Astoria

Space Settlement

Trinity Christian Academy
Lexington, KY, USA

16 March, 2011

18th Annual International Space Settlement Design Competition
Proposing Team Data 2011

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Names, [grade levels], and (ages) of 12 students currently expecting to attend the Finalist Competition:
(we request that participants be at least 15 years old, and not older than 19)

Caleb Voss	[11](16)	Jonathan Sekela	[10](16)
Paul Rockaway	[11](17)		[ ]( )
Joshua Miller	[11](17)		[ ]( )
Joel Cowen	[12](18)		[ ]( )
Andrew Brooks	[9](15)		[ ]( )
MyKalin Jones	[10](16)		[ ]( )

Names of two adult advisors currently expecting to attend the Finalist Competition:

Jayne Everson Carl Voss

I understand that if our Team qualifies for the International Space Settlement Design Finalist Competition July 29 - August 1, we will be expected to finance our own travel to / from Nassau Bay, Texas, USA.

Jayne Everson BV 3/12/11
Responsible Teacher / Advisor Signature Date

1 Executive Summary

1 Executive Summary

For 111 years, Northdonning Heedwell has been a faithful contractor and contributor for pioneering space endeavors. With the completed Aresam now serving as a gateway into the farther reaches of our solar system, and Argonom preparing to house the first permanent Martian settlement, it is time for the creation of a new infrastructure to tap into the limitless resources within the asteroid belt. Northdonning Heedwell here submits its proposal to apply for the Astoria Space Settlement Contract.

Our vision for the first large space settlement in the asteroid belt is a self-sufficient mining colony near (22) Kalliope, complete with infrastructure for the refining and processing of ore, the producing of supplies, construction materials, machinery, commodities, and amenities, the sustaining of a very aesthetic, livable residential system for 11,500 persons, and the providing of space services, such as towings, rescues, and repairs. Some brief points of important features and merit follow:

-The residential portion of Astoria's structure consists of a beaded torus rotating around a central hub to maintain 1g at all times; each of the 46 beads is a 100 m wide capsule, containing 8 40-foot high levels for housing, agriculture, entertainment, and infrastructure

-Also attached to the hub, perpendicular to the habitation ring, is a horseshoe-shaped manufacturing ring; 100 modified capsules are attached in pairs around it, containing docking ports, storage, and industrial centers for the processing of ore

-Astoria will orbit the Sun, maintaining a distance of 500 km from Kalliope, an enormous M-Type asteroid, containing copious amounts of iron and nickel, and likely silicates and hydrated minerals. Soon after the mining begins, an expedition will be dispatched to a nearby C-Type asteroid to harvest carbonaceous resources

-To minimize cost of construction, most of it will be automated, and only a single, all-in-one spacecraft will be sent to begin mining operations on the asteroid and the construction of larger factories; the initial craft and its factories will then begin production of more complicated robots for construction of Astoria

-In addition to the larger construction robots, many smaller robots will be produced to aid with the manufacture and installment of the finer details; these robots will serve as repair drones after Astoria is complete, fixing issues with the settlement and any damaged ships that dock

-Long-distance transport across the settlement will be provided by a maglev train system; the habitation torus will have two tracks for the two directions, while the manufacturing ring will have four tracks for higher transportation demand, plus an extra cargo track for large cargo

-Each habitation capsule will provide complete infrastructure for a 270-person community, a distinctive climatological and environmental theme, space for offices and laboratories, and plenty of entertainment opportunities, ranging from malls, to parks and pools, to performances and shows

-As a part of the infrastructure, each capsule will have a level designated to hydroponics and in vitro meat production, both of which will exceed the requirement for the population and will be used for ship provisions

-The settlement's main power source will be two molten salt cooled thorium reactors, located in the hub of the settlement; they will be able to provide adequate electricity to all the residents and meet the needs of the industrial processes taking place in the manufacturing ring

-Astoria's residents will experience a high quality of life on the settlement, and visitor accommodations will exceed the guests' expectations and provide them with both recreational and relaxing activities

-For convenience, much of the day-to-day functions will be performed by helpful repair and janitorial robots; these tasks include fixing broken appliances, operating the agricultural centers, manufacturing, and repair of hull damages to Astoria

-An active defense system will guard against medium-sized microasteroids, minimizing hull damage; it will consist of modified repair drones will patrol the perimeter and deflect incoming asteroids will rail guns; as a matter of proactive defense, Astoria will have 96 LOX/LH2 engines, each with 4 thrusters, to gradually push the settlement 1.6 km in any direction to avoid impact with larger asteroids, up to three times a month

As a contractor for the Foundation Society, Northdonning Heedwell will be able to fulfill, and surpass, the requirements it has requested. We will be honored if the Foundation Society should select our proposal for the construction and operation of Astoria. Our long-standing relationship with the Foundation Society will be sustained and furthered by our important participation in the establishment of the first large mining settlement in the asteroid belt, and we will continue to serve as an invaluable partner to the space industry.

2

Structural Design

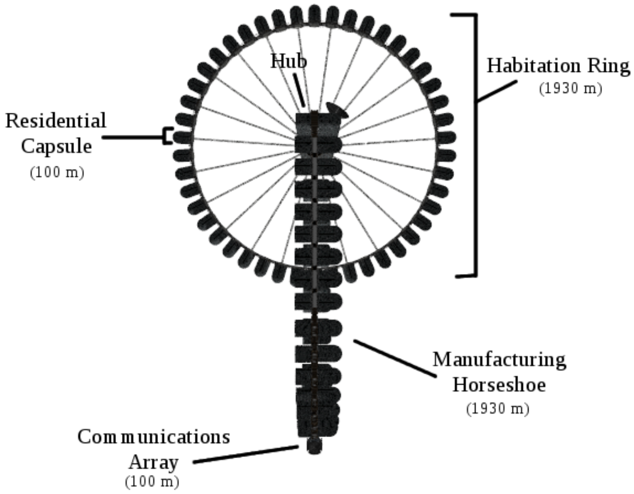
2. Structural Design

Astoria will be an enjoyable, safe environment for all of its 6,000 long-term residents, 5,000 semi-term occupants, and up to 500 short-term visitors. The station will be large, have room for expansion, and be able to fulfill its main function: provide facilities for mining, refining, and manufacturing operations that will take place in the asteroid belt.

2.1 External Configuration

2.1.1 Basic Structure

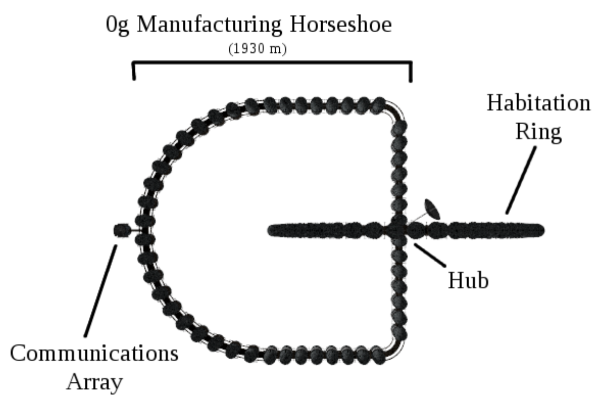
The basic structure of Astoria will be a large rotating beaded torus attached to the 0g (zero gravity) structure, a "horseshoe" shaped string of pressurize and unpressurized volumes sustained in microgravity. Each "bead" is a pressurized area which houses up to 270 persons; these "beads" will be referred to a "capsules". The Torus is held together by a large external structure made up of connecting materials, mainly carbon nanotubes, and a unique rail system. Transportation to any capsule in the structure is provided by trains.



Structural Overview

The beaded torus design has advantages over other space station designs that provide gravity in the form of centrifugal force, like the dumbbell, cylinder, Bernal Sphere, and Stanford Torus.

1. The beaded torus allows easy transportation between areas with gravity, unlike the dumbbell
2. It has constant gravity on down surfaces, unlike the Bernal Sphere
3. The structure can be manufactured in parts, unlike the Stanford torus
4. It has a reasonable down surface area to volume of atmosphere ratio, unlike the cylinder
5. Each capsule can be easily isolated in case of an emergency, unlike all other single volume structures



2.1.2 Design Features

The capsules on the torus will be relatively self sustainable areas. Forty-six capsules on the torus will mainly be for habitation and commercial use, but the extras can be used for manufacturing. Each capsule will grow food for its residents as well as provide entertainment. Each capsule will have 8 levels each 12.9 m tall with 15 buildings per level. Each building will hold three families or singles. Also, There will be two passenger train rails on the torus that can be used for cargo, these trains will provide swift transit throughout the station. There will be 50 capsules in the non-rotating (0g) section of the station. Capsules of the 0g area will be welded together with dry docks in groups of two, creating 50 pairs. One capsule of each pair will be a dock and the other will be a refining/manufacturing area depending on what is needed. Each capsule in the 0g area can be pumped full or drained of atmosphere. The train

Table 2.1.1 Overview of Major Structural Components							
Structural Component	**Amt.**	**Shape**	**Surface Area (m^2)**	**Volume (m^3) Mass (kg)**	**Use**	**Location**	**Gravity (g) RPM Pressure (atm)**
Habitation Capsules	46	Bullet	$2.53x10^6$	$1.05x10^6$ $3.73x10^7$	Multipurpose Pressurized Facility	Studded around Torus Superstructure	1 0.98 0.8
Torus Superstructure	1	Torus	N/A	$3.37x10^5$ $1.5x10^9$	Structural component of Torus	Large rotating base	1 0.98 N/A
Transportation Hub	1	Cylinder	$5.65x10^4$	$7.15x10^5$ $5.8x10^8$	Central Cargo Transfer Station	Center of Rotating Torus	1 0.98 0.8
0g Capsules	50	Bullet	$5.89x10^4$	$1.31x10^6$ $3.04x10^7$	0g Pressurized Facilities	Studded on 0g Superstructure	0 0 Fluctuates
0g Superstructure	1	Horseshoe	N/A	$1.52x10^5$ $1.07x10^9$	Structural component of 0g Area	Extending out from Central Hub	0 0 N/A
Docking Bays	50	Cylinder	$2.36x10^6$	$3.15x10^7$ $4.55x10^{10}$	Transport Stations	Studded on 0g Superstructure	0 0 Fluctuates

Table 2.1.4 Dimensions									
Component	**Amount**	**Shape**	**Location**	**Substructure**	**Radius (m)**	**Secondary Radius (m)**	**Height (m)**	**Width (m)**	**Length (m)**
Habitation Capsule	46	Bullet	Studded around rotating torus	Cylinder	50	20	100	N/A	N/A
				Halfsphere	50	N/A	N/A	N/A	N/A
				Short cylinder	52	N/A	6	N/A	N/A
Torus superstructure	1	Band	Main structure of rotating torus	None	965	955	10	106	N/A
Transportation Hub	1	Cylinder	Center of rotating torus	Main cylinder	70	N/A	50	N/A	N/A
				Secondary cylinder	20	N/A	10	N/A	N/A
				Tertiary cylinder	50	N/A	100	N/A	N/A
0g superstructure	1	Horseshoe	Extends from transport hub, then loops back	None	965	N/A	100	310	N/A
0g pressurized facilities	50	Bullet	Studded on 0g superstructure	None	50	N/A	100	N/A	N/A

system in the 0g area will consist of four passenger train sized rails and one cargo train sized rail, for bulk materials. In the 0g area, the train will extend through the center of each pair of capsules. The station will be powered by a nuclear reactor as there is not enough solar radiation to for solar panels to be effective. A high powered Doppler radar array will provide the colony with tracking of space debris within the station's vicinity to ensure the station's safety.

2.1.3 Construction Materials

The Materials making up Astoria will provide an incredibly strong, durable, and radiation proof environment for the residents of the colony. The capsules will each be constructed entirely in the asteroid belt from materials, mainly iron, nickel and silicon gathered there. Most of the station will be made of top quality steel. These materials will be mined, refined, and assembled by human supervised robots.

Table 2.1.2 Superstructure Construction Materials			
Material (Composition)	**Area to be Used**	**Properties**	**Strength (MPa)**
Carbon Nanotubes	▪Torus Superstructure ▪Elevator Cables	▪Structurally Strong ▪Resistan to Heat	1500
Grade 37 Titanium Alloy (Titanium, Aluminum)	▪Capsule Locks ▪God Colony	▪Extreme Strength ▪Chemically Inert	1241
Invar Steel	▪Central Node ▪0g Superstructure ▪Torus Superstructure	▪Superior Strength ▪Superior Toughness ▪High Malleability	795

2.1.4 Artificial Gravity

Table 2.1.5 Layers of Major Hull Components			
Component	**№ of Layers**	**Depth (m)**	**Layer Composition**
Habitation Capsules	4	0.7	0.02 m Invar steel, 0.5 m rubble, 0.1 m Invar steel, 0.08 cm dense foam with nanobot solution
Carbon Nanotube Band	2	0.1	0.05 m Titanium, 0.05 m Kevlar Weave
Transportation Node	3	0.5	0.2 m Invar steel, 0.08 cm dense foam with nanobot solution
0g Capsules	5	0.7	0.02 m Invar steel, 0.5 m rubble, 0.1 m Invar steel, 0.08 cm dense foam with nanobot solution

Gravity throughout the structure will be produce by the rotation of the torus. Studies have shown that rotations over two rotations per minute (rpm) have an adverse effect on the human body. Side effects include nausea, disorientation, claustrophobia, and dizziness. Astoria will be rotating at a leisurely 0.981 rpm, which will reduce the side effects of producing artificial gravity through centrifugal force. One gravity will be maintained throughout the torus, this will increase the cost of construction, but will also keep the inhabitants fit in the case that they will return to Earth (there is a good chance of this as almost half of the population is semi-term) and ensure the safe growth of children. There are multiple thrusters arrayed on the torus that can be used to increase or decrease the rpm as well as combat any wobbling that may develop over time. The thrusters will be fired automatically by reference gyroscopes placed throughout the torus. In addition to thrusters to keep the motion of the torus in check, there will also be counterweights attached to bottom of each capsule that can be raised and lowered to even the weights of opposite capsules, these will also be automated.

