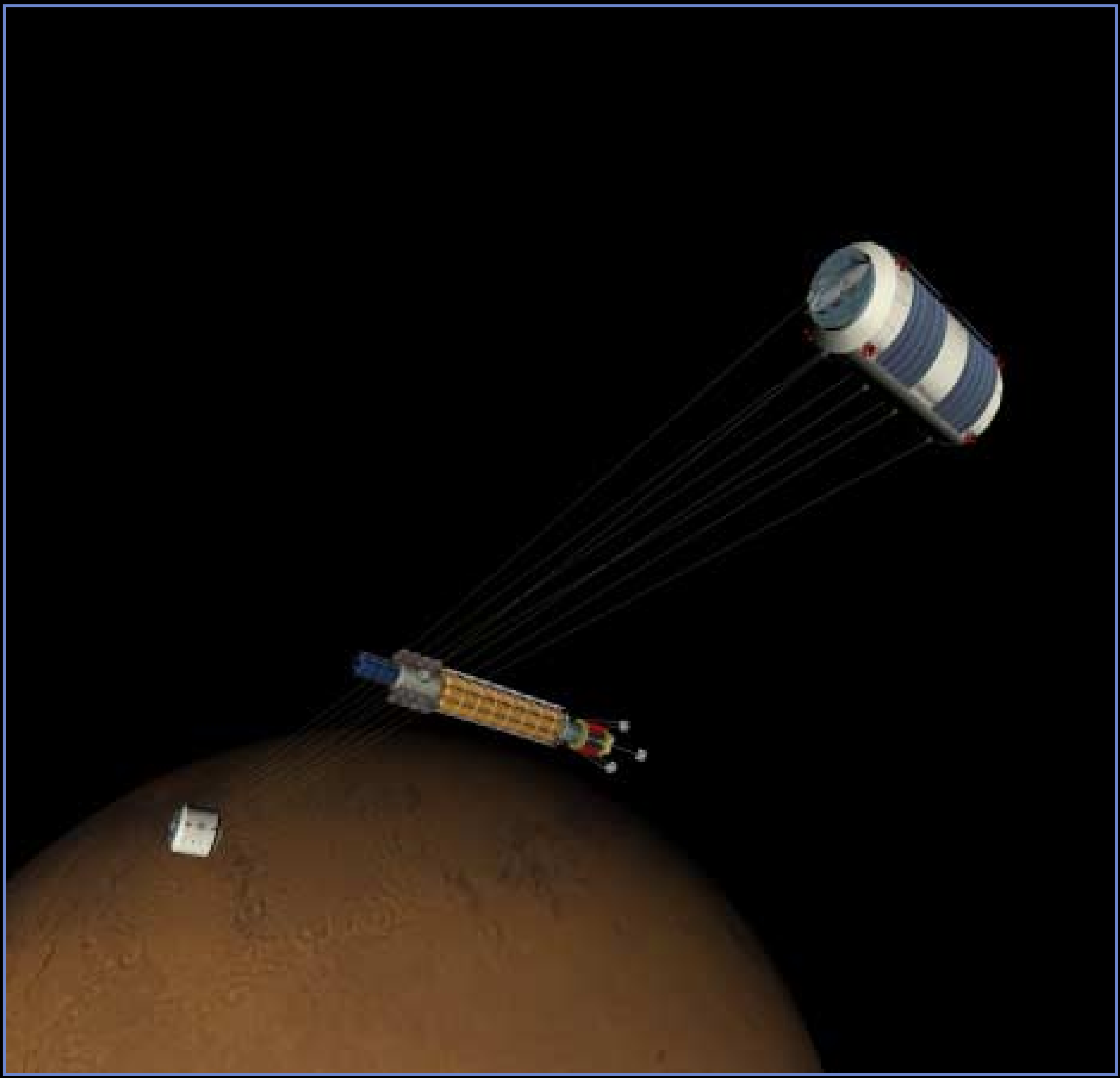

RINGː Rotationally INduced Gravity Vehicle
with elliptical pressurized modules

Sasakawa International
Center for Space Architecture
Gerald D. Hines
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The Sasakawa International Center for Space Architecture (SICSA) is undertaking a multi-year research and design study that is exploring near- and long-term commercial space development opportunities. The goal of this activity is to conceptualize a coordinated sequence of private enterprise initiatives that can carry humanity to Mars. Each development stage is planned as a “building block” to provide the economic foundation, technological advancement, and operational infrastructure to support others that follow.

Project RING is a research and design initiative that addresses important aspects of long-duration human mission and concepts for exploring our Solar System. The RING vehicle is proposed as a multipurpose space vehicle capable of providing rotationally induced gravity.

The following people contributed to this endeavor:

- Maijinn Chen, graduate student
- Elda Galvez, graduate student
- Martina Pinni, graduate student
- Luis Pulido, 5th year student
- Meshwah Abbas, 5th year student
- Vernon Sanford, 5th year student

We appreciate the help and support of all of those who helped us through our journey.

Special thanks are extended to Professor Larry Bell, Olga Bannova, Carl Merry, Krishnan Purushothaman, Kris Romig, Greg Scott, Scott Stover, as well as to Dr. Theodore Hall, Dr. David Zimmerman, Riccardo Bosca and Paolo Pognant and to all of our other fellow colleagues at SICSA.

RING PROJECT

This design proposal envisions to carry explorers on future long-duration human missions across the solar system. The Rotationally Induced Gravity Vehicle, or "RING", aims to accommodate multifarious mission objectives, providing a flexible and autonomous environment for a variety of destinations and operational scenarios.

RING is an explorer proposal to support a broad range of future long-duration human missions.

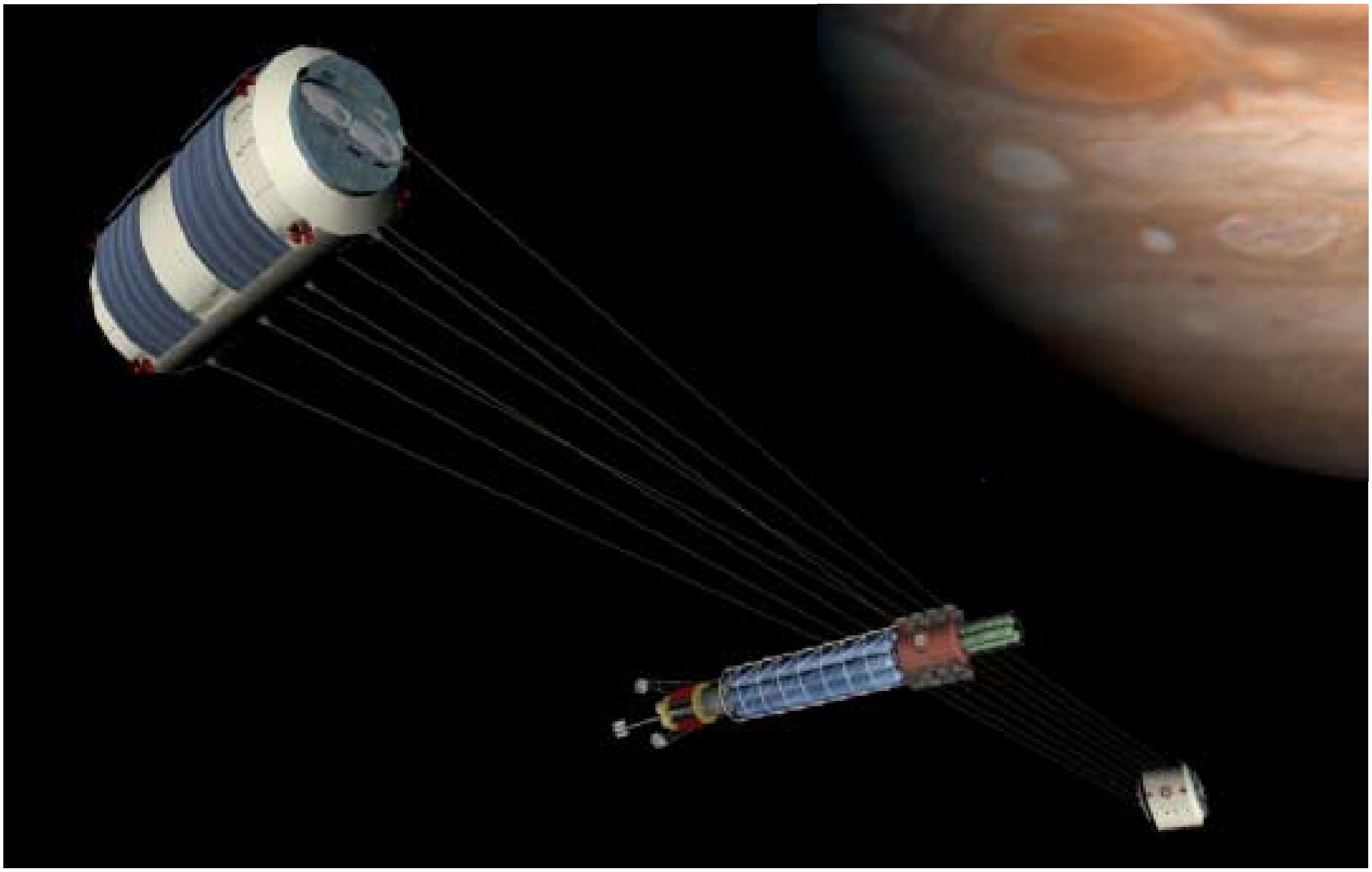
The "RING" concept features a tethered vehicle design capable of providing rotationally induced gravity to help mitigate the adverse physiological effects of long-duration exposure to a microgravity environment. An elliptical rather than a circular cross section was chosen for the habitable modules to optimize usable floor area for the simulated gravity environment. Other special design features include concepts for the vehicle's interior layout, module structure, tether retraction, launch configuration, assembly, and propulsion system.

The design addresses concepts for the overall vehicle and its habitable modules.

Three key design goals have guided the design process:

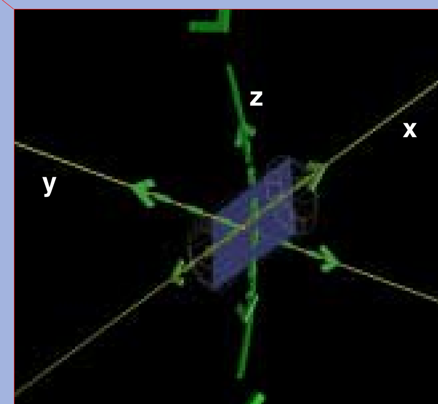
- Define system priorities for long-duration space travel
- Design a habitable simulated gravity environment
- Minimize the number of required launches and operations for on-orbit assembly.

The RING Vehicle in its Deployed Configuration



Vehicle dynamics: RING is moving along x (velocity vector), and rotates in the yz plane.

Any movement of crew members not parallel to the axis of rotation will incur Coriolis forces. The best translational path is along x-axis; the worst is along the y-axis.



ROTATIONAL GRAVITY CONSIDERATIONS

A simulated gravity can be created via acceleration or via mass.

Gravity can be defined as the state of having weight, or the tendency of a mass of matter to be forced towards a center of attraction. One way to simulate the effects of gravity is to rotate an object connected to a central mass to produce centripetal acceleration.

RG arises from centripetal acceleration in a rotating frame of reference.
RG is a form of Artificial Gravity, distinguished by a rotating mechanism.

Rotationally Induced Gravity (RG) therefore arises from centripetal acceleration in a rotating frame of reference. A spacecraft crew's perception of weight will result from the outward reaction to the centripetal force that must be exerted by the rotating structure towards the center of rotation. Rotationally induced gravity is better known as artificial gravity, but for clarity we chose to distinguish this form of gravity by its rotating mechanism.

In human space missions, long-duration exposure to microgravity is detrimental to the health of the crew. Adverse effects include osteoporosis and pulmonary diseases. It is believed that a vehicle capable of simulatng gravity can help minimize these effects.

For long-duration manned missions, crew health concerns must be given top priority.

However, complications abound in a rotational environment, specifically in the areas of spacecraft dynamics and human adaptation challenges resulting from Coriolis and cross-coupled accelerations (AGSEV, SICSA Brochure, 2000). Therefore, technical and human difficulties required in the development of a rotating spacecraft would only be justified for long-duration missions, when health consequences for crew members will be most serious.

MISSION CONTRAINTS

The volumetric requirements of RING are calculated based upon the two main mission determinates: mission length and crew size.

A two year mission period has been baselined for the RING vehicle allow a reasonable amount of time to accomplish a variety of missions.

A small four-member crew has been baselined to minimize the support infrastructure, thereby keeping the mission economical. It is also easier for a small crew to achieve consensus and interact without a complex command structure. Adequately cross-trained, the crew can perform different mission roles to meet mission requirements while reducing the likelihood of boredom in a long-duration journey.

It is assumed that there will be two major crew types with overlapping secondary roles: a vehicle-operating crew consisting of 2 members, and a mission-specific crew consisting of 2 members.

The crew selection has to consider different factors, including missions objectives, crew interaction, gender, culture, social versatility.

