer homely Earth-like experiences, with beautiful landscapes and scenery. VR on the ZERIC on the other hand, will mostly exist for pure entertainment purposes to give people other-worldly experiences.

4.2.2.3 Restaurants & Stores

Restaurants will exist in multiple diverse areas within the settlement. Some may be incorporated within malls or the Astran hotel (see section 3.3.3 for more details), and some may be independent. Restaurants must also be able to adapt to a fish and plant-based menu, as only those foods will be provided on the settlement. Besides this, restaurants in Astra will not be dissimilar to those on Earth.

Stores on Astra will range from grocery stores to toy stores. These too will not be different from those on Earth. However, some products may not be available, but will not be essential or be significantly inconvenient for Astra's residents/citizens.

4.2.2.4 Medical Care

Medical care will be equivalent to the finest standards on Earth. Besides regular diagnoses, instruments, procedures, etc., Astra will have two unique medical features:

1. There is a medical center within the ZERIC. Elderly people or people who suffer from significant injuries may find it easier to live and recover there. Zero gravity reduces stress on damaged body parts.
2. The psychological department will be significantly more advanced than those on Earth. This is required to help residents battle any potential psychological issues from not being on the Earth.

In the case of an extreme situation (such as psychological issues), patients can also be sent to the Earth for further recovery. However, such situations will be extremely rare, and nearly all ailments can be fixed on the settlement.

In the case of an infectious disease, the patient is diagnosed accordingly. Depending on the diagnosis, a patient may be placed under isolation to prevent the spread of a disease. A disease outbreak on the settlement may render the entire settlement extinct or may cripple it significantly. In some cases, and isolated patient may also be sent back to the Earth to prevent an outbreak.

4.2.3 Housing

Housing on Astra is designed to be expansive. For permanent residents, there are 4 options:

1. A 4 – person home with a base area of 120 m^2. This area meets the average area of a four-person home on Earth and has a comfortable size. There will be 2,000 of these on the settlement.
2. A 2 – person home with a base area of 84 m^2. This is also a comfortable area, equivalent to average sizes on Earth. There will be 500 of these on the settlement.
3. A 1 – person home with a base area of 48 m^2. There will be 3,500 of these on the settlement.
4. A 200 m^2 home. This home size of a home is designed for large families and for mansions. Mansions cost more than other homes. There will be 100 such homes.

Homes will be pre-ordered during or before the construction of the settlement. Depending on available money and requirements, people can select one of the four options above. A three – person family can live in a 4 – person home if required. People can also expand to a mansion if they wish. A large family could also occupy a home with the same area as a mansion.

For transient residents, the ‘Astran hotel’ will be available for temporary occupancy. This hotel is to be built over an area of 30,000 m^2 and can be occupied by 3000 people. It will include small shops and restaurants.

4.2.4 Governance

For administration, Astran citizens will practice a combination of direct democracy and representative democracy. A person can only be considered a citizen if he/she is a permanent resident.

11 representatives will be directly elected by the citizens of Astra and will form the ‘Council of Astra’. Any citizen can be a representative, under the condition that he/she falls under the ‘Adult’ category and is elected. Elections will be held every 4 years. The 10 nominees with the highest votes make up the rest of the Council. The Council of Astra and the Judge of Astra (will be explained later in section 3.3.4) will select a citizen to be the ‘President of Astra’.

The council acts as a legislature and as a pseudo-executive branch. It has supreme authority over the budget and spending of the government. The Council also manages civil services like maintenance and emergency care. It can pass laws that it creates under the condition that at least 5 members of the council of Astra pass it. The President of Astra has the right to reject a law, because of his/her veto powers, and the council then revises it. This process will repeat until the bill/law is passed. In the event of a disagreement between two majority opinions within the Council, direct democracy is practiced, and the people will vote for the bill/law and act as the executive. Direct democracy is to be practiced infrequently, as people may lack the foresight and time for thought while voting.

The Judge of Astra is elected every 3 years directly by the people. The Judge can only be removed if there is an 8/10 vote or more against him in the Council of Astra with the support of the President. A Judge can also suspend the Council if he/she has the support of over 70% of the population. This is the second case where direct democracy is practiced. A Judge can call for a vote to suspend the Council for a maximum of 4 times a year.

The Judge of Astra functions primarily as a supreme judge and is the final authority for a dispute between two citizens or groups of citizens. There are many judges beneath him. Lower authority judges can send a case to the Judge of Astra, who will give a final verdict declared by a jury. The Judge also has control over law enforcement.