2.1.5 Pressure

Pressure will be maintained at 0.8 atmospheres throughout most of the habitable areas of Astoria. This pressure has no detrimental effects on humans, there are several populations living comfortably at a high altitude with 0.8 atmospheres. Docks and manufacturing capsules will have the ability to vary in pressure for dry docking as well as for industrial and scientific needs.

Table 2.1.6 Gravity and Pressure Justification				
Structure	**Gravity (g's)**	**Justification**	**Pressure (atm)**	**Justification**
Habitation Capsules	1	▪Keeps residents fit for possible return to Earth ▪Ensures proper growth in children	0.8	▪Quite viable for human occupation
Central Node	Microgravity	▪Transport operations easiest under microgravity	0.8	▪Human transport through node needs comfortable pressure
0g Capsules/Docks	0	▪Industrial operations easier under 0g ▪Reduces wear on facilities ▪Allows for 0g recreation and entertainment facilities	0.01 to 0.8	▪Lower pressure may be needed for certain industries to make the processes simpler

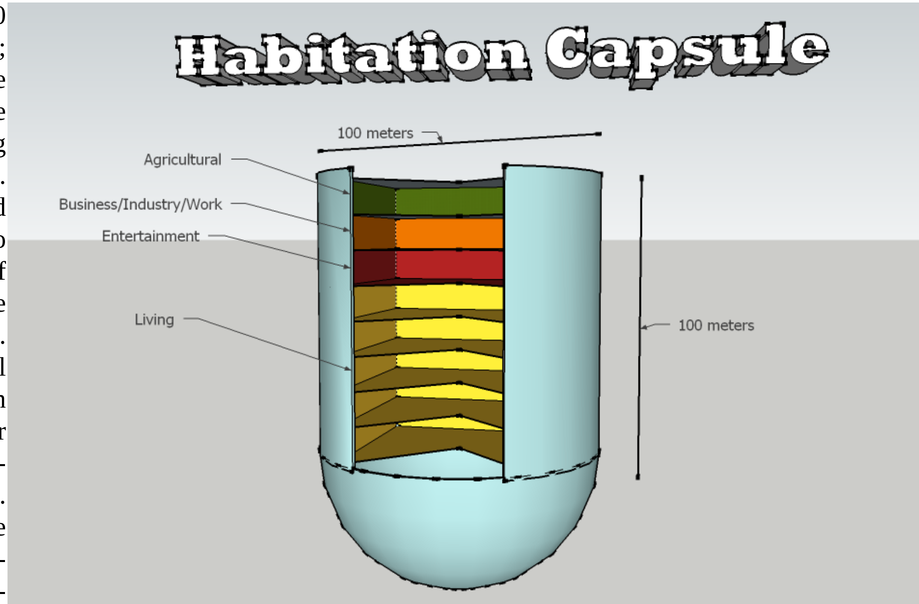
2.1.6 Emergency Precautions

The structural design of Astoria makes the implantation of emergency procedures very easy and safe. Each of the forty-five habitation capsules is connected to the others by the rail system. The pressure of each is maintained separately, so in the case of a large hull breach only one of the capsules (2.35% of the population) is lost—this being a worst case scenario. Each capsule can be released from the torus itself, and be flung into space. In this event, the capsules will also include an airlock, a small nuclear reactor, powerful communications equipment, and large provisions of preserved food.

2.2 Internal Layout

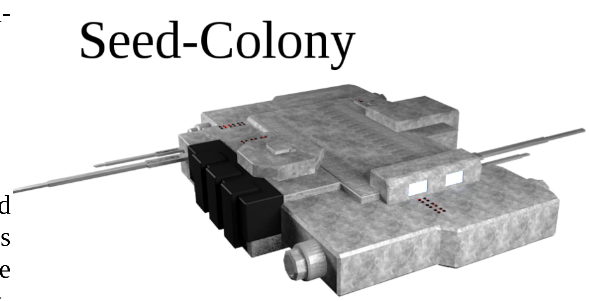
2.2.1 Capsule Layout

Each capsule is in the shape of a cylinder with a hemisphere at the bottom. The cylinder part of the capsule will have eight floors that are 40 feet or 12.192 meters apart; these are the levels of the capsule. On each level there will be buildings of varying sizes dispersed throughout. These buildings will be tilted slightly when necessary to keep the down surfaces of each house level (because the capsule levels are flat). Between the buildings will be, at minimum, seven meters. This leaves space for private gardens and wild animals, a small ecosystem. Some area between capsule levels will be reserved for environmental maintaining infrastructure, plumbing, floor supports, etc. Each resident will have a minimum of 83 m^2 living space. Elevators are stationed around the outside of the cylinder that lead to other levels as well as the train station. Each capsule will provide its own 100% recycling of all waste, and also produce most or all of the residents' food through hydroponics in the capsule.



2.2.2 Zero Gravity Areas Layout

The central node of the rotating torus provides a transportation hub between the living areas and zero gravity areas. The central node is entirely automated; personnel never leave their train car. It contains a total area of 6.28×10^5 m^3. There are 50 separate 0g capsules, in which various industrial and scientific processes can be performed. Their usage will be described more in depth in the Business and Development section. Additionally, there are 50 dry docks of approximately the same size as the 0g capsules attached across the train line from the 0g capsules, in which full pressurized spacecraft servicing and construction facilities will be present. These dry docks can also be used as additional 0g if the need arises.



2.3 Construction Sequence

2.3.1 Pre-Construction Procedures

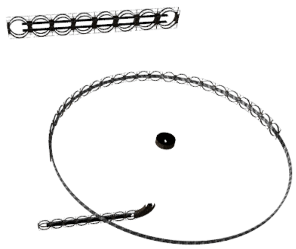
Before construction on Astoria can begin, research and testing must be completed to determine the best methods and procedures of construction as well as to verify that the specified materials will withstand the conditions on the settlement. Also prior to construction, the Seed Colony will need to be built in Mars orbit. The Seed Colony will be sent to Kalliope 22, a mid-sized m-type asteroid that contains large amounts of iron, nickel and possible silicon. After the Seed Colony lands, pre-made mining robots will begin sifting through the rubble on Kalliope with magnetic "rakes" that attract iron and nickel ore to them. The ore will then be refined at the Seed Colony and used in the creation of other robots, raw materials for Astoria, and expansion of the Seed Colony.

Time For Completion: 3 Years

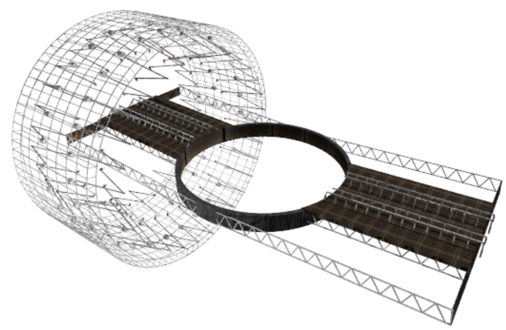
2.3.2 Construction Phase 1

Several hundred kilometers away from Kalliope, construction will begin on the framework of the torus and the 0g structure. The Robotic Cargo Barge (RCB) will transport raw materials to the area of the construction of the station. What will later be used as repair drones will move the raw materials into position for the Ring Frame Builder (RFB) that will construct the structure of the station.

Time For Completion: 2 Years



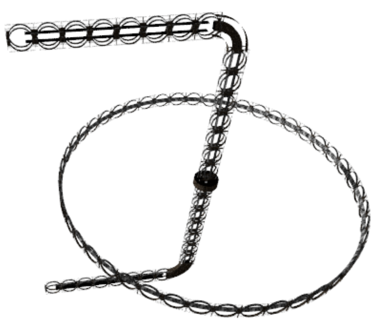
Ring Frame Builder (RFB)

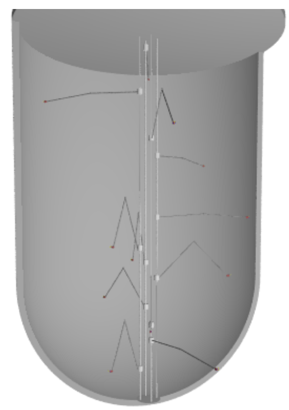


2.3.3 Construction Phase 2

The Capsule Frame Builder (CFB) will construct the internal structure of each capsule, and attach necessary recycling and environmental regulation equipment. Unused rubble from Kalliope will be placed inside the two steel layers of the capsule. The nanobot foam will also be manufactured and put in place at this time.

Time For Completion: 1 Year





Capsule Frame Builder (CFB)

2.3.4 Construction Phase 3

The pieces of the station will be combined, each capsule will be fitted into its yoke in the torus and 0g area and firmly attached by the Repair drones. The rail system will then be put together, also by the repair drones. At this point, organic compounds will be made from raw material mined from a near c-type asteroid. These compounds will be placed at the bottom of each level of the capsule for future use with plants.

Time For Completion: 2 Years

2.3.5 Construction Phase 4

Once work on the capsules is completed by CFB, the capsules will be filled with 0.8 atm and the hydroponics system will be activated. The torus will begin rotation using the thrusters arrayed around the circumference. Plants will be planted on each capsule level that matches the ecosystem there. This will make the station habitable.

Time For Completion: 3 Years

2.3.6 Construction Phase 5

The first wave of colonists will begin transportation to Astoria from mars. Upon arrival, they will finish any necessary construction, and build the recreation portions of the capsule according to their taste. Final quality checking of all systems and facilities will also occur at this time. The station will be ready for human habitation, and the full population will arrive over the next four years.

Time For Completion: 2 Years

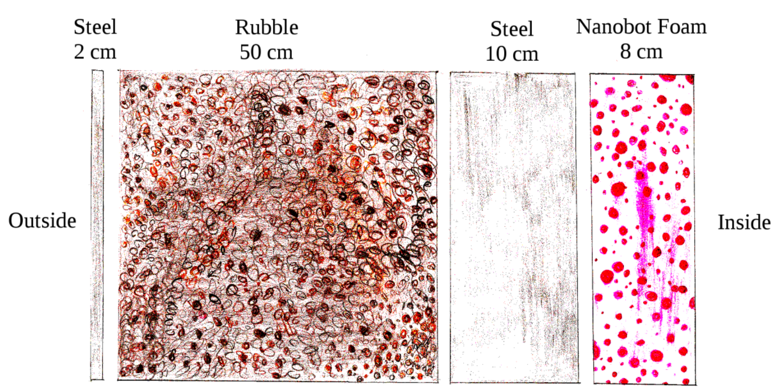
2.4 Station Shielding

Shielding is a very important part of any settlement. Astoria's shielding will have to deal with not threats from micro asteroids, but also radiation. Astoria's habitable areas will consist first of a nickel-iron steel called Invar that is 2 cm thick. Next will be a layer that is about half a meter thick composed entirely of pebble sized non-metallic rubble, this will prevent harmful amounts of radiation from reaching the inhabitants. The third layer will again be Invar, this time 10 cm thick. Finally, a layer of nanobots will be present between the layer of steel and a layer of 16 cm thick dense foam. If breached, the nanobots will reconstruct the foam in order to prevent a loss of atmosphere.

Table 2.1.3 Shielding Layers

Materials	Properties	Uses	Tensile Strength
Nanobot Solution in foam	▪water-based solution, filled with nanobots ▪quickly seals hull breaches	▪quick impact repair	0
Rubble	▪cheap ▪recycling	▪cosmic radiation shielding	0
Invar Steel	▪impact resistant ▪strong	▪shock absorption	485

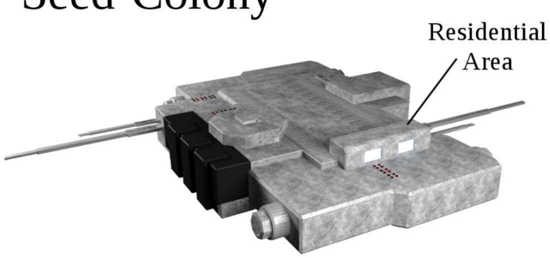
Shielding



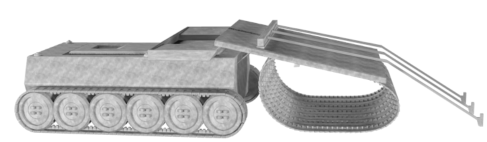
2.5 Mining Operation

Astoria will focus on the mining of Kalliope. Humans will not be present at the beginning of the construction process, however, they will be monitoring the activity of the Seed Colony from Mars. After living quarters have been built onto the Seed Colony, a pair of supervisors will fly out to monitor the colony in real time. This pair will continue to monitor for a year until they are swapped with another pair, this will go on for as long as the asteroid is being mined.

Seed-Colony



Mining Bot



3

Operations & Infrastructure

3 Operations and Infrastructure

The operation of Astoria, both during construction and normal operation, is described below, including its location, the inner-workings of primary subsystems that are involved in residents' daily lives, the conducting of mining and construction, and the means by which Astoria evades dangerous oncoming asteroids.

3.1 Orbital Location

As a primary mining target, we have selected the (22) Kalliope asteroid. It is a rather large asteroid, so it is unlikely that Astoria will deplete its resources in the foreseeable future. Astoria will orbit the Sun alongside Kalliope, maintaining a distance of 500 km from the center of the asteroid, to avoid conflict with Kalliope's natural satellite, Linus, which orbits at 1100 km with a 3.59 day period. Kalliope was chosen because much more is known about it than some of the more obscure asteroids, and it probably holds many valuable resources. Spectral analysis suggests that Kalliope is an M-type, or metallic, asteroid, likely containing large quantities of iron and nickel, which will be used for the Invar (steel alloy) in the settlement. It is likely that Kalliope can provide us with silicates, as well as hydrated minerals from which we can extract water. Most likely, the surface will consist of lose, magnetic rubble which we initially harvest very easily. We opted for an M-type asteroid instead of a C-type asteroid since about 75% of all asteroids are C-type. This way, if Kalliope is unable to provide us with necessary carbon and carbonaceous compounds, it will be a very minor expedition to locate and mine from a nearby C-type asteroid. The composition of Linus is not certain, but if it detached from Kalliope during its formation, it will contain the same resources.

