THE KON TIKI

A 2012 National Space Settlement Contest Proposal

Authored by

Robert Gitten
Zared Schwartz
Sam Tagger
Jackie Livensky
Eric De La Espriella
Siobhan Buckley

Cypress Bay High School Weston, FL

TABLE OF CONTENTS

Executive Summary

The Kon-Tiki is not a space colony in the traditional sense. Instead it is the name of a program, such as Apollo or Constellation, containing multiple spacecraft. The primary focus of this paper will be the Interstellar Vehicle, or **ISV**. This is a habitat that continuously travels between multiple colonized star systems. Each ISV carries 1200 people. The Kon-Tiki program intends to build ten of them, making the "total" population **12000**. The ISV must meet all the same requirements as a stationary space settlement such as food, water, gravity, and air for the population. It also has the additional requirements of needing a propulsion mechanism and coping with the isolation of decades in interstellar space; the ISV is **not a transport but a community**. This is because it will take over a decade to reach most nearby star systems; people traveling aboard it must be prepared to settle down for the long haul. The ISV must fulfill the same social and psychological roles as a person's hometown. A transient community implies the environment aboard an oilrig or container ship. As you will see this is definitely not the case on the ISV.

The Kon-Tiki program must also be economically viable. In this paper we will demonstrate that an interstellar transportation network will be a valuable asset. We have tried to be as even handed as we can in predicting future technology. This study assumes that the first ISVs will be flying in the mid 22nd century. Credit must be given here; history shows that the pace of technological development in human spaceflight is slow. Yet as the recent exploits of **Spacex** and **Scaled Composites** show us, the genie of private spaceflight is out of the bottle. However, the Dragon capsule represents a capability (orbital spaceflight) NASA developed forty years ago. We predict that it will take nearly a century for a large industrial base to develop in the inner solar system. Gerard K. O'Neil, in his classic book on space colonization, *The High Frontier*, talks about how orbital settlements will eventually evolve into mobile communities traveling throughout the solar system and beyond. While the majority of proposals for this contest deal with the initial orbital stages of space settlement, we have decided to explore what a travelling settlement could be like. We hope that you enjoy our proposal and see it as a refreshing reinvention of the traditional space settlement.

I. INTRODUCTION

“”I began to see the oceans not as barriers between ancient cultures but as highways.””

-Thor Heyerdahl

A. Why Kon Tiki?

Kon Tiki was a legendary Polynesian warrior who, according to myth was the son of the sun. When invaders threatened his kingdom and eventually overran it, Kon Tiki had his people build rafts and sail off towards the setting sun. After an epic journey across the sea, Kon Tiki and his people arrived at the Polynesian islands and founded the Polynesian civilization.

The tale of Kon Tiki and his voyage would remain myth had it not been for the work of Norwegian anthropologist Thor Heyerdahl. After living for nearly two years on a remote Polynesian island, Heyerdahl made some puzzling findings. He noticed that carvings of Kon Tiki made by the indigenous people closely resembled those of Peru, and not of Japan (where most experts believed the Polynesians originally came from). Heyerdahl also noticed how the Native Americans of Peru had a legend of a warrior king who lived high in the mountains and was eventually deposed by invading Incas. The king whose name was *Con-Tici* was a sun god. Finally, Heyerdahl recognized the similarities between Polynesian rafts and Incan rafts. These findings convinced Heyerdahl that Kon-Tiki was not a legend, but an actual Peruvian ruler who led his people to Polynesia after the Incas invaded his kingdom. [*Heyerdahl, Kon Tiki, 1950*]

Heyerdahl’s theory worked except for one large detail, how did Kon-Tiki’s people make it across the Pacific Ocean? Heyerdahl proposed that they rode balsa rafts of the type that the Incas used for deep-sea fishing. The archeological community scoffed at this on the grounds that a balsa raft could not survive the voyage. Heyerdahl determined to prove his theories, assembled a crew of fellow adventures and set out to re-create Kon Tiki’s journey. They went to Peru and built a traditional balsa raft, christening it the *Kon Tiki*. Setting sail with only a radio and some food rations, the *Kon Tiki* made it to Polynesia in 101 days using only the trade winds and current. Instead of finding the trip difficult, the crew enjoyed it, catching fish, watching the stars, swimming with sharks, and made it to Polynesia in good health. Heyerdahl had proved his theory and completed a historic journey at once. [*Heyerdahl, Kon-Tiki, 1950*]

Kon-Tiki was chosen as the name for our program of interstellar cyclers because it demonstrates humanity’s desire to face the unknown and triumph. Both the voyages of Kon-Tiki and Thor Heyerdahl are a testament to man’s ability to commit to voyages of exploration and colonization: even if we must cross uncharted and treacherous waters. Also like the rafts these men used to travel across the Pacific, interstellar cyclers have no onboard propulsion system. Instead of trade winds and currents, cyclers are moved by winds of particle beams and the reassuring tug of a star’s gravity. However, like a raft, a cycler spends most of its time drifting from stellar island to stellar island across the vast cosmic ocean.

B. The Kon Tiki Advantage

- Interstellar Range
- Multiple Habitats Reduce Life Support Load
- Efficient Propulsion System

The Kon Tiki program's vision is to transport large amounts of people, cargo, and equipment to interstellar destinations using a series of continuously traveling space habitats known as cyclers. This was chosen over a traditional O'Neilian L5 outpost due to a debate with one of our teachers, Mr. Rose. After viewing artwork from the 1970s depicting kilometer long Island 3 cylinders housing tens of thousands of people in a replica of suburban America, Mr. Rose asked, *Why should someone pay to build all of this?* One of our team members brought up the traditional justifications such as space based manufacturing and solar power satellites, but Mr. Rose refuted all of these by asking, *Since when does a mining company pay to house its workers in the lap of luxury?* It was this that shattered the optimism of O'Neil's *The High Frontier*. There was no shaking Mr. Rose's logic; constructing grandiose colonies to support a solar power platform effort would be like Chevron building luxury condos on its oilrigs. If space based industry was as profitable as O'Neil imagined, it would be cheaper to ship workers back and forth from Earth.

However, Rose did end the discussion by adding, *The only real thing this would be good for would be to take people to other stars, I mean if you went to the expense of giving it a closed life support system, then it could go anywhere*. This got some members of our team thinking, and it was quickly decided to make our colony interstellar in nature. The question then was; how do we move it? A generation starship was rejected due to the immense sociological and technical challenges of keeping a space habitat running smoothly for centuries. Obviously relativistic speeds would be needed.

Kon Tiki aims to launch ten space habitats to .70c. Each habitat will carry 1200 people, bringing the total population in transit at one time equal to **12000**. By distributing the population over multiple habitats, the Kon Tiki has an advantage over other designs by reducing the life support load per habitat. The habitats are accelerated to relativistic speeds by a particle beam in solar orbit hitting a plasma sail onboard the habitat. Since the energy requirements to do this are enormous, the habitats are only accelerated once and never decelerated. Instead they use small thrusters and orbital mechanics to change their flight paths so that they bypass many stars and eventually loop back to the solar system. At each star system, payloads are decelerated in low mass "taxi" vehicles. This way, the consumables and equipment needed for the journey only have to be accelerated once. The colloquial term for these continuously moving habitats is "cycler".

The bulk of this report will deal with the interstellar vehicle, or **ISV**. For purposes of the contest we would like to show how the cycler itself could be thought of as a space colony in its own right.

Needs of Cyclers vs. Needs of Traditional L5 Colonies

Cycler	**L5 Colony**
Closed loop life support	Closed loop life support
Ability to sustain a growing population for decades	Ability to sustain a growing population indefinitely
Ability to make medicines, replacement parts, rood, water, power, and atmosphere in house	Ability to import raw materials from Earth, the Moon, or the near Earth asteroids
Ability to deal with medical emergencies	Ability to treat ailments and, if necessary, ship critical patients back to Earth
Need to rendezvous with incoming taxi spacecraft at relativistic speeds	Need to dock with spacecraft operating in Cislunar space
Need to deal with psychological issues associated with long duration space flight	Ability to detect psychiatric cases and if needed ship them back to Earth
Ability to shield occupants from cosmic rays and particles while moving at relativistic speeds	Ability to shield occupants from solar flares, cosmic rays, and micrometeorites.
Need to economically justify itself	Need to economically justify itself
Need to communicate across interstellar distances with a significant γ factor	Need to communicate from Earth orbit
Need to accelerate to relativistic speeds	

In some ways, cyclers are easier to build than traditional colonies. For example, a space colony must deal with a growing population indefinitely while a cycler rids itself of a large portion of its population at every stop. However, in most cases the design criterions for a cycler are more difficult than those of a traditional space colony. A colony located at L5 can turn to Earth, the Moon, and the near Earth asteroids for resources. A cycler on the other hand, only receives new materials at each star system along its route and must deal with breakdowns, medical emergencies, and accidents entirely on its own.

C. Acknowledgements

We would like to thank our parents for supporting us and offering guidance during the design effort. We would also like to thank our sponsor Mrs. Ashley for making sure that our design always remained science fact. A special thanks goes out to Jeffery E. McAninch, CEO of EMC2 fusion who personally answered some of our questions regarding the ISV's onboard power source. Al Globus also deserves our gratitude for creating this competition and answering our numerous questions we e-mailed him. Finally, we thank you the judges, for taking the time to read our work.

II. PHYSICAL STRUCTURE

""*It looked extraordinarily beautiful, he thought, drifting in interplanetary space like this, and yet so odd, not so much a spacecraft as an industrial plant somehow uprooted and flung into the light.*""

-Stephen Baxter

A. Overview

The ISV is based around a central truss running from fore to aft. The truss is in line with the cycler's axis of flight; the truss points in the direction of the ship's acceleration. The truss is comprised up of a series of inflatable modules surrounded by a composite frame. The different elements attached to the truss from fore to aft are as follows.

- Whipple Shield and Laser Grid
- Laboratories
- Docking Module
- Rotation Cuff
- Habitat Wheel
- Reactor Compartments
- Plasma Sail and Ionization Lasers
- Liquid Droplet Radiators
- Communications Array
- MHD Generator

(Include Overview Picture)

B. Whipple Shield and Laser Grid

Since kinetic energy is defined as $\frac{1}{2}mv^2$ and the velocity of any interstellar particles relative to the ISV cycler is large, any unprotected collision with these particles will be dangerous. Even though the density of these particles, about one per cubic meter, is low, the speed at which the ISV travels will cause them to resemble a fine spray, each collision having the energy of an artillery shell. Thankfully, in interstellar space the largest particle to be expected is about the size of a sand grain. The odds of encountering anything larger are astronomically high. Also, since many of these particles are moving at a slower velocity compared to the ISV, the majority of collisions will be head on. [*Pellegrino, 2006*]

To protect against these collisions, the ISV uses both a passive and an active system. The passive system consists of a Whipple Shield. (http://stardust.jpl.nasa.gov/tech/whipple.html) This is comprised of nearly 5000 sheets of Mylar stacked into five shields. These multiple layers combine to absorb the impact of a dust-sized particle. Each shield is shaped like a square. The Whipple Shield design assumes that any particle will vaporize on impact and not actually punch a hole through all of the layers.

For larger debris, liquid droplets of Ammonia, or any other fluid with a low vapor pressure, will be sprayed in front of the ISV. These droplets will collide with any oncoming particles and vaporize them into clouds of smaller particles that can then be handled by the Whipple Shield. [*Pellegrino, 2006*]

Finally an active system of three 100-kilowatt solid-state lasers will vaporize any debris larger than a pebble. We have assumed that by the mid 22nd century powerful solid-state lasers for tactical use will have been developed. The lasers will be guided by an array of pulse Doppler radars. Laser firing will be automatic and coordinated by a dedicated AI system.

Behind the main Whipple Shield will be a 1.5-meter thick slab of RXF1 polyethylene-based material to shield residents from oncoming cosmic radiation. Since the ISV will be travelling at relativistic speeds, the majority of cosmic radiation will come head on. This slab will have the same dimensions as the Whipple Shield.

C. Weightless Laboratories

The first module of the truss will be dedicated to scientific research. Certain measurements and experiments can be performed in interstellar space that cannot be preformed in the solar system. These include…

- Measure the properties of interstellar plasma
- Measure the outer extent of the heliopause and its interaction with interstellar space.
- Map the extent of the Ort Cloud
- Measure the galactic magnetic field
- Perform astronomical observations free of any EM interference form the solar system.
- Hunt for new exoplanets by using each ISV as a telescope in an immense interferometry array
- Take measurements on the cosmic rays
- Observe the effect of the interstellar medium on ISV components

[*Mallove and Matloff, 1989*]

The weightless laboratories will also be used to manufacture materials and medicines that can only be manufactured in the absence of gravity. These include

- Perfect Crystals
- Foamed Metal
- Improved semiconductors

D. Docking Module

The docking module will be the module that receives incoming Taxi craft. It will have four docking arms and be able to accept four taxis at once. The arms will use the American ISS docking device used by the Shuttle, Orion, and Dragon spacecraft. Each docking arm also contains umbilicals that connect the Taxis to the ISV's power grid while they are linked up.

Cargo will enter the docking module through an external airlock. A system of four remote manipulator arms will remove cargo pallets form the Taxis' payload bays and feed them into the airlock. These arms will be teleoperated by the flight team from inside the habitat ring. There are also **four small airlocks** used for the deployment and retrieval of exterior repair robots.

The interior of the docking module will be a reception area for incoming passenger residents. When Taxis are not visiting the ISV, the space will be used for weightless recreation.

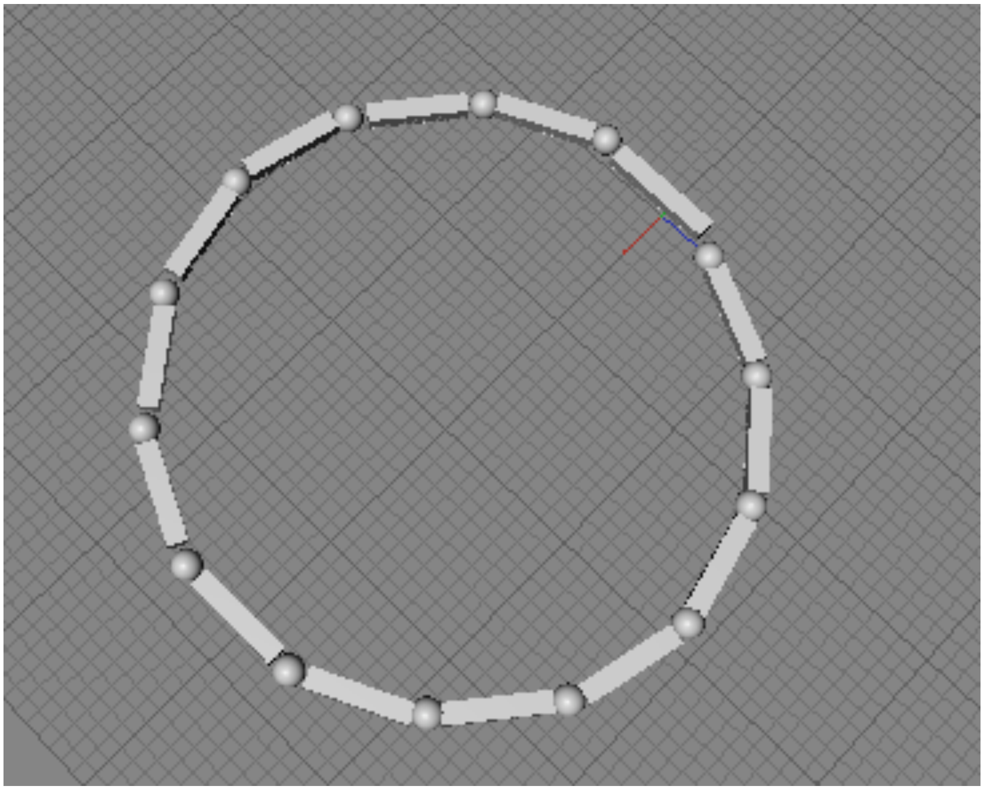
E. Rotation Cuff

The rotation cuff fits around the truss like a rigid sleeve on an arm. The cuff revolves around the truss, while the truss remains stationary, allowing the habitat wheel to spin. The rotating wall of the cuff forms the outer pressure wall of the habitat wheel's hub. Two flywheels, one on either side of the cuff connected to the habitat ring, spin opposite to the rotator cuff. These counteract the torque created by the revolving habitat wheel. A narrow passage passes through these flywheels before opening up on the chamber surrounded by the rotator cuff. Between the walls of the passage and the walls of the flywheels are bearings. The actual device that spins the wheel consists of two **helicon double layer thrusters** located on the rim of the wheel. The thrusters sit opposite from one another and fire in opposite directions. A tight fit between the flywheels, rotator cuff, and truss modules maintains atmospheric pressure within the hub.

A stationary truss skewers the interior of the rotator cuff. Since the entire interior of the rotator cuff is pressurized, the truss is purely structural. Its purpose is to connect the fore and rear parts of the ISV together. The rotator cuff is connected to the habitat wheel by fourteen spokes. Twelve of these spokes are wires that give the habitat wheel structural support. They connect externally to the rotator cuff. The other two spokes are elevator shafts that pierce the outer shell of the rotator cuff. These shafts swing around the internal truss where residents can enter them. Cargo is placed inside rotating elevators via two remote manipulators located on the stationary internal truss. The elevator shafts will not be spinning quickly, and catching one can be likened to boarding a moving sidewalk or escalator.