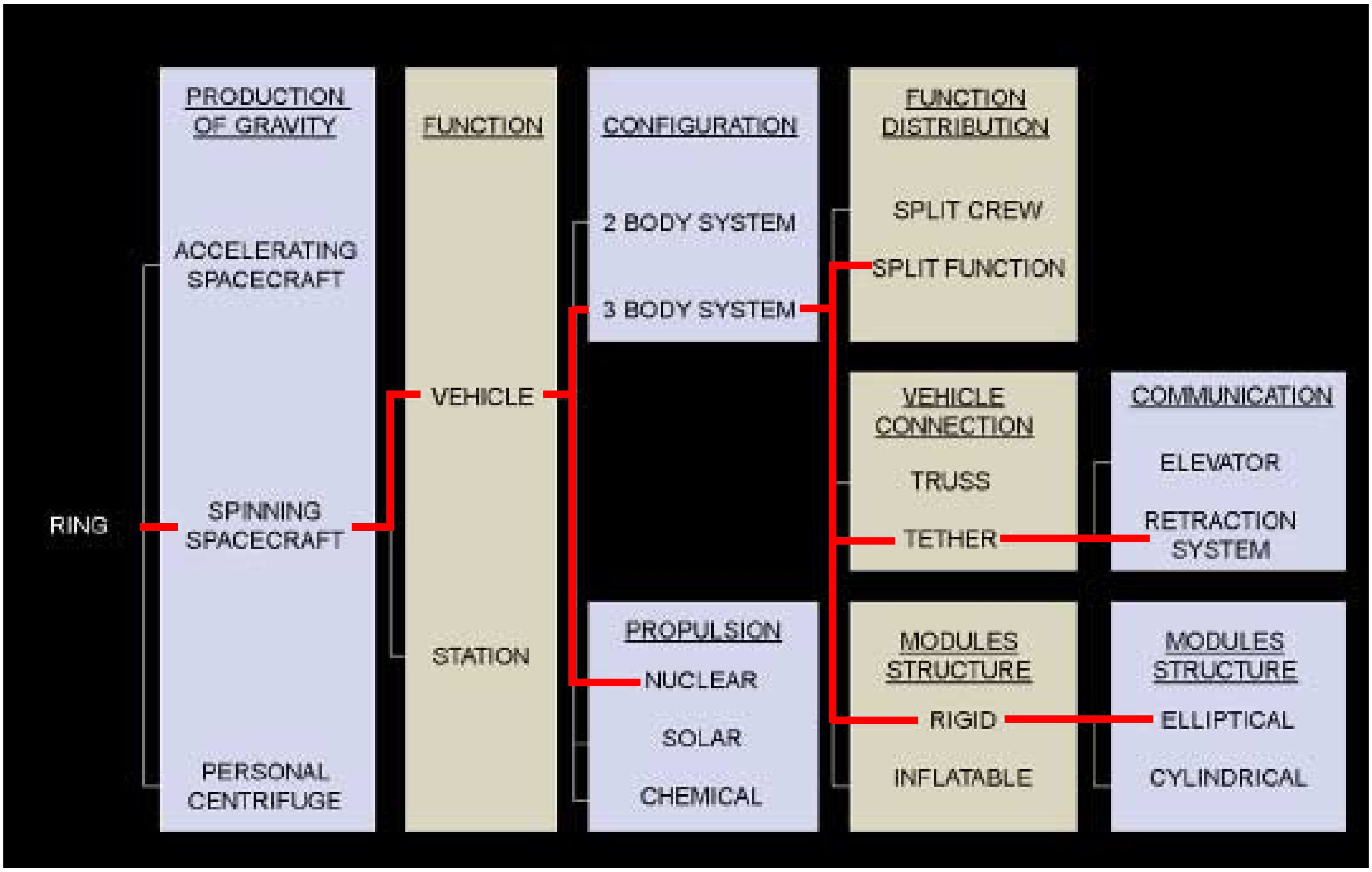
There are great advantages for prolonging space missions, to conduct further experimentation near earth or to initiate long-duration missions to other planets.

Crew selection is not merely about finding people with the right kinds of behavior, but finding people whose behaviors interact in a positive way.

Crew member roles

Vehicle-Operating Crew: Member 1 & 2	
The well-being of the crew depends on the correct functioning of the vehicle. The vehicle-operating crew is therefore the most important.	
Primary functions	
Operational knowledge of the rotating vehicle Communications with Earth and other vehicles Docking management Maintenance and repair management	Pilot for exploratory missions Assembly supervision Supervision of automated rotation Path correction for mission destination
Secondary functions	
Garden assistance Test subjects for human life science investigations on-board	
Mission-Driven Crew: Member 3 & 4	
Primary functions	
Scientific research of biological life in different gravity conditions Garden management Principal investigators for exploratory missions	
Secondary functions	
Docking, assembly and repair assistance Test subjects for human life science investigations on-board	

The final RING configuration is derived from a serie of requirements analyses



DESIGN OPTIONS

Multiple design options are evaluated during the vehicle design.

The RING vehicle configuration is determined from careful evaluation of different design parameters based upon key mission goals and requirements.

For instance, a gravity environment can be created in a spacecraft using different means, either by linearly accelerating the vehicle, spinning the vehicle, or providing a personal centrifuge within the vehicle. To create enough g-force with linear acceleration, a vehicle would need to be equipped with high-thrust propulsion system which is not compatible to the long-duration nature of RING. A personal centrifuge option, though it would eliminate the technical and operational complications of a rotating vehicle, presents its own challenging requirements in terms of habitable volume and module structure. The option of spinning the vehicle is therefore chosen to support RING's mission goals.

Gravity-inducing mechanisms, functional distributions, vehicle configurations, propulsion systems, structural systems, and connection / communications systems are some of the design parameters considered.

A three-body is chosen over a two-body configuration to achieve greater vehicle stability. A nuclear system is chosen to power both the propulsion and onboard systems to support RING's long-duration missions. Tethers are chosen over rigid trusses as the primary vehicle connecting structure due to their light mass, high flexibility and transformability. The retractions of tethers will help RING respond to the variable mass equilibrium between the rotating outer modules. The technical complexity of a retraction system however dictates that constant communications must not be required between the outer modules. For this and other reasons, it is determined that the outer modules will be split into a crew habitation module and a logistic module. This way only periodic docking will be needed for the duration of RING missions.

VEHICLE CONFIGURATION

The radius of RING, measured from its center to its outer modules, is 100 meters. With rotational speed of 1.63 rpm, RING achieves a centrifugal force of 0.3 g.

RING can achieve a centrifugal force of 0.3 g.

RING Components

RING is comprised of a central body and two outer modules, with Habitation Module on one end, and the Repair/Storage Module on the other end. The three-body system is connected by tethers that retract to enable direct docking between modules.

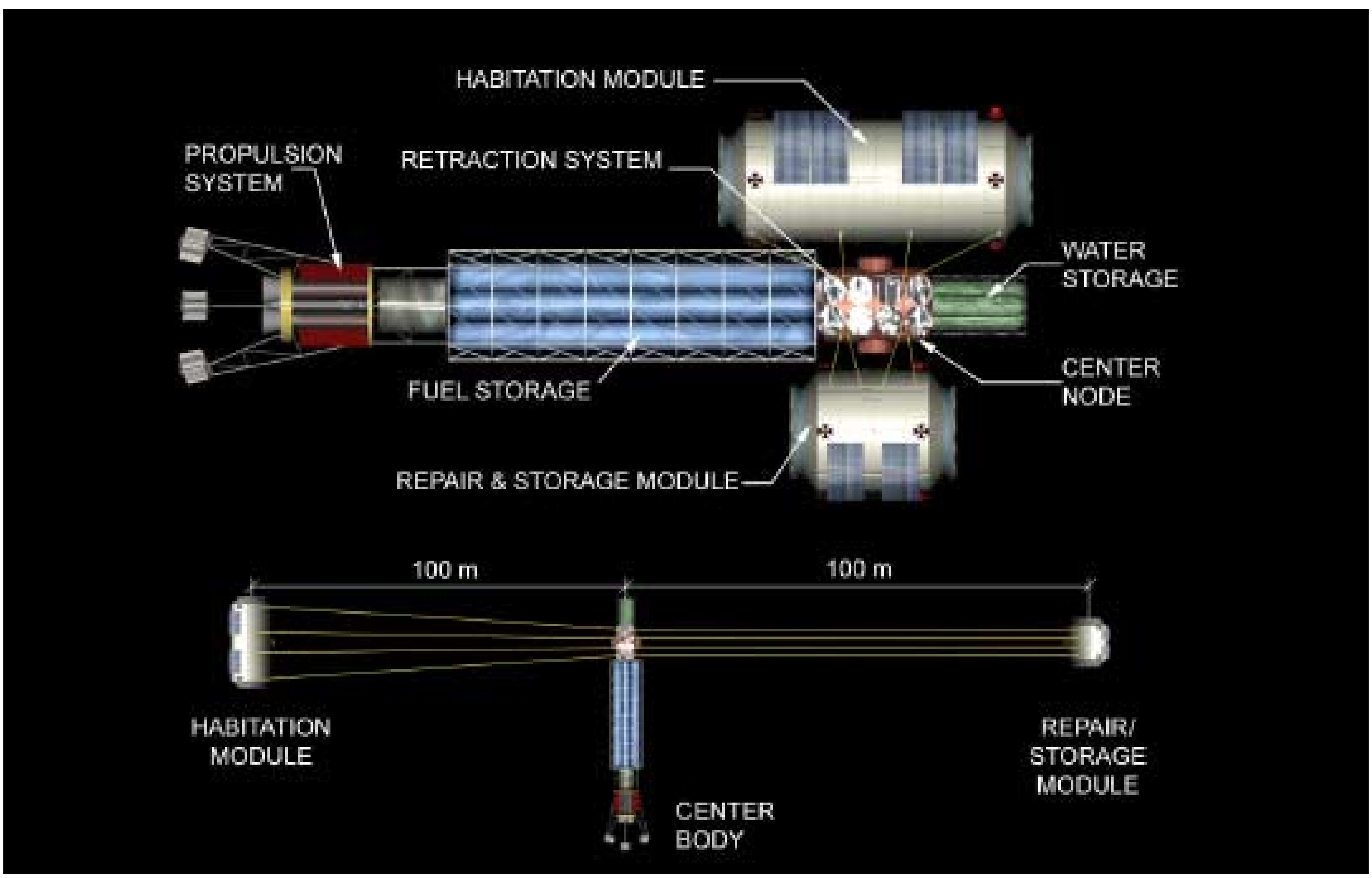
RING consists of three main bodies: the Center, the Habitation Module, and the Storage/ Repair Module

The central body consists of a docking node, tether retraction mechanism, water storage, fuel storage, and main propulsion system. The docking node serves as a connection between the outer modules when RING is fully retracted.

The retraction mechanism is positioned within a structural frame on the top and bottom of the docking node. The system is designed to retract once every two months for resupply and maintenance. During this period water, fuel, food and other supplies will be transferred from the Storage/Repair Module to the Habitation Module via human transport and pump systems.

With tethers RING can retract and dock in order to supply the Habitation Module with food, water and fuel

Components of RING in docked and deployed configuration



VEHICLE CONFIGURATION

RING will use a propulsion system similar to VASIMR.

RING Components (Cont'd): RING's main propulsion consists of an advanced propulsion system similar to a Variable Specific Impulse Magnetoplasma Rocket (VASIMR). (Mars, SICSA, 2002) VASIMR is a monopropellant engine that will most likely use liquid hydrogen as the fuel source. Nuclear reactions will power the propulsive processes as well as all the onboard vehicle systems, including those for navigation, life support, attitude controls, and many others.

The cost of launch and re-entry is significant compared to the per-day cost of living in space. RING can be transported and assembled in LEO with only 3 launches.

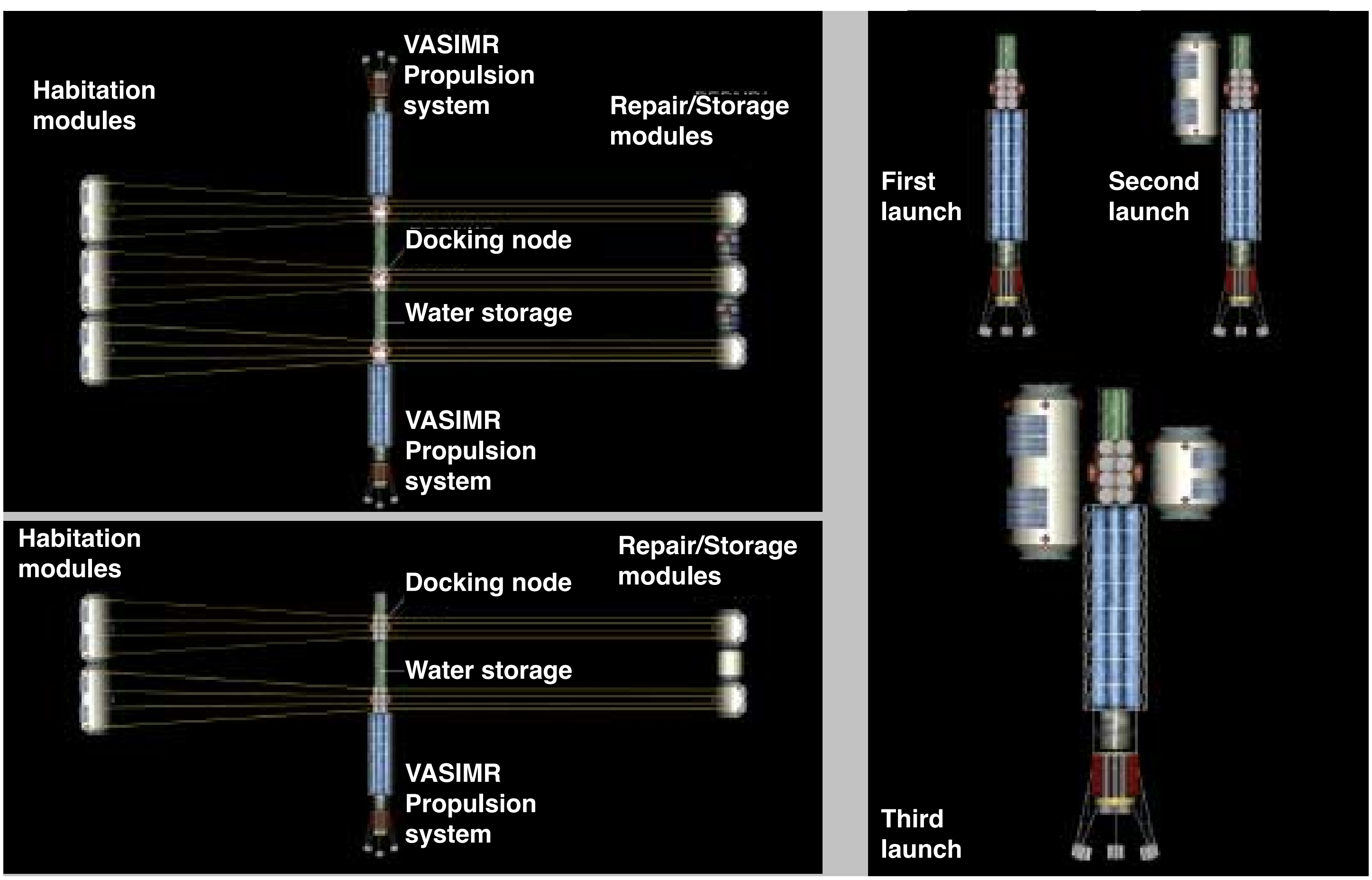
Launch Configuration: In order to minimize the number of launches and the time of assembly, a Heavy Launch Vehicle with a minimum capacity of 70 metric tons will be required to transport large RING segments to LEO. We have baselined the HLV's payload dimensions to be 10 m in diameter and 20 m in length, to keep within realistic manufacturing constraints.