Table 3.1.1: Kalliope Orbital Data	
Mean Radius	~83.1 km
Rotation Period	4.148 h
Aphelion	3.2085 AU
Perihelion	2.6139 AU
Orbital Period	4.97 yr

3.2 Community Infrastructure

The residential community on Astoria will require efficient systems to maintain a clean, livable environment that manage food, water, waste, weather, etc.

3.2.1 Atmosphere, Climate, and Weather

Astoria will provide a clean, pollution-free atmosphere with a suitable temperature, pressure, and humidity. Many external plants (i.e., those in the capsule, but not in an enclosed building) require plentiful rainfall, and these plants and humans, alike, require a sun-like light source, with an intensity comparable to that which reaches Earth. To simulate earth-like weather, meteorological events will be induced by an Artificial Meteorological Device (AMD) on each level of each habitation capsule. The AMDs are responsible for five major climate aspects and will customize each capsule level to a specific climate environment. The ceiling of each capsule level will be made of an artificial light source that replicates the same radiation we receive on Earth, but with less of the harmful UV light, and can draw a realistic sky. This light source can be brightened/dimmed to suit the simulated season and nightfall. Throughout the residential area will be personal gardens, containing many plants that suit the environment and can replenish the O_2 supply. Additionally, transpiration will return water vapor to the air. Large fans on all sides will circulate air outdoors, and produce wind. The ceilings are not high enough for real clouds, but the overhead screen can simulate clouds and the AMD will produce precipitation (rain or snow) from the ceiling. Finally, the AMD contains a ventilation system which moderates both outdoor and indoor air conditions. It can purify the air, remove pollutants, adjust humidity and temperature, and maintain appropriate gas ratios and pressure.

Table 3.2.1 Atmospheric Composition

Gas	Total Mass	% of Volume	Source
Nitrogen	434558 kg	78.00%	-nitrogen-containing compounds on Kalliope / nearby C-type asteroid
Oxygen	128001 kg	19.90%	-oxygen-containing compounds on Kalliope / nearby C-type asteroid -replenished by plants
Water Vapor	11461 kg	2.00%	-hydrated minerals from Kalliope -AMD moderates humidity
CO_2	60kg	0.10%	-introduced naturally -moderated by plants

Table 3.2.2.1 Minimum Crop Production							
Crop	**g/person/day**	**g/m²/season**	**Season days**	**m²/capita**	**Frac. of 4 m story**	**m²/capsule**	**Total m²**
Wheat	1000	855.7	120	135	1/3	11250	517500
Rice	600	1327.1	100	45	1/3	3750	172500
Corn	400	1133.1	70	25	1/2	3125	143750
Vegetables	1200	~4000	~90	27	1/8	845	38812
Total	3200	N/A	N/A	232	N/A	18970	872562

3.2.2 Food Production

Food production on Astoria will come from an NFT hydroponics system for crops and an *in vitro* meat production system in every habitation capsule. The hydroponics system had been chosen instead of traditional soil-based agriculture to facilitate automation and because it creates a substantial increase in crop yield (between 50% and 1500%, depending on the plant). The space requirement is therefore minimized due to the absence of deep soil and the higher crop density. A wide variety of plants can be grown, ranging from cereal grains to vegetables to spices. Growing meat products *in vitro* is extremely advantageous over real livestock since it eliminates the need for additional plant material used in animal feed, the need for large farmland expanses for animals to roam, and the need for an additional system to care for the livestock. The *in vitro* system can produce most common meats, including beef, pork, poultry, and fish, at a growth rate of 1200 g/m³/day. Each habitation capsule will have a hydroponics system and *in vitro* meat production system on the level designated for agricultural use. There about 1530 m² of extra space (20% of the total space) on these levels than is necessary to supply all the residents with adequate food. As such, extra rations will be specially packaged for longer-term storage in the 0g area for use during emergency interruption of food production and for provisioning visiting spacecraft.

Table 3.2.2.2 Meat production				
Meat	**g/capita/day**	**m³/capita**	**m³/capsule**	**Total m³**
Beef	24	0.02	5	230
Pork	15	0.0125	3.125	143.75
Poultry	18	0.015	3.75	172.5
Fish	12	0.01	2.5	115
Misc.	6	0.005	1.25	57.5
Total	25	0.0625	15.625	718.75

Table 3.2.2.3 Food Provision	
Growing	All crops will be grown in an NFT hydroponics system on one of the levels in every habitation capsule. There will be no livestock; all meat will be grown *in vitro* from stem cells.
Harvesting	The harvesting processes for both crops and meat will be entirely automated.
Processing	Growing facilities will be kept clean and free from harmful bacteria; even then, the food will be washed before being given to the residents.
Packaging	Often, residents will request fresh, unpackaged food from the same day, in which case it will be directly delivered to them; otherwise, the food will be packaged for short-term storage, except for ship provisions which are packaged for long-term storage.
Storing	Storage facilities will be located in the bottom dome of the capsule, and will include refridgeration/freezing to prevent spoiling; ship provisions and emergency storage is located in some of the 0g capsules.
Delivering	Food will be automatically delivered to where ever residents request it—their office, laboratory, home, etc.

3.2.3 Electrical Power Generation

Due to the great distance between the asteroid belt and the Sun, it becomes very inefficient to attempt to construct a solar panel array large enough to glean sufficient energy from the weak radiation. As such, Astoria will be powered by three liquid fluoride thorium reactors (LFTRs). The advantage of this particular kind of reactor is the the coolant is a molten fluoride salt, in which the nuclear fuel can be dissolved. Thus, fuel can be added while the reactor is live, rather than in the older fuel-rod system, where the reactor must be shut down to replace the rods. The reactor will follow the thorium fuel-cycle, converting Th-232, in the form of nat-

Table 3.2.3.1 Electrical Power Wattages				
Reactor	**Location**	**Standard Power**	**Maximum Power**	**Purpose**
Reactor I	God-colony	15MW	20MW	-construction, mining operations
Reactor II	Astoria Hub	37MW	100MW	-habitation torus - all residential/infrastructure use
Reactor III	Astoria Hub	60MW	100MW	-manufacturing ring - ore refining/processing, industrial products
Standby	1 per capsule	800kW	1MW	-emergency, single-capsule power supply, normally off-line

ural ThO_2, into U-233, which then powers the reactor. One of the reactors is integrated into the Seed-colony, and will power the construction process and the mining functions during normal operation. The other two, initially aboard the Seed-colony, will be placed in the central hub of the Astoria. Both reactors will run concurrently, one powering the habitation torus, the other powering the manufacturing ring; however, should one need to be shut down, the other can increase its power output to meet the whole settlement's requirements. In a worst-case scenario, and the capsules must detach from the structural ring, a very small, 800 kW reactor will come on-line in each capsule.

Table 3.2.3.2 Power Allocation	
Use	**Power**
Living/Office Space	18.5 MW
Personal Electronics	6.9 MW
Public Transport	1.9 MW
Food	9.2 MW
Industry	60 MW
Total	96.5 MW

3.2.4 Water Management

For the most part, Astoria's water cycle will be closed after the initial supply extracted from hydrated minerals on Kalliope, so the rate at which the supply must be replenished is very slow. The primary reason for obtaining more water is to supply the LOX/LH2 fuel tanks addressed in 7.2. Astoria will need approximately 20957160 L of water in order to function, given a purification turnover time that is twice as long as the time spent in our of the purification system. The primary consumer of water on Astoria will be the hydroponics system, which requires about 86% of the supply at all times. The people will use water from their residences for routine activities, such as bathing, washing clothes, dishes, etc., and recreational use, such as swimming. The manufacturing areas will also need a significant supply of water for industrial functions, mainly as a coolant. The water recovery system must will be able to process and purify used water very quickly in order to keep up with the high usage rate. The system will use various methods to cleanse the water, such as sedimentation, filtration, irradiation, distillation, etc. The water vapor in the atmosphere will recycle naturally through the plants and the AMDs on each capsule level. Since the hydroponics systems require mineral-enhanced water and only use their water supplies for a single, specific purpose, the individual systems will clean, filter, and re-enrich its own water to suit the nutritional needs of the plants. For medical and safety reasons, the water used in the manufacturing areas will also be isolated from the public water supply to reduce the possibility of toxic chemical leaks. A small amount of water will be treated beyond industry standards to remove all sediments, contaminates, and bacteria via distillation, to be set aside for use in laboratories. The public water supply is handled by a system located in the bottom dome of every capsule. There it is filtered, irradiated, and chemically treated before having small amounts of fluoride and minerals added for dental health and taste enhancement. Large reservoirs adjacent to the purification facility will hold waste water awaiting treatment, and purified water awaiting use. In addition to the static water supply, Astoria will also have a throughput of water that is purified and stored in the 0g warehouses for supplying visiting spacecraft.

Table 3.2.4.1 Water Allocation	
Purpose	**Usage Rate (L/hr)**
Industrial	136000
Aesthetic Plants	71137
People	145107
Hydroponics	8004000
Total	9256244

Table 3.2.4.2 Water Treatment	
State	**Processes**
Going on to industrial use	-sedimentation, chemical pollutants, and bacteria removed
Going on the laboratory use	-complete purification via sedimentation, irradiation, distillation
Hydroponics recycling	-waste chemicals removed, irradiation, enrichment
Returning to public water supply	-irradiation, fluoride added for teeth, vitamins, minerals for taste

3.2.5 Household and Industrial Solid Waste Management

Since Astoria will have separate capsules for industry and habitation, there will be two distinct types of solid waste processing centers. All household waste will be managed in the bottom dome of every habitation capsule. Almost all of the disposable products residents will go through will be made of recycled materials, and thus themselves be recyclable. If the materials of some products cannot be directly recycled back into the same form, they can at least be downgraded for use in different, lesser products. Any plant waste can be broken down into constituent minerals that will be returned to the hydroponics facility. In order to salvage everything that can be salvaged, the recycling centers will have thorough systems that continue to break down the waste in various ways (sorting, incineration, emulsification, melting, etc.) until it is in a form from which other products can be made. Materials not immediately usable in the habitation capsules can be sent to the manufacturing capsules for production. As for industrial waste, scrap metals, and slag can be salvaged for reuse and/or recycling, and can be melted down. Broken electronic systems, such as circuit boards, can be disassembled, and the parts can be remade. Ash and sludge, the mostly solid substance that is extracted from waste water (i.e., sewage), can be reintroduced into the hydroponics systems as minerals. Hazardous chemicals and materials, like radioactive waste, for instance, if it absolutely cannot be reused, will be jettisoned into the asteroid field.

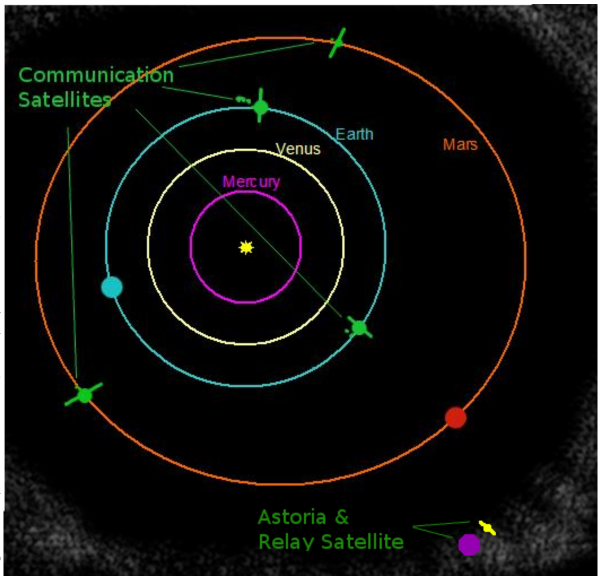
Table 3.2.5.1 Household Waste				
Type	**kg/capita/day**	**Total kg/day**	**Biodegradable?**	**Recyclable?**
Food Scraps	0.272	3128	Yes	No
“Green” Waste	0.974	11201	Yes	No
Metals	0.128	1472	No	Yes
Glass	0.116	1333	No	Yes
Plasitcs	0.260	2990	No	Yes
Hazardous Mat.	0.246	2829	No	Some
Total	1.996	48417	N/A	N/A

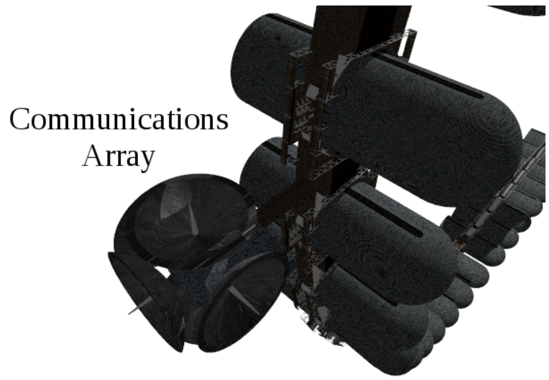
Table 3.2.5.2 Industrial Waste		
Type	**Biodegradable?**	**Recyclable/Reusable?**
Scrap Metal	No	Yes
Slag	No	Yes
Ash	Yes	No
Slugde	Yes	No
Inert Waste	No	Some
Electronics	No	Yes
Hazardous Mat.	No	Some
293 g/m²/day * 230,000 m² = 67,390,000 kg/day		

3.2.6 Internal and External Communications Systems

3.2.6.1 External Communication

In order to facilitate communication with Mars or Earth, Astoria will use relay satellites at the Sun-Mars and Sun-Earth L4 and L5 libration points. There will also be a satellite orbiting the Sun directly above Astoria, out of the primary inclination range of the main belt (20°), so that communications with other satellites is not obstructed by other asteroids in the field. These satellites will collect and resend information so that there is a smaller chance of corruption and interference over long distances. Astoria and the satellites will be equipped with support for quantum encryption of high-security data. Astoria's communications array will be located on the furthest end of the manufacturing ring and will support a 10 TiB/s transmission speed. At regular intervals, updates from the high-traffic internet sites on Earth and Mars will be dumped into Astoria's two cloud servers (this would occupy a good 1 pebibyte), and important data on Astoria's local internet will be sent back. This way, residents can have immediate access to common external media, albeit the data could be outdated by as much as and hour and a half. Residents can also request specific data if it is not included in the dumps and make special transmission back to Mars / Earth. In addition to the communications array's main receiver/transmitter, dishes will also be listening to the designated distress radio frequencies for any ships that might need assistance from the “Space Tug” services or mining locations that might need rescue operations.