F. Habitat Wheel

The habitat wheel is of the beaded torus design in that it is a torus comprised of separate modules. There are two basic module shapes, cylindrical and spherical. The wheel is comprised up of fourteen of each module for a total of twenty-eight modules. It will spin at **1.51 rpm** to generate **1g** of gravity.



1. Cylindrical Modules

The fourteen cylindrical modules are the actual habitats themselves. Not quite a perfect cylinder, they have an ovoid cross section akin to an airliner. The technical term is **scalene spheroid**. They are divided into different types for different purposes, but are all structurally identical. The fourteen modules on the ISV in this study are…

- 4 Residential (living)
- 1 Recreation (living)
- 1 Fitness (living)
- 4 Agriculture (industrial)
- 1 Educational/Command (living)
- 1 Manufacturing (industrial)
- 1 Healthcare (living)
- 1 Commercial (living)

The modules are divided into two basic types **industrial** and **living**, the difference being that living modules are designed to be as earthlike as possible while industrial modules are intended to be as efficient as possible. Industrial modules resemble factories or submarines while living modules have aesthetically designed interiors.

Since the ISV will experience periods of acceleration in addition to coasting, the modules are designed to rotate 90 degrees. During the acceleration phases of the flight, the modules will turn so that their floors point in the direction of flight. “Up” is now the front of the ISV and “down” is now the rear. The ISV will maintain a comfortable acceleration of about 1g-2g whenever it needs to make a course correction. When the acceleration phase is completed, the modules rotate so that “up” points towards the hub of the wheel and “down” points towards the rim. Each individual module is spun about its linear axis by a series of cogs and electric motors. Once a module has spun to the proper orientation, clamps lock it in place. This is why the designers chose a beaded torus as the geometry for the ISV's habitat wheel. Unlike a cylinder, sphere, dumbbell, or solid torus, a beaded torus is the **only** geometry that can compensate for acceleration in this way yet still maintain a large habitable volume (dumbbells can compensate for acceleration, but are limited in habitable volume).

The cylindrical modules are divided into two decks with the top one being 10.668 meters high, and the lower one being 6.096 m high. The top deck, which is nearer to the hub, is where the equipment to carry out that specific module's function is placed, whether it be residential, environmental, or manufacturing. The lower deck, which is nearer to the rim, is primarily used for cargo storage. Placing the cargo here adds extra cosmic ray shielding for the people living on the deck above because the cargo can absorb the particles.

2. Spherical Modules

The spherical modules serve as connectors between the cylindrical modules. They also connect the habitat ring to the ISV's rotator cuff, and for this reason do not rotate independently as the cylindrical modules do during periods of acceleration. Twelve of the cylindrical modules connect to the rotator cuff via a cable. These cables maintain the habitat wheel's structural integrity. The cables connect to the rotator cuff through an external anchor.

Two of the spherical modules house elevator shafts that allow people and cargo to be moved between the habitat ring and the hub. Each shaft contains two elevators, making for a total of four.

3. Symmetry

The habitat ring is divided into two hemispheres of seven modules each. The division occurs at the two elevator shafts, which directly oppose each other. Each hemisphere has identical numbers of living, agricultural, and life support modules. This adds redundancy to the craft and ensures that each hemisphere has access to the resources it needs. The recreation, fitness, hospital, educational, manufacturing, and commercial modules are divided randomly between the two hemispheres. If each hemisphere were identical in every way, there would be little incentive for someone in one hemisphere to go to the other. By splitting up the non essential modules, people are forced to interact with others as they travel from one module to another.

Modules of a similar mass sit opposite each other on the habitat wheel. Residential modules oppose residential modules and the recreational module opposes the fitness module. Without this, the wheel would be out of balance and would develop self destructive vibrations. A system of water reservoirs and pumps shunt water around the wheel to fine tune the distribution of mass. These reservoirs are also the holding chambers for the ISV's water filtration and storage system.

G. Reactor Compartment

The rotator cuff is the official center of the ISV. Whereas the modules in front of it were made for direct human use, the rear truss components are more industrial.

The reactor compartment fits two 200-megawatt Polywell fusion reactors, boron fuel, and their support equipment. The reactors themselves are kept in a vacuum chamber; the vacuum is maintained through a direct opening to space. Since the fusion of boron is aneutronic, no shielding is required.

Fusion products are directly converted into electricity using a grid of wires to intercept charged particles given off by the reaction. A traditional water loop also passes by the reactor to generate power from the waste heat. Boron fuel is stored in non-volatile powdered form in fuel bunkers.

H. Plasma Sail

The ISV cycler must be brought up to relativistic speed in the first place before it can coast. The ISV uses Mini Magnetosphere Plasma Propulsion, or M2P2 for short, to do this. This “plasma sail” is generated by small solenoids located on arms jutting out from the truss. There are six arms, each arm connecting to two trash can sized solenoids. These solenoids generate a large magnetic field similar to that created by the Earth. The collision between the charged particles of the particle beam and this field are what propel the ISV. The “sail” itself can be as large as is needed because it is not a physical device but an energy field. This field must be “inflated” so that it can grow to immense sizes. The sail is inflated by injecting plasma into the field. Initially the field will be inflated using an onboard supply of hydrogen. Eventually this plasma leaks out of the sail and must be replaced. Once the particle beam collides with the sail, the beam itself will be used to replenish the sail [*Landis, 2001*].

Photo Credit: University of Washington

Photo Credit: University of Washington

The particle beam will travel to the sail in a neutral state, if it were charged; the particles would quickly repel each other making the beam useless for propulsion. A ring of ten 100-kilowatt solid-state lasers will be affixed to the truss behind the M2P2 arms. These will point toward the incoming particle beam and ionize it so that it may interact with the sail. However the lasers will miss some of the particles, and the neutral particles will pass right through the magnetic sail. These particles will be ionized due to their interaction with the plasma already in the sail and become trapped there due to their charge. It is these trapped particles that can be used to inflate the sail. [*Landis, 2001*]

The field has the added benefit of shielding the harmful ionizing radiation of the particle beam from the ISV's passengers. The plasma within the sail will not pose a threat to human health due to its low density.

The equation that determines the sail's virtual radius is

$$R_{sail} = \frac{R_c}{\dfrac{B_{mp}^{\frac{1}{n}}}{B_o}}$$

- R_{sail} = Radius of sail (meters)
- R_c = Coil radius (meters)
- B_{mp} = Field strength (tesla)
- B_o = Coil field strength (tesla)

- n = Magnetic field profile parameter

The equation describing the power required to operate an M2P2 coil is

$$P = IV$$

- P = Power (watts)
- I = Current (amps)

The strength of the coil field (B_o) is

$$B_o = \sqrt{\frac{P}{L_w}\frac{\mu_o}{2\pi L_c R_c}}$$

- B_o = Coil field strength
- P = Power (watts)
- L_ω = Wire length (meters)
- L_c = Coil length (meters)
- R_c = Coil radius (meters)
- μ_o = Vacuum Permeability. This is a constant describing the magnetic permeability of a vacuum it is $4\pi \times 10^{-7} V \bullet s/(A \bullet m)$

[*Barrie*]

These equations describe only **one** of the solenoids; the ISV has a total of twelve. Resistance is not being factored because the ISV uses superconducting wire which has 0 resistance.

Solenoid Length	20m
Solenoid Radius	5m
Resistance of YBCO Wire	1×10^{-9} Ω (YBCO is a superconductor, meaning that the actual resistance is asymptotically close to zero)
Thickness of YBCO Wire	.15m
Transition Temperature of YBCO	90 K
Radius of Sail	8.8×10^{5} km
Length of Solenoid Arms	900m
Power Requirement (Supplied by MHD generator)	2.656×10^{6} Gw
Field Strength	428 μT

I. Radiators

The radiators on the ISV serve two purposes

- Cooling the plasma sail while in operation
- Cooling the spacecraft as a whole

The ISV uses liquid droplet radiators due to their high efficiency and low mass. There are three to ensure triple redundancy. The radiators are larger than what would be needed to normally cool the spacecraft because they need to keep the plasma sail at superconducting temperatures while it is in operation.

J. Communication Array

Behind the radiators is the ISV's communication array. The array can handle optical, radio, and microwave transmissions. The array uses three inflatable parabolic dishes to intercept signals. Transmitter equipment will be relatively low powered due to the Kon-Tiki network's use of gravitational lensing. The array is designed to pivot so that it can align with "listening post" stations in colonized star systems.

K. MHD Generator

At the tail end of the truss is the Magnetohydrodynamic (MHD) generator. This is a six-kilometer diameter loop of wire. It acts like the stator in an immense generator while the incoming charged particle beam acts like the rotor. This motion of charged material through a loop of wire creates electricity. The MHD loop is used to power the magnetic sail while it is in operation. It also powers the ISV's onboard systems while the ship is undergoing acceleration. When the ISV is not receiving a particle beam from the LALIP, two Polywell fusion reactors provide power.

L. Dimensions

Object	**Dimension**	**Formula**	**Value**
Cylindrical Module (actually a scalene spheroid)	Length ($2a$)		131.674 m
	Major Axis ($2b$)		56.693 m
	Minor Axis ($2c$)		16.760 m
	Volume	$V = \frac{4}{3}\pi abc$	65509.171 cubic meters
Spherical Module	Diameter		43.891 m
	Radius		21.946 m
	Volume	$V = \frac{4}{3}\pi r^3$	44274.609 cubic meters
Habitat Wheel	Circumference	$C = \pi d$	2100.5 m
	Diameter	$d = \frac{C}{\pi}$	668.6 m
	Volume	14 cylindrical modules + 14 spherical modules	1.537×10^6 Cubic meters
Pressurized Portions of the Truss	Length		250 m
	Diameter		10 m
	Volume	$V = \pi r^2 h$	$1.963 \times 10^4 \text{m}^3$

Spokes	Length		327.31 m
Radiators	Length		125 m
	Width		25 m
	Area		3125 m^2
	Total Area		6250 m^2
Plasma Sail	Length of Arms		900 m
MHD Generator	Diameter		6 km
	Area of MHD generator	$A = \pi r^2$	$2.83 \times 10^8 m^2$
Communications Array	Diameter of Dish		25 m
Whipple Shield	Side Length		700m
	Area		4.9×10^5 m^2
Thickness of rxf1 cosmic ray shield			1.5 m
ISV	Length		1200 m
	Beam		6 km
	Total Habitable Volume		1.557×10^6 m^3
	Estimated Mass		1.31×10^6 metric tons

M. Hull Composition

1. Inflatable Modules

The **pressurized cylindrical, spherical, and truss modules** will be i**nflatable**. By making the modules inflatable, the ISV is able to maximize internal volume while minimizing mass. In the vacuum of space, a pressure vessel is essentially a balloon, whether it is made from aluminum or fabric. Fabrics such as Kevlar are more durable than many metals and lighter as well. The fact that the modules can be collapsed means for easy transport from factory to the ISV's construction site.

The inflatable modules on the ISV will have a similar composition to the **Transhab** modules NASA designed in the 1990s to use on interplanetary missions. The private firm **Bigelow Aerospace** has successfully flown these modules on two occasions, proving their value. The layers that make up the inflatable modules are as follows from innermost to outermost.

LAYER	THICKNESS	PURPOSE
Nomex	1 cm	Protects module structure from fire
Self Healing Fabric	Three 2 cm layers	Pressure retention, three layers make it triple redundant.
Kevlar	3 cm	Structural strength
Nextel alternating with foam	Ten 2 cm foam/Nextel sandwiches	Thermal insulation
RXF1	50 cm	Cosmic Ray Shielding
Polyethylene Ceramic Whipple Shield	50 cm	Debris protection and cosmic ray shielding
Thermal Protection Layer	2 cm	Thermal protection
Total Thickness	**182 cm**	

a. RXF1

RXF1 is a polyethylene-based material developed by NASA to shield astronauts from radiation on deep space missions. It is **3 times stronger** than aluminum and **2.6 times lighter** [*NASA*]. It also makes a superb shielding material against ionizing radiation and cosmic rays. The fact that it is a hydrogen-rich plastic is RXF1's secret. If a metal were used as the shielding material, the crew would receive an increased dose due to "backscatter" when the incoming cosmic rays energize the metal atoms causing them to throw off more radiation.

The RXF1 and Whipple Shield will be cut into tiles and inserted into pockets sewed into the outer skin of the inflatable module. This allows for the module to be collapsed during transport and the ability to replace damaged panels during flight. This is similar to how modern ceramic body armor is inserted into soldiers' uniforms.

b. Composite Ribs

Spaced at equal intervals along the outer walls of the inflatable modules are a series of carbon fiber ribs. These give the module added strength for little mass and help the module maintain its shape during a loss of pressure.

c. Self-Healing Layer

Advances in nanotechnology and materials science have allowed for the creation of materials that are self-repairing. The pressure retention membranes are imbedded with microscopic capsules of resin. When the material is punctured, these capsules burst filling the rupture with resin. This hardens, sealing the leak.

2. Hard Shelled Modules

Even though the tensile strength of the fabrics used in the inflatable modules is adequate for most uses, due to the low compression strength of fabrics, two modules will be hard shelled; the **rotator cuff and flywheels**. They will be built from layers of carbon fiber composite similar to the type used in modern aircraft fuselages. Like the inflatable modules, **the hard-shelled modules are coated in the 152 cm thick cosmic ray, debris, and thermal protection layers.**

III. OPERATIONS

“”*Rue knew all about cyclers. She had read cycler romances, watched movies about cycler captains, participated in sims about them ever since she could remember. They were a matter of practical fact in her life. They were also unbelievably romantic.*””

-Karl Schroeder

A. The Kon Tiki Network

The Kon Tiki system is a network of devices working in unison to accelerate, transport, and brake interstellar payloads.

VEHICLE	PURPOSE
Linear Accelerator for Launching Interstellar Payloads: **LALIP**	Accelerates and breaks taxi craft, alters trajectory of ISV, initially accelerates ISV.
Taxi	Accelerates/breaks cargos and passengers to relativistic speeds and rendezvous with the ISV.
Interstellar Vehicle: **ISV** (Primary focus of this paper)	Transports passengers and cargo from star system to star system in a continuous loop.
Shuttle	Carries cargo and passengers from planetary surface to orbit and docks with the taxi.
Solar Power Satellite Array: **SPSA**	Provides power to the LALIP
Listening Post	Receives Interstellar Communications

1. The Shuttle

a. Description

The shuttle is a large hypersonic waverider and is based off of the research done for the X-20 Dynasoar in the 1960s. The shuttle’s payload bay is smaller than that of the space shuttle. Due to an existing space based manufacturing capability, there is no need to lift excessively heavy payloads from the Earth. The shuttle is primarily relegated to passenger transport and light cargo lifting.

The shuttle uses two conical aerospike rocket engines fueled by LOX and LH2. It only carries enough fuel to reach suborbital altitudes. By utilizing an air launch, the shuttle is able to use 1/3 of the fuel had it launched from the ground [*Stratolaunch, 2011*]. A **Carrier Aircraft** carries the shuttle to the edge of the stratosphere. The carrier aircraft consists of a massive wing with two outrigger fuselages hanging from it. The shuttle sits between these fuselages.

Once above the atmosphere a space based particle beam, orders of magnitude smaller than the LALIP, hits a small M2P2 sail on the rear of the shuttle and boosts the craft to orbital velocity. This **Space Based Beam Driver or SBBD** is also used to change the shuttle’s orbit and retrograde the shuttle at the end of its mission. The SBBD is solar powered and more akin to a helicon thruster than a LINAC.

b. Shuttle Stats

Payload	80 passengers or 10 metric tons
Propellant Mass	700 kg
Dry Mass	6 metric tons
SBBD power output	300 MW
Wingspan of Carrier Aircraft	350 ft.

2. LALIP

a. Description

The LALIP is a massive linear particle accelerator located in the vicinity of Earth's orbit. The LALIP must produce a total of 3.6×10^{16} joules of embodied energy per kilogram to accelerate payloads to .7c. To prevent the particle beam from thrusting the LALIP in the opposite direction, a large mylar mirror, thousands of kilometers across points opposite to the beam emitter. The mirror uses solar pressure to keep the LALIP in its orbit. At the emitter of the LALIP is neutralizer that injects the proton beam with electrons to ensure that the beam remains neutral as it travels through space. If the beam were not neutral, it would quickly expand due to the particles repelling each other. The ISV then uses lasers to re-ionize the beam. To further increase beam coherence, four lasers firing on the beam squeeze it into a collimated stream. Despite this the beam will still spread out due to thermal expansion. The equation that dictates this is

$$R_T = \tan[5 \times 10^{-9}(\sqrt{B_T})]\sqrt{\frac{80}{B_N}}(D)$$

- $R_T =$ Radius of beam at target in meters
- $B_T =$ Temperature of beam in Kelvin
- $B_N =$ Atomic number of beam material
- D = Distance to target in meters

The LALIP uses hydrogen as its working fluid, which is regularly delivered by tankers from the gas giants. Power is beamed to the LALIP via microwave beams from the SPSA constellation. The LALIP is aimed through a star tracker and uses flywheels to orient itself. **Payloads always arrive or depart above or below the elliptic** so that the LALIP always maintains line of sight and is not obstructed by the sun. The LALIP has massive liquid droplet radiators to vent away the waste heat generated while it fires.