The first launch with 56 tons will take the central body to orbit. The second launch with 70 tons will take the Habitation Module without the crew. The third launch with 68 tons will take the Storage/RepairModule and the exploration equipment, including satellites, probes, and instruments for a specific mission. The crew The components from the second and third launches will dock with the central body to form RING.

Multiple RINGs can be assembled like train cars, to accommodate diverse mission scenarios.

Multi-RING Assembly: RING can be thought of in modular units. One RING can carry out a mission of a certain size. Multiple RINGs assembles into one larger vehicle, or even a station, to increase critical systems redundancy in a mission. It can also accommodate an expanded crew size, extend mission duration, and support evolutions in mission complexity.

Multiple RING can become a larger vehicle. RING can be operational in three launches



VOLUMETRIC & MASS STUDIES

The volume of each pressurized module is determined based upon RING's mission requirements, and constrained by its design parameters including launch and other logistical concerns. Two references, "Human Spaceflight-Mission Analysis" by W. Larson and L. Pranke, and "Volumetric Study for Habitat Design in a Partial Gravity Environment" by S. Capps are used as design standards to determine the required volumes of all major functional areas within the partial gravity vehicle.

RING's estimated volumetric requirements call for a total volume of 716 m3.
RING's estimated mass is determined to be 176 tons.

The mass of each pressurized module is approximated using the results from the volumetric study and the estimated density of occupied volume of the ISS Laboratory Module.

The mass of RING's central body is estimated based upon the 2-year mission requirements with added contingencies. Water volume is calculated to meet the crew's consumption needs. Water also serves as fuel for the exterior thrusters located on the outer modules during RING's retraction and deployment phases. Finally, water is also critical for the operation of RING's Plant Growth Facility, otherwise known as the Garden.

Ideal-rocket equation is used in the fuel calculations.

Liquid hydrogen is used as the fuel for RING's main propulsion system (baseline VASIMR). Fuel for a roundtrip to the Jupiter System is calculated using a Delta V of 18,000 m/s and an ISP of 20,000 s.

RING will carry exploratory equipment including probes for planetary robotic exploration.

Mass estimates of numerous probes and satellites are researched and included in the overall mass of RING. The exploratory equipment is expected to satisfy RING's diverse mission scenarios.

Volume estimations based upon mission requirements

Crew habitation Module	Volume (m3)
Habitat (Subtotal + 10% Integrat Systems)	250
Galley	18
Dining & Wardroom	28
Communal & Recreational	38
Exercise & Medical Facility	34
Personal Quarters	28
Personal Hygiene & Waste Mgmt System	8
Laundry & Miscellaneous	7
Circulation	53
Life Support System	12
Water Storage	1
Laboratory (Subtotal + 10% Integr Systems)	212
General Laboratory	50
Analytical & Biochemistry Facility	40
Astronomical Science Facility	40
Maintenance / Repair Area	10
Circulation	53
Garden (Subtotal + 10% Integrative Systems)	254
Garden Modules (8% Food Consumption)	116
Plant Growth Facility 65	65
Microbiological / Algae Growth Facility	50
Total	**716**

Repair/Storage Module	Volume (m3)
Galley and Food Systems	55
Waste Collection Systems	5
Personal Hygiene &Waste Mgmt System	4
Housekeeping	7
Repair/Maintenaince	34
CO2 for plants	8
Life Support System	9
Total	**324**

Mass Estimations	
Total Occupied Volume of Hab Module	329 m3
Total Occup. Vol. of Repair/Storage Mod.	253 m3
Density of ISS Occupied Volume	208 kg/m3
Estimated Mass of Hab Module	68,432 kg
Estimated Mass of Repair/Storage Mod.	52,636 kg
Estimated mass of Central Module	12,301 kg
Estimated required Mass Water & CO2	25,624 kg
Mass of Retraction Sys & Nuclear Devices	1,042 kg
Total	**715,391 kg**

Comparative analysis of different module cross sectional shapes

Different module volumes are rated using architectural and volumetric parameters.

Parameters		Diameter or Minor Axis	Major Axis	Area of Crossection	Length	Total Volume	Usable Floor Area	Launch Configuration	Vertical Circulation	Horizontal Circulation	Coriolis Force	Assembly Time	Rack Standardization	TOTAL	Weighted Totals
Shape	Levels	m	m	m^2	m	m^3	3.0	3.0	1.0	1.0	1.0	0.5	0.5		10
	1	4.45	-	15.54	50.18	780.00	1	4	4	1	4	1	4	19	27
	2	7.00	-	38.47	20.28	780.00	2	1	3	4	3	3	4	20	23
	3	9.55	-	71.59	10.89	780.00	3	1	2	3	2	4	1	16	22
	4	12.10	-	114.93	6.79	780.00	4	3	1	1	3	4	1	17	29
	1	4.45	5.34	18.65	41.81	780.00	1	4	4	1	4	1	4	19	27
	2	7.00	8.40	46.16	16.90	780.00	3	4	3	4	4	3	4	25	36
	3	9.55	11.46	85.91	9.08	780.00	3	1	2	2	4	4	1	17	23
1.2	4	12.10	14.52	137.92	5.66	780.00	4	2	1	2	3	4	1	17	27
	1	4.45	5.79	20.21	38.60	780.00	1	4	4	1	3	2	4	19	26
	2	7.00	9.10	50.00	15.60	780.00	3	4	3	4	4	3	3	24	35
	3	9.55	12.42	93.07	8.38	780.00	4	3	2	2	4	4	1	20	32
1.3	4	12.10	15.73	149.41	5.22	780.00	4	1	1	1	2	4	1	14	22
	1	4.45	6.23	21.76	35.84	780.00	2	4	4	1	3	2	4	20	29
	2	7.00	9.80	53.85	14.48	780.00	3	4	3	4	4	4	2	24	35
	3	9.55	13.37	100.23	7.78	780.00	4	3	2	2	3	4	1	19	31
1.4	4	12.10	16.94	160.90	4.85	780.00	4	1	1	1	2	4	1	14	22
	1	4.45	6.68	23.32	33.45	780.00	2	3	4	2	3	2	4	20	27
	2	7.00	10.50	57.70	13.52	780.00	3	1	3	3	4	4	2	20	25
	3	9.55	14.33	107.39	7.26	780.00	4	1	2	2	3	4	1	17	25
1.5	4	12.10	18.15	172.40	4.52	780.00	4	1	1	1	1	4	1	13	21

PRESSURIZED MODULES: ELLIPTICAL CROSS SECTION STUDY

An elliptical rather than a circular cross section has been chosen for the habitable rigid modules.

The unique requirements of RING, including long-duration missions and induced gravity conditions, warrant an alternative to the conventional circular cross sectional shape for the pressurized modules.

An extensive study is conducted to validate the advantages of an elliptical cross section over a circular one. Habitable volume is kept constant to provide the basis for comparison. The design parameters used to rate the designated shapes include usable floor area, launch configuration, vertical circulation, horizontal circulation, Coriolis force, assembly time, and rack standardization.

The circular cross section is shown to have many disadvantages with regards to interior circulation, while an elliptical cross section provides better circulation. It also affords greater usable floor area that is most suited to long-term, gravity-influenced habitation.

The best cross sectional shape and size is:

- **Ellipse 1: 1.4, 2-Level**

The worst shapes and number of levels are:

- **Circle, 3- & 4-Level**
- **Ellipse of 4 levels**

Different module shapes with equal habitable volume are evaluated based upon architectural requirements.

ELLIPTICAL CROSS SECTION STUDY

Precedents: There are currently no elliptical modules designed for space use. However, there are many comparable examples of elliptical pressurized structures, including airplane fuselages, pressurized tanks and submarines. There is also a branch of biomechanics which studies the efficiency of elliptical cross section in nature, such as the body of sharks and human blood vessels. Among these precedents, the cross section of the fuselage of the aircraft Airbus 380, still under construction, closely resembles our RING modules in eccentricity and dimensions.

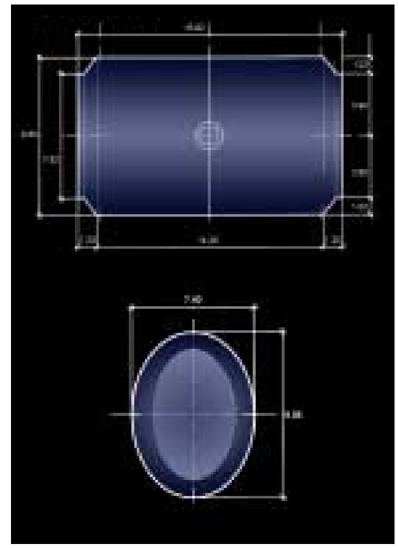
Optimal Elliptical Cross Section: Based on our elliptical studies, the optimal shape of our elliptical module is determined to be 2 levels, with eccentricity of 1:1.4. This, together with our volumetric requirement of 780 m^3, determines the overall module dimensions:

	Major axis (meters)	Minor axis (meters)	Length (meters)
Exterior dimensions	9.85	7.40	16.82
Interior dimensions	9.45	6.70	14

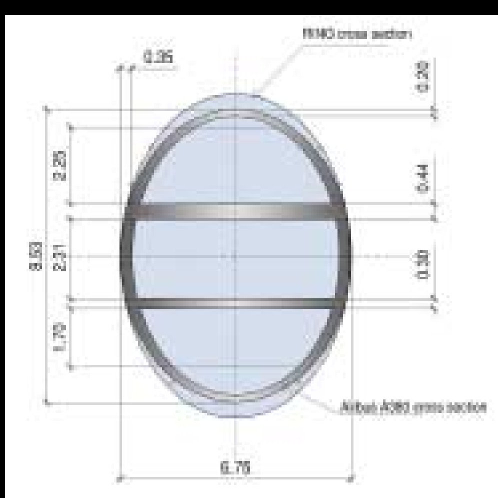
Counterweight Module: These dimensions are determined for the Habitation Module, while for the Counterweight Module other volumetric requirements are considered. Therefore, the Counterweight will have a similar cross section for standardization, but different length to accommodate multiple missions requirements.

The cross section of the Airbus 380 fuselage provides a good precedent for RING modules.

Habitation Module dimensions.



Precedents considered in the RING design process



Airbus A380 cross section compared to RING.

"It would appear that future transport fuselage could have noncircular corss sections, in particular, oval or elliptical cross sections. Blended wing-fuselage concepts, improved aerodynamics, and increased payload efficiency are but a few of the reasons why noncircular corss sections may be used."