3.2.6.2 Internal Communication

Astoria's could servers, containing the better part of the interplanetary internet, will be made accessible to all residents' personal electronic devices. This network will be transmitted throughout the settlement through a system of routers on every habitation capsule level, the main hub, and some of the manufacturing capsules. The routers will be organized in a hierarchical system according to usage demand, with the lower routers having a bandwidth of 100 Mbps, and higher routers having a bandwidth of 500 Mbps.

3.2.7 Internal Transport Systems

Astoria's modes of internal transportation consist of maglev trains, elevators, bicycles, and cargo carts. Four maglev trains will run a circuit around the two tracks of the habitation ring, two in each direction, and four will do the same for the manufacturing ring, where there will be four tracks. Additionally, between those four tracks will be a much larger cargo train track for ferrying bulk shipments back and forth along the manufacturing ring. Also, a train in each spoke of the habitation ring will ferry people and cargo between the ring and the central hub. The tracks, though outside the capsules, will be covered in the same shielding that the rest of the settlement has. The cars of the trains can use acceleration / deceleration tracks to slip into the empty frames of the trains so that the trains themselves never waste time stopping. Elevators will be staggered around the side walls of every capsule to convey cargo and residents to other levels. The only motorized horizontal transportation within the capsules are carts for cargo. The width of each capsule is small enough to allow walking; however, many residents may choose to use bicycles for convenience.

Bicycle

3.2.8 Day and Night Cycle Provisions

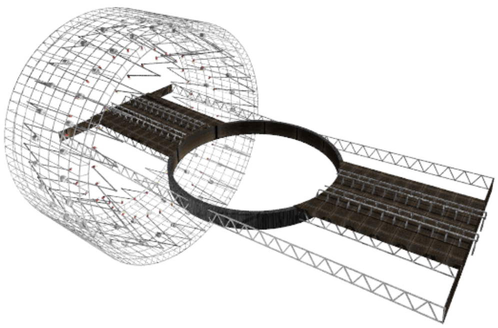
The responsibility of day / night cycles falls on the AMD in each capsule level, described in 3.2.1. It will control the image of the sky displayed on the ceiling, the intensity of the light source, the temperature, and the humidity to mimic Earth circadian cycles; however, Astoria will operate on a 25-hour day cycle since humans tend to prefer it and since the nearer colonies of Aresam and Argonom will likely be using the 25-hour Martian day. Out of the habitation capsules, however, there is no need for day / night cycles since automated functions like some manufacturing operations can proceed 25/7.

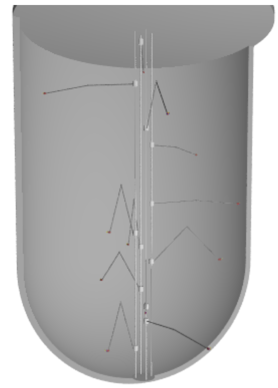
3.3 Construction Machinery

The original expedition to Kalliope will be made by an unmanned vessel. We call it the 'Seed-colony' because it possesses the equipment necessary to begin mining operations can construct the other devices that will ultimately construct the colony, and it contains all supplies needed that cannot be harvested from asteroids. It is powered by a small, active nuclear reactor, and it contains two larger prefabricated reactors that will eventually power Astoria. After landing on the asteroid, the Seed-colony, which has now become the main base of mining operations, dispatches a small army of mining drones to harvest and return magnetic rubble, rich in iron and nickel. The Seed-colony contains a single manufacturing center capable of building more mining drones as needed, and of building the parts of larger manufacturing centers. What will later become repair drones for Astoria will assemble the parts into several factories at Astoria's final location.

After the mining rate has increased to supply the factories with sufficient iron, nickel, etc., they will construct two main types of robots: the Ring Frame Builder (RFB) and the Capsule Frame Builder (CFB), both of which use a scaffolding of arms and assemblers to create the settlement. The RFBs will assemble the habitation torus's and the manufacturing ring's main structure. Each capsule will be constructed by its own CFB which attaches it to the frame. Then the CFB will continue to assemble the interior structure of the its capsule. While this is occurring, the Seed-colony will create a smaller mining based, not as elaborate as itself, to ship off to the nearest C-type

Ring Frame Builder (RFB)





Capsule Frame Builder (CFB)

asteroid that it has located. From there, mining drones will harvest the necessary materials not found on Kalliope, such as many carbonaceous compounds, and they will be shipped back on cargo transport carriers. Many more of the original factories will be constructed to be placed into the industrial capsules for use during settlement operations. When the habitation capsules are completed, they will be pressurized with nitrogen and oxygen extracted from various minerals, and the water supply will be filled with water extracted from hydrated minerals.

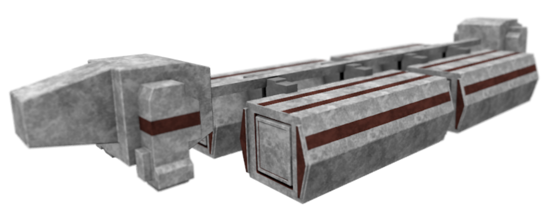
3.4 Settlement Propulsion

When grapefruit or larger sized asteroids are detected and in danger of impacting the settlement, Astoria will fire up its LOX/LH2 thrusters located at between every capsule on both the manufacturing and habitation rings. The engines will be able to direct the exhaust through one or more of the four thruster cones to determine direction. The reason there needs to be so many thrusters is so that the structure is not placed under too much stress by unevenly distributed forces. There is no need to move quickly, just fast enough to relocate the settlement 1.6 km out of the way in about one day, well before the asteroid arrives. That means a top speed of no more than 0.0185 m/s. There is no need to move back afterward unless Astoria has shifted too far away from its original position after many moves. The oxidizer and fuel tanks will be located at each thruster and will hold enough fuel for three consecutive 1.6 km moves in case of emergency, though they will ideally be refilled withing a week each move.

Table 3.4 Thruster Data	
Mass of settlement	3e10 kg
Specific impulse of LOX/LH2	4423 kg*m/(kg*s)
Fuel for whole settlement at 0.0185 m/2	125481 kg / 1 s
# of Engines	100
Fuel for each engine	1254.81 kg over 1 s
Ratio of LOX to LH2	4:1
Mass of LOX per engine	1003.8 kg * 2
Mass of LH2 per engine	250.95 kg * 2
Volume of LOX per engine per move	1.17595 m^3
Volume of LH2 per engine per move	7.40265 m^3
Max. volume of LOX tanks	5.2785 m^3
Max. volume of LH2 tanks	22.20795 m^3
Total LOX	527.85 m^3
Total LH2	2220.795 m^3

3.5 Raw Ore Import

Robotic Cargo Barge (RCB)



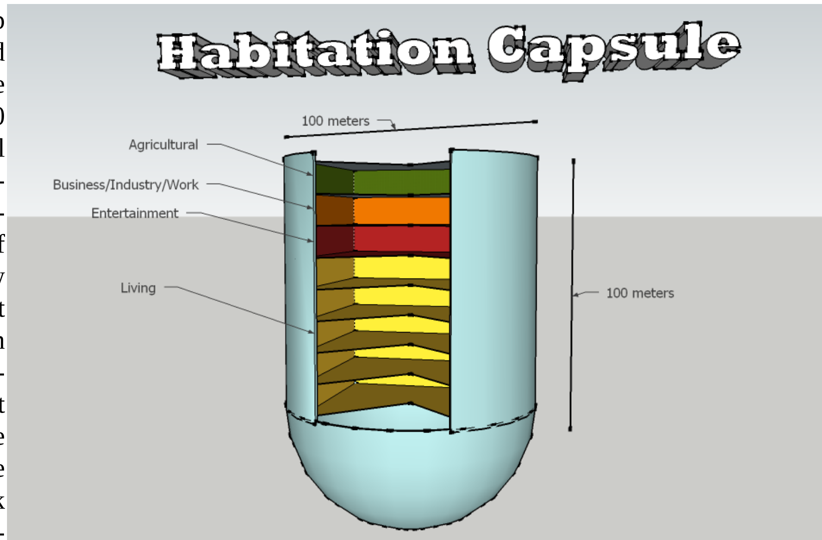
During the initial construction phase, Astoria will already be utilizing materials from another asteroid besides Kalliope. Large cargo transport carriers will deliver the materials in bulk to the main factories. After Astoria is complete, and the new factories have been installed in the manufacturing capsules, the cargo will be delivered the ports on the manufacturing ring and be sent by train to the appropriate capsule. After constructed is completed, unassociated mining operations are fully welcome to pay to use Astoria's ports and manufacturing centers, as well, to refine their own ore. They may even wish to lease out entire capsules for their own private use.

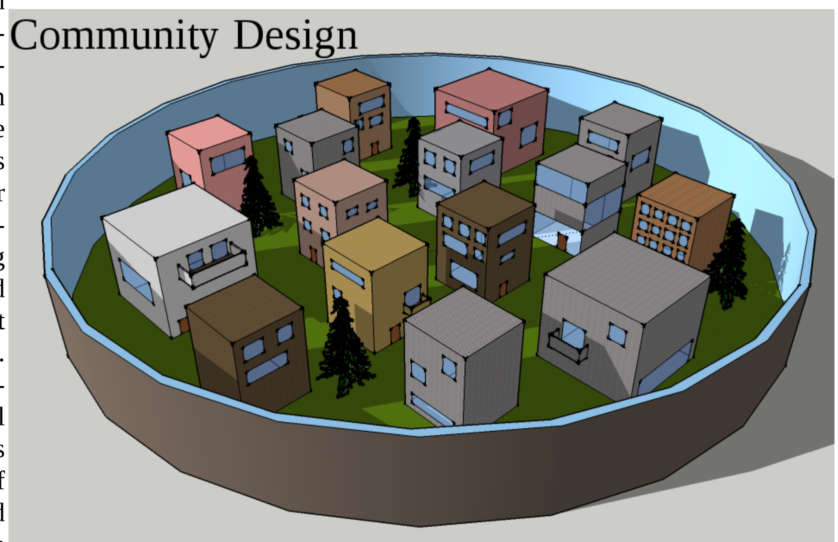
4
Human Factors

4 Human Factors

The purpose of the human factors aspect is to layout a manner of living that will be safe, purposeful, and pleasurable life for all inhabitants of the Astoria space station. Nations on planet Earth that have culture stretching back for many years have existing layers of culture and history around which the people of that nation can gather. Being an nation created by combining peoples of many cultures, it will be up to the people of Astoria to build their own culture, and it is the responsibility of human factors to lay a solid foundation of living on which they can do just that. It is absolutely necessary that inhabitants on Astoria have the ability to participate in work that they find satisfying, in the relationships they want, and in recreation that they enjoy. Also, it is our responsibility to make this lifestyle as safe as possible but at the same time as unrestricted as possible. In this section of our proposal to the Foundation Society, we will lay out how we plan to create a beautiful, cultural society that is safe, satisfying, and enjoyable.

4.1 Community Design





Communities will be divided up amongst the capsules allocated around the edge of the torus. Each capsule will have an inside diameter of 100 meters, and the habitation areas will take up 100 vertical meters of the capsule as well. Each level of the habitation areas will have a ceiling height of 12.192 meters (40 feet); this will allow buildings as tall as three stories to exist within a single level of the habitation areas. There will be room in each capsule for 8 of these levels to exist. Out of these 8 levels, five will be set aside for living. The living areas will be open and spacey, with room to walk around, and houses will remain unconnected from one another. (see section 4.2) There will be space on the habitation levels for personal gardens, sculptures, and small recreational areas such as playgrounds or small parks. The other three levels will be allocated as follows. The first level will be used for entertainment purposes. This is includes, but is not limited to, shopping areas, movie theaters, restaurants, and other such recreational activities that humans are accustomed to on Earth. The second level will be used for agricultural purposes. Some of area will have a practical purpose, such as providing food for the inhabitants of the capsule, other parts will be used for scientific research and will have the ability to be sectioned off from the rest of the area, and the remaining area will be used for ornamental and recreational agriculture, such as parks and forested areas. The third level will be devoted to business and industry purposes, as well as to education. Any offices or industrial zones existent in the habitation capsules will be located here. Education will be offered for children and young adults, much in the same way as it is on Earth. General education, such as grade schools and high schools will be taught by human teachers, and more specific education, that deals with careers, will be taught electronically. (Many industrial and manufacturing zones will be located elsewhere on the ship; see section 4.3) Underneath the eight levels used for habitation, recreation, business, and education will be an inverted dome that is the bottom of the capsule. Inside of this dome will be put all of the requirements of living that are usually hidden from sight. Water, recycling, food distribution, and other 'guts' of the capsule will exist in this area.

Inside of the living areas, there will be plenty of headroom, specifically 12.192 meters. The inside diameter of the habitation area will be 100 meters, but this will be made to seem larger through the use of lighting and screen displays. On each level, there will be room for up to 54 people to live comfortably, so each capsule can hold 270 people. (see section 4.2 for further details) Each level of a capsule will be designed after a different geographical location on Earth, such as the desert, the rainforest, the tundra, the mountains, etc., and there will be many ways to help this appear more realistic. The walls will be covered in a flexible display material that will display the landscape and horizon of the chosen geographical location, or in some areas, a live video feed of the space outside. On each level of the capsule will exist a device called an AMD (Artificial Meteorology Device) that will change the weather of that level. The AMD's are standard, but each possesses the ability to create any type of weather, to match the theme of that floor, whether it be snow, rain, or wind. Between this device and the changing wall displays, habitants will be provided with diversity in their environment, as well as the feeling of having an even longer range of sight than they already do. Groundcover will be determined by the theme of the level, but a range of groundcover growing mats will be available from the agricultural laboratories that will be able to grow any sort of groundcover required, as well as plants for personal gardens.