The LALIP in the vicinity of Earth is designed to boost ISVs as well as taxis. Earth bears the economic burden of accelerating cyclers in the return that when the cycler completes its loop, it returns with all the diverse goods it picked up along the way. Smaller LALIPs are located at other star systems to handle taxi traffic. They are also used to deflect incoming cyclers and put them on the trajectory to their next destination.

b. LALIP Stats

LALIP Length	20 km
Energy Output	5.3×10^{18} joules per second
Radius of Beam at .12 Light Years (Distance where the ISV stops accelerating)	1.70×10^{6} Km
Beam Velocity	.9c
Efficiency	90%
Temperature	10000 K (theoretically beams as low as 45K can be reached [*Landis, 2001*])

3. Taxi

a. Description

The taxi transfers passengers and cargo between star systems and the ISV. By having the life support system required for the interstellar flight already moving at relativistic speeds, all that needs to be accelerated or decelerated is the mass of the cargo and passengers. This means that in order to maximize performance, the taxi is as light as possible. The taxi consists of a Whipple Shield, inflatable module, radiators, M2P2 generator, and MHD ring. The inflatable module is of the same material type as those on the ISV. However, the taxi module is a perfect cylinder. It also does not rotate because the taxi is undergoing acceleration for most of its mission. By orienting the interior decks so that "up" is in the direction of flight, artificial gravity is produced when the LALIP accelerates the taxi.

The accommodations on the taxi are spartan, only having essential items in order to keep the mass down. Whereas the interior of the ISV is akin to a traditional O'Neilian space colony, the interior of the taxi is like a nuclear submarine. Like the shuttle there are separate taxis for passengers and cargo.

b. Taxi Stats

Payload	120 Passengers
M2P2 Arm Length	30m
MHD Diameter	2 km
Module Length	42m
Module Diameter	10m
Habitable Volume	3300 m^3
Vehicle Length	80m
Vehicle Width	60m (without the MHD generator)
Top Speed	.7c

4. SPSA

a. Description

The Solar Power Satellite Array is a constellation of hundreds of solar power stations located near the vicinity of Mercury. Their job is to provide power to the LALIP when it is use. When the LALIP is offline, the individual satellites provide power to colonies and cyclers within the solar system, including the Earth. The satellites are colossal sheets of nanoantenna solar panels. Nanoantennas generate electricity through the absorption of infrared light and have 80% efficiency. The nanoantenna material is flexible and can be printed. Each solar array is printed in a lunar factory, rolled up like a carpet, and shot off into space using a mass driver. The moon is the manufacturing base for the array because it is rich in the metals required and is relatively close to the Earth.

Power generated by each individual satellite is converted into either microwaves or a laser and beamed to where it is needed. When the LALIP is in use, some satellites act as relays for others that are opposite the sun from the LALIP.

b. SPSA Stats

Dimensions of Individual Satellite	112 km by 112 km
Area of Individual Satellite	12544 km^2
Area of Entire Array	1.254×10^{8} km^2
Power Generated by Individual Satellite	5.3×10^{14} joules per second
Power Generated by Entire Array	5.3×10^{18} joules per second

5. ISV

a. Description

The Interstellar Vehicle is the primary subject of this report. It is a habitat that carries 1200 people plus cargo between star systems. Once it has been accelerated to relativistic speeds, the ISV never slows down, instead it uses **thrusters, Lorentz force turning, orbital mechanics, and particle beam deflections** to modify its trajectory into a giant loop passing multiple star systems. At each star system it receives taxi craft and offloads/picks up cargo and passengers. This prevents the heavy life support equipment on the ISV from having to be decelerated and once again accelerated. The life support equipment being referred to here are the habitat ring and consumables required to keep a population alive for decades. There is no point in decelerating this because it is only used during the actual flight. By using cyclers, the energy required for interstellar trade and commerce is severely lessened.

6. Listening Post

a. Description

The listening post is a satellite located at the gravitational focus of the star it orbits (770 AU for the sun). It is a modified taxi craft that carries an optical, radio, and microwave communications array. The entire spacecraft is automated and a fleet of four is needed to intercept signals from every part of the sky. The listening post is propelled to its destination using the LALIP. It is braked by using its

M2P2 device to enact a 180-degree turn and retrograde. The LALIP fires at the now incoming station and slows it down. At virgin star systems, listening posts are detached from passing ISVs and break in the star's heliopause using their plasma sails.

The most challenging task for the listening post is to remain fixed on to the antenna of an ISV or a listening post orbiting another star. To take advantage of the low transmission power rates offered by gravitational lensing, the antennas cannot be more than a few meters out of alignment. It is the responsibility of the ISV to maneuver its communications array so that it is aligned; the listening post remains fixed in place.

When not in use, the stations can be used for astronomy. Optical resolution using a gravitational focus is so powerful that the listening posts could image the surfaces of exosolar planets.

b. Listening Post Stats

Station Length	80m
Diameter of Optical Dish	50 m (164.042 ft.)
Diameter of Radio Dish	100 m (328.084 ft.)
Diameter of Microwave Dish	100 m (328.084)
Broadcast Power	100 watts

B. Acceleration Phase

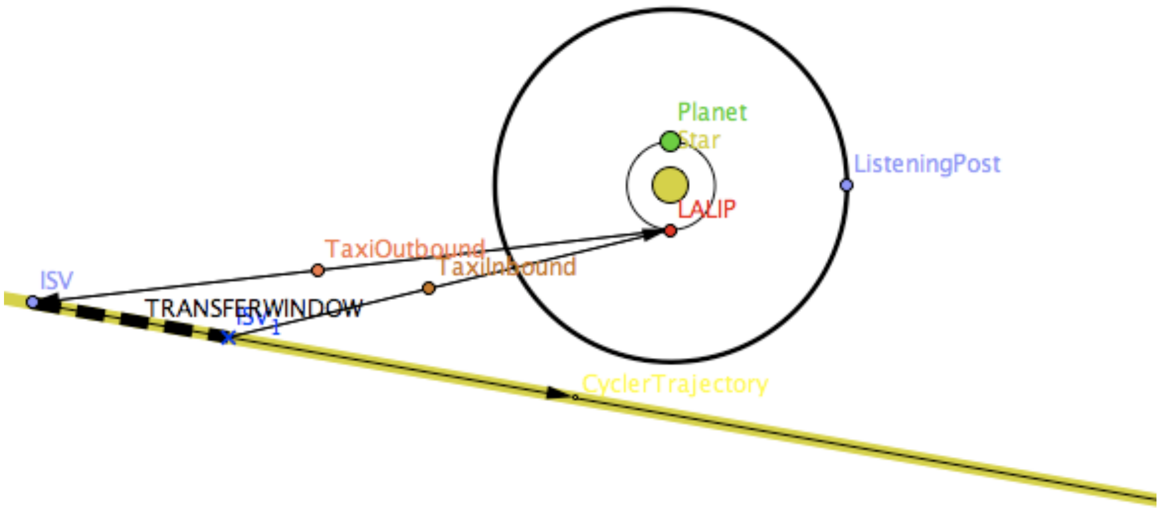
1. The ISV

Even though it will spend its operational life at relativistic speeds, the ISV must first reach these speeds. To do this it rides as massive particle beam from the LALIP. If it accelerates at 2g it will reach its cursing speed of **.7c** in **4 months** at a distance of about **.12 light years from Earth**. In order to save energy, the ISV will be launched empty and with only a skeleton crew. A lighter ship means that the LALIP needs to expend less energy. Passengers and cargo will follow it in taxis.

The ISV launches at an angle above or below the elliptic so that the LALIP may maintain line of sight without being blocked by the sun.

2. Taxis

Taxis also accelerate at 2gs for a period of four months. Incoming ISVs alert systems to their arrival months in advance in order to give the taxis an opportunity to reach them. Taxis rendezvous with the ISV before the cycler has even passed the star system. By meeting the ISV head on the taxis get a low energy return to their system of origin; the ISV literally "throws" them back home.



C. Cruise Phase

Once maximum velocity has been reached, the cycler is placed on a trajectory to its destination star. Cycler routes are only referred to as "loops" because they eventually return to their star system of origin. This is done for economic reasons and will be discussed later. As long as they don't decelerate cyclers can go anywhere. They use a system of low energy techniques to alter their course to any destination they want. The Kon-Tiki project envisions a fleet of ten cyclers making rounds between a dozen or so worlds. If the cyclers are properly staggered, a system will be visited every year or so.

It will be noted that all of the methods discussed below will decrease the cycler's forward velocity to some degree. However, the energy loss here is negligible compared to what would be required to completely stop and restart the interstellar vehicle. The energy lost turning will be recovered when the cyclers receive a small boost from the LALIP at each star system they visit.

1. Thrusters

The simplest method of altering a cycler's trajectory is to use onboard thrusters to apply a force that changes the craft's velocity vector. Since cyclers take decades to reach their targets, the thrust does not have to be large meaning that high efficiency thrusters such as ion engines can be utilized.

2. Lorentz Force Turning

This technique uses the interaction between the galactic or stellar magnetic fields and charged wires on the cycler to turn the ship. The **right hand rule** dictates that electric force runs perpendicular to current and the magnetic field. If wires are deployed perpendicular to the ISV's trajectory, this force can actually turn the spacecraft. The thrust felt is small, but over time it can accomplish great feats. It is even possible to use the Lorentz force to cause the cycler to loop around and head in the opposite direction.

$$r = \frac{mV}{QB}$$

- r = Radius of trajectory
- V = Velocity of starship
- Q = Charge of wires
- B = Magnetic field vector
- m = Mass of starship

The starship will move in a circular orbit perpendicular to the magnetic field and the above equation provides the instantaneous radius of that trajectory. [*Mallove and Matloff, 1989*]

3. Particle Beam Deflection

This is the primary method that will be used to alter ISV trajectories. In this case, as a cycler passes an already colonized star system, it receives a small nudge from that system's LALIP. This applies a force to the cycler's velocity vector, causing it to accelerate in a different direction. Acceleration, though a fraction of what is initially required to get the ISV up to speed, can last from hours to days. During this time psuedogravity will be felt along the axis of thrust. This is when the cylindrical modules orient themselves so that their floors are in line with the ISV's thrust axis and the habitat wheel is stopped. Doing this prevents the passengers from feeling two strong psuedogravities at right angles to each other.

D. Seeding

Star systems for future colonization will first be reconnoitered from telescopes based in inhabited systems. Once a target has been selected, a cycler is dispatched carrying a series of small, unmanned, taxi vehicles. The cycler deploys these like paratroopers into the heliopause of the target system where they use their small M2P2 sails as "parachutes" in the stellar wind. Using advanced robotics, these vehicles scour the system for raw materials and build a LALIP. Pioneering humans can also be dropped off to oversee this process. When the cycler returns in a few decades, the system will have an infrastructure capable of sending out and receiving taxis. Eventually, the system will build and launch cyclers of its own. [*Schroeder, 2002*]

E. Construction

The construction of the ISV is shown below; a schedule for the construction of the cycler network as a whole is presented in chapter seven of this study.

Step
• Truss modules are inflated and linked together • Habitation modules are inflated in a separate location
• Truss modules are fitted out • Habitat modules are linked together

to form the habitat ring
• Ring is spun up and habitat modules are fitted out • Reactors and radiators are installed and go online
• Whipple shield, manufactured at a separate location, is fixed to front of truss • M2P2 and MHD coils are affixed to rear of ISV
• Communications array installed
• Two year shakedown period in lunar orbit
• Acceleration Phase

1. Construction Site

The ISV is built at a "drydock" located at the L1 point between the Earth and the Moon. This location is perfect because of its close proximity to the Earth and the special gravitational properties that exist there. L1 is gravitationally neutral, meaning that it takes little energy to launch from here, and that anything placed at L1 will remain in place, balanced by the tug of the Earth and the Moon.

A physical "drydock" will not be needed, because unlike an Earth ship, the ISV does not need to be supported by scaffolding due to the lack of gravity. Instead, components will be pre assembled across the inner solar system and delivered to L1. Upon arrival, the parts will be handled by a flotilla of manned and robotic "worker" spacecraft. These worker spacecraft will actually assemble the ISV.

Once construction is completed, the ISV will enter lunar orbit for a two-year shakedown period so that all onboard systems can be properly tested. The actual launch itself will occur far from any inhabited world such as the Earth or Moon due to the massive ionizing radiation created by the LALIP. The ISV maneuvers to the launch point using its M2P2 sail and the stellar wind.

2. Material Sources

This study assumes that by the time the first ISV is launched in the mid 22nd century, humans will have colonized the inner solar system and created an industrial base there.

Body	Resources
Earth	• Advanced Technology • Volatiles • Ceramics • Carbon Compounds • Nuclear Fuel
Moon	• Metals • Ceramics • Nuclear Fuel

Mars	• Volatiles • Metals • Ceramics • Carbon Compounds • Nuclear Fuel
Near Earth Asteroids	• Metals • Volatiles • Ceramics • Carbon Compounds • Nuclear Fuel

- **Volatiles**: reactive elements, primarily oxygen and hydrogen
- **Metals**: aluminum, iron, chromium, copper, etc.
- **Ceramics**: materials made from compacted dirt or regolith
- **Carbon Compounds**: materials from which plastics can be made
- **Nuclear Fuel**: materials that can be used for nuclear power

F. Emergency Contingencies

Scenario	Response
Fire	• Sensors located in module detect smoke • Hatches between modules shut to stop the fire from spreading • People inside the affected module locate emergency oxygen supplies and safe rooms • Foam is used to put out the fire
Air Contamination	• Sensors detect contaminant • If the contamination is localized, hatches shut off the affected module from the rest of the ship. • Emergency oxygen supplies and safe rooms protect residents in the affected module while the air is filtered
Water Contamination	• Backup water loop is brought online • Primary loop is filtered and sterilized
Food Contamination	• Biosensors and human specialists locate source of pathogen • Contaminated food is recalled • Reserve food supplies are accessed • Medical staff alerted

Hull Puncture	• Hatches between modules close to prevent widespread pressure loss • Residents move to safe rooms • If rupture is small, the hull material repairs itself • For larger ruptures, flight crewmembers in pressure suits and robots apply a patch. • Module is pressurized and tested for leaks
Power Failure	• Emergency fuels cells are activated • All non-critical systems are shut down • Sensors and engineers locate source of power failure
Equipment Failure	• Backup system is brought online • Components are repaired in the manufacturing module
Disease	• The ill are placed given medical assistance • If over 84 people are ill, a quarantine is established
Cyber Threat	• If computer system is compromised, backup system is activated • Antivirus program is written
Data Storage Failure	• Backup data cache is accessed
Collision With Interstellar Debris	• Emergency services deal with immediate problems such as fire, pressure loss, or power failure. • Once the ship has been stabilized repairs are made.
Taxi misses rendezvous with ISV	• A combination of Lorentz force turning, thruster and the LALIP maneuver the taxi back to its system of origin. • If the taxi cannot steer itself back, the star system launches a rescue taxi.
ISV misses LALIP-based trajectory change	• Lorentz force turning is utilized to put the ISV on its proper course (at the expense of increased flight time)
Onboard Riot	• Shipboard law enforcement use knockout gas to subdue the belligerents. Belligerents are

	detained before they awaken. • Long Range Acoustic Devices (LARDs) can be used to deter a mob from damaging shipboard infrastructure.
Terrorism	• Ship's council attempts to negotiate with the terrorists. • If negotiations break down, the ISV's internal law enforcement unit neutralizes the terrorists.
Stowaway	• Stowaway is sent away with the next available taxi rendezvous.

1. Safe Rooms

Located throughout the ISV are a series of safe rooms to protect residents in the event that a module becomes uninhabitable. These rooms are located below a module's main deck and are accessed through hatches embedded at street level. Each room has its own reserve oxygen supply and can support at least eighty people for forty-eight hours with a breathable, pressurized atmosphere.

If there is a fire or atmosphere loss, residents will hurry to the nearest safe room. Fluorescent strips set into the floor guide residents to the nearest safe room in case the lights are cut off due to power failure or smoke. Portable breathing masks are located around the ISV so that residents can safely navigate contaminated air or loss of pressure and reach a shelter in time.

2. Outside Repair

Manned spacewalks will not occur aboard the ISV. The cosmic ray and debris hazards present while moving at .7c make such an endeavor highly dangerous. Instead, humanoid robots similar to NASA's **Robonaut** will do all exterior repair work. They will be equipped with a variety of tools and use a combination of remote manipulator arms and thruster to maneuver. The robots will be controlled from within the government module through telepresence.

IV. HUMAN FACTORS

“”*You came in that thing? Your braver than I thought.*””

- Princess Leia

A. Community Design

1. Compartmentalization

The individual cylindrical modules are linked together like cars on a train, with the spherical modules as the connectors between cars. Each module becomes a destination in itself, much like a neighborhood. Doing this adds variety to the otherwise mundane life aboard a spacecraft.

2. Hemispheres

The habitat ring is divided into two hemispheres. Each hemisphere contains

- 2 Residential Modules
- 2 Agricultural Modules

Each hemisphere is nearly a mirror image of the other so that the habitat wheel is balanced. The distribution of mass must be roughly equal on each side; otherwise vibrations will develop as the ring spins that would eventually tear it apart. The two elevator shafts linking the ring to the rotator cuff serve as the boundary line between hemispheres.