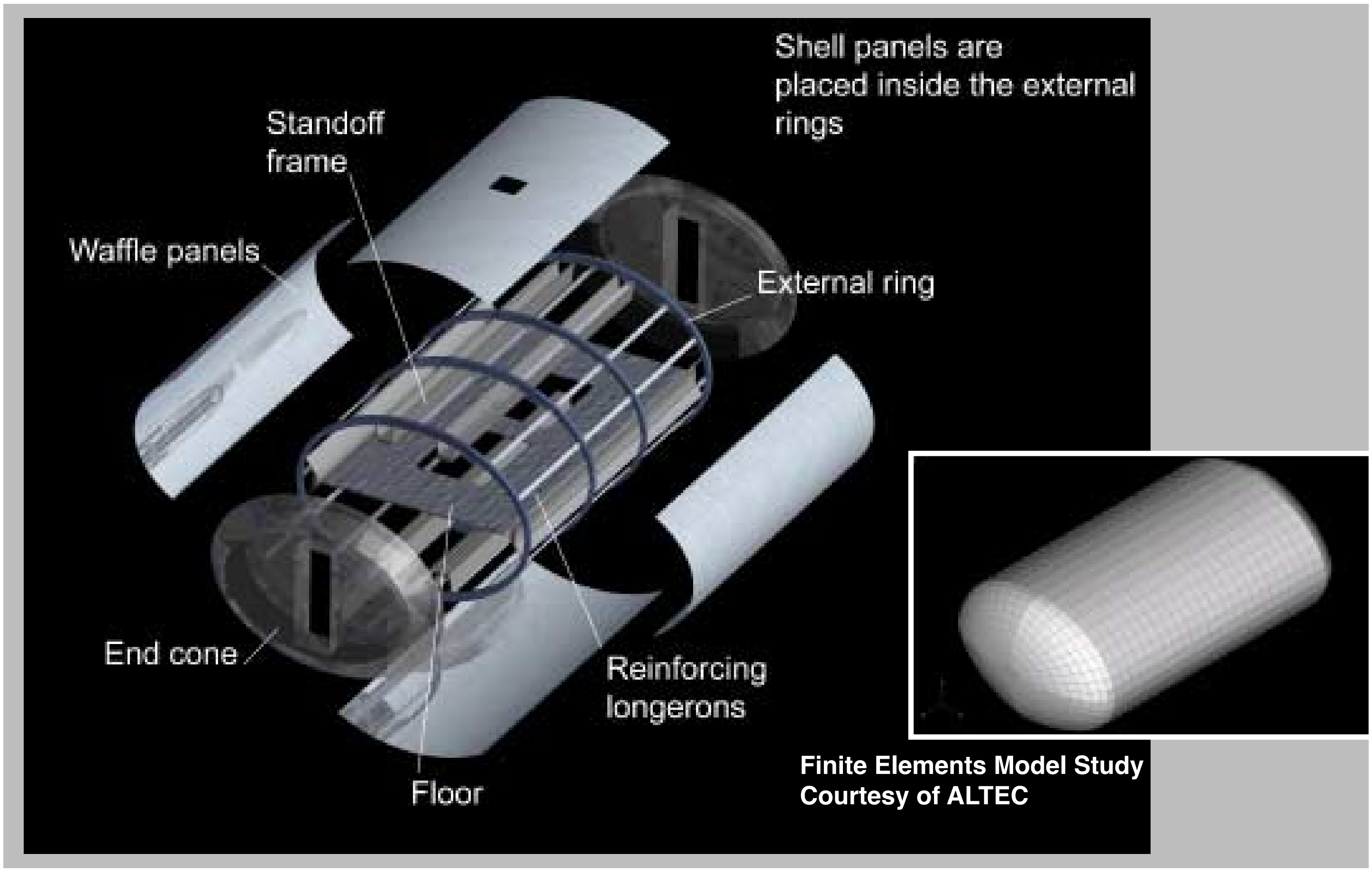
McMurray, Hyer (1999).

Vorticity Control Unmanned Undersea Vehicle (VCUUV): An Autonomous Robot Tuna.

"The Tuna's fusiform forward body has nearly elliptical sections within which internal arrangements are made more easily than with cylindrical sections."

DOT-406 Elliptical Petroleum Trailer is a pressurized tank with an elliptical cross section.

Main components of RING's shell: axonometric view and FEM structural study



Finite Elements Model Study Courtesy of ALTEC

PRIMARY STRUCTURE

ALTEC conducted a FEM study to analyze options for the construction of the shell.

FEM Study of ALTEC -The Italian Gateway to ISS

The construction of an elliptical section is a new problem for space technology. The Italian company ALTEC (ASI/Alenia) conducted a study for RING on a Finite Element Model, to analyze the possible options. They include:

- **machined, welded and formed aluminum panels (type 2219 or 2195)**
- **steel honeycomb sectors formed and welded**
- **composite materials (carbon fiber or Ti/SiC)**
- **inflatable technology (for launch constraints)**

Due to the project's large volumetric requirements, without the availability of a Heavy Launch Vehicle, the only viable option for the RING modules would be inflatable structure. An estimated structural mass for an inflatable module is expected to range around 15 tons. However, the inflatable concept is not compatible with the module's proposed shape. The elliptical profile would have to be approximated possibly with the use of internal cables.

A rigid aluminium module was preferred to the inflatable technology.

The conventional rigid option, with components made of aluminum, is therefore preferred. The shape can now be achieved precisely with material and structural stiffness. Such a module is projected to have a mass of 12 tons, with the average aluminum shell thickness of about 30 mm. Like the conventional space modules, elements which constitute the shell include external rings and longerons, waffle panels and end cones.

PRIMARY STRUCTURE

Future Alternative for Shell Construction

A possible future option for shell construction is to use composite materials. Recent research indicate that material orthotropy of composites may help to mitigate the differential stresses experienced by internally pressurized volume with a non-circular cross-section. The coupling between advanced materials and elliptical sections may help achieve greater strength-to-mass ratio than aluminum structure, leading to a further reduction of a module's material mass.

The coupling of orthotropic materials with a non-circular cross section is an interesting future option.

Tether Systems

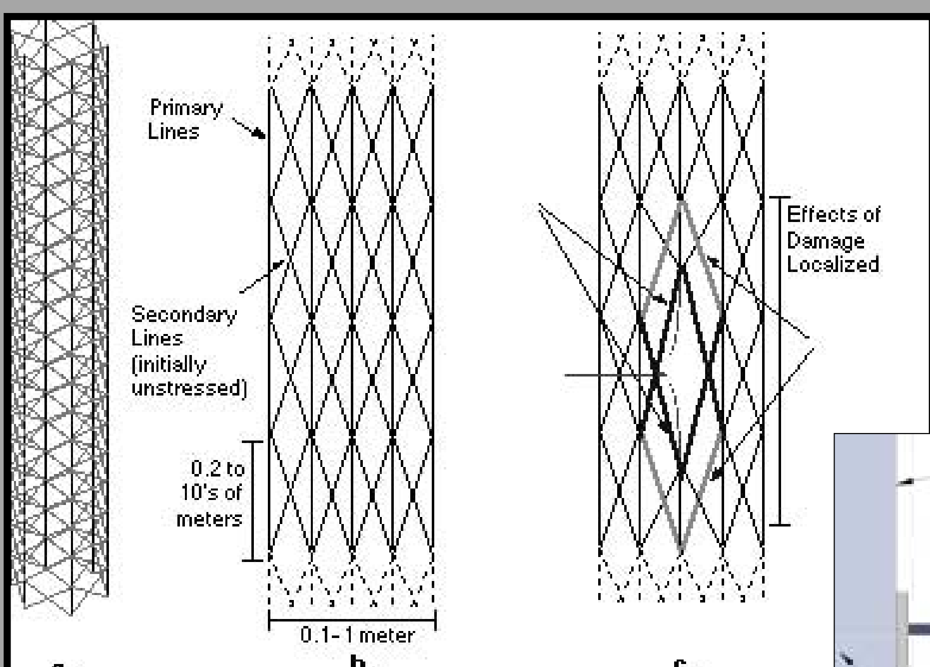
The pressurized modules have to be designed for the centripetal force as well. The retraction system consists of 16 retraction wheels, each responsible for the retraction of one tether. Each tether is attached to the module shell, at locations corresponding to the structural rings. Both of the outer modules are equipped with thrusters which slow the rotational speed during the retraction to offset increases in velocity resulting from the conservation of angular momentum. This would help maintain a reasonably comfortable level of g-force for the crew during docking.

Hoytether technology has the advantage of reducing mass while providing structural redundancy.

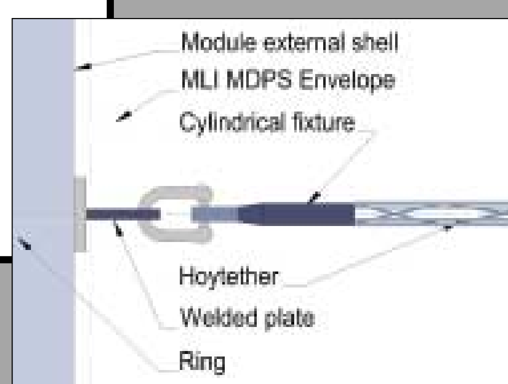
Tethers, unlike a rigid space truss, have the great advantage of providing a large rotational radius without huge mass penality. Tether technology like the Hoytether can provide redundancy in case of damage due to meteoroid impact. Assuming a material like Zylon (density 1.520 Kg/m^3, tensile strength 5.8 GPa), Hoytethers of very small cross section (0.4 diameter each RING tether) will be capable of fulfilling the projected load requirements.

Zylon is an advanced material capable of fulfilling the strength requirements.

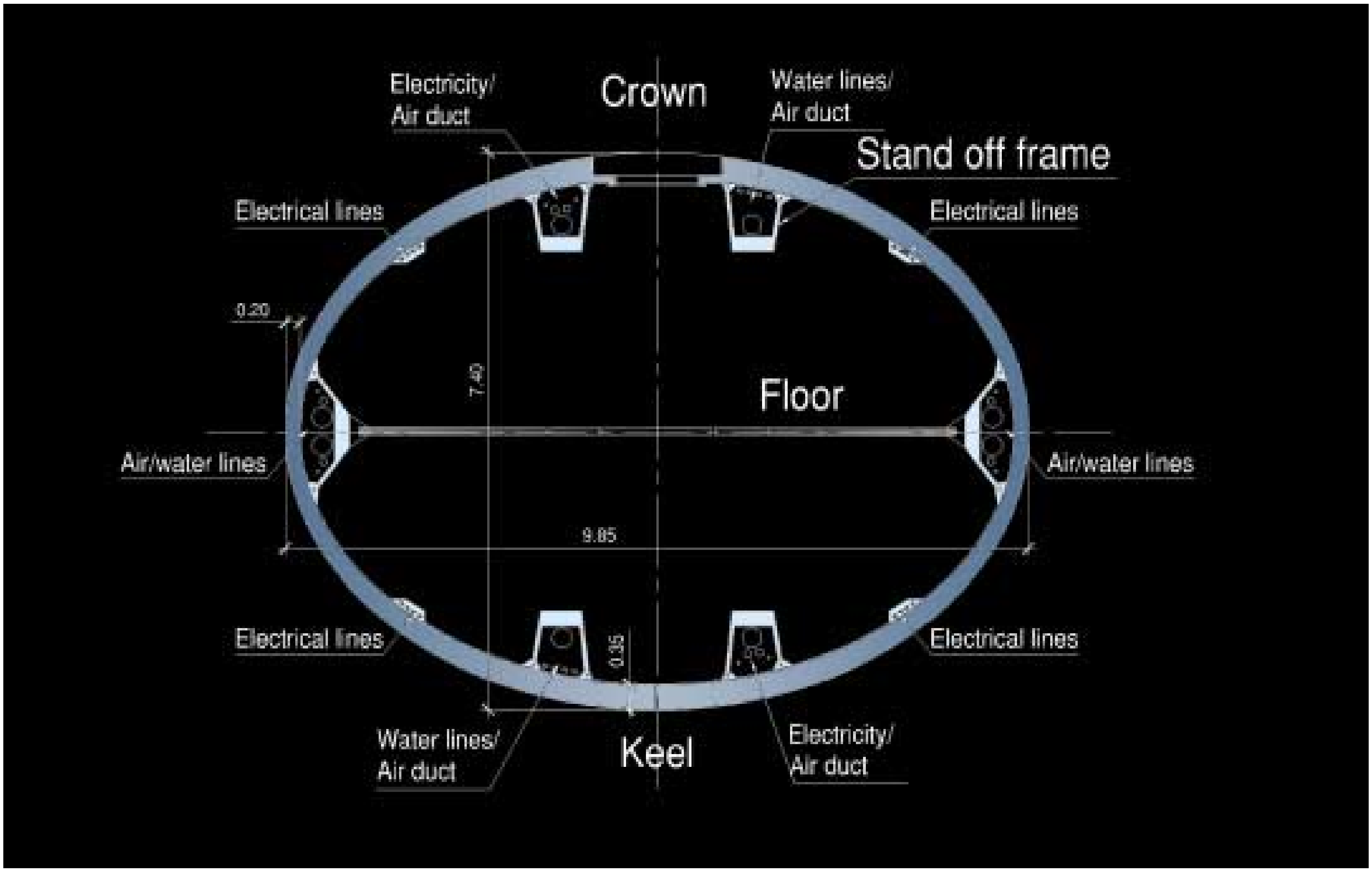
The inherent weaknesses of traditional tethers are improved upon with Hoytether technology



Hoytether Technology Courtesy of TUI



Cross section showing the main components of the secondary structure: standoffs, floor, racks and utilities.



THE SECONDARY STRUCTURE

Main components of the secondary structure are standoffs, floor, and rack support system.

The secondary structure enables the use of the internal spaces of the module, providing a support structure for utilities and equipment. It is comprised of stand-off frames, floor structure, rack support and hinge systems. The floor is supported by the lateral standoff frames. Racks and compartments are supported by the ceiling and floor standoffs.

Due to the large rotational radius, the curvature of the floor approximates a flat surface.

In a rotational gravity environment, the floor should be curved in such a way that the gravity vector (the force that direct objects toward the ground) is constantly perpendicular to the floor plane. Curving the floor structure would introduce a greater complexity to the rack and standoff systems.

RING's large rotational radius helps to mitigate this problem, as it keeps the floor curvature small enough to approximate a flat surface, thereby simplifying the module's internal architecture and subsystems.

Standoff must be accessible and racks must be modular and movable.

Since the standoffs house the utilities, they must be easily accessible for repair and maintenance. The racks, compartments and equipment must be movable to facilitate access. Floor and ceiling racks can rotate on hinges connected to the standoffs. Lateral racks can slide on rails connected on the floor structure. All racks and equipment are designed with the modular width of 1 meter.

THE UTILITY ARCHITECTURE

Utilities run all along the module to the end-cones.

RING's utility system is very similar to that of a conventional rigid modules. Utility ducts run along the length of the module inside the standoffs to the end cones, where connections with the other modules are provided.

RING proposes a separation between fluid and electrical lines.

Utilities include air and fluid lines (atmosphere supply and return, vacuum and water), and electrical lines (high and low voltage, data and communications cables). RING's standoff configurations allow for necessary separation of the eletrical/data lines from the fluid lines. The air and fluid lines would run in the lateral standoffs, and in two of the central standoffs. Air and electrical/data lines would run in the other two central standoffs, and in the dedicated corner standoffs.