4.1.1 Consumables

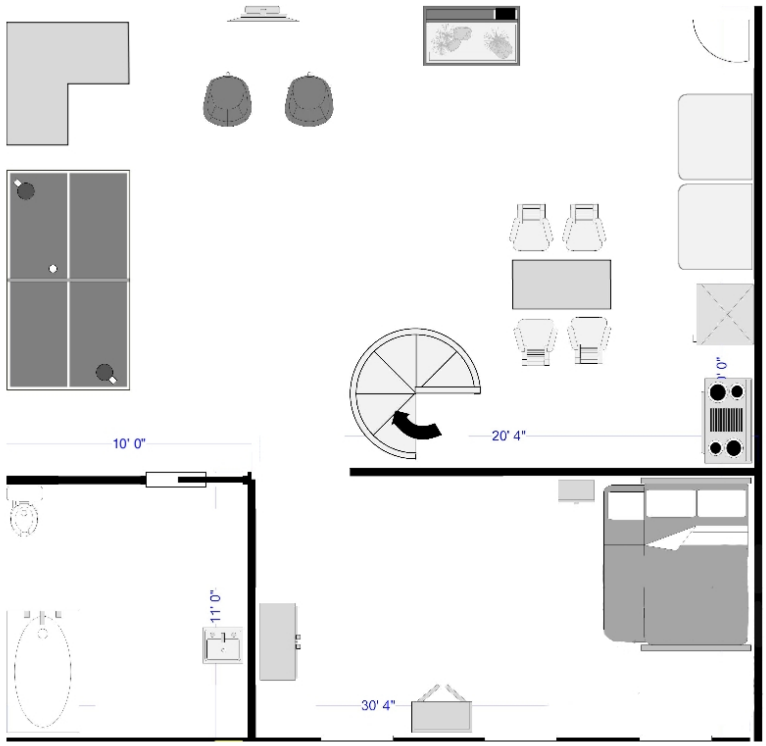
If habitants wish to save money on consumables, they will be given the opportunity to grow their own personal gardens near their homes in the habitation levels, much like on Earth. This will both promote healthier living, and assist in the oxygen replenishing process. For gardens, the seeds of all fruits, vegetables, and grains that are grown on Earth will be available. However, if habitants do not wish to do so, food will be available from supermarkets and grocery stores on the recreational level of the capsule. The bulk of consumables available for purchase on the capsule will be grown or produced outside of the habitation capsules, due to lack of space. Some food can be grown in the agriculture area of the capsule, but most will be grown or produced in separate capsules seeded around the space station. Consumables will include meat and dairy products, a wide variety of fruits, vegetables, and cereals. In the production of said consumables, multicultural diets will be taken into consideration, and there will be ample food variety to accommodate restricted diets such as vegetarians, diabetics, religious dietary restrictions, etc. At start-up, a small quantity of seeds of many different plants will be sent to the space station, where the laboratories will work to multiply this number and begin producing the plants.

Once food is produced and packaged, it will be shipped to the appropriate habitation capsules by way of the inter-capsule train system. Once there, it will be stored in the bottom dome of the capsule, where it will be readily available for the grocery stores to pick up and place on their shelves. Elevator systems will be constructed into the sides of the capsules that will serve as transport between levels, for both humans and products.

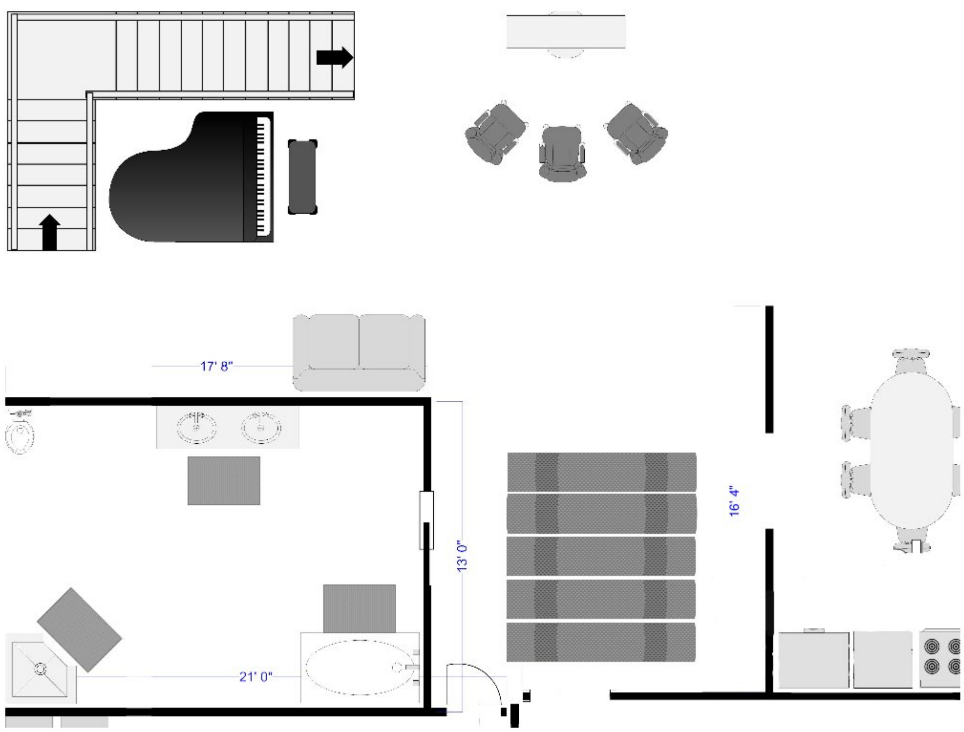
4.2 Residential Design

Housing will be divided up amongst separate houses. On each floor, there will exist two sizes of house, each three stories tall, but these can be divided up in a variety of ways. The smaller of the two house sizes will be 9.144m by 9.144m, which in feet is 900 ft2. This floor plan can either be divided up between 3 single individuals, one single individual and one couple, or a family of three, allowing one floor per person. The larger of the two house designs will have a floor size of 13.63m by 13.63m, or 2000 ft2. Following the pattern of allowing two people to live on one floor, this could be divided up amongst 3 couples, one family of four and one couple, one family of six, or up to six single individuals. On each floor there is room for 3 of the larger size buildings and 12 of the smaller size buildings, and therefore each floor can hold up to 54 people, and each capsule can hold up to 270 people.

The insides of the houses will begin totally open. Before they are moved into, the people moving into them will be able to design their floor plan. This will allow diversity in houses, and give the habitants the opportunity to accommodate for any specific needs, such as small children or religious requirements. Once the floor plan is determined, it will be constructed using panels that can be installed by construction robots. Furniture will be available to order, and will be manufactured on the space station. Most household items will be made out of the metals and silicates that will be harvested from the surface of the asteroid, but after the agricultural capsules are in full swing, indoor amenities made out of wood, such as furniture, appliances, and decorations will be available as well, only they will cost more, due to the availability of wood on the space station. There will be manufacturing capsules de-



Small Floor Plan



Large Floor Plan

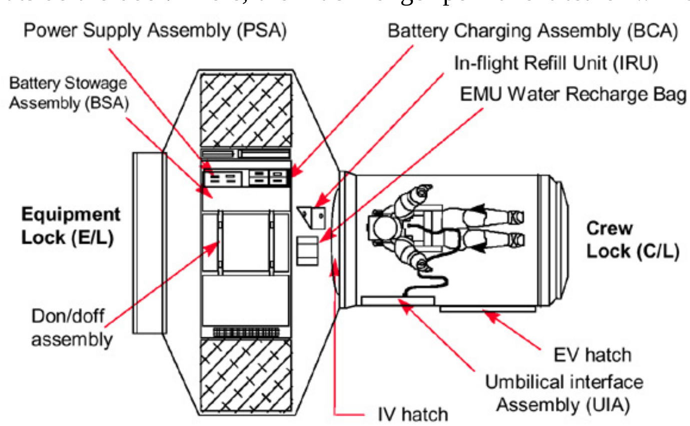
voted purely to the manufacturing of domestic products. Houses will be highly upgradeable; habitants can decorate as much as their financial situation will allow. Computer screen wallpaper like that on the inside of the levels will be available for the inside of houses, culture specific decorations and accommodations will be accessible, and the opportunity for family growth is offered. When a family, couple, or single moves into their residence, they will first go to a store in the public area that sells necessities, such as appliances, furniture, and decorations. After that, they will be able to purchase anything that they were not able to bring with them to the space station, such as clothing, food, and other such items.

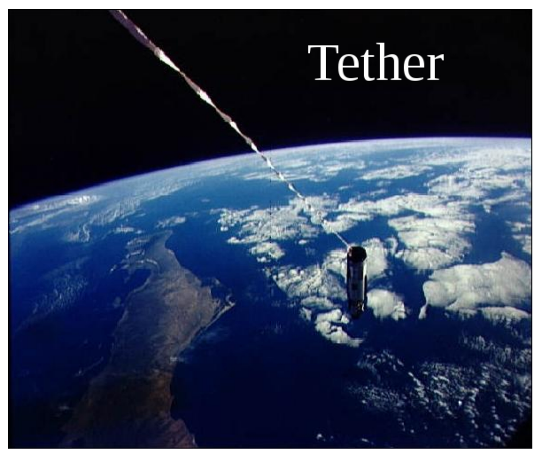
4.3 Safe Access

4.3.1 Exits

Airlock

On the space station, there will be two methods for direct access to the outside by individual human beings, along with the customary methods of exiting the space station in larger numbers. If there arises a need for human beings to move on the outside of the space station, they will have two choices. The first will be an airlock. This airlock will have two doors, one leading to the inside of the space station and one leading to the outside, separated by a small room. When exiting the space station, a person will don their space suit and walk into the airlock. The first door will close, the atmosphere will be sucked out of the room to preserve as much oxygen as possible, after which the initial tether line will be attached to the space suit by a robotic arm. This tether is not the permanent tether; it simply holds him in place until he can attach to his permanent tether. Once the astronaut's tether has been attached, the second door will open and the astronaut will move to just outside the door. There, the much longer permanent tether will be attached to his

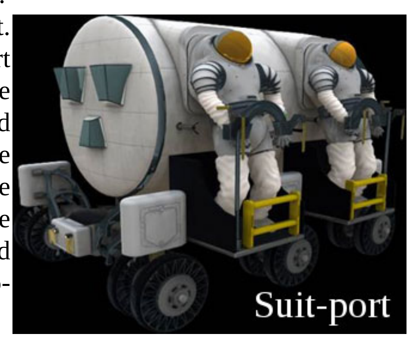




Tether

suit, and the initial tether will be detached and drawn back inside, at which point the outside door will close. Now the astronaut is free to move about on the outside of the space station. Tethers will be long enough to allow astronauts to travel as far as the next airlock, and the excess tether will be coiled up in the side of the capsule.

One airlock will be located on the outermost point of each capsule, both habitation and non-habitation, on the tip of the dome. Also, airlocks will be scattered around the inside edge of the Taurus ring that creates the structure, as well as the center node and the 0g area extending from the center node.



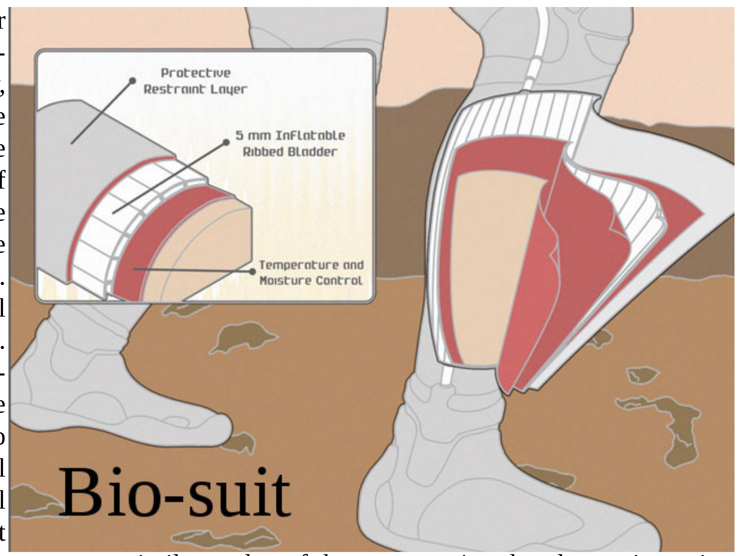
Suit-port

The other option for walking in the vacuum of space is the suitport. The suitport is similar to the airlock, but it is mobile and smaller. The suitport will not be used on the space station as much as it will be used on the surface of the asteroid, partially because airlocks will already be more commonly used on the space station. The suitport is a small, pressurized room that has space suits anchored to the outside of the port. Astronauts enter the suits from the back, the suit is sealed, atmosphere is pumped into the space suit and out of the port, and then the suit detaches from the port. When the astronaut is finished with his/her space walk, the suit simply reattaches to the suitport, and the astronaut climbs out.

For larger items, such as ships, larger airlocks will be employed. This will be similar in design to the smaller, individual airlocks, but with some slight modifications. Because these airlocks must function as docks, they will be contained within the capsules, instead of being on the outside like the individual airlocks. These docks will include maintenance and repair equipment, and unloading equipment to work with incoming and outbound ships. There will not be any docking airlocks on the habitation capsules, only on the manufacturing, research, and 0g capsules.

All areas that grant access to outer space will be have high security precautions. All entrances will require both a typed password and a face recognition scan, so as to minimize the possibility of someone breaking into the airlock, or even accidentally going in. Only humans employed in jobs that require use of the airlock will be granted security access to airlocks.