The other module types are randomly divided between the each hemisphere. Certain types of module have approximately the same mass distribution and are therefore located in opposite hemispheres from each other. These pairs are

- Recreation and Fitness Modules
- Hospital and Education/Command Modules
- Manufacturing and Commercial Modules

To fine-tune the mass distribution a system of pumps and tanks shuffles water ballast around the wheel to perfectly balance it. This system is monitored from the command module.

B. Lighting

1. Industrial Lighting

In the **industrial zones** of the ISV such as the agriculture and manufacturing modules, no attempt is made to produce artificial sunlight. This is because the entire module space is taken up by equipment that causes the interior to resemble more of a nuclear submarine than the Earth analogues of the habitation, recreation, and health modules. Even in the agricultural modules, the aeroponic gardens are lit by lamps designed to meet the needs of growing crops, which are different than those required to maintain human health. The lighting in the industrial areas is provided by ordinary LEDs. These same lights are used in the weightless areas.

2. Human Lighting

The lighting in the areas where people will live, relax, exercise, and play is designed to be as earthlike as possible. The "sun" is a strip of LED sunlamps running across the module's ceiling. LEDs were chosen because of their low energy requirements, ease of manufacture, and long life span. Sunlamps are commonly used on Earth to cure depression in people who live in sun deprived areas such as the far north. UV LEDs will be mixed among the sunlamps so that people living aboard the ISV can get their necessary dose of vitamin D. The lamps are set to wax and wane as the day progresses, reaching their full strength at noon and dimming until dusk. The length of day is altered in accordance with the seasons.

3. Sky

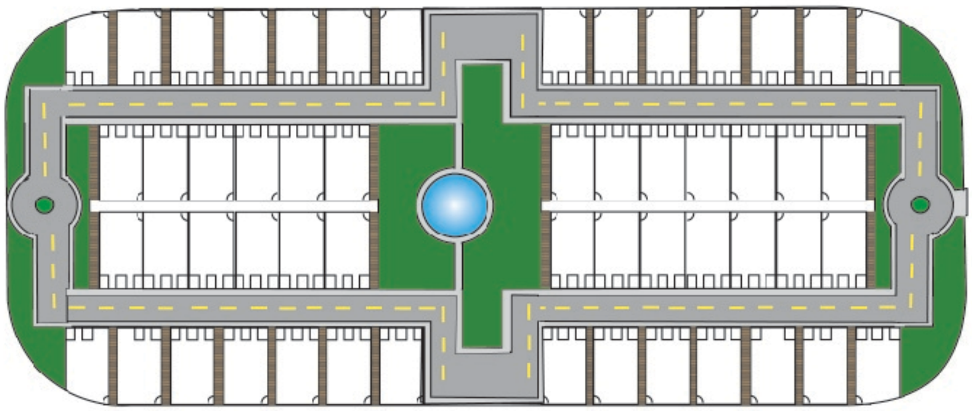
An enormous LCD screen covers the ceiling of each living module to provide an artificial sky. The screen is painted on to a special fabric and affixed to the module's ceiling like wallpaper. The screen is controlled through mini electrodes weaved into the fabric. During the day the screen displays an Earthlike sky with the occasional cloud. A fractal program continuously generates the clouds in order to make them appear as realistic as possible. At night, the screens can display constellations, the moon, planets, or even movies. Control of the screen is vested in the ship's council.

C. Living Accommodations

1. The Residential Module

Each hemisphere of the habitat ring has a pair of residential modules. They are placed on the portion of the wheel farthest from the elevator shafts. They are separated from each other by either the recreation or fitness module. Residential modules do not connect to each other so that each one develops its own separate flavor, much like a neighborhood. A single residential module can house a maximum of 312 people.

Apartment blocks are located on the upper deck of the module and appear as two story high buildings. A cross section reveals that there are four rows of buildings. Two touch the outer walls of the module and have apartments on both floors. The other two are clustered together in the center of the module. Here apartments are only located on the top floor, the bottom floor being devoted to businesses. The center units have a break in their center to fit a small park. Two Personal Rapid Transit (PRT) roadways on either side of the central buildings divide them from the buildings touching the exterior wall. PRT stations are located on the exterior wall across form the small park. The PRT enters the module as one roadway but branches off into two using roundabouts located at the two entrances to the module. These roundabouts hide freight elevators that grant access to the cargo deck below the living one.



(Blueprint depicts second floors of buildings)

(Vertical section of habitation module, up is towards the center of the habitat wheel)

2. Apartments

Each living module contains 78 apartments, each capable of housing four people. The apartments are 10.973 m by 6.4 m giving each an area of 70.2272 square meters. Depending upon their location within the module, apartments have different layouts. In the central unit, the door is located along the shorter wall. In the outer units the door is located on the longer wall either in the center (bottom floor) or the corner (top floor). Having different door placements gives residents the feeling of variety.

To further add variety, the walls within each apartment are attached to tracks in the ceiling. This allows each apartment to be reconfigured into one of **24** different designs, ensuring that residents never get bored of their home.

Each apartment has a kitchenette and a small bathroom with shower. These are located in the same corner in every apartment so that water mains can be easily built. The toilets in the bathroom can work in both gravity and weightless environments as well because the habitat wheel will have to be routinely despun for maintenance.

D. Recreation

1. Recreation Module

The entire recreation module is devoted to a wilderness park. Here residents can walk amongst trees and feel the therapeutic affects of nature. The module is an integral component of the ISV's mental health program because it is a quiet place, secluded place where people can go to escape the stresses of daily life. The module has a small stream for meditation and is only disturbed by a small PRT road. Wild animals such as birds and insects would disrupt the ISV's daily operations, so they are not included in the forest. However, an intricate audio system pipes in birdsong and insect chirps in order to add to the natural ambiance of the module. A series of small cabins is located in an isolated corner of the module. These cabins are used as a retreat for mental patients and are used every year to hold a summer camp for the onboard children. When cabins are not being used residents can rent them out and take vacations. This provides a further escape from the normal routine of life aboard the ISV.

The trees are planted according to a fractal pattern in order to appear as natural as possible. The tree roots are anchored into a sponge like material from which they draw their nutrients and water. An artificial soil made from recycled plastics and organic waste blankets the forest floor. Small sensors are placed in unobtrusive places in order to monitor the health of the forest.

When the artificial gravity is shut down so that maintenance can be conducted, the forest must be prepared. This includes putting a waterproof covering over the stream and placing a mesh over the ground so that water and soil does not float free. Residents are not encouraged to enter the recreation module when the habitat ring experiences weightlessness.

[*Original Artowrk*]

2. The Fitness Module

The fitness module is the center of all athletic activities aboard the ISV. It contains a pool, gym, basketball courts, and tennis courts. The module is free and can be used by any resident at any time. Two PRT roadways trace around the outer walls of this module, leaving the majority of the interior unobstructed. Unlike the small park in each living module, the fitness module is large enough that most sports can be played. There are different shipboard teams and games are held regularly. The module is also the base of operations for the ISV's physical rehabilitation program.

Since the habitat is normally under a 1g artificial gravity, exercise is not as encouraged as would be the case in a habitat with lesser gravity. However, it is still recommended that all residents regularly visit because it is an opportunity for social interaction.

When the gravity is shut off for maintenance on the spin bearings, a waterproof skin is placed over the pool to prevent the contents from escaping. The pool deck is made from soft rubber, similar to what is found in some playgrounds, in order to prevent injuries from people colliding with it during periods of weightlessness.

3. The Docking Module

Since the ISV only receives taxis every decade or so, the docking module remains largely unused for many years. During this time, the space is reconfigured through the hanging of mesh partitions into a venue for a variety of zero gravity activities. These include zero gravity sporting events, dances, and theatrical performances.

[*Original Artwork*]

4. Media

Through their personal media devices, residents will have access to a large on board database of literature, movies, music, and art. New media, including live television, can be transmitted from Earth to the ISV through the listening posts. Residents will also be encouraged to create art on their own using the resources available to them. Works are on regular display throughout the spacecraft. Live performances can occur in the school's auditorium and creative residents can hold zero gravity performances in the docking module. The ISV will have its own internal television network showcasing programs created by members of the community. An internal network similar to the internet will provide all of the outlets of traditional digital media.

E. Education

Education will be compulsoratory for all children ages five to eighteen. The educational system will be based on the work of B.F. Skinner, the father of operant conditioning. Skinner believed that education is only successful when it has achieved the highest level of personalization. He proposed that an individualized computer teach every student; however, this only works to a point. It would be great for developing a student's cognitive skills, but would be greatly lacking in providing the emotional and social skills that make the well-rounded student. The education provided on board the ISV will combine the best of Skinner's vision with other means of education. [*Myers, 2005*]

1. The Education Module

The school is placed in the same module as the center of government. This will allow for students to interact with their community leaders and become active members in their society. There will be thirteen grades, K-12, and each grade will have at least one classroom. Class size will not exceed twenty students and the classroom is any space to facilitate interaction between students. Classes can be held in part of the ship, but facilities are provided within the education module.

Years K-5 will focus on basic cognitive development. Years 6-9 will focus on helping students discover what they are interested in and tailoring a curriculum to those interests. Years 10-12 will focus on career exploration and development.

2. Cognitive Development

The brunt of instruction will be through the personalized media devices given to every resident. These devices will teach a curriculum tailored to the student's individual needs using an advanced form of A.I. An individualized curriculum will increase the logical intelligence of a student and make the student personally invested in their education. If a student gets an answer wrong, the device will show the student the steps to achieve the correct answer and provide multiple examples as well. Instruction of this sort will take place within the classroom environment so that teachers can ensure that their students are on task and monitor the progress of the class as a whole.

3. Emotional Development

The software used on the personal media devices will be designed to recognize the emotional cues a student leaves in their work. These will be used to determine if the student truly accepts the curriculum. If not, the teacher can make adjustments. Students can emotionally connect to their work through class wide discussions or social media. During these exchanges, the educational software and teacher will monitor the emotional cues present.

4. Social Development

It is unreasonable to expect that a student who spends their entire day before a computer screen will be balanced. The traditional social classroom environment will still be needed. To achieve this, the students will participate in group projects and discussions. The personalized curriculum allows each student to come to the group with a different perspective on the material being taught, students will be encouraged to share their perspectives with each other. Another motivator of social development will be the application of social media. This will allow the class to remain as a social group even when the school day is over.

5. Higher Education

Children growing up aboard the ISV will have the opportunity to choose any career they want. Since no college that is small enough to fit in a space habitat can hope to teach all the subjects that need to be covered, education will be primarily on the job. Students will enter apprenticeships with adults already in the field they want to enter. However, this by no means can fully train a doctor, lawyer, engineer, or other professional. This additional study will be accomplished through lessons given on personalized media devices as well as mentoring from an already established professional.

F. Health

1. Health Issues

The primary physical health issue on board the ISV will be an increased likelihood of cancer resulting from cosmic ray exposure. In addition to this, any medical facility must be able to deal with the same range of ailments that any terrestrial hospital faces. To add difficulty to all of this is the fact that the ISV is separated from the pharmaceutical infrastructure associated with a developed planet. The ISV cannot just store drugs because many of these medicines have a limited shelf life. Medicine will be primarily focused on prevention of ailments due to the difficulty of creating treatments.

a. Major Musculoskeletal Conditions

Conditions	Definition	Diagnosis	Treatment
Carpal Tunnel Syndrome	The compression of the median nerve as it passes through the carpal tunnel, a narrow bony passage below the inner surface of the wrist.	• Classic CTS Symptoms. • Electrodiagnostic Test. • Specific physical findings.	• Carpal Tunnel Release Surgery. • Nonsteroidal Anti-inflammatory Drugs. • Physical Therapy.
Muscular Dystrophy	A group of inherited muscle disorders that cause muscle weakness without affecting the nervous system.	• Blood Enzyme Tests. • Genetic Testing. • Muscle Biopsy. • Nerve Conduction Tests.	• Corticosteroids. • Physical Therapy. • Respiratory Care.
Osteoporosis	A marked loss of bone density and	• Chemistry Panel. • Diagnostic	• Actonel • Boniva,

	an increase in bone porosity, open spaces between bones.	Ultrasounds.	• Fosamax. • Menopausal Hormone Replacement Therapy. • Physical Therapy.
Spina Bifida	The congenital defect in which the spinal canal fails to close around the spinal cord	• Amniocentesis. • Diagnostic Ultrasounds. • Maternal Serum Alpha-fetoprotein Test.	• Daily Living Assistance. • Surgical Removal of the Cyst.

b. Major Onocological Conditions

Conditions	Definition	Diagnosis	Treatment
Bronchial Cancer	Cancer of the bronchioles.	• Bronchoscopy. • Diagnostic Ultrasounds.	• Sound-wave Therapy- The destruction of cancer tissues with the use of ultrasonic waves. • Lung transplant.
Colorectal Cancer	Cancer of the colon and rectum.	Fecal Occult Blood Test. Sigmoidoscopy. Visual Colonoscopy.	Sound wave Therapy-The destruction of cancer tissues with the use of ultrasonic waves.
Lobular Carcinoma	Cancer of the mammary glands.	• Breast Self-examination. • Mammograms.	• Sound-wave Therapy- The destruction of cancer tissues with the use of ultrasonic waves. • Breast Transplant.
Malignant Melanoma	Cancer derived from the skin cells that are capable of forming melanin.	• Exfoliative cytology. • Incisional biopsy. • Needle biopsy.	• Sound-wave Therapy-The destruction of cancer tissues with the use

			of ultrasonic waves. • Cutaneous transplant- Skin transplant.
Non-Hodgkin's Lymphoma	Cancer of the lymph nodes.	• Incisional Biopsy. • Diagnostic Ultrasounds.	• Sound-wave Therapy- The destruction of cancer tissues with the use of ultrasonic waves. • Lymphatic Transplant.

2. The Hospital Module

The hospital module will contain three buildings. Two of these will be connected by enclosed hallways and comprise the hospital proper. The third will be the pharmacy and drug manufacturing plant. It is separated from the hospital to avoid contamination. In the event of an epidemic, the hospital portion of the module will isolate itself through the use of inflatable walls and an independent life support system.

3. Hospital

The hospital is designed to deliver world-class care in a limited space. Normally, a hospital of this size would be four stories high but has been trimmed to two two-story buildings in order to fit inside the module. These building are connected by enclosed walkways to ensure that personnel can move between buildings, yet ensure that each floor on each building remains separate. The hospital will be staffed with 4 ambulatory physicians, 3 pediatrics, 5 anesthesiologists, 10 surgeons, 34 nurses, 7 techs, and 7 technologists.

a. First Floor Building One

The first floor of building one is devoted to the emergency room and ambulatory care. Due to the relatively controlled environment onboard the ISV, the emergency room will be small able to handle about ten people. Instead of ambulances, patients will be delivered in PRTs that have a priority routing. Pressing an emergency button on the PRT's control panel will do this. Instead of EMTs the entire adult population will be trained in CPR, HAA First Aid, and BLS. People assisting patients on their way to the hospital can use the PRT's control panel to video link with the emergency staff.

The ambulatory care clinic will be the most commonly visited part of the hospital. It is where adult residents come for their regular checkups and minor procedures such as blood tests or dermatological work. The clinic can see ten people at a time and has the ability to hold fifteen in its waiting room.

b. First Floor Building Two

This is where the ISV's operating rooms and imaging centers are found. There are five operating theaters equipped with advanced robotics and ultrasonic equipment to make surgery as non-evasive as possible. The prep and recovery areas for the operating department can each hold fifteen patients.

There are three types of imaging suites, FMRI, x-ray, and ultrasound. The FMRI machine is located in a special room with electromagnetic and extra cosmic ray shielding to ensure the instrument's accuracy.

c. Second Floor Building One

This houses the ISV's pediatric and maternity center. Children go here to receive their checkups and expectant mothers come for their OBGYN exams and procedures. Children born aboard the ISV are born here and the wing has the proper neonatal equipment.

d. Second Floor Building Two

This houses the hospital's lab. Here lab techs conduct tests on tissue samples from patients throughout the hospital. They also prepare dosages of medicines manufactured at the pharmaceutical plant. The hospital has its own internal pharmacy in order to make it easy to transport drugs around the hospital without having to constantly shuttle them over from the pharmaceutical plant.

4. The Pharmaceutical Plant

Due to the relative isolation of the ISV, regular drug delivery is impossible. Even if incoming taxis resupplied it every time the ISV approached an inhabited system, the medicines would not be able to last for the decades it would take to reach the next star. The only reasonable option is to make medicine in house.

The pharmaceutical plant is perhaps the most fortified structure within the habitat wheel. This is because the medicines within must be protected from cosmic radiation, contamination, and theft. Most medicines are biological in nature. This means that they can either be grown (penicillin and antibiotics) or synthesized from plant extracts (morphine and anesthetics). The pharmaceutical plant contains its own aeroponic garden to grow all of the plants it needs. This garden is used to supply a small chemical plant that makes the pharmaceuticals. Advances in nanotechnology and biotechnology will allow engineers to create a wide variety of substances. The drugs are then stored in a specially sealed vault until they are needed. This vault protects the medicines from contamination and cosmic radiation.