Assuming the velocity of the air is between 3.8 and 5.95 m^3/minute (like the ISS modules), the diameter required for the air ducts is determined to be 26 cm in diameter, leading to a total of 4.5/7 changes of air per hour.

RING assumes recycling technologies with 95% efficiency.

RING's air and fluid systems utilize recycling technology with a 95 % efficiency. All systems must be designed for both micro- and partial gravity conditions.

Power is transported from the source to the modules through power beaming.

The power for the electrical devices and equipments will come from the nuclear source located at the propulsion system, and it is transported to the modules through cables or power beaming technology (Landis, 1999). Additional backup with batteries will also be provided.

THERMAL CONTROL AND RADIATION PROTECTION SYSTEMS

RING has to be protected from the extreme environment of the worse-case scenario.

A multipurpose vehicle like RING has to anticipate extreme mission destinations, including the harsh environments of the jupiter System at 5.2 AU from the Sun. There, temperatures can range from -160^o to +180^{o}C. Passive thermal protection system provided by thermal blankets will not sufficiently protect the space modules from these extreme temperatures. For environments beyond 1AU, RING must rely completely on active thermal control system.

Meteoroids protection is very critical for planetary exploration.

The protection from meteoroids and debris is also a critical requirement. This will be needed in the orbital trajectories as well as during interplanetary travel. The module will be equipped with a kevlar shielding that enables it to withstand the impact with small debris. The guidance and control system will enable RING to avoid impact with the larger meteoroids.

A magnetic shielding is necessary for active radiation protection in the most extreme mission scenario.

The magnetic field of Jupiter is a vastly stronger version of Earth's Van Allen Belts. A human crew traveling in the Jupiter System will be exposed to four millions times the deadly radiation dose for humans. Radiation of this magnitude can also degrade structures and satellites in a very short time. Shielding provided by the aluminum shell would be limited, with huge mass penalty.

An active radiation protection system is therefore required in the Jupiter environment. Magnetostatic/plasma shielding may be a future possibility. The electrostatic field generated can shield the positive particles, while a magnetic field can confine the electrons from the space plasma to provide neutrality.

INTERIOR ARCHITECTURE: Habitation Module

First planning concept: segregation of zones according to usage

The Habitation Module interior is organized into 4 usage zones: Habitat, Lab, Garden and Support areas. Horizontally, the interior is divided into Habitat and Lab, buffered in between by a Support zone. The interior is further segregated vertically, with the public, noisier spaces on the upper level, and quiet and semi-quiet zones on lower level. Areas requiring re-supply, such as Galley and Lab, are located on the upper level, since this level is also the docking level.

Second planning concept: A central Garden in the Habitation module to provide spatial and visual relief for a crew living in confined environment

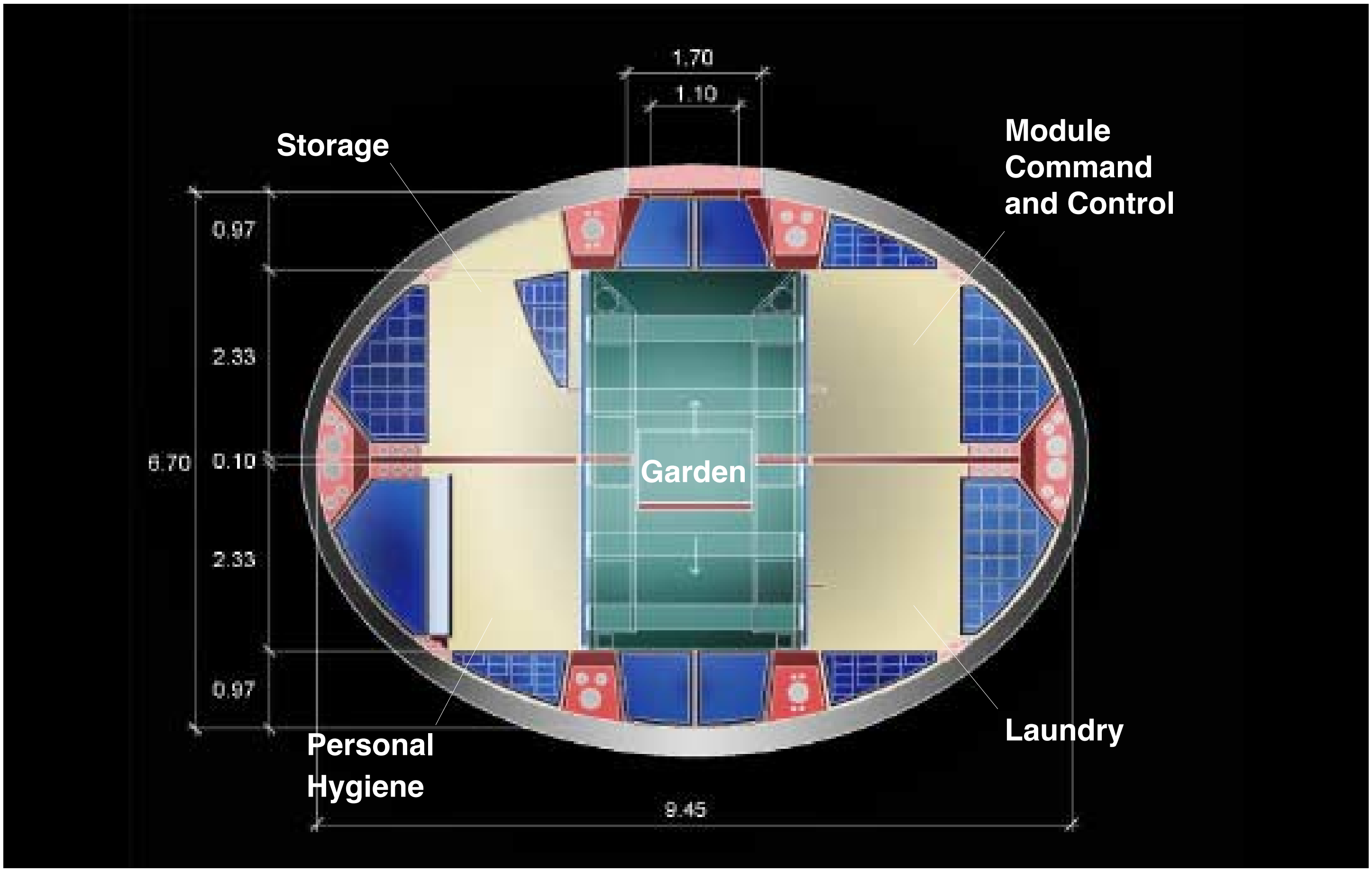
Central Garden: A double-height plamth growth facility, known as the Garden, is located in the center of the Habitation module. It provides spatial and visual relief for a crew that lives in close quarters for long periods of time. As well, in a long-duration mission, the Garden can increase self-sufficiency of the crew as it grows its own food. The act of maintaining the Garden will also serve as a much desired distraction from the primary duties of the crew. The Garden is therefore the spatial and aesthetical as well as therapeutic centerpiece of the interior.

Third planning concept: Racks and standoffs are configured to efficiently service the module

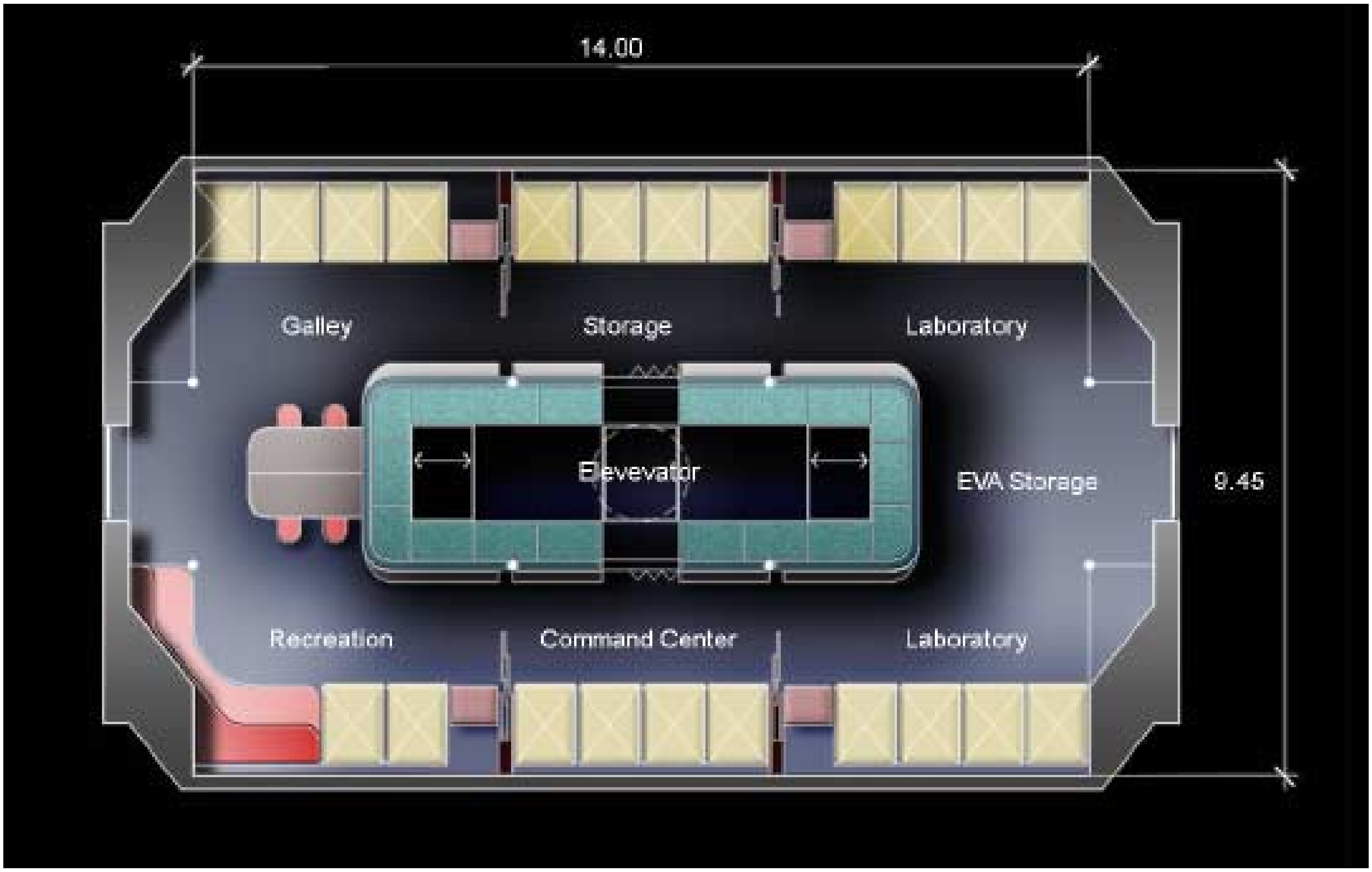
Racks and Standoffs Configuration: Racks are organized into 3 types: side racks for the equipment and infrastructure for our functional areas, top and bottom racks for the storage of the consumables, and central racks for our life support system. The side racks can be pulled out via a rail system, while the top and bottom racks can be pulled out via a hinged system.

A general body restraint system will be needed to accommodate microgravity conditions when RING docks its outer modules.

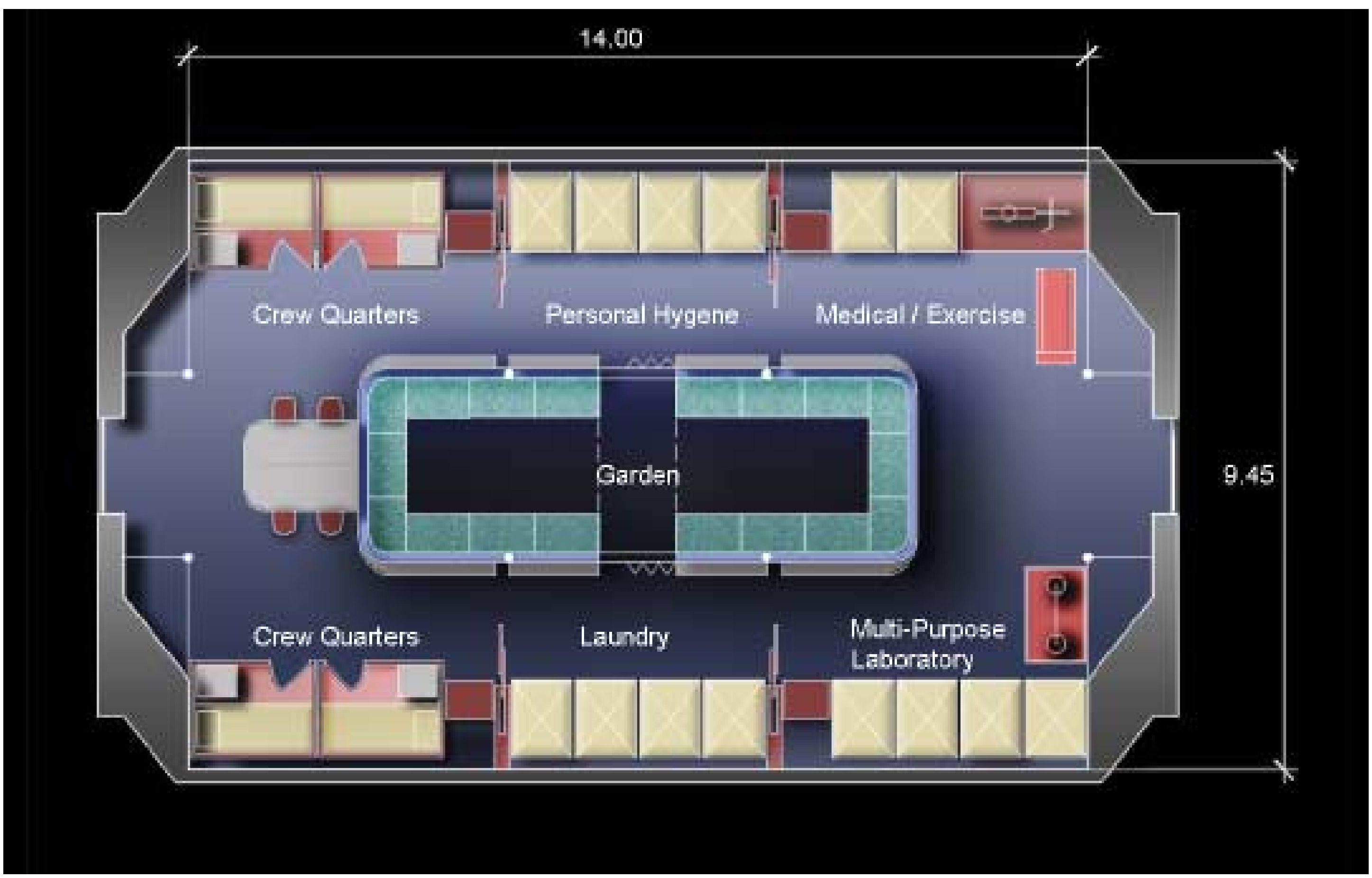
Cross section showing the internal arrangements of the Habitation Module



Habitation Module, Upper/docking level



Lower level plan



HABITATION MODULE: Garden

The Garden can be the main imaging and information center of the Habitation module

The central Garden provides spatial and visual relief for the crew in two ways. First, its double-height space creates a different spatial volume within our module. Then, by being in the center of the module, the Garden is visually accessible from all areas. Its transparent envelope will not only allow views into the garden interior, it can also support LCD, LED, or projection video imaging and information display.