4.3 Electricity

4.3.1 Power Consumption

Astra has a massive power draw. The estimated distribution and usage of power is as follows:

Reason	Maximum Power Draw per Day
Households	100,800 kWh
Heat & Pressure Regulation System	150,000 kWh
Agriculture & Industry	200,000 kWh
Power Draw From ZERIC	100,000 kWh
Stores & Other Buildings	150,000 kWh
Water Purification System	50,000 kWh
Miscellaneous	100,000 kWh

Astra will have a maximum energy of draw 850,000 kWh per day.

4.3.2 Power Supply

In space, only two means of power are feasible – nuclear and solar. Nuclear energy has the clear disadvantages of nuclear waste, loss of self-dependency, toxicity, dangers, and potential meltdowns.

Solar arrays in space also have disadvantages. If the settlement is hidden by the Earth or Moon (which will happen because of Astra's orbit), the power supply will be severed. However, these events are predictable, and massive backup battery systems exist to power the settlement when sunlight is blocked. At all other points in the orbit, Astra will receive constant parallel rays from the Sun.

<u>4.3.2.1 Solar Array</u>

The solar array system needs to generate 850,000 kWh every day. The array will be circular, with a non-generating circle in the middle used as a mount which connects the array to the central shaft. The area of the circular array can be calculated as given below:

$$power\ required = (area\ of\ array\ circle - area\ of\ mount) \times energygenerated\ per\ m^2$$

From this, we substitute our values:

$$850{,}000\ kWh = (\pi r^2 - \pi 10^2) \times 175\ Watts$$

After solving, we then get:

$$r = 254\ meters$$

Note: kWh was converted to Watt based on 24-hour power intake

Hence the radius of the solar array is 254 meters and is positioned over the central shaft.

As mentioned earlier, the panel will face constant parallel rays of light 27x7.

4.3.2.2 Backup Batteries

Astra's orbit occasionally causes the Earth or Moon to block the Sun's light. In such an event, solar arrays will not be able to power the settlement. Astra cannot have its electricity supply shut off even for a second, so ensuring constant power supply is paramount.

In such events, an array of 15,500 litres of Lithium-Ion batteries will power basic settlement operations for the duration of the pass behind the Earth or the Moon.

4.4 Agriculture, Food, and Water

Food is a fundamental requirement for all life as we know it. On Astra, nutritious and gastronomically pleasing food will be provided. This food will be distributed to restaurants and markets within Astra.

Some food items, including all animal products (meat, diary, etc.) and a few plants that cannot be grown with aeroponics are not produced within Astra, and are not consumed.

In practical modern agriculture, there are 3 mediums in which crops can be grown:

1. Soil, as traditionally used,
2. Aquaponics, suspending in water, without the use of soil,
3. and Aeroponics, which suspends plants in 'air', which also does not require soil.

Method	People that can be fed per km^2
Conventional Farming (Soil-based)	2,350
Aquaponics	13,300
Aeroponics	49,210

The above table is based on the calorie intake from sweet potatoes, if people have a 2000 calorie/day diet. While the citizens of Astra will not eat only sweet potatoes, it provides a sense of scale of the variations of the different systems.
Source: https://worldbuilding.stackexchange.com/a/9601/47116

Growing plants in soil has a range of disadvantages when comparing with aquaponics or hydroponics, the 3 biggest being:

- Soil can become infertile with extensive use of fertilizers, which are required.
- Soil cannot offer the same output as modern hydroponics or aeroponics in a specific area.
- Requirement for pesticides is high.

Both aeroponics and aquaponics both offer solutions to all three problems – soil doesn't become infertile (there is no soil in the first place!), can produce large outputs, and do not require pesticides or insecticides (pests and insects require soil to thrive).

Aeroponics and aquaponics are only inferior to soil by being complex and not being able to offer the same output for a few specific plants.

However, on Astra, with high technology, complexity of the system becomes irrelevant, with the several hundred specialists working on the system. Plants that grow better in soil than in aquaponics or hydroponics can still be grown with the systems but may offer lower outputs (which seems to contradict with disadvantage 2) – however, they are a minority, and the aquaponics and hydroponics systems strive by fixing the other issues with soil-based crops. Most crops will grow better and yield higher outputs in aquaponics and hydroponics systems.

When choosing between aeroponics and hydroponics, the disadvantage with aquaponics is the quick spread of potential diseases, and the reduced crop production area per square meter. Aeroponics is only more complex, but this is irrelevant on Astra, which has high-technology and hundreds of technicians.