The plant will have a genetics lab that will allow doctors to grow replacement tissue from a patient's stem cells. The lab has the ability to grow anything from skin grafts to entire replacement organs. This will be done through the use of a type of additive 3D printer that uses human cell culture instead of ink. The practice of generating replacement tissues from a patient's healthy cells will be instrumental in the treatment of cancer and other degenerative diseases.

a. Sample Treatments

- Synthetic Immunoglobulins- Laboratory-produced immunoglobulins, which are disease-fighting proteins.
- Synthetic Interferon- Laboratory-produced interferon, which is a family of proteins released by cells when invaded by a virus, that causes noninfected cells to form an antiviral protein that slows or stops viral multiplication.
- Monoclonal Antibodies- Laboratory-produced antibodies that are all clones of a unique parent cell.
- Isolation for severe immunocompromised patients- Wash hands before and enter the room, wear gown, wear gloves, wear mask, and put patient into a special ventilated room that flow air backwards.

5. Handicap Assistance

a. Possible Disorders

1. Blindness
2. Paralysis
3. Deafness
4. Mental Retardation
5. Autistism Spectrum

b. Assistance

Condition	Service
Blindness	Guide Dog
Paralysis	• Neurosurgery (if possible) • Mechanical Exoskeleton
Deafness	• Sign Language Education • Sign Language Translation Through Digital Technology
Mental Retardation	• Human Assistance • Exceptional Student Education (ESE) Programs
Autistic Spectrum	• Speech Therapy • Early Intervention Programs

G. Psychological Considerations

1. Issues

Due to the long-term isolation faced by the community on board the ISV, psychological health will be paramount. The two predominant mental ailments on board the ship will be depression and anxiety. Depression will manifest for a wide range of reasons ranging from the lack of a truly natural environment to remorse over leaving loved ones behind on Earth. Living in a hostile environment such as interstellar space will give rise to anxiety as well. Children born aboard the ISV will be considered at a low risk for either of these ailments because they will accept the on board environment as being natural.

2. Treatment

The ISV will have a mental staff of eight psychiatrists, yet the entire community will be involved in the mental health effort. All residents will be encouraged to express themselves through creating a journal. The journal will be a place to vent energy and put emotional energy into focus. Psychiatrists will occasionally read the journals to assess the mental state of the writer. Community support groups will also be a major line of defense. The groups don't necessarily have to be centered on psychological needs but can be any sort of social group. Regularly interacting in a social setting can be cathartic and increase positive emotions. There will also be quiet secluded areas, primarily the recreation module, where people can get away from the stresses of daily life. If formal psychological treatment is needed, the psychiatrists have offices spread throughout the ship. Extreme cases can be detained in the ISV's brig. However, the ultimate goal of all on board treatment programs is not institutionalization but reintegration.

3. Sample Diagnosis

Diseases	Definition	Diagnosis	Treatment
Anorexia Nervosa	Abnormal fear of losing weight despite being underweight.	• Amenorrhea. • Intense fear of gaining fear. Negative self-concept. • Refusal to maintain body weight at or above a minimally normal weight for age and height.	Client-centered Therapy: Utilizing active thinking within a genuine, accepting, empathic environment to facilitate client's growth.
Antisocial Personality Disorder	Lack of conscience.	• Lack of conforming to laws. • Lack of feeling guilty about wrong-doing. Lack of taking. Responsibility. • Impulsivity. • Tendency to	Cognitive Triad: Changing the client's negative, irrational thoughts of oneself, the world, and the future into more positive, rational thoughts.

		be aggressive.	
Major Depressive Disorder	Idiopathic depression that prolongs more than two weeks.	• Lethargy. • Negative self-concept. • Social withdrawal.	Rational Emotive Therapy: Changing self-defeating thoughts into more positive, rational thoughts.
Phobia	Abnormal fear to a specific object or situation.	Defining the illogical fear of the specific object or situation.	Systematic Desensitization: Associating a pleasant relaxed state with gradually increasing anxiety-triggering stimuli in order to change unwanted responses.
Schizophrenia	A group of psychological disorder marked by disorganized and delusional thinking, distorted perception, and inappropriate emotions and actions.	• Catatonic behavior. • Delusions. • Disorganized speech. • Hallucinations. • Social withdrawal	Antipsychotics: Medication that act against psychosis. • Thorazine • Haldol • Perphenazine • Fluphenazin

[*DSM-5*, 2012]

H. Transportation

1. PRT System

Besides walking and cycling, the primary method of transport around the habitat ring of the ISV will be the **Personal Rapid Transit (PRT)** network. The PRT network is comprised of a fleet of thirty automated electric vehicles known as **pods**. The pods will travel at an average speed of thirty miles an hour. A central computer mainframe manages the system as a whole. Passengers board the four-seater pods by pressing the call button at a nearby station; there are several stations in each cylindrical module. Once the pod arrives at the station, the passengers board it and select a destination using an onboard screen. While this is happening, the pod recharges using an induction plate on the floor. When the destination has been selected, the pod immediately zips off to its destination. Transponders embedded in the roadway and located on the pod allow it to navigate. Since all of the roadways carry only PRT traffic, the system is easier to manage because all of the pods can be networked and think as one.

To ensure the safety of the passengers, the pod will not depart the station unless the seatbelt in every occupied seat is fastened. The pods onboard sensors scan the surrounding environment every twenty seconds in order to detect pedestrians. In the event of an emergency, the pods can function as ambulances. If the passengers hit an emergency button, the pod is given priority routing to the hospital. The screen normally used to select destinations now becomes a video link to specialists in the hospital module's emergency room. In emergency mode, the pod's speed will increase from thirty miles an hour to fifty miles an hour.

I. Computing

1. Paperless Society

On Earth, the paper industry uses up tremendous amounts of resources in the form of trees and chemicals. It also releases a tremendous amount of pollution as greenhouse emissions and chemical waste. Since this kind of exchange cannot happen on board the small ecosphere of a space habitat the ISV will be a paperless society. Instead of writing everything on paper residents will utilize electronic tablets called **Personal Media Devices**. Each resident will be issued one upon boarding the ISV. Devices will communicate with the public mainframe and each other using wireless broadband connections (8000 kbps). The nodes for the network will be nondescript routers located in each module. Often they will be hiding in plain sight, embedded in the ceiling. If the network is down, residents can jack their devices into the walls of their apartments. If a device breaks, it can be fixed using the advanced equipment in the manufacturing module. Fixing the occasional fried microchip or cracked screen uses the fraction of the resources that the continuous production of paper would.

A resident's personal media device will be his or her most prized possession. Through it she or he can reach the public data networks giving the owner access to digital media and an immense database of music, literature, art, and film. Monetary transactions will be digital as well and handled from the personal media device.

2. Centralized Mainframes

Centralized mainframes are the ones that monitor and regulate the physical functioning of the ISV. These mainframes will be responsible for

- Life Support
- Guidance and control
- Navigation
- Interstellar communication
- The laser grid
- M2P2 operation
- E-financial system
- PRT operation
- Medical records
- Pharmaceutical database
- Educational curriculum

These mainframes will be under the exclusive control of the ship's council and the Department of Flight Operations. The primary mainframes will be located in the government module with backups being spread throughout the ship. **Moore's Law** demonstrates that the size of computers is exponentially decreasing; by the mid 22^{nd}

century, a the hardware capable of supporting a computer mainframe of the size required could fit in an area the size of a small apartment.

The PRT mainframe will not be on a physical computer but will be distributed between the individual pod cars. This will allow the pods to think as a single organism and behave in an efficient manner. Medical records will only be available to a patient's physician. Doing this ensures that the medical staff on board maintain the same ethical standard as terrestrial doctors. The mainframe that creates a student's individualized curriculum will only be accessible to students and educators. Educational records should be private and free from external tampering.

Hacking is a serious threat because tampering with these systems puts everyone on board at risk. To prevent this, the central mainframes will utilize **quantum cryptography**. This encryption system utilizes the physical properties of subatomic particles. It can reach a level of complexity that would be impossible to achieve with binary encryption. The ship's council will also have a dedicated cyber security task force to prevent outside agents from affecting these mainframes.

3. Public Mainframes

The public mainframes are designated for general use. While the central mainframe is akin to the ISV's command and control software, the public mainframe is like its Internet. Residents will have full access to a database of art, literature, film, and music. By the 22nd century this could take the form of completely immersive virtual reality experiences. The public mainframe will welcome residents to create their own websites and upload content to digital media outlets. The mainframe must have a capacity of about **120 Terabytes** (this is roughly two Libraries of Congress).

J. Communications

1. Gravitational Lensing

Einstein's theory of relativity demonstrates that gravity can bend electromagnetic radiation. A massive object such as a star or galaxy can actually act like a lens, magnifying and focusing incoming frequencies. There is no focal length; just a minimum focal distance a receiver must be away from the lensing object in order to feel the effect. Scientists regularly use nearby stars and even galaxies to bring into focus images of distant objects that could never be captured even with the most advanced optical telescope. This effect can also be used to create an incredibly efficient interstellar communications network. If a telescope was placed pass the sun's gravitational focal distance, it could take detailed images of the surfaces of exoplanets. Gravitational lensing allows for the transmission of relatively low power signals across vast distances.

2. Operations

The **listening post** is a satellite positioned beyond the gravitational focal distance of the star it orbits. In the case of the sun, it must be located at least 550 AU away. However, the star's corona will also bend incoming EM radiation. A listening post orbiting the sun must be located at least 770 AU away to compensate for this. The expense of deploying a communications satellite out here is considerable; however, a substantial amount is saved. The ISV no longer needs to carry a high power communications system. A message with no bit errors can be sent from the listening post to an ISV in the vicinity of Alpha Centauri for as little as 10^{-4} watts [*Gilster, 2009*]. If a listening post is established at each star system the ISV fleet colonizes, a true "interstellar internet" will develop. Instead of beaming messages to each other, ISVs will route transmissions through listening posts.

There is a draw back to this system; the listening post satellite must be perfectly aligned with the object it is transmitting to. This is why the Kon-Tiki network will utilize at least four listening posts per star. This ensures a 360-degree sweep of the sky. Instead of maneuvering the listening post to align with the ISV, the ISV will maneuver to align with the listening post. This makes sense because compared to the ISV the listening post will be a fixed object. The communications array on the ISV is designed to pivot so that it can face the nearest listening post.

3. Wavelengths

a. Optical

Optical transmissions exist in the 400-700 THz range and take the form of a laser beam. Optical transmissions have the advantage of being able to transmit more data than radio or microwave frequencies. Most importantly, optical transmissions will not be affected by the strong magnetic fields generated when the M2P2 sail is operating. However, they have one large drawback, interstellar dust and gas will eventually obscure and scramble the transmission. This is why astronomers can only see so far in the optical range. Radio waves and microwaves are better at long distance communications. Also, optical transmitters and receivers must be in near perfect alignment. Despite this, optical frequencies will be the ISV's communication medium of choice due to the hide bandwidth it offers. They will also be the only choice of communications during periods when the M2P2 sail is in operation.

b. Microwaves

Microwaves exist in the 500 MHz to 300 GHz range. They can carry more information than radio waves but not as much as optical. Their high energy allows them to punch right through interstellar dust and gas. This high-energy nature is why scientists can look all the way back to the big bang using microwaves. However, microwaves, like optical waves, require line of sight alignment with the receiver. Also, microwaves can be easily scrambled by the magnetic fields generated by the M2P2 sail. Despite this, microwaves are among the most common used to transmit information on Earth. They will be the second choice of communications on the ISV. The microwave array will only be brought online when the M2P2 sail is deactivated.

c. Radio

Radio waves are the earliest form of wireless communication and exist in the 3 KHz to 500 MHz range. Their primary advantage is that a radio transmitter broadcasts in a wide sweep. They do not carry the same information as optical and microwaves, but their ability to fan out makes them invaluable. The listening post does not need exact line of sight to receive radio frequencies. However, like microwaves, radio waves can be severely affected by magnetic fields. The radio on the ISV will primarily serve as a dependable backup for the other two systems.

4. Relativity

Since the ISV is traveling at .7c, Einstein's theory of relativity comes into play. This will take the form of time dilation, when time aboard the ISV passes at a slower rate than time on Earth. Many people assume that this means a person on Earth would perceive a video transmitted from the ISV as if it were in slow motion. This assumes that the communication is occurring in real time. In reality, time dilation will manifest itself in **the length of time** it takes for a message to reach its destination. If the ISV agreed to send out one pulse per year, the rate of pulses would gradually slow down as the ship accelerated. If a resident sent a message three years from the day he departed, the Earth would view it as being six years from the day he left. Another common misconception is that an observer on the ISV will see a "starbow" as the craft's speed makes the outside world seem severely redshifted. This is also a misconception because the spectral change will be so small that only scientific instruments could detect it. All measurements involving time dilation involve a scalar known as the γ **factor**.

$$\gamma = \frac{1}{\sqrt{1 - \frac{V^2}{c^2}}}$$

- $\gamma = \gamma$ Factor
- $V =$ Velocity of starship
- $c =$ Speed of light

[*Matloff and Mallove, 1989*]

All of the equations dictating Newtonian mechanics change to include γ when dealing with relativistic scenarios. The very term "relativistic" relates to situations when Einstein's equations need to be used.

K. Population

1. Population Growth

It would be unreasonable to expect a population to exist inside an enclosed environment for decades and not experience growth. Any study on the feasibility of a space habitat must take this into account. The ISV is designed to have a carrying capacity of around 1200 people. Using the colonization of North America as a model, it can be expected that the population will double every twenty-five years due to natural fertility. If the ISV makes a trip from the Earth to Gilese 581, the trip will take about 27 years of shipboard time. This means that the ISV cannot depart the solar system carrying no more than 600 people.

Every child who comes of age on the ISV will have the right to have two children. This policy will not be enforced but subtly encouraged. For example, the apartments in the residential modules are only designed to sleep four people and the PRTs only seat four. Also the internal economic conditions aboard the ISV may make it fiscally impossible to support a third child. Despite these precautions, the occasional irregularity will occur. The ISV is designed to house slightly more than 1200 people (about 1206). If the population threatens to outpace the life support capabilities of the ISV, more drastic measures such as adoption or sterility treatments can be used. However, these are only for extreme scenarios and are not intended to become common practices.

2. Age Echelons

There are two factors determining the age of incoming residents aboard the ISV. The first is that the person must be young enough to survive the decades long trip to their destination star without dying from old age. The second is that the person must be old and healthy enough to withstand the four month 2g acceleration period on the outbound taxi flight. The first requirement caps the maximum age of the incoming population in their mid forties. The flight profile of the taxi craft determines the lower bookend. On the outbound dash to meet the ISV, the taxi has no choice but to pull 2g acceleration for four months. If the child was kept under bed rest during the flight, the youngest that could be expected to make it through the trip would be a seven year old. During the inbound flight from the cycler to the taxi's home system things are different. This time, the taxi can brake with a more gentle acceleration by utilizing the star's heliopause. The trade off is that this takes much longer than it would had the taxi utilized the LALIP. If the taxi undergoes a leisurely deceleration, the minimum age can be that of a four year old. Younger passengers are not recommended because it is unknown what adverse effects months in an accelerating or weightless craft could have on an infant. Pregnant women are also barred from taking a taxi flight.

If a family on Earth decides to emigrate to a nearby star system, the children are only forced to go if they are under eighteen. If a child is truly against going, special arrangements could be made for him or her to live with a relative or friend. However it would be in the best interest of the parents' and child's well-being for the child to come along. If by the time the family reaches its destination the child has come of age, he or she may have the option of remaining on the ISV and returning to their planet of origin. Hopefully by then the child would have made friends aboard the ISV who were also getting off at his or her destination planet.

3. Death

Despite the best precautions there will be deaths onboard the ISV. If a resident dies their body is not to be jettisoned from the ISV. This will create a debris hazard to other spacecraft because the body will be traveling at .7c. Also, throwing the corpse overboard will remove materials from the closed loop life support system. Elements such as potassium and phosphorous are normally reincorporated into the system through human waste. If the body is expunged, these minerals are lost to space. There will be two options for mortuary services, cremation and burial. Cremation will be the preferred choice due to the little waste left behind. Ashes are chemically less complex than a body and can be reincorporated into the onboard ecosystem more easily. This will take the form of sprinkling the ashes around the forest of the recreational module. Also ashes are portable and can be taken by loved ones when family members reach their destination system. If burial is preferred, bodies can be interned in the recreation module. The body will be buried wrapped in a biodegradable cloth to ensure that it is reincorporated into the onboard environment.

L. Government

1. The Government Module

The other half of the government/education module is taken up by the governmental building. It is the "capitol" of the ISV and is the center of ISV operations. It is a building located across from the school and contains the offices and computer mainframes needed to run the ISV.

2. The Flight Team

The flight team is a group of fifty individuals who represent the entity (Corporate, private, or governmental) that owns the ISV. In some cases, the ISV may be politically autonomous. The **Captain** heads the flight team and it is his job to manage the physical operation of the ISV. The flight team

- Navigates the ISV
- Operates the M2P2 sail
- Arranges rendezvous with taxis at destination systems
- Maintains external communications
- Operates the reactors
- Manages life support
- Makes repairs to the ship

Flight team positions are appointed by the entity that owns the ISV and can either be for life or rotating. They have been trained in how to run the ISV. Residents who are not official members of the flight team can volunteer to carry out some of its tasks such as making routine repairs. The onboard constitution prevents the flight team from interfering in the affairs of the ship's council and visa versa. The ISV is controlled from a "bridge" located in the government module.