4.3.2 Suits



While on space walks, astronauts will wear slimmed down bio-suits, instead of the traditional bulky space suits. For maximum safety, the outermost layer of these bio-suits will be made out of a smaller scale version of the same Kevlar weave that is used in the construction of the space station itself. Underneath this weave is an air system for creating atmosphere in the suit, along with maintaining constant pressure. Underneath this is a cooling system that will regulate the body temperature of the astronaut. On the astronauts back he/she will carry a backpack that contains the life-support system, the control module, and all of the other essentials to space survival. For mobility in 0g, the suit will have built into the forearms of the suit small thrusters that the astronaut will use to direct their movements. Included in the bio-suit will be a system similar to that of the space station that detects incoming projectiles and alerts the astronaut of the projectiles location, speed, and direction, giving the astronaut ample time to move out of the way, if evasive maneuvers should be necessary. If the astronaut is making repairs on the outside of the space station, or simply needs to anchor there, there will be electromagnets located on the toes, knees and back, which can be separately turned on, allowing the astronaut to attach himself/herself to the surface of the space station. A similar system will be placed on large containers, which will be used to hold anything large that the astronaut needs to use in space. These containers can be driven by remote either inside the space station or by the astronaut, and then anchored to the surface of the space station, if the astronaut needs to bring along tools or materials that are too large to carry. This system will eliminate the need for any handrails or cages on the outside of the space station.

4.4 Earth Gravity for Children

The habitation torus will be continually rotating at a rate sufficient to maintain constant earth gravity. This eliminates the need for special devices or locations for children, and provides earth gravity at all times, rather than just the required three hours per day.

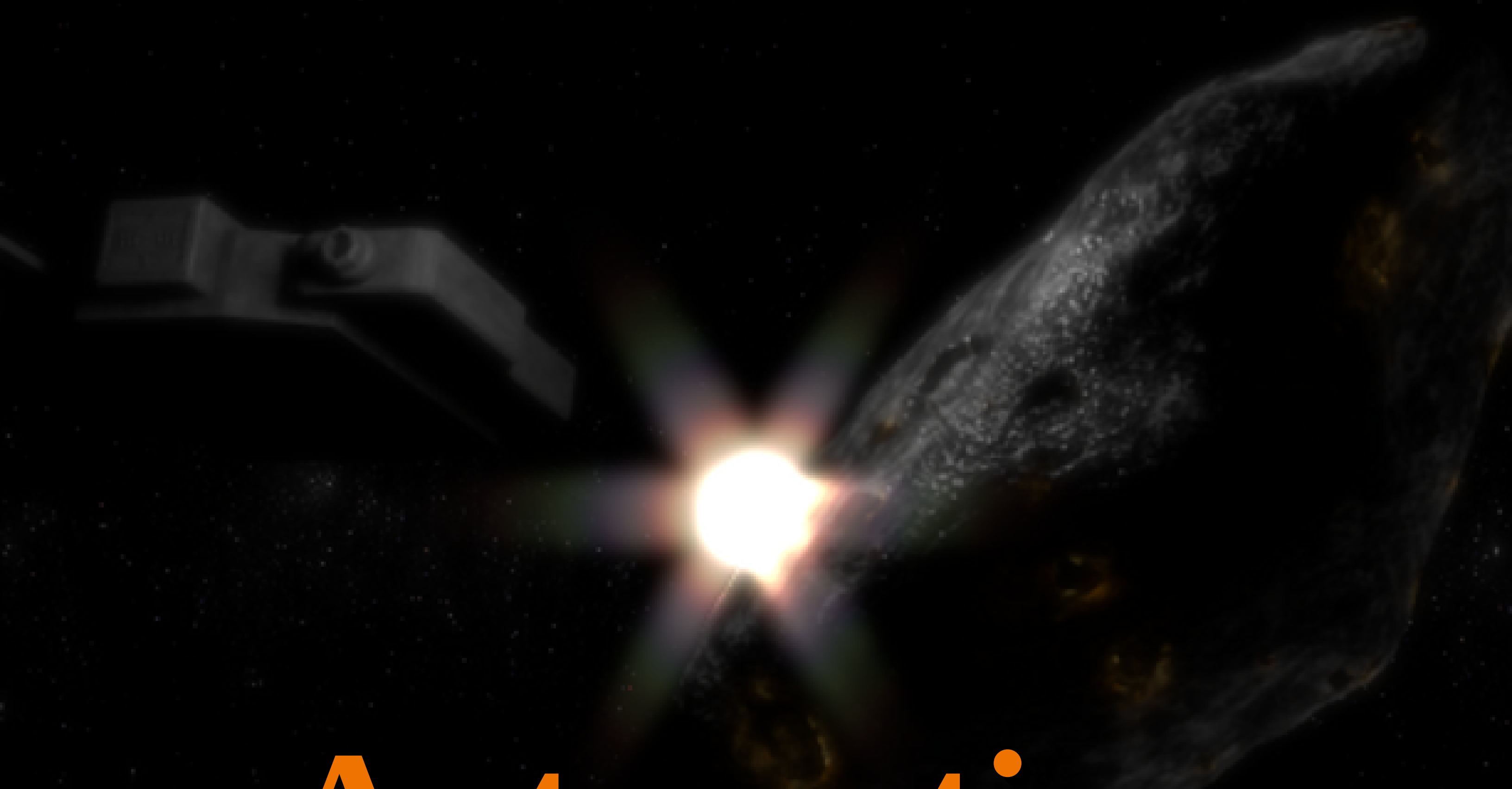
4.5 Integration of Semi-term Occupants

Integration into Astorian society will be a relatively easy process, thanks to the designs for capsules that have been put in place. As described in section 4.1, different levels of habitation in the habitation capsules will be designed with different geographical and climatological themes, nomadic visitors to Astoria will have their pick of what type of geography to live in. Whether the visitor is from the mountains of Nepal, the rainforests of Brazil, or the plains of Africa, they will find themselves with living in an area that reminds them of home. The purpose of this is to ease the integration of travelers to Astoria. Space travel is a long, potentially tiring process, and being put in strange living conditions can increase feelings of discomfort or depression. If, however, travelers are able to move into homelike living conditions, it will ease the difficulty of changing homes, and increase their ability to function in society.

The original population of the space station will be 10,000 people. The space station will have 46 capsules, each capsule having the capacity to house 270 people, which means that the space station has an initial maximum capacity of 12,420. This leaves room for 2,420 extra people, after the initial immigration. Specifically, each capsule has capacity for 52 extra people, and therefore each level can hold 10 extra people. Housing (as described in section 4.2) will be designed with nomadic peoples in mind. Walls will be movable, and all necessary amenities can be moved from the storage section of the capsule to the house within an hour. If any specific amenities are needed, such as health or religion specific items, they can be ordered from manufacturing and shipped to the individual with a few days. Once the individual move away, items can be either cleaned and sent back to storage, or recycled for their materials. Visitors will not be made to live in their own capsule; the day that a visitor moves to the space station, they will have the opportunity to be meeting neighbors who have been living on Astoria for their whole lives, and will only be a short elevator ride away from their work and their pleasure.

5

Automation Design & Services



5 Automation Design and Services

Astoria, in order to operate efficiently, acceptably, and enjoyably, requires several automation services to keep things running and to enhance livability. This section details the automated construction process of Astoria, repair and access control operations, automations used in houses to make the experience more enjoyable, and all robots used for the purposes of asteroid mining.

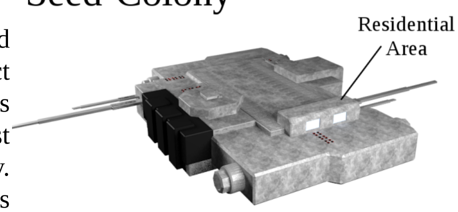
5.1 Automation of Construction Processes

Initial construction will be performed by one, multi-purpose robot/facility, the Seed-Colony, to refine the ore harvested by the first mining bots. After what will later become the repair drones assemble more factories, the Seed-Colony will construct more mining and repair bots. These factories will begin large-scale production of the materials need for construction. Meanwhile, some mining robots and cargo transport barges will travel to a nearby C-Type asteroid to obtain extra resources. Two main construction robots will be fabricated: the Ring Frame Builder for the underlying settlement structure, and the Capsule Frame Builder to construct the capsules themselves. Smaller elements and details, such as repair robots, the habitation capsules, and the maglev trains used to transport people and materials, will be added on as they are manufactured. For rapid movement, small robots can use xenon-fueled ion thrusters, whereas the larger robots will use a LOX/LH2 fuel system. Both the Seed-Colony and factories will be equipped with large reservoirs of LOX, LH2, and xenon to refill the fuel tanks of the other robots. For interior finishing, standard maintenance robots as defined in 5.2 will be initially used to install final components. After construction, the factories will be relocated inside some of the manufacturing capsules.

5.1.1 Seed-Colony

The Seed-Colony is the only non-personnel shipment made to the asteroid belt for construction. It contains all the resources it will need to conduct construction, and it will locate and land on a suitable stretch of Kalliope's surface. Initial tasks, like dispatching the mining robots, refining the first materials, constructing more robots, etc. will be performed automatically. After construction, the Seed-Colony will become the center of operations for the mining of Kalliope. After large-scale mining is underway during settlement operations, however, a few technicians will live aboard the Seed-Colony to oversee procedures.

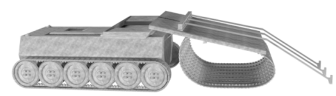
Seed-Colony



5.1.2 Mining Robots

Some mining robots will be initially contained within the Seed-Colony. After they have acquired sufficient resources, more will be made. They use electromagnetic rakes to harvest iron and nickel containing rubble from the surface of the asteroid, and they use small ion thrusters to keep themselves from floating away. The ion thrusters are convenient because they require only small amounts of fuel to move small loads like the mining bots must.

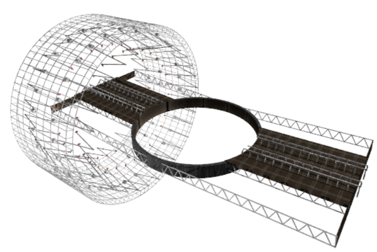
Mining Bot



5.1.3 Ring Frame Builder (RFB)

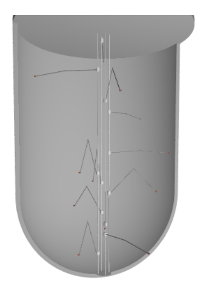
The RFP is designed as a scaffold-like robot that will slowly make its way around, building the torus or horseshoe frame as it goes. It will construct the ring-necks that hold the capsules in place. The entire underlying structure of the settlement's habitation torus or manufacturing ring will be built by a number of these working concurrently.

Ring Frame Builder (RFB)



5.1.4 Capsule Frame Builder (CFB)

The CFB is a cylindrical structure with many arm-like appendages used to construct the shell of the capsule, install its shielding, and being work on the interior structure of the capsule. The will be one CFB per capsule, and each will be assimilated into the capsule's structure or broken down for resources when construction is complete. The CFB will not handle small installment details.



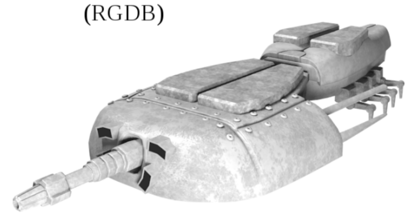
Capsule Frame Builder (CFB)

5.1.5 Repair Drones

The Seed-Colony will construct many repair drones that will put small parts and pieces in place during construction to aid in the finer details. These drones will fly in and out of the capsules during the construction phase, but will remain outside for exterior repairs only during normal settlement operations. A modified version of the repair drone will carry a rail-gun that it will use to fire deflecting ammunition at medium-sized microasteroids that are not large enough to warrant a move of the settlement, but are large enough to cause significant damage to the shield. When detected far enough in advance, even a minor deflection can prevent the asteroid from striking the settlement. When shield damage does occur, the repair drones will attend to the issue and restore the shield to its proper condition.

Repair Drone

Rail Gun Defense Bot
(RGDB)



5.2 Facility Automation

In order to carry out internal repairs and maintenance, as well as simple cleaning functions, there will be many automated maintenance robots (AMRs) with rotating cylindrical bodies, which would serve as storage space for trash and important parts and materials, and a robotic arm with various tools, including a spot-welder, screwdriver, and nail gun. When a problem/failure is found/detected, these robots will be dispatched to take care of it. These robots will be propelled by their omni-directional wheels, which are mounted on the bottom of 3 tripod-like extensions of the body for stability.

Automated Maintenance Robot (AMR)

For external maintenance, a somewhat larger robot will be used. This robot will have a box-shaped body which will also carry important materials, as well as two high-power robotic arms. It will cling to the settlement by using electromagnetic feet, and would crawl around on the external surface to resolve problems. This robot would be will shielded from threats from outside the settlement, such as high levels of radiation and undetectable, small, drifting objects outside.

For safety and security, AMRs will not perform any repair if people are close enough that any harm could befall them. There would also be an administration room in which robots can be individually shut down if one is seriously malfunctioning. A number of "police" robots would also be present to patrol and monitor unruly behavior and to guard restricted areas. For guarding purposes, these can be entirely automated; however, they can be remotely operated when on patrol.

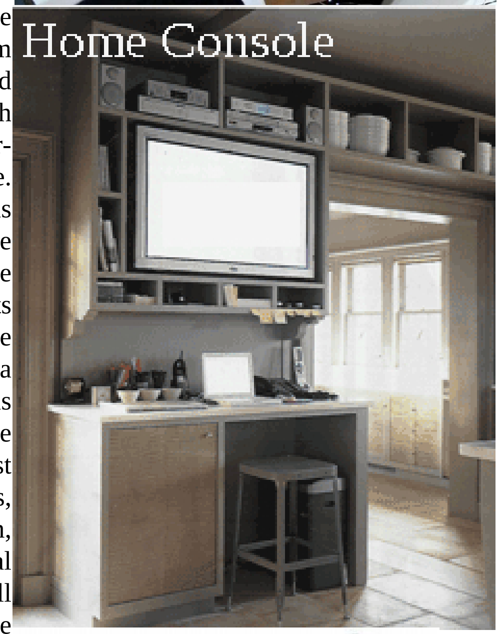
To backup all data, personal and scientific, gathered aboard the spacecraft, one cloud server, equipped with large arrays of solid-state storage media will backup all data from all computers in the settlement. There would also be a second cloud server to backup the first one, should it fail.