The system to be used on Astra for growing nearly all crops is Aeroponics.

Multiple layers of aeroponic crops will be grown across the height of the inner floor of the HAC. These aeroponic crops will be able to further increase production due to Astra's ability to utilize natural sunlight.

Water on Astra is highly abundant, due to massive imports from the lunar base(s). Water will be pre-purified and refined on the Moon, so no major water purification facilities will be required.

4.5 Lighting

Natural sunlight has numerous advantages over artificial lighting. This is owed to the intensity of sunlight. This also allows for better plant growth in agriculture. Sunlight allows the skin to produce vitamin D in humans. It appears far more natural and comforting than artificial lights.

Usually, space settlement designs utilizing sunlight use elaborate complex mirror systems, suspend large mirrors in space, use a complex array of prisms, or other systems. These are complicated, expensive, and in some cases, there are chances of failure if one system fails to work. Astra requires none of these.

The orbit of Astra gives it nearly 24x7 sunlight exposure with the exception of times when the Earth or Moon block the Sun. The top side of the HAC (perpendicular to the curved surface) is transparent and will always face the sun. The bottom side is mostly opaque, reflecting light back into the settlement. No sector of the HAC is away from sunlight because the axis of rotation is parallel to the sun's rays.

However, because of the dissipation of light and lack of distribution, buildings away from the HAC's transparent side may be blocked from sunlight by buildings closer to the transparent side. For this, 'light tubes', which help receive and distribute light away from the windows will be used. A light tube is a tube which is completely occupied by highly reflective material, which can 'transfer' light (in this case, sunlight) to areas further away from the glass.

To control color temperature and day/night cycles, the glass on the HAC will feature 'smart glass'. 'Smart glass' allows for a variable allowance of sunlight within the settlement. A type of ‘smart glass’, called Suspended Particle Devices (SPD), will be used on the settlement. SPDs use a thin layer of suspended rod-resembling particles, which can align and disabling depending on voltage. SPDs offer advantages over other ‘smart glass’ technology. SPDs offer the ability to precisely control the amount of light entering the settlement; the amount of voltage applied can change the degree of alignment of these particles. This also allows for some control over color temperature.

Day and night cycles will not be constant on all of Astra, i.e., half of the settlement will have sunlight, while the other half will not receive sunlight, instead of the whole of Astra having day or night. This is to allow for Astra to have operational personnel and a 24x7 running time, increasing productivity. Specific transparent areas will have electrical signals changed to make the glass become opaque, allowing the area to have night-time. This can be further personalised and configured within people’s homes.

On the ZERIC and Central Shaft, LED lights will be used. Sunlight is blocked from the ZERIC by the solar array and the HAC, and the Central Shaft only receives sunlight at its top. No agriculture takes place in these areas and are not occupied by people for long time durations (they aren’t used for habitation), so sunlight is not necessary.

5. Alternative Design & Future Settlements

This chapter deals with the settlements made after 2048, the time when the first Astra is completed and operational. An alternative Astra design that could be used in settlements is also proposed.

5.1 Alternative Astra Design

Astra's original design features a single HAC and a solar array between the HAC and the Central Shaft. A second design could be used for Astra involving multiple HACs starting small from the top and cylinders becoming larger as you go down from the top of the Central Shaft. All these HACs will spin at different rates, allowing for a constant 1g of gravity on all HACs. Around the final and largest HAC, a ring of solar arrays will be placed for power generation. The rest of the settlement is nearly identical, with a ZERIC and SJSF.

5.1.1 Advantages

The alternative design offers the following advantages:

- Significantly larger area for habitation and other activities
- Allows for more area of solar panels
- Allows for the settlement to easily be expanded

5.1.2 Disadvantages

Several moving HACs are extremely complex. It is extremely difficult to transfer people, materials, and objects between HACs, which severs connections. An elaborate and complex elevator system involving changing the angular velocities of masses within the central shaft will be required for this system to work. This is very difficult and perhaps impractical.

5.2 Future Settlements

After the first Astra is built, space settlement construction will not stop there. The lunar base on the Shackleton Crater will still be able to produce materials for another settlement, regardless of the design (alternative design/original design). More lunar bases could be built, and more and more people could start living in space affordably as the production increases.

In the distant future, orbital settlements like Astra could extend to other worlds in the solar system, and may be an effective way to help the human species grow and to pave humanity's path to the stars.

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