3. The Ship's Council

The Ship's Council is the governing body of the community aboard the ISV. It is chartered in a written constitution. It oversees

- PRT system
- Educational system
- Agricultural production
- Law enforcement
- Legislation
- Holidays
- Seasonal changes
- Community event

There is a two-house legislature consisting of the **forum** and the **senate**. These houses work together to pass legislation and constitutional amendments. The head of state is the democratically elected **president**. He or she has veto power over the legislation passed by the forum and the senate. A third branch, the **judiciary** branch, oversees the legal system and can determine if acts of either the flight team or the ship's council are constitutional.

a. The Forum

This is an assembly comprising of all adult residents. It is similar in format to a traditional town meeting. The forum can propose, discuss, and vote on legislation. Most of this is done through personalized media devices making the house a “virtual” assembly. Direct democracy is required on the ISV due to the small size of the ship’s population. The government must in affect be more similar to a tribal council than the current U.S. federal government.

b. The Senate

This is an assembly of twenty elected legislators. Elections are held every two years and any adult resident can run. If the ISV is less than two years away from a resident’s destination system, the resident cannot run. The senate is in charge of creating revenue and creating a budget. Bills must pass through both the forum and the senate before they can be signed into law. Having an elected legislature ensures that the common people cannot achieve mob rule through the forum. The constitution is designed to limit both what the government and the people can do.

c. The President

This is a democratically elected official who is over the age of thirty. Elections are held every four years, and a president can only serve two terms. If an election occurs less than four years before the ISV arrives at a resident’s destination system, that resident cannot run. The president has veto power over the legislature and is the ISV’s head of state. The president is the chief sergeant of the law enforcement division. He or she is also the social head of the community and is primarily tasked with ensuring that things run smoothly. The position is not so much of a politician as that of a community organizer.

d. The Judiciary Branch

The judiciary branch is a panel of ten judges who conduct trials and hearings. They are appointed by the president and serve for the duration of their time aboard the ISV. Judges have the ability to deem an action of either the flight team or the ship’s council unconstitutional. Preferably, members of this branch have had previous legal experience before boarding the ISV. They maintain a pool of attorneys to provide to defendants. The judges are also responsible for onboard legal education including the ISV’s bar.

4. Law Enforcement

The law enforcement division is comprised of fifty volunteer officers and deputies. Their commander and chief is the president and their task is to enforce shipboard laws and the constitution. They carry nonlethal electric stun guns, pepper spray, and sleeping gas. Firearms would be dangerous due to their ability to puncture the ISV’s hull. Law enforcement members cannot invade a resident’s privacy without a warrant from the judiciary branch.

Punishment is designed to rehabilitate the criminal and reincorporate him or her back into society. This will often take the form of community service or probation.

Imprisonment is not recommended due to the space constraints of the ISV, but there are ten cells located on the cargo deck of one of the agricultural modules. If a resident is convicted of a capital crime and sentenced the death penalty, he or she will be executed using the humane technique of nitrogen asphyxiation. The sentenced is led into an airtight chamber, restrained, and sealed. The air mixture is than slowly changed so that the atmosphere within the chamber is almost pure nitrogen. The sentenced will die from oxygen deprivation. First he or she will get drowsy and then doze off. Death will occur while asleep. The body is then interned in the ways mentioned before. This does not require the complex chemical cocktail of lethal injection and is more humane than hanging or electrocution. Since this will be very rare, there will be no official execution chamber; instead, a service airlock will be modified.

M. Industry

1. The Manufacturing Module

This is the center of light industrial activity aboard the ISV. The industrial module is under the jurisdiction of the flight crew, who allocates facilities for both private and public purposes.

a. Public Roles

The manufacturing module serves as the ISV's repair bay where spacecraft components are fixed and overhauled. The flight crew gives priority to projects involving ISV components because they are crucial to the survival of the settlement.

b. Private Roles

The flight team also rents out the manufacturing module to private interests. A private interest can range from an individual enterprise to a shipboard business. Individuals can pay money to replace manufacture new clothing, electronics, and other items on their own. They can also purchase them from onboard businesses that have a license to use the manufacturing module's facilities.

c. Techniques

Since materials such as metal and glass are scarce on an interstellar habitat, the majority of consumer goods on the ISV are organic in nature. Polymers made from byproducts of corn and soy can replace most plastics in everyday life. Hemp and cotton can make clothing, and if processed properly, building materials.

The primary method of manufacturing will be that of **sterolithography**, or 3D printing. 3D printers use liquid polymers and a laser to build an object layer by layer. Combined with the traditional fixtures of a machine shop such as lathes, auto mills, and drill presses, a diverse variety of products can be brought to the shipboard market. Products are delivered to retail centers throughout the ship through the PRT network.

2. The Commercial Module

a. Private Enterprise Aboard the ISV

Residents that do not have a job maintaining the ISV will be encouraged to seek employment in the private sector. Having a job will ease anxiety and depression amongst the population by giving people a sense of purpose. Private businesses such as restaurants and cottage industry have a place in shipboard life. Even though residents are given much of their basic needs of food and shelter for free, there still needs to be some sort of incentive for productive activity. There is no better form of incentive than a token-based economy, where goods and services are exchanged for a currency of some sort. On the ISV, money will take the form of digital credits workers earn at their job. These credits can be redeemed for products outside of what is given to people for free.

These additional goods and services will be provided through small privately owned businesses. Companies are allowed to rent spaces such as aeroponic growth chambers and parts of the manufacturing plant in order to produce these products. The reasons for opening a private business are numerous and can range from a want of profit to an end to boredom. For example, a recently arrived Venezuelan family aboard the ISV might be saddened by the lack of Venezuelan food available onboard. The family could seek a permit with the Ship's Council to open up a small Venezuelan café in one of the ISV's modules. The café can even rent aeroponic chambers to grow special Venezuelan foods such a yucca and plantains, foods that are not part of the ISV's normal growth manifest. The family will charge credits to those who use its café. In turn, the family can use these credits to buy more specialty ingredients and other products.

Businesses will not actually own the venues they operate out of but will rent them from the Ship's Council. The largest storefronts will be given to the more successful businesses, while others will be set up in the commercial module. The mass trading of interest in a company that occurs on Earth will not place on the ISV. Instead of a stock market, businesses will accept donations from private, individual investors. It will be the responsibility of the Ship's Council to ensure that these investors receive a return on their expense. To prevent onboard depressions and recessions, the Ship's Council will create an environment unfavorable to large-scale investment. The largest of the shipboard companies will be mom and pop affairs. When it is time for the owner of a shipboard business to disembark at his or her destination system, he or she is faced with two options. He or she can either have the business end at this time or can relinquish it to a resident who is remaining on the ISV.

b. Commercial Module Layout

The purpose of the commercial module is to give every onboard business, big or small, the opportunity to compete fairly on the open market. The interior of this module resembles a cross between a Moroccan Kasbah and a modern day flea market. By having all of the shipboard industries gathered in one area, consumers can compare products and prices, allowing natural market forces to regulate what businesses are successful and which are not. This is where a resident goes to get clothing, buy art, or eat at a specialty restaurant. A simple permit from the Ship's Council is all that is needed for a resident to own and operate a stand.

V. LIFE SUPPORT

“”Earth is the cradle of humanity, but one cannot live in a cradle forever.””

-Konstantin Tsiolkovsky

A. Power

1. Polywell Fusion Reactor

The Polywell reactor is an innovative design for fusion power that is well suited to deep space operations. The design was developed by Dr. Robert Bussard and the U.S. Navy from the mid 1990s to the present day. The Polywell is classified as an Inertial Electrostatic Confinement or IEC reactor. The reactor itself is comprised of a sphere made up of metallic donuts. Each donut is electrically isolated from one another so as to prevent arcing and corrosion. When a current is passed through a donut, it generates a ring shaped magnetic field. Multiple donuts operating at once form magnetic cusps that trap charged particles inside the center of the sphere. Negatively charged electrons, whirling around the cusps provide the energy to fuse positive ions of fusion fuel. If an aneutronic fuel cycle is used, the charged byproducts can directly be converted into current. To derive more power, the heat from the reactors is used to drive a conventional thermal power plant and generator. Two thermal cycles will be used to maximize efficiency.

Photo Credit: EMC2 Fusion Development Corporation

IEC does not require the massive magnetic fields of magnetic confinement fusion or the immense laser banks of inertial confinement fusion. Fusion reactors of any type are preferable to fission reactors because fusion has much less catastrophic failure modes than fission. A fusion reactor must be kept in a vacuum with a constant supply of fuel and current. If any of these needs are compromised, fusion becomes impossible and the device shuts down. [*EMC2 Fusion Development Corporation, 2006*]

The ISV's two onboard Polywells provide power during the cruise portion of a flight. Whenever the ISV is accelerating, it is powered by the energy beamed to it by the LALIP. This saves mass on fusion fuel because the Polywells do not have to generate the energy to operate the M2P2 sail full time. When the ISV is coasting, the two reactors operate at 50% capacity in the case that one breaks. The ISV will require a power supply of approximately **300 MW**, about that of a small city, to power the onboard systems.

2. Fusion Fuel

The fusion fuel used in the ISV's Polywell reactors is boron-11. Boron-11 is preferable for long duration missions for two main reasons. The first is that when boron-11 is fused with itself, the reaction is **aneutronic**. All byproducts of the reaction are charged particles that can be deflected using magnetic fields or converted directly into current. Aneutronic reactions do away with the need for heavy shielding required by fission and neutronic fusion systems. The second benefit of boron-11 is its stability. The fuel is solid at room temperature. Unlike deuterium and helium-3, boron-11 does not need to be kept in cryogenic tanks, nor does it boil off over time. Boron-11 is also a stable isotope. While uranium-238 and tritium will eventually decay into materials that are useless for nuclear fuel, boron-11 will remain potent indefinitely. Boron-11 is a common isotope of boron, and is expected to be found across the universe. New fuel will be brought to the ISVs by taxi craft. Refueling will not take place all at once; instead taxis will only bring what is needed to top off the ISV's bunkers.

The equation describing the fusion of boron-11 is

$$p + {}^{11}B \rightarrow 3\,{}^{4}He + 8.7\ \text{Mev}$$

If converted into megawatts, the reactor will have to burn 1.429×10^{-8} kilograms of boron-11 per second to generate a constant one megawatt of power. It has been. 99% of this energy will be lost as heat while 1% will be directly converted into electrical current using a wire grid surrounding the reactor. [*EMC2 Fusion Development Corporation*, 2011] To recover this lost energy, the waste heat is used to boil water which will power a turbo generator. Assuming that the minimal thermal efficiency for a combined cycle generator is 60% [*Siemens*, 2012], the reactors will have to consume 6.86×10^{-3} grams per second of fuel to produce 300 megawatts of electrical power. Over the course of a forty year flight, the Polywells will consume **9 metric tons** of boron-11. [*Atomic Rockets, 2011*]

3. Secondary Power Supplies

In the event that both Polywells shut down, a series of onboard fuel cells come online to power critical systems. Any system not relating to life support, guidance/control, reactor repair, or communications is shut down. For example, during a reactor failure, low energy emergency lights will replace the normally brightly lit LCD "sky" of the habitat wheel. The emergency fuel cells that serve to power the ISV during this time can run on either hydrogen from the water supply, or methane from the anaerobic digesters. These systems are only intended to serve as an interim solution until the reactors are repaired. The ISV has two Polywells in the case that one becomes permanently inoperable. The reactors are isolated from each other so that failure in one does not cause serious damage to the other. Reactor repairs will be conducted using the equipment in the industrial module.

B. Gravity

Prolonged exposure to weightlessness has adverse consequences for human health. Years in zero-g will cause the human skeleton to become brittle and human muscles to atrophy. This is unfavorable for residents aboard the ISV because they must be able to perform manual labor at their destination world. To maintain a strong skeleton and healthy muscle tone, the habitation modules are spun around at 1.51 rpm to produce 1g of gravity. 1g is considered the standard for any potential exoplanet that may be colonized. It represents the median for which humans can thrive, the range being about 0.3 gs to 1.5 gs.

1. Acceleration Phases

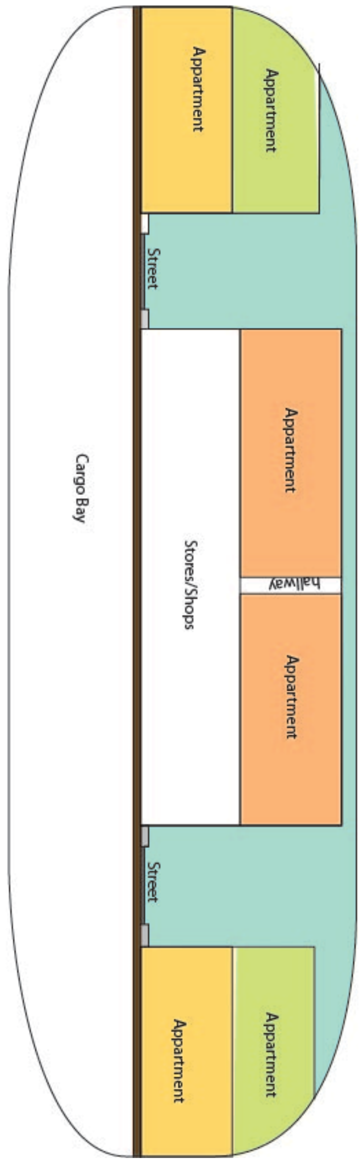
Throughout its mission, the ISV will be accelerated multiple times for the purpose of course correction. This acceleration will be enacted through the action of a departure star's LALIP. During this time, the rotation of the habitat wheel will be stopped, and each module revolved 90°. The modules' decks will now be aligned with the line of flight so that residents feel the ISV's acceleration as artificial gravity. When the ISV stops accelerating, the modules are rotated back into place and the wheel is restarted.

COASTING

Direction of Flight →

↑
Towards the Center of the Habitation Wheel

ACCELERATION



Direction of Flight →

↑
Towards the Hub of the Habitation Wheel

C. Atmosphere

1. Atmospheric Composition

GAS	PERCENTAGE
Nitrogen	78%
Oxygen	21%
Carbon Dioxide	0.04%
Water Vapor	.95%
Other	0.01%

[*PhysicalGeography.net*, 2009]

The atmosphere aboard the ISV will be identical in composition to that of the Earth. Having an atmosphere of pure oxygen would be a bad choice because it would increase the likelihood of fire. Oxygen, if taken in a high enough concentration can be harmful to human health as well. Metallic components of the ISV will rust at a lower rate in a mostly nitrogen atmosphere than they would in a pure oxygen one.

2. Pressure and Mass

The ambient pressure aboard the ISV, will be **14.7 psi**, which is the atmospheric pressure on Earth at sea level. If the pressure were lower, some of the residents may develop hypoxia, more commonly known as altitude sickness. A higher pressure would result in nitrogen narcosis, or the bends. If the density of air at room temperature at sea level is 1.204 kg/m^3 and the total pressurized volume on the ISV is 1.557×10^6 m^3, then the total mass of the ISV's onboard atmosphere is **1875 metric tons**.

3. Air Processing

The primary mechanism for removing CO_2 from the ISV's atmosphere is photosynthesis. The crops in the four agricultural modules along with the trees in the recreational module act as the "lungs" of the ISV. Blowers continuously move air clockwise around the habitat wheel so as to bring stale into these modules. Since it takes more plants to keep a population breathing than to feed it, tanks of algae with LED sunlamps are stationed in every module to locally purify the air. A computer system constantly monitors the CO_2 levels in the air to regulate gas concentration. If the CO_2 level is to high it activates tanks of dormant algae spores to make additional oxygen. If the level of oxygen threatens to become to much, the system directs workers in the agricultural modules to trim leaves off of plants in order to prevent them from overproducing oxygen.

Water vapor is extracted from the air through a condenser. This water will be added to the drinking supply or be used in agriculture. Sensors will shut off the condenser if the air threatens to become to dry. Other potentially harmful contaminants such as dust, smoke, and metal fuels will be cryogenically filtered out of the air. The cryogenic filter uses helium produced as a byproduct in the IEC reactor to chill air until reaches liquid form. Undesired gases can then be removed from this liquid through various physical means. These are then fed to the **Super Critical Water Oxidizer** and converted into plant nutrients.

4. Air Circulation

In the habitat wheel, air constantly moves in the direction of the wheel's rotation. This is done through a series of large yet silent blowers located in each module. Having the air always moving around ensures that stale air passes through modules with plants, and that fresh air reaches areas without many plants. The blowers are able to generate a stream of air that feels like natural wind with little noise or buffeting. This is done by using bladeless fan technology, originally developed by the Dyson corporation. Bladeless fans draw in air using a small turbine and expel it through a tube. The tube is specially shaped so that air is drawn into it from behind as air leaves it from the front. This multiplies the airflow, creating a smooth and even breeze. [*Jonathan*, 2012]

To carry air to the weightless portions of the ISV, flexible ducts are inserted into the elevator shafts connecting the wheel to the hub. The ducts are flexible because the closer the duct is to the hub, the less gravity it experiences. A solid duct designed to deal with this difference in force would be to heavy. The flexible duct resembles an inflated tube sock and is kept inflated through its own blower.