The administration room for all robots and computers will have all actions logged, and will be able to be shut down temporarily by triggering 5 of 7 kill-switches entrusted to security personnel, in case the administrative powers to control all the robots and data are compromised. All computers and their users will observe prudent security practices, such as setting good passwords, and file-system privileges will be maintained using discretionary access control methods, similar to those in any modern-day UNIX operating system, although it is not unlikely that those standards would be deprecated in the future. Any secure data communication will occur through quantum encryption lines.

5.3 Habitability and Community Automation

In order to enhance livability in Astoria, each home has the option to be equipped with a janitorial robot, which is just a specialized AMR, capable of performing basic household chores, such as laundry and cleaning up miscellaneous objects. There will also be several command consoles to control all robots inside the house, to report problems, and to serve as communication devices. Many items that engage in specific, routine, automated tasks will have short-range, passive RFID tags containing instructions for the involved devices; for example, clothing tags could contain specialized washing instructions. Homes would be capable of basic self-maintenance using an internal repair robot as specified in 5.2, which can efficiently locate, identify, and fix problems in the many devices with tracers in their circuitry and other helpful signals.

Astoria residents will have access to state-of-the-art personal electronic devices, such as flexible LCD newspapers with live update and sleek personal computers. Houses will contain consoles from which residents may monitor the status of warning sensors placed throughout the home for the AMRs to locate issues, communicate with other rooms in the house or even other computers and houses, and order commodities, food, etc. which will be delivered to the house. Cellphones will be able to access the users other computers systems throughout the settlement, and even act as a remote console for the house. Facial recognition and good password practices guarding secure quantum encryption system will suffice for data protection. All robots will be equipped with long-lasting rechargeable batteries. The same televised programs, music, and other media will be available in Astoria as on Earth, and they would be received through the communications array, and the Astoria servers will maintain an updated copy of the greater part of the internet on Earth and Mars. In order to guard against interference in the form of debris, radiation, and large moving objects, the data will be sent with redundancies, and the satellite relay system, described in 3.2.6.1, will circumvent denser debris fields. Internal broadcasts by television of events taking place on the settlement will exist as well. All computers will have access to a server, located on the settlement, with all nature of educational information, in a fashion similar to Wikipedia. All residents will have a small, portable computer that will have constant internet access, will be able to access news broadcasts, and would serve as a general-purpose, portable communication hub.



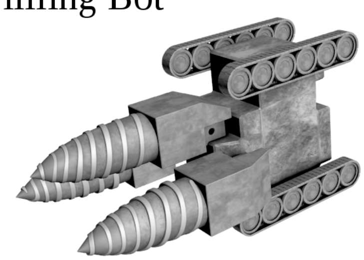
5.4 Mining Automation

After construction is well underway, a few technicians will move into the residential quarters on the Seed-Colony and will conduct large-scale mining operations.

5.4.1 Drilling Bots

The mining robots used during construction will continue to be used throughout settlement operations. However, as rubble is cleared away from the surface of Kalliope, it may become necessary to drill into the rock. For this, the Seed-Colony, which is now the mining operations control center, will construct drilling bots. They will be equipped with small ion thrusters to hold them to navigate the asteroid, and will be able to keep a strong electromagnetic grip on the surface of the asteroid as they drill, and may be permanently attached in place with the aid of simple metal screws. The drilling robots will be used in conjunction with the standard mining robots: one to grind the asteroid, the other to collect the ground-up ore.

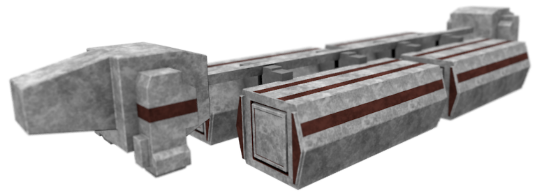
Drillling Bot



5.4.2 Robotic Cargo Barge (RCB)

After the mining rate accelerates to meet the load the factories on Astoria can handle, it will become necessary to have large carries for bulk shipments of ore from the asteroid. Also, materials will be sent in bulk quantities from the nearby C-Type asteroid. For this, we have the RCB. It consists of a cockpit, attached to four very large cargo holds, and strong LOX/LH2 engines to push the barge along.

Robotic Cargo Barge (RCB)



5.5 Raw Ore Import Automation

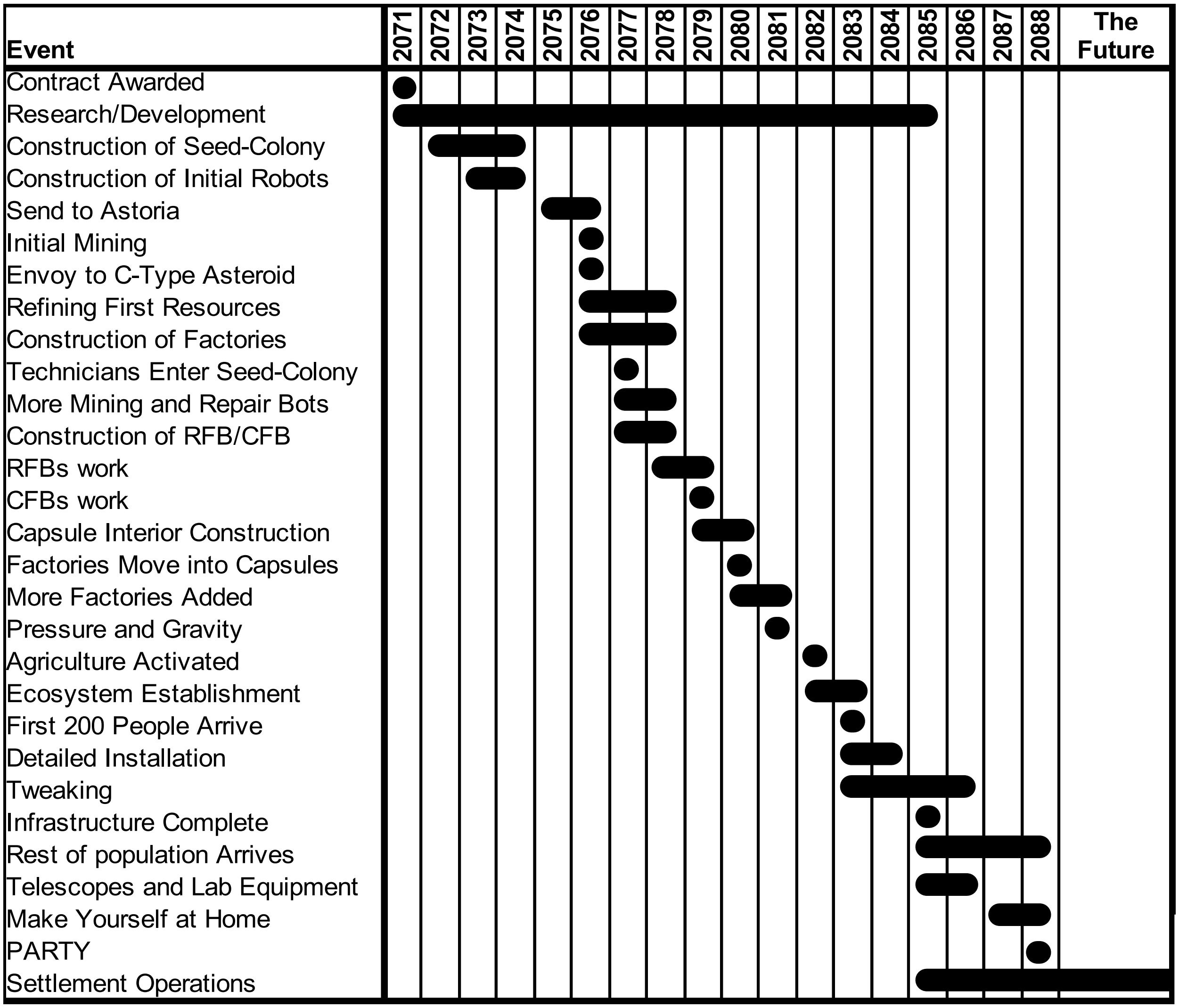
All ore will be accepted in bulk through the ports on the manufacturing capsules. Astoria, itself, uses its CTBs for these kinds of transport. Infrastructure will already be established for handling it since that is how Astoria was constructed originally, and many of the original construction factories have been relocated into these capsules. Upon arriving via cargo ship, the ore will be pushed out of the hold and directly into a train car. The large cargo maglev train will then carry the ore to the correct facility in the 0g manufacturing ring. The ore will be melted down and separated by a centrifuge. Ore waiting to be processed will be stored in warehouses near the refinement facilities, and purified materials will be stored near the 0g factories, awaiting forging, welding, drawing, etc. At this point, the purified materials are fit to be transformed into any industrial products.

6

Schedule & Cost

6 Schedule and Cost

6.1 Schedule



6.2 Cost

Table 6.2.1 Raw Materials			
Material	**Cost ($/kg)**	**kg**	**Total Cost ($)**
Carbon Nanotubes	75	$8.23x10^{8}$	61.7 B
Titanium Alloy Grade 37	50	$1.08x10^{9}$	54 B
Nanobot Solution	200	$7.14x10^{7}$	14.3 B
Polystyrene Foam	2	$4.06x10^{8}$	0.8 B
Total			130.8 B

Table 6.2.2 Salaries				
Job Type	**Job**	**Annual Salary ($)**	**Man-Years**	**Total (Million $)**
Engineers	Design	80,000	500	40
	Automation	95,000	700	66.5
	Rockets/Transportation	85,000	350	29.75
	Operations	75,000	325	24.4
	Agricultural	75,000	300	22.5
	Biological	70,000	300	21
	Electrical	90,000	250	22.5
Researchers	Societal	60,000	75	4.5
	General	70,000	20	14
	Medical	90,000	100	9
Management	General Management	125,000	320	40
	Engineering Management	120,000	50	6
	Public Relations	120,000	100	12
Misc.	Facilities Upkeep	30,000	100	3
	Communications	60,000	50	1.5
	Astronauts	170,000	600	102
Total			4320	418.65

Table 6.2.3 Transit Costs				
Location	**Transit Type**	**Price**	**Amount**	**Total Cost**
Earth Orbit to Asteroid	Seed-Colony	$850	1	$850 B
Mars Orbit to Asteroid	Personnel	$200,000/person	11,500	$2.3 B
	Equipment	$3,000/kg	17,500,000	$52.5 B
Total				$904.8 B

Table 6.2.4 Equipment Costs		
Category	**Type**	**Price**
Robotics	Electronics	$38 M
	Motors	$48 M
	Misc. Parts	$136 M
Agriculture	Minerals	$9 M
	Hydroponics	$520 M
	Misc.	$44 M
Instruments	Communications	$110 M
	Computers	$560 M
	Radar	$20 M
	Scientific	$1,400 M
Other	Ion Thrusters	$18,000 M
	Nuclear Reactors	$65,000 M
	LOX/LH2	$32,000 M
Assembly	Seed-Colony	$87,000 M
Total		$204.9 B

Table 6.2.5 Total Costs	
Area	**Cost**
Raw Materials	$130.8 B
Salary	$418.65 M
Transit	$904.8 B
Equipment	$204.9 B
Total	$1.2409 T

7

Business Development

7 Business Development

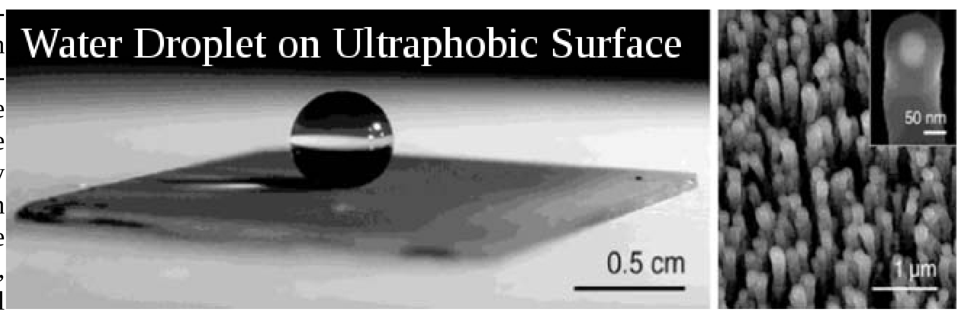
Astoria's infrastructure will be innately set up to provide lucrative business opportunities by interacting with other ships and mining operations nearby to supply services and resources. These features will develop over time, creating a large revenue for Astoria.

7.1 Asteroid Mining Operations

In order to minimize shipment of construction and mining robots to Astoria's location, only the original Seed-colony robot will be sent. Upon landing on Kalliope, it will deploy a modest army of mining drones, and as it gathers more materials, it will construct more. The first mining drones will just collect magnetic rubble from the surface with electromagnetic rakes, while the later, more advanced drones will be capable of drilling into the asteroid surface.

At first, the Seed-colony will be use its small, on-board refining facility to produce construction materials from the raw ore. Eventually, larger factories at Astoria's construction site will be assembled by another small army of robots that will later become the repair drones. Small transport vessels, also manufactured by the Seed-colony, will then take the ore from the asteroid to Astoria's construction location. Later, when the factories are finished and can support a much greater work load, larger transport vessels will be built to transport materials in bulk. After construction, these factories will be relocated to the manufacturing capsules. They will be capable of initial refining into basic raw materials. More specialized facilities will be constructed to manufacture specific products and commodities. An expedition will go out to a nearby C-type asteroid to harvest resources not found on Kalliope. Most, if not all, of the non-luxury class products Astoria will use can be produced *in situ*.

The refining facilities will have large ports for bulk transport ships to dock and unload raw ore. Some of these capsules will have expansive warehousing and storage allocations to hold overflow that the facilities cannot process yet. The more specialized factories will have both small and large ports for the import and export of products in both bulk and small shipments. They too will have warehouses to store products awaiting shipment or awaiting further processing. Partially completed products waiting to enter the next phase of production will be moved to the warehouse facility closest to their next factory via the maglev train system. Other corporations and autonomous mining operations will either pay for unloading at Astoria's ports and having Astoria owned and operated machinery process their ore, or they may wish to lease out entire manufacturing capsules and ports for their own private use.