Mechanical lifts within the Garden eliminate the Coriolis effects from ascending and descending with respect to prograde and retrograde directions in a rotational environment

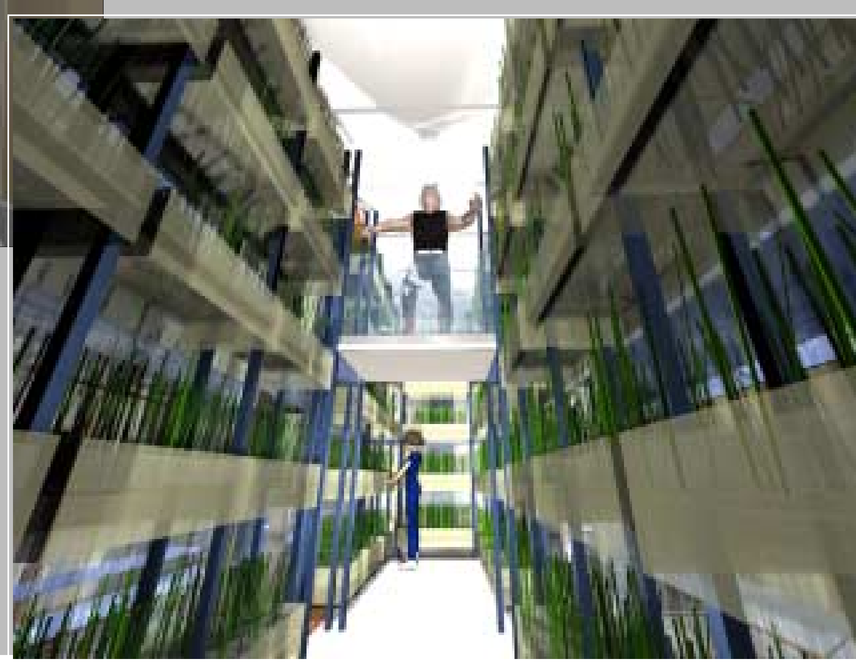
The Garden's centrality also allows it to be integrated with the vertical circulation system. Mechanical lifts, rather than ladders, are proposed to assist vertical movement and eliminate inconveniences of Coriolis effects. They will also provide the crews with the means to access the planting modules within the Garden.

The idea for a double wall system for the Garden's envelope is currently being explored. The double walls can be the supporting structure for the selected display technologies. Alternatively, it can be filled with water to provide radiation protection, making the Garden a safe haven. The double wall envelope will be supported by the module's secondary structure.

The Garden's Environmental Control must be separated from that of the module. Plant growth creates higher temperature and humidity loads that require additional treatment. A separate EC system will also help reduce the threat of contamination.

Garden interior views

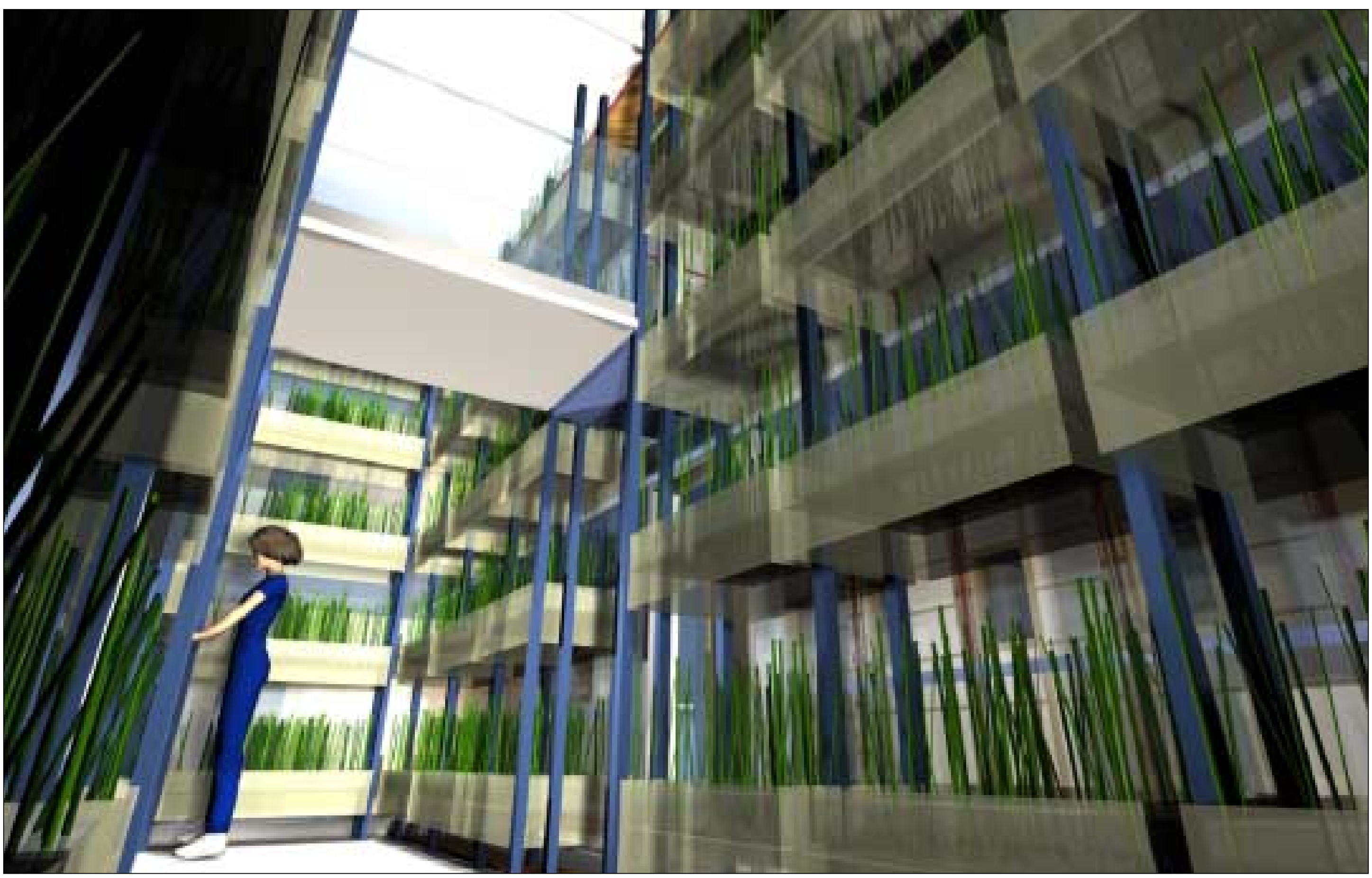
View of Garden from the corridor



Garden interior

Garden interior, view from the bridge

Garden interior



HABITATION MODULE: Habitat Zone – Upper Level

Galley is divided into four major areas of use: storage, food preparation, dish and hand-washing disposal and waste disposal.

Habitat Zone on the upper level consists of the Galley/Wardroom,and Common/Recreation areas.

Galley /Wardroom
Four major areas of use include:

- **Storage Area** (food storage in the top racks,and utensil storage in the side racks)
- **Food Preparation Areas** (re-hydration station,food warming station,and preparation area)
- **Dish and Hand-washing Stations**
- Waste Disposal Station

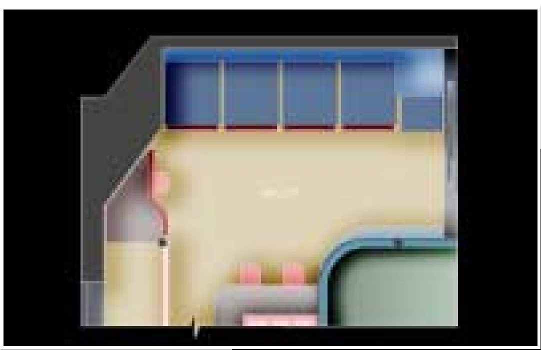
Playing board games in the main gathering area.

The area in between Galley and Common/Recreation serves as a main gathering area,and contains a multi-purpose table,where the crew would share meals,conduct meetings and socialize.

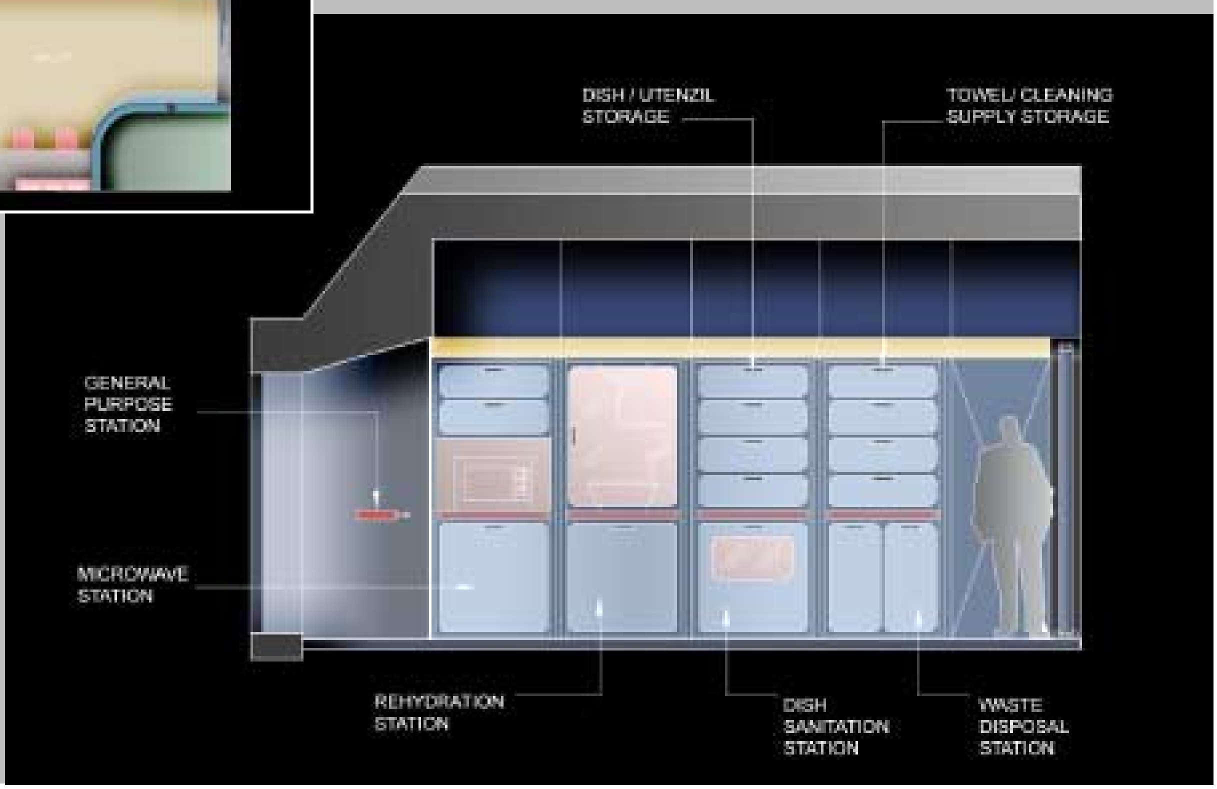
Recreation area consists of areas for both individual and social uses.

Common /Recreation
In the Common/Recreation area,two imaging stations allow for individual viewing of videos or electronic mail.These imaging stations are oriented to provide partial privacy.They are equipped with transformable furnishings so they can be compacted when not in use.The Recreation area also includes a lounge area,appropriately adjacent to the Galley and the main gathering area,for socialization and relaxation of the crew.