D. Water

1. Daily Water Usage

SOURCE	AMOUNT PER CAPITA	TOTAL AMOUNT	REASON
Leaks	0.1 gallons	120 gallons	High-efficiency plumbing system combined with a comprehensive sensor network t instantly detects leaks and assigns a rapid response team to fix them.
Drinking	2.5 gallons	3000 gallons	This is what is required for a human to survive.
Showers	7 gallons	8400 gallons	To conserve water, bathtubs will be a luxury aboard the ISV. Instead high-efficiency showers will be used for all bathing needs. These showers actively monitor the bather to regulate the flow of water. For example, when the bather is putting shampoo into his or her hair, the water can be turned off.
Faucet	10.8 gallons	12960 gallons	Like the showers, the faucets will also be computer regulated, delivering the proper amount of water when it is needed. For example, a

			faucet would deliver more water for washing dishes than for washing hands.
Clothes Washing	.25 gallons	300 gallons	New types of washing machines currently in development use electrostatically charged polymer beads to attracted stains out of clothes. These beads are reusable and allow for the machine to wash with little water. On the ISV these beads will be made from plant material and will be biodegradable. Washing machines will not be located in every living unit but will be clustered in communal "Laundromats" . Each habitation module will hold two-dozen machines.
Dish Washing	0 gallons	0 gallons	New types of dishwashers currently in development around the world use high energy UV and pressurized CO_2 to sanitize dishes. These devices are more akin to hospital sterilization equipment then to dish washers. On the ISV, these units will fit into every kitchen in every apartment. CO_2 will be generated as through aerobic respiration and can be extracted from the air.
Toilets	3 gallons	3600 gallons	High efficiency toilets of the kind on ships and airplanes use about 0.5 gallons per flush. On average, a person flushes about six times per day.
Aeroponics	0.02-0.03 gallons	24-36 gallons	Aeroponics use 98% less water than standard agriculture. If it takes 264 gallons of water to grow one

			gallon of wheat in a field, it would only take 5.3 gallons to do it aeroponically. However, wheat takes 10 months to grow, meaning that only .02 gallons of finely misted water would have to be used per day. [*NASA*, 2007] If a resident eats between .861 and 1.3 kg of produce per day, the water required to grow this food could range from .02 gallons to .03 gallons per day.
Aquaculture	N/A	157 gallons	If 60% of a resident's protein intake comes from seafood, then 44676 kg of seafood would have to be produced per year. If farmed fish are harvested with an average density of 25 kg per m^3 of water, 471 gallons of water are required to make the yearly output. However, since it takes four months for an average farmed fish to reach maturity, only a third of this water needs to be in a tank at any given time.
Livestock Drinking Water	N/A	10000 gallons	A medium sized livestock such as a pig or goat needs to drink about five gallons of water per day. If the average mature pig or goat weighs 113 kg, three animals will have to be slaughtered each day to give the human population meat. 2000 animals is a good approximation of what is needed at any given time. Every year about 1000 would be slaughtered, while the other 1000 come to maturity for the next year.
Pool	N/A	1000 gallons	Since water is so heavy, it is impractical to carry around a large amount purely for

			recreational purposes. Also, the pool in the recreational module and the river in the forest module are not intended to be substantial bodies of water. A pool in which a resident can do a brief series of laps is all that is needed to keep him or her healthy. If the pool were 1000 gallons and a perfect cube, it would be about 16 m on each side.
River	N/A	1000 gallons	

VOLUME OF WATER SUPPLY: 80,000 gallons

2. Wastewater Processing

All sewage will first pass through a device known as an **anaerobic digester**. Special bacteria that survive without oxygen consume the waste and convert it into sludge, methane, and other gases. Sludge, gases, and unpurified wastewater will then enter a chamber known as a **Super Critical Water Oxidizer or SCWO**. The SCOW heats the byproducts from anaerobic digestion with unpurified water under extreme pressure. The intense pressure and heat literally burn the waste in water, producing basic salts, nitrates, minerals, and clean water, as byproducts. Methane produced by the anaerobic digester fuels a fuel cell to power the SCWO. This fuel cell is also a back up power source for the ISV in case the Polywells shut down.

The nitrates, minerals, and salts that come out of the SCWO are dissolved in water to make the nutrient solution sprayed at plants in the aeroponic growth chambers. They can also be used to feed algae and shellfish. The water coming out of the SCWO is unappetizing to humans because it has been mechanically purified from feces and urine. This water will be used in agriculture, aquaculture, and the Forest Module's river. Drinking water will be obtained through an additional filtration process that uses special plants such as grass and bamboo to clean the water and give it a natural taste. Water can also be recovered as a byproduct of the fuel cells.

Losses will occur at every stage of this process through leaks and evaporation. One way in that this can be compensated for is to condense moisture out of the ISV's air supply. Eventually the water is consumed, flushed, and anaerobically digested, beginning the process anew.

The use of both an anaerobic digester and a SCWO, to purify water and recycle waste is superior to other methods. Physical filters would have to be regularly replaced, and carrying spares would take up to much mass. The SCWO and anaerobic digester are relatively simple in design and operation. At least one of each will be installed in every residential module to ensure redundancy. [*Dietzler,* 2011] [*Savage*, 1992]

3. Distribution

Water will be piped from holding tanks in each module to where it is needed. Water is moved through the pipes by an automated pumping station. This station is designed to work in both the presence and absence of gravity so that residents can receive water even when the habitation module needs to stop spinning during repairs. Unlike people on Earth, the ISV's residents cannot afford to ignore leaky pipes. Sensors stud the pipelines in order to detect leaks as soon as they happen. In the event that a leak is detected, a team of engineers is immediately sent out to fix the problem.

E. Food

1. Minimum Daily Food Consumables

FOOD GROUP	AMOUNT PER CAPITA	TOTAL AMOUNT	EXAMPLES	RATIONALE
Fruit	0.36-0.37 kg	432-444 kg	• Blueberries • Tomatoes • Pomegranates • Citrus	Fruit provides the vital nutrients of potassium, fiber, vitamin C, and folic acid. The antioxidants in fruit will be a powerful weapon in the fight against cellular damage due to cosmic radiation. Vitamin C will prevent a great scourge of explorers past, scurvy.
Vegetables	0.36-0.71 kg	432-852 kg	• Broccoli • Spinach • Potatoes • Squash • Cabbage	Vegetables like fruits, are a source of vital vitamins and minerals such as iron and vitamin A. These are

				essential to keeping a healthy population.
Grain	0.14-0.23 kg	180-276 kg	• Wheat • Corn • Rice • Quiona • Oats	Grains are a source of carbohydrates, these provide energy for the body to function. Grains also contain fiber that is essential to digestive tract health.
Protein	0.11-0.17 kg	132-204 kg	• Poultry • Pork • Lamb/Goat • Soy • Nuts • Fish (sorry cows are to heavy to bring aboard and consume to much life support)	Proteins are the building blocks of body tissues. A diet high in protein will be vital for trying to remain healthy in a reduced gravity, increased radiation environment.
Dairy	0.61-0.73 kg	732-876 kg	• Yogurt • Cottage Cheese • Milk	Even though the habitat ring produces 1g of gravity, many residents will still spend hours in the weightless parts of the ship. This combined with boned degradation due to cosmic radiation will cause bones to weaken. A diet

				high in calcium will serve to counteract this.
Oils	0.02-0.03 kg	24-36 kg	• Olive Oil	Contrary to popular belief, eating unsaturated fats in moderation helps the body process its own fat.
Spices	.001-.005 kg	1.2-6 kg	• Cinnamon • Sage • Garlic • Curry • Cilantro • Parsley • Bay Leaf • Saffron • Cumin • Pepper	On the ISV, the role of spices will primarily be psychological instead of nutritional. Having a wide selection of flavorings will add some "spice" to life. This will break up the monotonous daily routine of many residents and help prevent anxiety and depression.
TOTAL	1.6-2.25 kg	1933-2694 kg		

[*USDA, 2012*]

2. Agriculture

The ISV is equipped with four agricultural modules. Whereas the habitation and recreation modules are set up to resemble a terrestrial community, the agricultural modules are designed for efficiency. Unlike most other modules, the agricultural modules do not have a lower deck devoted to cargo, instead every available space is devoted to agriculture. One thing that agricultural modules do have in common with other modules is that there is a PRT road running through them. This transport axis is vital to moving produce from the growth chamber to the consumer. Agricultural modules are divided 60:40 with **60%** of the volume being taken up by **produce** and **40%** being taken up by **livestock**.

a. Produce

Plants are grown in individualized growth chambers tailored to the needs of specific plants. This allows for variety in food because different chambers can be tailored to different climates. This partitioning allows for seasonal plants such as apples to be grown in rooms adjacent to tropical ones such as pineapples. All produce will be grown using a method known as **aeroponics**. Plants are not grown in soil, but in a frame with their roots dangling in the air. Every few hours the roots are sprayed with a nutrient rich mist to provide them with vitamins and minerals. The mist is a byproduct of the ISV's water reclamation system. Aeroponics is preferable to terrestrial farming because it does not require soil, which is heavy. It also uses less water than other soilless farming techniques such as hydroponics. Plants are provided with artificial sunlight through banks of LED growth lights on the ceiling of each chamber. These lights are similar to the ones on the ceilings of the habitat module except that they have been optimized for plant growth instead of human comfort.

b. Livestock

Even though livestock are allocated 40% of each agricultural module, they are able to be raised in humane conditions. This is due to the nature of the animals eaten aboard the ISV. Large animals such as cows are unfavorable due to their large mass. Cows also consume massive amounts of water and feed and have an inefficient digestive system, producing pounds of manure each day. Smaller animas such as goats, sheep, turkeys, and pigs are more favorable because they can be raised in large numbers with little resources. It is in the best interest of the ISV's human population to avoid the factory farm model. This is because factory farms promote the incubation and spread of disease, a poor choice for a closed off space settlement. Animals will be raised in well-lit, well-ventilated areas with clean feed and water. Due to this, meat will not be a primary part of the onboard diet. Whereas on the Earth, meat is often the mainstay, it will take the role of an accompiament to a meatless entre.

Seafood on the other hand, particularly shellfish will be abundant. Fish, unlike land-based livestock can be raised by the thousands in a single tank. Bottom feeders such as flounder, crabs, and clams will help with water filtration by consuming the sludge produced by the anaerobic digester. Unlike terrestrial water, the ISV's water loop is not subject to industrial runoff. Residents therefore can eat as much as they want without fear of mercury poisoning.

3. Food Distribution

Produce will be harvested by a combination of human and robotic pickers. The goal is to pick the fruit or vegetable without destroying the plant. This will be simple in the case of apples which will grow from dwarf trees, but difficult for items such as potatoes and grapes. Livestock will be efficiently and humanely slaughtered in a small area of each agricultural module. The carcasses will be processed carefully to prevent contamination, and by-products will be sent disposed of as organic waste.

After harvesting, the food is packed in a , automated, plant. Packaging material will be produced in the industrial module and will be both reusable and biodegradable. After use, residents will leave these materials on the side of a PRT road for automated pick up, much like how families once left milk bottles on the street curve for collection.

After packaging, the food is sent via PRT to the food distribution center in each module. Here residents are given an allotment of food and can purchase extra if they want to. A high degree of automation over the food distribution process will prevent shortages and the forming of bread lines.

4. Diet

Having a limited number of ingredients is no excuse for not having good food. Creativity with what is available on the ISV will allow for a variety of cuisines. The key to this is a culinary school of thought known as **molecular gastronomy**. Molecular gastronomists use the properties of proteins and taste receptors to turn any food into any other food. For example, chefs in Chicago have created a hamburger from nothing but beets, corn, and barley. It is so like actual beef that it even bleeds red is undercooked. The average resident will not be expected to come up with this wizardry on his or her own accord, so a digital recipe library will expand the full pallet dishes into every household.

F. Trash Disposal

1. Collection

Trash will be collected in communal bins located in each residential module. Residents will be responsible for moving trash from their homes to these bins. Trash will be segregated into organic, nonorganic, and metallic wastes. Each bin is emptied by an automated into a PRT that carries the waste to the proper processing center.

2. Organic Waste

This is any waste that is made from living things or is carbon based. It is the most versatile type of waste because it can be recycled through relatively simple means. The majority of personal and consumer items on the ISV will be organic in nature to take advantage of this ability. Organic trash can be composted, fed to livestock/fish, anaerobically digested, or processed by the SCWO.

3. Nonorganic Waste

Nonorganic waste includes materials that are neither carbon based nor metallic. Examples include glass, semiconductors, and certain types of polymers. Recycling these materials is the most difficult form of recycling aboard the ISV due to the diversity of techniques. Many methods use the specific chemical properties of the material to break it down using catalysts or other chemicals. Nonorganic materials can also be incinerated in a second SCWO purposed just for inorganic waste. The byproducts of this will be basic inorganic compounds from which new products can be made.

4. Metallic Waste

Trash that is mostly made up of metals is considered to be metallic waste. The techniques for smelting and reusing metal have been around for thousands and are still used on the ISV. All smelting, separating, and recasting occur in the manufacturing module. A portion of this recycled metal will be processed in the zero gravity portion of the ISV. The special environment of zero gravity allows for the metal to be given unique properties of strength and lightness that are different from those in a metal made in a gravity well.

G. Radiation

1. Radiation Hazards

Since the ISV is travelling at 0.7c the background radiation the habitat is exposed to is much greater than what would be experienced by a habitat orbiting the Earth. Radiation hazards at relativistic speeds come from three main sources.

SOURCE	DOSE AT 0.7c
Neutral Atomic Particles of Dust and Gas	10^5 rem per second
Charged Interstellar Particles	10^5 rem per second
Cosmic Rays	4.059×10^{-5} rem per second

[*Semyonov*, 2012]

The greatest threat to human health at relativistic speeds is the radiation dose provided by small particles of interstellar dust and gas. 1000 rems will kill a person, and anyone unfortunate enough to be unshielded would die instantly at relativistic speeds. Cosmic radiation is increased at relativistic speeds, but it is easier to mitigate then it would be in Earth's orbit. This is because at high fraction of light speed, all cosmic rays hit the spacecraft head on. The ISV is moving so fast that it very unlikely that a cosmic ray coming from the side or behind would hit it in time. This is opposed to an orbital habitat where the cosmic rays seem to be coming from every direction.

2. Shielding

The ISV, and taxi craft have two types of radiation shielding, active and passive. Active shielding is intended for dealing with charged particles in interstellar space, and passive shielding is for neutral particles/cosmic radiation.

The active shield is generated by the ISV and taxi's M2P2 coils. Less energy is required to generate magnetospheres for radiation protection than for propulsion. During acceleration phases, the taxis and ISV must make fields thousands of kilometers in size to catch the particle beam from the LALIP. The exact opposite is the case with radiation deflection because a giant field would only serve to create drag. Since a shielding field should be smaller than a sailing one, less energy is needed to operate it.

Passive radiation shielding is built into the ISV's mylar whipple shield. The whipple shield is designed to absorb debris ranging from something the size of sand grain and down. High-energy particles such as cosmic rays and small atoms can pass through the bonds between the mylar molecules like bullets through mist. A 1.5-meter thick panel of rxf1 is located behind the whipple shield to stop these stray particles. The rxf1 panel creates a "shadow effect" creating an expanding cone of safe radiation levels. This is like how putting a penny on the lens of a film projector will cause a large part of the movie screen to be blacked out. The blacked out portion is safe for human habitation. For additional protection, all inhabited modules are coated in their own 1-meter deep layer of rxf1. Since the ISV is not travelling at exactly .999c, there will still be the occasional cosmic ray coming in from the side. This combination of active and passive shielding will give each resident a dose of **0.5 rem** per year, or the maximum dose the department of energy allows for a civilian population.

VI. SCHEDULE AND COST

“”Now nothing shall be restrained from them that they have imagined to do.””

- Book of Genesis

A. Program Schedule

Date	Event	Rational
2035	Cycler is established between the Earth and Moon.	Allows for development of hyperbolic rendezvous and docking techniques for future cycler/taxi operations.
2065	Earth-Mars cycler is established.	Tests the combination of cycler trajectories with beamed energy propulsion.
2080	Technology to build the Kon-Tiki system is in place.	Actual development of the spacecraft will wait another thirty years. This will give time for a sufficiently large industrial base to be established in the inner solar system.
2100	Scientists, through a combination of probes and telescopes have scouted out and mapped nearby, potentially habitable exoplanets.	An interstellar cycler network is only viable if there exists potentially habitable exoplanets for colonization and commercial development. Mission designers need to know where the ISV will travel to so that they can design its trajectory.
2110	The international Kon-Tiki Consortium is founded; design work begins.	The financial requirements of establishing an interstellar transportation network are too large for any individual government or corporation. Like the transcontinental railroad of the 1870s, a project of this magnitude can only be completed through a combination of government and private organizations.

2120	Design work is completed.	The design process will take about a decade due to the complex nature of the Kon-Tiki project. Modern projects such as the LHC. The ISS, and aircraft carriers had a similar design period.
2121-2131	Construction of the LALIP and the SPSA.	The LALIP and its power source are the most complex parts of the Kon-Tiki network. The energy that these devices will have to able to harness is unlike anything that humanity has ever handled before.
2125-2131	Construction of ISV and Taxis.	The ISV and Taxi craft will be constructed in a short period of time compared to the LALIP and SPSA. This study assumes that by 2125, constructing habitats in space will be as commonplace as building an ocean liner is today.
2135	First ISV departs.	Years of testing will be needed between the completion of the ISV and its maiden voyage.
2155-2175	ISV seeds first star system with automated and manned construction modules. Construction of a local LALIP is begun immediately.	The exact year with which the seeding takes place is entirely dependent on what star system has been selected as the location for humanity's first exosolar colony. If Epsilon Eridani or Tau Ceti has suitable planets, then the seeding will take place about twelve years after launch. If the nearest potentially habitable star systems are further out (Gilese 581), then the seeding flight can take over two decades.