Most ships and robots that traverse between the settlement and an asteroid will be required to have a ultraphobic coating. The suits of workers that may interact with the unclean vessels, the interior of the manufacturing capsules, and their machinery will also have this coating. One good way to achieve such a coating is to perform a chemical vapor deposition (CVD) of vertically oriented carbon nanotubes, followed by a another CVD of polytetrafluoroethylene. This results in a surface that can be both textured and also extremely resistant to the adhesive properties of water. A quick water rinse will instantly remove all dust on the surface. Of course, to perform this rinse in 0g require a high pressure water jet and a vacuum to collect it again. The used water will then go to the nearest water treatment facility to be purified. Once a ship enters the port, that section of the capsule is locked down, labeled as 'contaminated', and no one / nothing may enter or leave until the cleaning has finished, so as to prevent the dust from migrating through the train system to the other parts of Astoria. For older / cheaper vessels that may not have this ultraphobic coating, the vessel itself will not be cleaned and the capsule will remain 'contaminated' all throughout interaction with the vessel. After it departs, the interior of the capsule and all its machinery will then be cleaned.

7.2 Remote Expedition Services

In order to service visiting space vessels with food, each capsule actually has 18666 m3 more hydroponics and meat production space than is necessary to accommodate the standard number of residents. This extra food will be processed the usual way, but packaged with a more longterm shelf-life in mind. The food will then be located to storage spaces in some of the manufacturing capsules, near the ports. The food will be divided as needed between acting as a buffer when blight or some other disease strikes or being loaded as provisions onto visiting manned spacecraft. The maximum extra supply is 20% of the agriculture's total output. Also in some of the warehousing will be excess purified water for supplying the ships.

Visitors wishing to spend time resting and engaging in recreational activities will have accommodations made in the pre-furnished houses used as hotels for short-term residents. They will be directed to the entertainment levels of the capsules, which will contain malls and restaurants, and have performances musical or otherwise. Also, visitors can spend time at the pools and parks, as well as engaging in activities such as watching movies, gaming, etc. Visitors can also opt for a tour of Astoria, complete with a behind the scenes look into the inner-workings of the agricultural and manufacturing centers. The adventurous guest may even wish to put on a spacesuit and tether to brave the great outdoors—out-airlocks that is. All of these luxuries will bring in capitalistic revenue for Astoria.

Some of the ports on the 0g section, both large and small, will be specifically designed for damaged vessels in need of repair. Minor, external repairs can be done in unpressurized volumes; however, extensive repairs will be conducted in capsules that have been pressurized after the vessel docks entirely inside. Owners will pay for Astoria technicians or repair drones to fix anything on the ship from a damaged hull, to a crashed computer system, to a leaky ammonia line for the air conditioner.

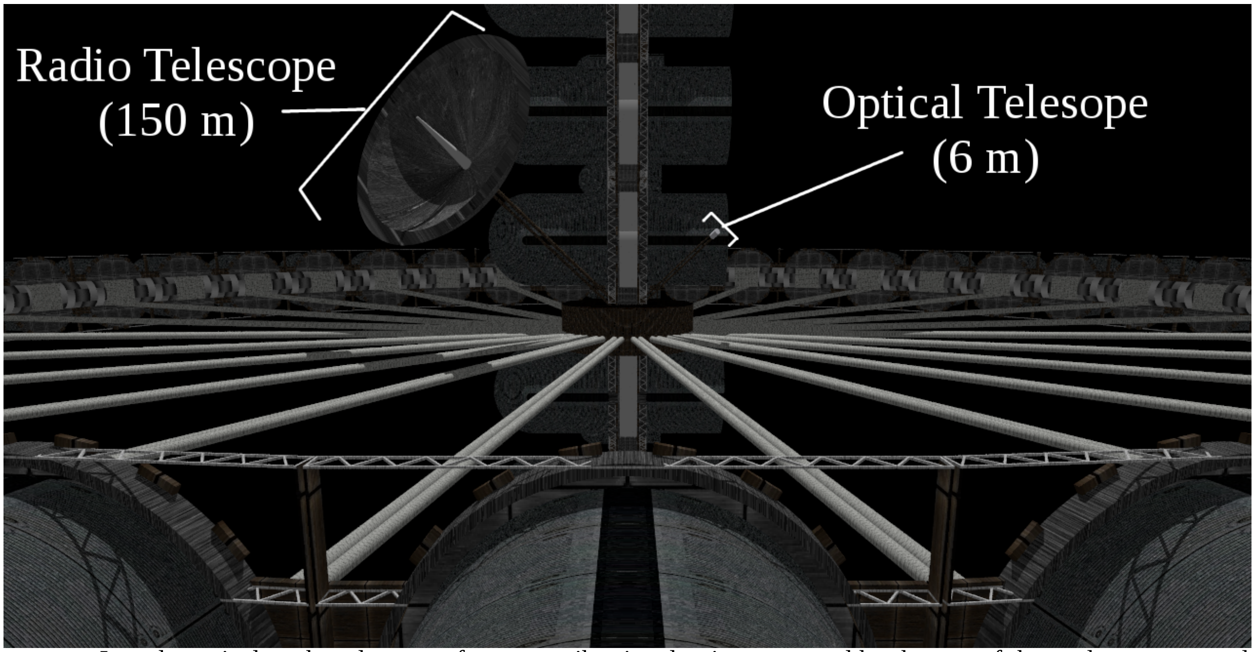
All of the ports on Astoria will have nearby LOX and LH2 fuel tanks, as well as liquid NH3 tanks. Each of the 20 LOX tanks will hold 60 m3 of LOX and each of the 30 LH2 tanks will hold 60 m3 of LH2. The LH2 tanks will be kept at 20 K at 12.8 atm and the LOX tanks at 90 K under 1 atm, both using cryogenic cooling methods. Due to the rather extreme conditions under which the LH2 must be stored, only half of the store will be on hand at one time. The other half will be contained in the much easier to accommodate liquid ammonia. Halfway through the month, the NH3 will be broken down and the H2 will be placed in the LH2 storage. At the beginning of every month, the LOX and LH2 tanks will be refilled directly, and half of the H2 allotment will be catalytically combined with N2 to form the ammonia via the Haber-Bosch process. The O2 and H2 will be produced from water extracted from the hydrated minerals on Kalliope with heat, which will then be electrolyzed to separate the O2 from the H2. This requires 2.18 x 106 kg of fresh water extracted form the asteroid every month in addition what is already being harvested for the settlement's thrusters, which equates to about 1/10 of the total water in Astoria's closed water cycle.

Astoria will also provide a “Space Tug” service to tow spaceships with damaged thrusters / empty fuel tanks back to Astoria for repairs / refueling. The tugs will consist of the front end of the cargo transport ships for the crew, with the addition of extra LOX/LH2 fueled engines and several steel cables, reinforced with carbon nanotubes. Some ships may have a place for the cables to attach, other ships will be pulled by electromagnets at the end of the cables, while still others may require that the cable be tied around a part of the ship. Of course, Astoria's services will be limited to within a reasonable radius so as to not require extensive provisions.

Should tragedy strike on-asteroid miners, Astoria will be ready to dispatch a fully equipped rescue envoy within 24 hours. This envoy will consist of a cargo transport ship that can hold 25 people total and can carry provisions that can last up to 10 months for all 25 people, 5 repair drones, 2 raking miner-bots, and 3 drilling miner-bots in case repairs must be made on nearby facilities or surgical operations need to be performed on the asteroid itself. The provisions will be quickly loaded into the cargo ship from Astoria's emergency / provisionary storage warehouses, already in the 0g section. The food will have already been packaged for longer-term storage. Also, the emergency water tanks will fill the ship's tanks. Since Astoria's agriculture can supply food 25% above necessary capacity, the stores will easily be kept full between rescue missions, even with visiting ships requesting provisions. The crew members will immediately pack and depart as soon as the provisions are loaded—they can sleep on the way if they have to be woken in the middle of the night.

7.3 Sensing and Imaging

For the purposes of detecting of potentially harmful objects outside of the settlement, the identification of likely mining targets, and imaging distant celestial bodies, a 500-foot radio telescope and a 20-foot optical telescope will be created. The optical telescope will use a series reflecting mirrors. Parabolic mirrors will be fabricated by rotating a dish filled with plaster, allowing it to harden while spinning so that a parabolic mold is formed. From there, the now-curved solid can be plated, coated, or painted with a reflective material in order to give it the necessary reflective qualities. A radio telescope could be trivially created from a conductive wire mesh that can be fabricated from metals found on the asteroid shaped into a dish form, similar to a common satellite TV antenna.



In order to isolate the telescopes from any vibrational noise generated by the rest of the settlement, several precautions have been taken. Industrial processes, like mining, drilling, and refining, will be produce minimal vibrations since all sections reserved for industrial processes will be anchored through a noise- and vibration- resistant padded joint. The telescopes will be gently attached to the main hub via five 200 m x 1 m steel rods, buried at both ends in a vibration-resistant gel. At the juncture of the rods to the hub, a vibration-inducing device will match incoming vibrations with a phase-shifted, deconstructive vibration, in a similar fashion to that of noise-canceling headphones.

A portion of the bandwidth of the main communications array will be electronically and physically isolated from the main data transfers. The telescopes will send live, streaming data back to Earth through the same satellite system, but will use analog image data. That, is the raw radio image and raw optical image from the two telescopes will be sent back to earth as is, without being converted into digital image data. This eliminates any need for high-speed image processing computers to convert the data to a different form and maintains an impeccably high resolution. After the images reach Earth, they can be filtered for the most useful frames and will be converted to digital data after the size of the data has been significantly reduced.

8

Appendices

Appendix A: Operational Scenario

It's 6:00 am, and the alarm clock goes off—the start of a typical, ordinary day for a typical, ordinary family, the Burbanks. Mrs. Burbank pushes her husband out of bed and goes to take a hot shower, while he rouses the kids and heads downstairs to the kitchen. The console there greets Dr. Burbank with a warm "Good morning, Dave! What would you like for breakfast?" After ordering a wholesome array of warm breakfast foods for his family, he sits down to review the morning news on his flexible, live-updating news paper. After the family has finished getting ready for the day, they sit down together to enjoy their freshly cooked and freshly delivered breakfasts.

Mrs. Burbank, a repairing technician for mining drones departs their two-story home on foot for the elevator 30 m away. It is a quick, one-minute ride to the top of her habitation capsule—Capsule XI, that is—followed by a 2:30 minute wait for next train to take her to the central hub. Passing into the 0g sector was a little strange when she first moved in; however, she has long been quite accustomed to it by now. She then takes the next train around the manufacturing ring, which takes about 4 minutes. Finally, she has arrived at her job site about 10 minutes after she left her home, and that was during rush hour! Soon, a cargo ship enters the port in the capsule, carrying this week's batch of damaged mining drones. A quick water bath in a centrifuge cleans all the dust off, thanks to their sophisticated ultraphobic surfaces. She harnesses into a tether to keep from floating off and begins her work on fixing the drones.

Meanwhile, Dr. Burbank sees his kids, Felix and Fanny off to the elevator, which takes them to the capsule's top. An assistant is waiting there to chaperon all the kids from that capsule to the nearest school on Astoria, which teaches preschool through 12th grade, by human teachers! Including time spent waiting on the other children, Felix and Fanny arrive at their school after about 15 minutes.

Dr. Burbank returns to the house, since his job is conducive to working from his home office today. The latest high-resolution images of nearby asteroids from Astoria's optical telescope are delivered to his personal computer from the cloud server. He proceeds to cross-examine those images with the ones taken yesterday, when the asteroids were rotated differently, and he observes streaming, live footage of the asteroids' rotation.

The sink in the Burbank's kitchen springs a leak. Sensors detect the excess water beneath the sink and send an alert message to Dr. Burbank's computer and Mrs. Burbank's phone. Knowing that her husband is likely to be too lazy to want to get up, Mrs. Burbank calls him to make sure he takes care of it. Dr. Burbank checks the leak to verify that it is not a false alarm and requests an AMR. The bot arrives promptly and follows standard leak-fixing procedure: shut off the water to the house, drain excess water from the pipe, remove the pipe, replace it with a spare that was brought in the hollow body of the AMR, and turn on the water again. Afterwards, the janitorial robot enters to clean up the water spillage.

Lunchtime. Mrs. Burbank orders a meal from her phone, Dr. Burbank does so from his personal computer, and the kids at school receive meals from a menu that was scheduled weeks in advance. Then, Mrs. Burbank finishes her repairs and Dr. Burbank successfully locates a suitable S-type asteroid for mining in the coming months. Elated, he video calls his boss, Dr. Lodder, to let him know. Felix and Fanny ride the train back with the chaperon and the other kids from Capsule XI, take the elevator back down, and walk home.

On her way back from work, Mrs. Burbank stops on the entertainment level of the capsule to buy a shiny new pair of red shoes and a new remote-controlled miniature spaceship for Felix's birthday, that he can release out the airlock and fly around the outside of the settlement with an RF tracker. She gets home much later than expected after running into her best friend, Lucy, from across the settlement. Back on her own level, she stops by the convenience store's console to request that a jug of milk and some ibuprofen be sent to the house. Dr. Burbank orders supper from his kitchen console and return to his personal computer to purchase and download an electronic copy of *A Tale of Two Cities*. While the family eats supper at their kitchen table together, Astoria's most watched television show, *AI Jeopardy*, comes on the kitchen console for the next half-hour. Afterwards, the family relocates to their living room to play the kids' favorite card games and dive into some great literature for an hour and a half. After the kids go to bed, Dr. and Mrs. Burbank stay up late, since it's Friday, and tune in to the internet radio to listen to some oldies from the 2010's.

Appendix B: Bibliography

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Appendix C: Compliance Matrix