Galley plan and elevation



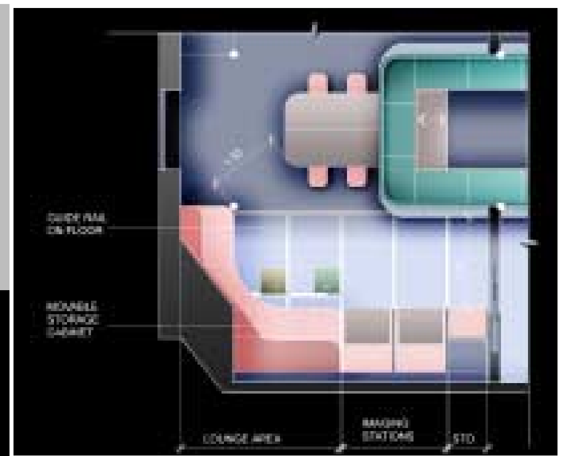
Plan

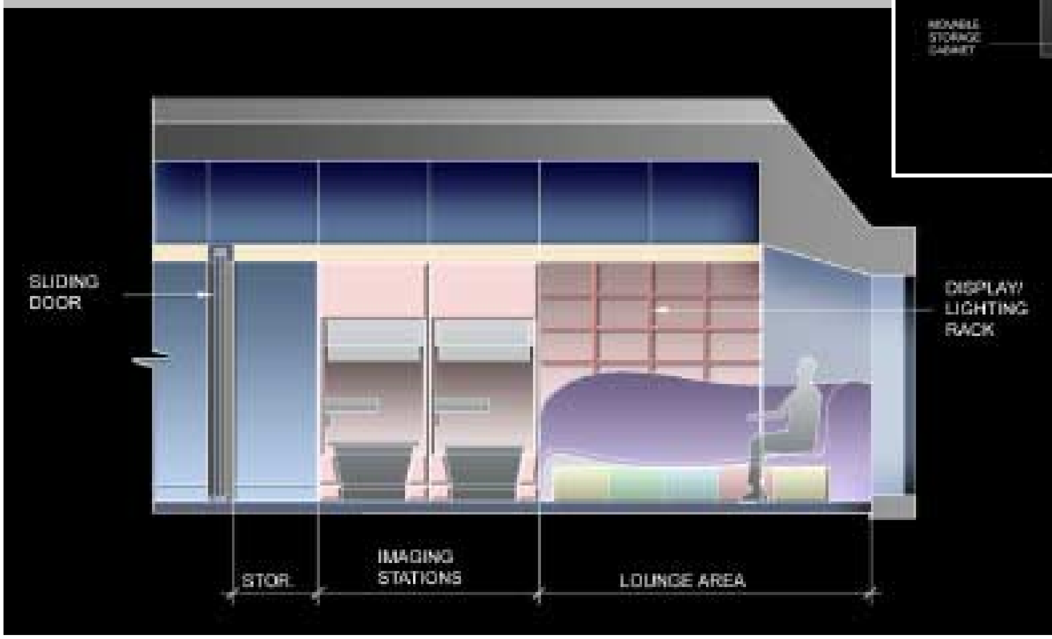


Elevation

Recreational Area

Plan





Elevation

View from the Recreational Area

HABITATION MODULE: Lab Zone – Lower Level

The MEF maintains the health of the crew by supporting its exercise regiments, and providing both routine healthcare.

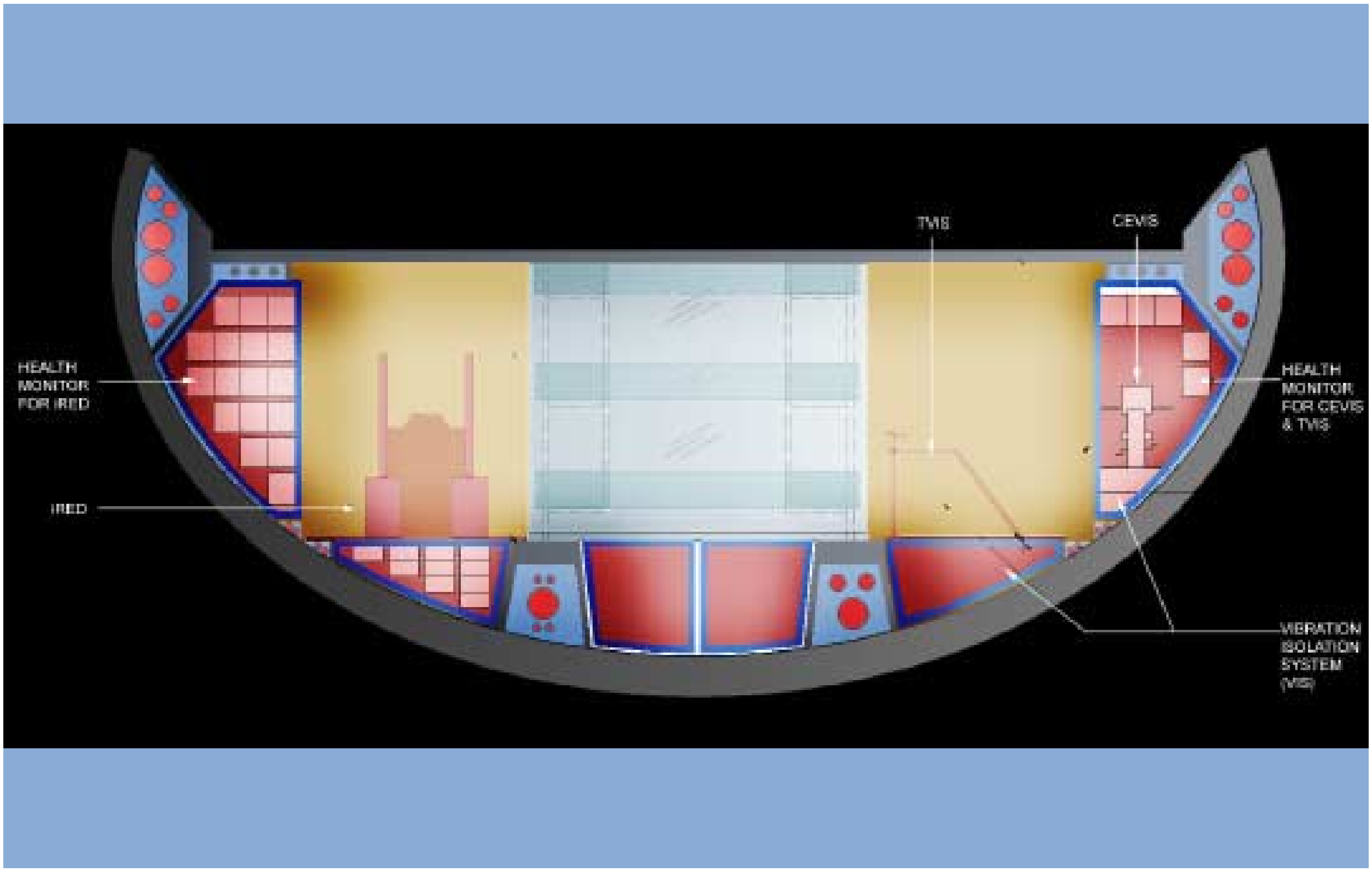
Lab zone on the lower level consists of the Medical / Exercise Facility
The Medical/Exercise Facility has the prime function of maintaining the health of the crew during its long-duration mission. The facility is comprised of Countermeasure Exercise Equipment, Crew Health Care System, and Recreational Equipment.

Countermeasure Exercise Equipment (CEE)
CEE is used by the crew in exercise regiments to counteract the physiological deterioration of the crew caused by living in reduced gravity conditions. CEE includes one Cycle Ergometer with Vibration Isolation System (CEVIS), one Treadmill with Vibration Isolation System (TVIS), and one Interim Resistive Exercise Device (RED). All exercise equipment will be connected to a health monitor system to record measurements and monitor the crew during exercise.

Crew Health Care System
The Crew Health Care System has the dual functions of providing routine healthcare as well as emergency care to the sick or injured crew. It consists of two racks equipped with Defibrillator, Medical Aid System, Crew Contamination Protection Kit, Crew Medical Restraint System, Respiratory Support Pack, Ambulatory Medical Pack, and Health Maintenance System Ancillary Support.

Recreational Equipment
All exercise equipment will also be equipped with video screens to reduce monotony of the exercise regiment, providing both entertainment and telecommunication capabilities.

Medical/Exercise facility, cross section



HABITATION MODULE: Support Zone – Lower Level

PHF utilizes expandable rack system to increase the usable spaces within

Support zone on the lower level consists of Personal Hygiene Facility (PHF), Laundry, and Storage.

The Personal Hygiene Facility occupies 4 rack-compartments, providing 4 major areas of use: shower, dressing, hand-wash and toilet. By separating the toilet and shower with the hand-wash area, they can be used simultaneously without interferences. These rack-compartments are expandable to increase the usable space within the facility, while remaining compactable during launch or repair and maintenance.

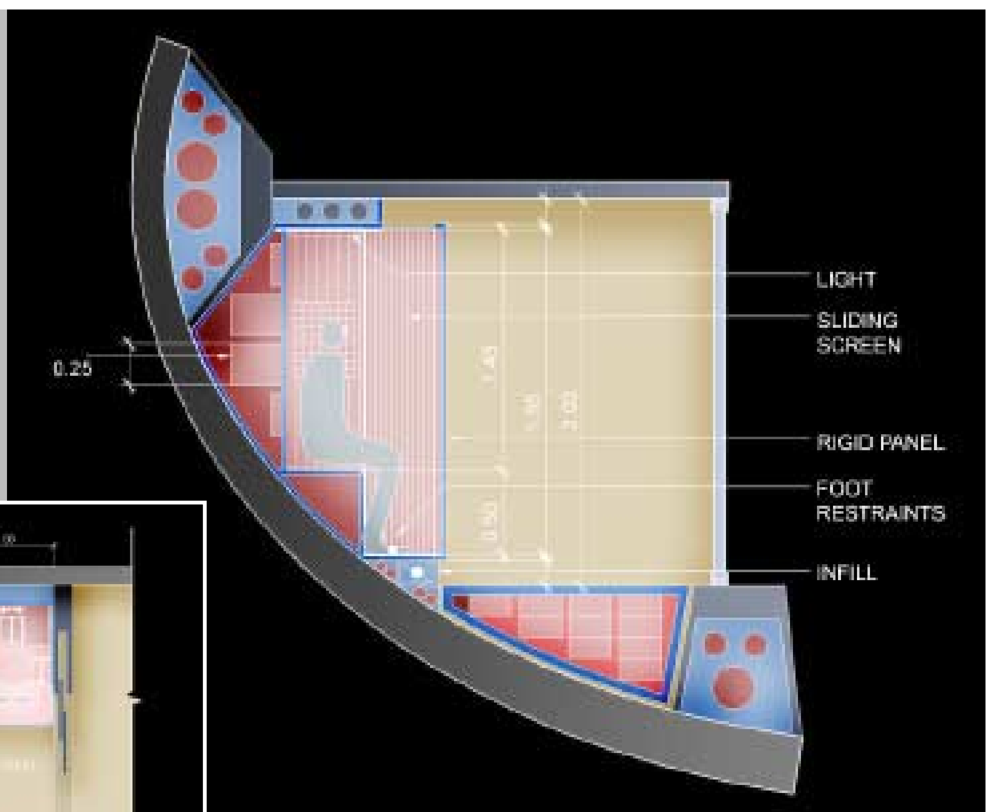
HABITATION MODULE: Habitat Zone – Lower Level

Habitat Zone on the lower level consists of Crew Quarter (CQ) areas and an informal gathering area.

CQ utilizes expandable rack system as well as transformable furnishing to optimize usage in the compact interior.

The Crew Quarter area provides for 4 expandable rack-compartments similar to those of the PHF. Within the CQ compartments, the bed is elevated to allow for storage spaces and a work area underneath. The compartments will be equipped with transformable furnishings, such as a collapsible bed and desk, to optimize usage within the compact interior space.