2180-2200	Regular cycler service is established between the solar system and various exosolar colonies.	It will take about a decade for the automated and manned construction units to construct a LALIP and fleet of Taxis at the destination star system.

B. Cost of Kon Tiki

Item	Cost Per Unit	Quantity	Total Cost	Rationale
LALIP	$100 billion	1	$100 billion	This is the current cost of the ISS, what is arguably the cutting edge of early 21st century aerospace technology. The LALIP will be the pinnacle of mid 22nd century technology due to its ability to collect and channel immense energies.
ISV	$5 billion	10	$50 billion	This is the price of a Nimitz class aircraft carrier. The Nimitz class is arguably the most advanced ship afloat today in the modern world. Just like the ISV, they must support a population of thousands and are designed to function for decades. This study assumes that by the early 22nd

				century, spacecraft will be common in the inner solar system. The ISV then will be the most advanced spacecraft of its day.
Listening Post	$3 billion	4	$12 billion	This is the cost of the Mars Science Laboratory. Like the MSL, the Listening post must be able to operate autonomously for years in an alien environment. Since this study assumes that the inner solar system is developed by the early 22nd century, the Kuiper belt will still remain largely unexplored. It will be the "Mars" of the 2100s.
SPSA	$5 million	10000	$50 billion	This is the cost of an Iridium communications satellite. Like the Iridium constellation, the arrays of the SPSA will be mass-produced and launched in the dozens. If space based solar power is developed in the mid 21st century then costs could be offset by renting platforms not owned by the Kon Tiki consortium. From a technical standpoint, each platform is simple to manufacture. All it consists of is a massive solar array and a microwave transmitter. The material to produce the solar array can be cheaply mined on the moon. The idea is to

				mass produce the arrays by the thousands so that the price is driven down.
Taxi	$300 million	4	$1.2 billion	This is the price of an Airbus A380 jumbo jet. Just as the A380 is the pinnacle of mass travel in the 21st century, the Taxi is the pinnacle of rapid transport in the 22nd. Taxi technology can be based off of designs utilized for transport across the inner solar system in the late 21st and early 22nd centuries. Taxis could cost less than slower spacecraft due to their lightweight structures and short mission times.
Shuttle	$250 million	N/A	N/A	The shuttles will be operated by organizations that are not part of the Kon Tiki consortium. The study assumes that by the 22nd century there are a large number of private companies offering Earth to orbit transportation. Therefore, the shuttles' costs will not be factored into the overall estimate. The price provided for an individual shuttle is that of a Boeing C-17 Globemaster. Like the Globemaster, the shuttle must be able to transport a diverse amount of payloads rapidly and efficiently.

Shuttle Carrier Aircraft	$100 million	N/A	N/A	This is the cost of Scaled Composites' SpaceshipTwo. The carrier aircraft is simple in design and only needs to perform the mission of carrying the high-performance shuttle to launch altitude. Like the shuttle, the carrier aircraft will be owned by businesses outside of the Kon Tiki consortium.
SBBD	$5 million per satellite	N/A	N/A	The Space Based Beam Driver will be owned by businesses that are not part of the Kon Tiki consortium. If the beaming of power from space to the Earth becomes common in the late 21st century, then there will be hundreds of orbital power stations by the 22nd century. These will not only provide power to cities on the ground, but will also provide the energy needed to boost shuttles into orbit.

TOTAL COST: $213.2 billion

NOTE: All Costs Are Adjusted to Early 21st Century Dollars

1. Labor

Constructing the ISV, LALIP, listening posts, and SPSA will not require as large a workforce as expected. This is due to the high degree of automation that will exist in the manufacturing sector by the mid 22nd century. The majority of the labor therefore will be devoted to the designing, engineering, and testing of all of the equipment required for the Kon Tiki program. The authors of this study estimate that the total workforce for project Kon Tiki will number around **300,000**. This is similar to the number of scientists who worked on the Manhattan and Apollo projects.

C. Business Value

Everything in the Kon Tiki study up to this point has shown the *how* of establishing an interstellar cycler network, now it is time for the *why*. The ISV will generate revenue through one thing and one thing only, **trade**. ISV's will act like the FedEx and UPS of interstellar space. Various groups will pay their owners for cargo and passenger space on outbound cyclers. Initially, this trade will be one way as groups use the ISVs to send settlers and equipment to virgin planets. After a decade or so, these pioneers will have constructed LALIPs and taxis of their own and can send cargoes back to Earth. The question then is, what kinds of goods will be traded over interstellar distances?

One of the greatest tropes in science fiction is of aliens coming to Earth to plunder the planet for a material that is rare to them such as gold, iron, or water. It is unlikely that humans in the solar system would need these materials from other star systems because the solar system has enough natural resources to satisfy a growing population for millennia. It is equally unlikely, that colonists in virgin star systems will find mineral resources completely unlike anything in the solar system. This is because the distribution of elements throughout the universe is roughly even, and any mineral that exists in foreign star systems will almost certainly exist somewhere closer to the Earth.

What the ISV's will trade in are things that *cannot* be locally obtained at a star system. The largest commodity that the ISVs will transport will be people. Talent, skill, and drive are not universal, this is why the pioneers of the wild west were a minority in the late 19^{th} century. To settle the interstellar frontier will take special kinds of people, and these people must be transported to their destinations. The majority of these passengers will be contracted by business interests with large operations around other stars. Some may be individual homesteaders travelling to the new worlds to live a life of adventure. If a scientist would like to conduct field research in an exosolar environment, it would be cheaper for him or her to transport his or her expedition party via ISV than it would be to raise the funds to build a completely private craft. With these pioneers, the ISVs will have to move all of the equipment, livestock, and plants required to establish a self sufficient colony.

In addition to transporting people, the ISVs will carry products between the stars. Physically carrying thousands of individual consumer goods is impractical due to the mass involved. It would be simpler for the ISV to send the instructions on how to make these goods at the destination system using some form of automated manufacturing or sterolithography. This data cannot be transmitted, even using gravitational lensing, because it is orders of magnitude more complex than a simple communication. A few bit errors due to cosmic rays or interstellar gas can make the difference between a working and defective product. The instructions on how to make the latest cell phone, car, or computer would be much safer riding between the stars in the secure computer banks of an ISV. The same goes for digital copies of art, music, literature, and film. There will also always be those objects that must be transported in physical form. These will primarily take the form of small souvenirs from various planets that will be sold as novelty items on Earth. Institutions, museums, and private citizens will pay top dollar to purchase material that originated light years away.

Amortizing the cost of the ISV, a single cycler has a payback period of about 50 years. This is the time it will take to send out an ISV, colonize a star system, and build the infrastructure to begin two way trade. This assumes that the star is about 25-30 light years away, about the distance of the more interesting stars such as Gilese 581. If the entire program costs $213.2 billion, and only pays to fly 12000 people on the first ten ISVs, the cost per person roughly $18 million. This includes the supplies he or she will need to survive upon arrival at the colony world. This price is comparable to what Spacex intends to charge for a human passage to the planet mars (50 tonne spacecraft @ $200 per kg). [*Next Big Future*, 2012]

VII. EPILOGUE

“”Take my love, take my land, take me where I cannot stand. I don’t care, I’m still free, you can’t take the sky from me.””

-Firefly

The authors of this study feel that there must be some discussion on the type of civilization and culture that will develop in the world of Kon Tiki. Since the ISV’s cannot travel faster than light, any products or information from the Solar System will be decades old by the time they reach a colony star system. This may not matter because; if the ISV’s are properly staggered then there would be a constant influx of goods coming from out of system. For example, a director on Earth makes a movie and four years later a sequel. As soon as each movie is released, a high quality digital hard copy is shipped via ISV to a star system thirty light years away. It will take over three decades for the film to arrive, but culturally, the experience on the colony world will be the same as it was on Earth. If a cycler from Earth passes the system on an annual basis, then the inhabitants only have to wait four years between the delivery of the movie and the arrival of its sequel. This is the same time Terran audiences had to wait between movies, even though viewers on the colony planets had to initially wait decades. Businesses could make profits selling old products to the colonies because they would seem state of the art from the colonies’ perspective. It would be physically impossible to conduct trade otherwise due to the light barrier.

Foreign relations between different star systems will prove difficult due to the light speed barrier as well. Ambassadors would have to operate with complete autonomy from their systems of origin, making decisions that affected constituents who would probably not have been born until decades later. Therefore, government on the interstellar scale will most likely prove impossible. Due to the limits of electromagnetic based communications technologies, a government could only stretch its sovereignty across its own system. Wars between star systems will also be impractical due to the decades of flight time it would take for a military ISV to reach the combat zone. By the time the soldiers arrived at the theater of operations, the conditions that started the war in the first place could very well be no more. What will unite the systems will be trade. The ISVs will be interstellar caravans travelling a silk road of the night. Camel caravans allowed for the fusion of ideas and culture that fueled the great trading cities of Alexandria and Constantinople. The ISV’s will be the melting pots where people from a multitude of different star systems and cultures will live together for decades, sharing, cooperating, and hopefully creating something new.

It took the descendants of Kon-Tiki thousands of years to spread out and populate the Polynesian Islands. Even though his people colonized thousands of separate islands, they were able to develop and maintain a common culture that was distinctly *Polynesian*. The descendants of those who travel aboard the ISVs may be separated by light years of space, but ties that are distinctly *Human* will unite them all.

BIBLIOGRAPHY

1. "(a). Atmospheric Composition." *7(a) Atmospheric Composition*. PhysicalGeography.net, 7 May 2009. Web. 11 Mar. 2012. <http://www.physicalgeography.net/fundamentals/7a.html>.

2. Barrie, Alexander. *M2P2 - USING VARIABLE POWER RADIAL THRUST FOR INTERPLANETARY AND INTERSTELLAR TRAVEL*. American Institute of Aeronautics and Astronautics. PDF.

3. "Choose a Food Group." *Food Groups*. USDA. Web. 10 Mar. 2012. <http://www.choosemyplate.gov/food-groups/>.

4. Chung, Winchell. "Atomic Rockets." *The Weird World of Winchell Chung*. 02 Aug. 2011. Web. 29 Dec. 2011. <http://www.projectrho.com/rocket/>.

5. "Cryogenic Air Separation." *Cryogenic Air Separation*. Indiamart. Web. 11 Mar. 2012. <http://sourcing.indiamart.com/engineering/articles/cryogenic-air-separation/>.

6. Cummings, Hillary, Daren Welsh, Paul Choe, Derek Inaba, Chris Kachel, Katherine Ready, Elspeth Suthers, Ben Warrick, Luke Winstrom, and Allen Yoo. "Incorporation of the Mini-Magnetospheric Plasma Propulsion System (M2P2) in a Manned Mission to Mars." Diss. Ed. Adam Bruckner and Robert Winglee. University of Washington. *Incorporation of the Mini-Magnetospheric Plasma Propulsion System (M2P2) in a Manned Mission to Mars*. University of Washington. Web. 28 Dec. 2011. <http://www.lpi.usra.edu/publications/reports/CB-1106/wash01.pdf>.

7. *Diagnostic and Statistical Manual [for] Mental Disorders,*. 5th ed. Washington: American Psychiatric Association, 1960. Print.

8. Dietzler, Dave. "L1 Space Station." *The Moon Miner*. Web. 29 Dec. 2011. <http://www.moonminer.com/L1_spacestation.html>.

8. "Elon Musk Says He Will Put Millions of People on Mars." *Next Big Future*. 22 Dec. 2011. Web. 13 Mar. 2012. <http://nextbigfuture.com/2011/12/elon-musk-says-he-will-put-millions-of.html>.

9. Galea, Pat. "Project Icarus, Project Daedalus, Interstellar Communications — Project Icarus." *Project Icarus*. Web. 29 Dec. 2011. <http://www.icarusinterstellar.org/blog/sun-gravitational-lens/>.

10.Gilani, Natasha. "Microwave Radio Communications Advantages & Disadvantages |

EHow.com." *EHow | How to Videos, Articles & More - Discover the Expert in You. | EHow.com*. Web. 29 Dec. 2011. <http://www.ehow.com/list_6137210_microwave-radio-communications-advantages-disadvantages.html>.

11. Gilster, Paul. "The Gravitational Lens and Communications." *Centauri Dreams — The News Forum of the Tau Zero Foundation*. 06 Nov. 2009. Web. 29 Dec. 2011. <http://www.centauri-dreams.org/?p=10123>.

12. "HSF -- TransHab." *NASA Human Space Flight*. Ed. Kim Dimukes and John Ira Petty. NASA. Web. 29 Dec. 2011. <http://spaceflight.nasa.gov/history/station/transhab/>.

13. Landis, Geoffery A. "Interstellar Flight by Particle Beam." Proc. of STAIF Conference on Innovative Transportation Systems for Exploration of the Solar System and Beyond, Albaquerque. Web. <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20020023956_2002030230.pdf>.

14. Mallove, Eugene, and Gregory Matloff. *The Starflight Handbook: A Pioneer's Guide to Interstellar Travel*. Ed. David Sobel. Stephen Kippur, 1989. Print. Wiley Science Editions.

15. Myers, David G. *Exploring Psychology*. New York, NY: Worth, 2005. Print.

16. *NASA*. Progressive Plant Growing Is a Blooming Business, 23 Apr. 2007. Web. 11 Mar. 2012. <http://www.nasa.gov/vision/earth/technologies/aeroponic_plants.html>.

17. Pellegrino, Charles. "Relativistic Robots and the Feasibility of Interstellar Flight The Valkyrie Antimatter Rocket." *Charles Pellegrino Web Site*. 2006. Web. 30 Dec. 2011. <http://www.charlespellegrino.com/propulsion.htm>.

18. Quick, Darren. "â˜Waterlessâ™ Washing Machine Cleans Using Nylon Beads." *â˜Waterlessâ™ Washing Machine Cleans Using Nylon Beads*. Gizmag, 25 June 2009. Web. 10 Mar. 2012. <http://www.gizmag.com/xeros-washing-machine/12088/>.

19. Savage, Marshall T. *The Millennial Project: Colonizing the Galaxy in Eight Easy Steps*. Boston: Little, Brown, 1994. Print.

20. Schroeder, Karl. "Interstellar Cyclers — KarlSchroeder.com." *Ashes of Candesce — KarlSchroeder.com*. Web. 29 Dec. 2011. <http://www.kschroeder.com/my-books/permanence/interstellar-cyclers>.

21. Semyonov, Oleg G. "Radiation Hazard of Relativistic Interstellar Flight." Web.

<http://arxiv.org/pdf/physics/0610030.pdf>.

22. "STARDUST's Whipple Shields." *Stardust - NASA's Comet Sample Return Mission*. NASA. Web. 29 Dec. 2011. <http://stardust.jpl.nasa.gov/tech/whipple.html>.

23. Strickland, Jonathan. "How the Dyson Bladeless Fan Works." *HowStuffWorks*. HowStuffWorks. Web. 11 Mar. 2012. <http://electronics.howstuffworks.com/gadgets/home/dyson-bladeless-fan.htm>.

24. "Tilapia Culture." *Malcolm Dickson*. Web. 10 Mar. 2012. <http://www.pathfoot.demon.co.uk/tilapia.htm>.

25. "Trailblazing Power Plant Efficiency." *Press Releases*. Siemens. Web. 11 Mar. 2012. <http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2011/fossil_power_generation/efp201105064.htm>.

26. "Turn On, Tune In, Power up." *Royal Society of Chemistry | Advancing the Chemical Sciences*. 05 May 2011. Web. 29 Dec. 2011. <http://www.rsc.org/chemistryworld/News/2011/May/05051103.asp>.

27. "UNSW Rockpool - Waterless Dishwasher." *TreeHugger*. TreeHugger, 15 Dec. 2004. Web. 10 Mar. 2012. <http://www.treehugger.com/clean-technology/unsw-rockpool-waterless-dishwasher.html>.

28. Wallenstein, Kelly. *M2P2: "Mini Magnetosphere Plasma Propulsion"* PPT. MIT. Web. 28 Dec. 2011. <web.mit.edu/22.012/www/.../Kelly%20Wallenstein%20M2P2.ppt>.

29. "Water Use Statistics." *American Water Works Association Ã¢ÂÂ" Www.drinktap.org Home Water Information Conservation*. American Water Works Association. Web. 10 Mar. 2012. <http://www.drinktap.org/consumerdnn/Home/WaterInformation/Conservation/WaterUseStatistics/tabid/85/Default.aspx>.

30. Winglee, Robert, and B. R. Robertson. M2P2 Sail in Operation. Digital image. *Advanced Electric Propulsion*. University of Washington. Web. 28 Dec. 2011. <http://www.ess.washington.edu/Space/propulsion.html>.

31. Winglee, Robert M. *M2P2 Lab Prototype*. Digital image. *Mini-Magnetospheric Plasma Propulsion (M2P2)*. University of Washington, Nov. 2011. Web. 29 Dec. 2011. <http://www.ess.washington.edu/Space/M2P2/theory.html>.