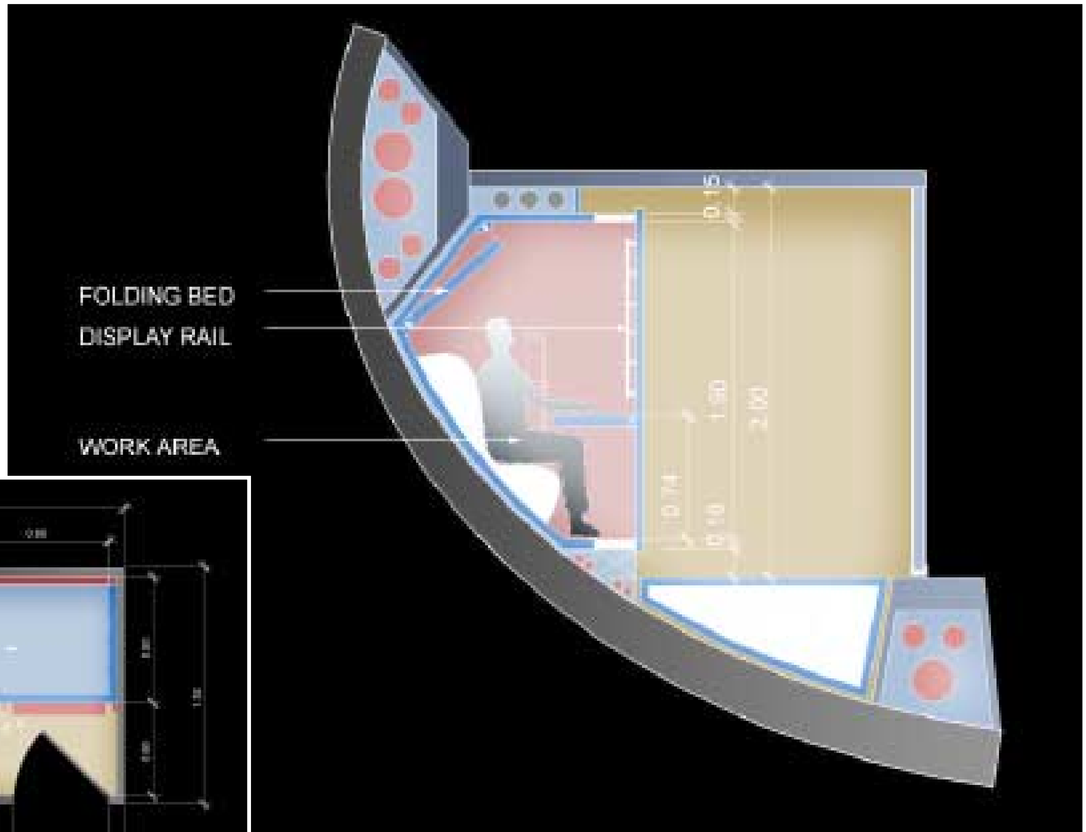
Personal Hygiene Facility



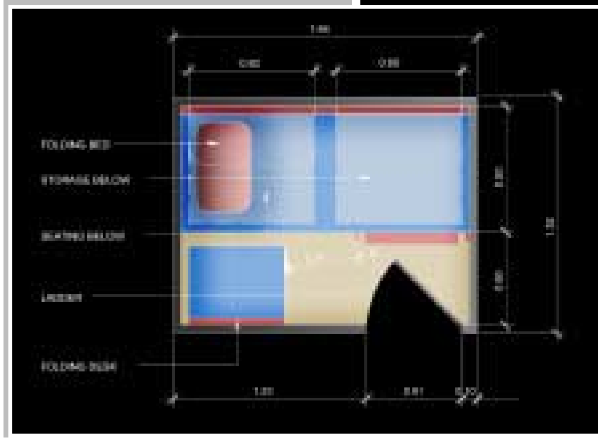
Section thru the shower

Plan

Crew Quarters



Crew Quarters plan



Crew Quarters section

Crew Quarters Interior views

Workstation inside the crew quarters

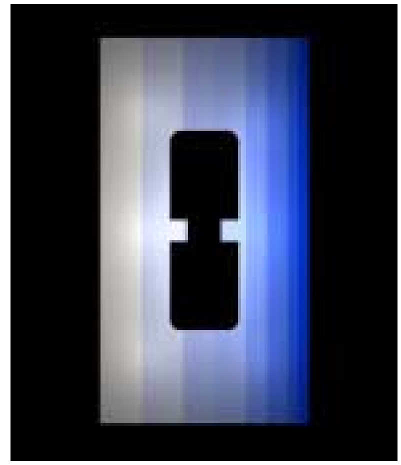
Deployable bed

HABITATION MODULE: Other Interior Design Concepts

Color and Texture

The undesirable effects of moving within a rotational environment include disorientation resulting from the Coriolis forces. One way to counteract this is simply to constantly remind crewmembers of their orientation with respect to the direction of rotation, so that they can minimize certain ways of moving. We can achieve this through subtle architectural interventions, such as floor or ceiling patterns, or trim colors applied in small quantities to various racks or furnishings. As an example, the upper level floor and the lower level ceiling can be treated with a gradation of colors, so that the direction towards the darkest hues coincides with the prograde direction of the rotation.

Color and Texture play a role in informing the crew of the nature of their rotating space.



Lighting

The lighting system consists of primary ambient lighting with lower lumens to provide a uniformly lit environment, and secondary task lighting with higher lumens to target specific task areas. In addition, lighting within the module must be able to stimulate crew performance in the absence of natural light. It must also help to recreate day-night cycles to support the crew's circadian rhythms.

Primary lighting of the module is provided by lighting fixtures mounted in the data and communication standoffs. The Garden will have its own lighting system to stimulate plant growth, with lighting fixtures fully integrated with the planting modules.

Lighting is designed to provide both background lighting and task lighting.

INTERIOR ARCHITECTURE: Repair/Storage Module

The Repair/Storage Module serves as a counterweight to balance the rotating vehicle. It also serves as a logistics module supporting the RING missions and providing for the overall maintenance of the RING.

The Repair/Storage Module consists of a pressurized rigid module, with the same elliptical cross section as the Habitation module.

The counterweight module serves as storage and repair facility for the RING.

The upper level will serve as the Storage Facility, storing consumables for the period of 20 months. This include food and water, items for the housekeeping of the Habitation module and for maintaining the Garden. Trash generated throughout the mission will also be stored here. The lower level of the pressurized module will be the Repair and Maintenance Facility. It includes work spaces for repairing larger equipment, and storage for tools and spare parts.

Equipment Hanger

With the expanded capacity of a multiple-RING assembly, unpressurized, external equipment hangers will be provided in-between Repair/Storage modules. In multiples, the equipment hangers and the Repair/Storage modules will match the length of the Habitation Modules on the other side.

Unpressurized Equipment Hangers will be provided in-between the pressurized modules to house mission related equipment.

The hanger will house exploration equipment necessary for the particular mission at hand, such as satellites, probes or landers. If repair work is required, small satellites can be brought into the pressurized module. However, repair of the larger exploratory equipment will require EVA activities in the hanger.

Mission Scenarios

RING and its multiples are designed to accommodate a variety of mission scenarios, especially those involving long-duration space missions where gravity is a necessary condition. Its flexibility allows it to be configured as either a vehicle or a station. In the future it can be equipped with more advanced propulsion systems to travel greater distances and support more complex missions.

RING can accommodate a variety of missions. It can be equipped in the future with more advanced propulsion systems.

Several scenarios for RING emerge: it can be stationed on Earth's orbit or at its Lagrange Points serving as a partial-gravity habitat, an industrial or scientific lab facility, or even as an orbital repair facility. It can help to establish human presence on the Moon, Mars, and in the Jupiter system. Ultimately, RING can be used to assemble a network of habitable stations in space, thereby establishing a transport infrastructure across the Solar System.

A particularly challenging scenario for RING is a mission to the Jupiter System. RING can serve as an orbiting platform from which one conducts scientific research on Europa, other Galilean moons, and Jupiter's magnetosphere. Such a mission can provide insight into the creation of our solar system. It may also allow scientists to determine the ability of Europa's icy oceans to support life.

Ultimately, RING may help establish an interplanetary transport infrastructure.

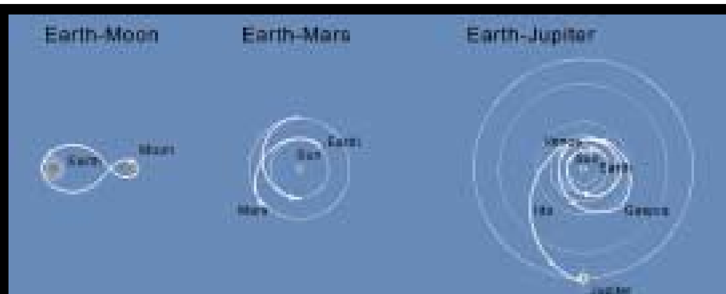
A minimum of two to three RING multiples would be required to support such a complex mission. RING's counterweight modules, including the connecting equipment hangers, could contain all the necessary exploratory equipment for Europa, such as surface landers, drilling gears, probes, rovers, and underwater vehicles. As an orbiting facility, RING can assist in the mapping of Europa's oceans and ice crust, implement studies of the Europa's atmosphere, its surface and sub-surface, and observe Europa's geological processes. A successful RING mission to the Jupiter System will be able to pave the way for subsequent human exploratory missions to other Outer Planets.

A challenging RING mission is the exploration of the Jupiter System. Europa, with its oceans, is the most interesting of Jupiter's satellites.

RING can be used to explore the internal planets and the Jupiter system (photo courtesy of NASA).

RING on Moon orbit

RING as part of a Mars Mission



Collage of images of the Jupiter system (Voyager 1998)
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Courtesy Calvin J. Hamilton

References

Anderson, J.M.; Kerrenbrock, P.A.(1999): “Vorticity Control Unmanned Undersea Vehicle (VCUUV): An Autonomous Robot Tuna”, 11th International Symposium on Unmanned Untethered Submersible Technology, Durham, NH, August 23-25, 1999

Capps, Stephen D. (1988): “Volumetric Study for Habitat Design in a Partial Gravity Environment”, Report for NASA/ Universities Space Research Association/University Advanced Design Program.

Chen, M.; Galvez, E.; Pinni, M.; Pognant, P. (2004): “RING: Rotationally INduced Gravity Vehicle with Elliptical Pressurized Modules”, 9th ASCE Aerospace Division International Conference on Engineering, Construction, and Operation in Challenging Environments, Houston, 7-10 March, 2004.

Diaz, C.; Franklin, R.; others (2000): “The Physics and Engineering of the VASIMR Engine”, AIAA-2000-3756.

Hall, Theodore W. (1999 July): “Artificial Gravity and the Architecture of Orbital Habitats”, Journal of the British Interplanetary Society, vol. 52, no. 7-8, p. 290-300. London, England, UK: British Interplanetary Society.

Hall, Theodore W. (2002 July): “Architectural Considerations for a Minimum Mass, Minimum Energy, Artificial Gravity Environment”, (SAE 2002-01-2431), 32nd International Conference on Environmental Systems (ICES), San Antonio, Texas, USA, 15-18 July 2002. Warrendale, Pennsylvania, USA: Society of Automotive Engineers.

Hall, Theodore W. (2002). “Artificial Gravity.” http://www0.arch.cuhk.edu.hk/~hall/ag/

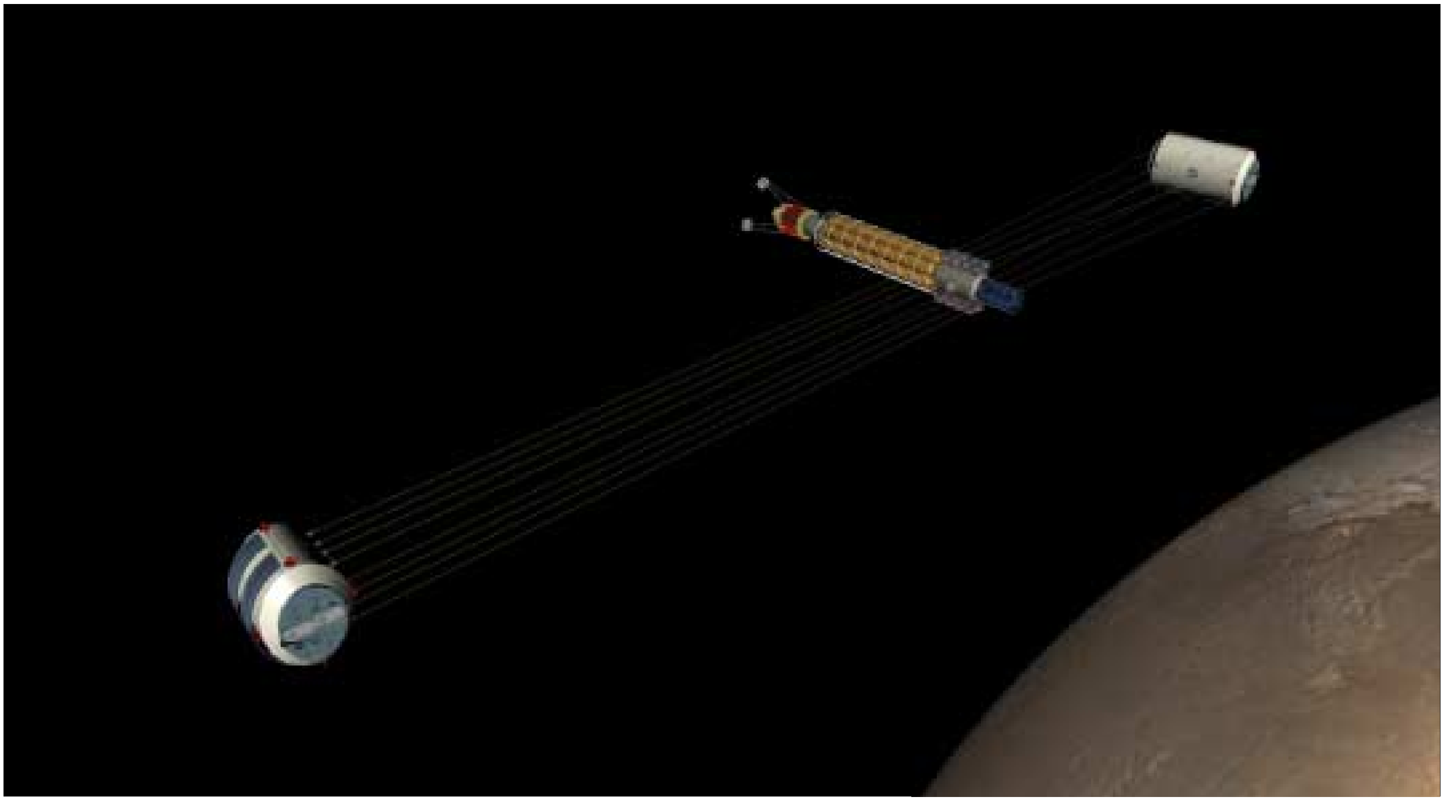
Hoytether: http://www.tethers.com/Hoytether.html

Larson, Wiley J.; Pranke, Linda K. (1999): “Human Spaceflight: Mission Analysis and Design” (Space Technology Series) McGraw-Hill Primis Custom Publishing; October 26, 1999.

McMurray, J.; Hyer, M.W. (1999): “Influence of material Orthotropy on the Response of Elliptical Composite Cylinders to Internal Pressure”, Master’s thesis, Virginia Polytechnic Institute and State University, Department of Engineering Science and Mechanics.

SICSA brochure: “The Artificial Gravity Science & Excursion vehicle (AGSEV)”, July, 2001.

SICSA brochure: “The first Mars Outpost: Planning & Concepts”, July, 2002.



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