Commercial Space Development Plan

SICSA
Sasakawa International Center for Space Architecture
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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 central goal of this activity to conceptualize a scenario of private enterprise initiatives that can carry humankind forward to Mars. Each development stage is planned as a "building block" to provide the economic foundation, technological advancements, and operational infrastructure to support others that follow.

The concepts presented in this report illustrate and briefly describe summary aspects of much more detailed SICSA proposals that were produced over a two year period. The "Artificial Gravity Science and Excursion Vehicle" (AGSEV) work segment occurred during the 1999-2000 academic year, and the low-Earth Orbit (LEO) planning and design effort followed in 2000-2001. All of this work was undertaken by fourth year, fifth year, and graduate students in the SICSA program within the Gerald D. Hines College of Architecture, under the supervision of SICSA's Director, Professor Larry Bell. These contributors are:

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A Comprehensive Long-range Approach

SICSA's development scenario encompasses materials processing, tourism, and ultimately, Mars missions and settlements.

The Sasakawa International Center for Space Architecture is addressing opportunities for commercial development of space through staged revenue-producing initiatives that can be financed primarily or exclusively by the private sector. SICSA's plan entails a coordinated sequence of initiatives within a comprehensive long-range program. It commences with small scale facilities for man-tended operations in low-Earth orbit (LEO); evolves to support sustainable space tourism; and ultimately creates an infrastructure of service accommodations, spacecraft and habitats to realize lunar/Mars missions and settlements.

Space development offers expansive potentials that can be realized through a staged approach.

Space commerce, driven by scientific and technological advancements that could not have been predicted even a few decades ago, is already impacting many aspects of our personal, institutional and business lives. Satellite telecommunications companies, supported by commercial launch operations, connect people together globally, offer access to limitless information sources, and comprise large growth industries. It is reasonable to expect that space business applications and benefits will continue to expand as a natural condition and consequence of human progress.

New technological advancements can be incorporated into the plan as they occur.

Prospects for commercial space development will be greatly facilitated by advancements in propulsion technologies and spacecraft designs that can significantly reduce transportation costs. Until more efficient launch systems are forthcoming, this plan baselines operating characteristics and payload capacities associated with the US Space Shuttle and Russian Proton launcher. Improved alternatives can be incorporated into the plan when available. SICSA is supporting the development of new launch technologies through parallel planning and design of commercial ground-based spaceport facilities for reusable launch vehicles (RLV's) in cooperation with the Texas Aerospace Commission and other organizations.

Program Goals

Space manufacturing.

Expanded means to transport groups to and from orbit, to support diversified orbital operations, and to carry people and cargo to the Moon and Mars.

Earth observations, movie production, and space tourism.

Construction and servicing of large space systems.

Segments & Elements	Program Stages					
	A	B	C	D	E	F
Segment 1	**Materials Processing in Space (MPS)**					
Industrial Space Facility (ISF)	Man-Tended Operations	Habitat & Lab Additions	Tether Glass Production	Commercial Expansion	Commercial Expansion	Commercial Expansion
Segment 2	**Space Transportation Systems (STS)**					
Orbital Transfer Vehicle (OTV)	Development & Testing	Operational Status	ISF-SOC Transfers	CSF-SOC Transfers	Maintenance Platform	Maintenance Platform
Emergency Return Vehicle (ERV)	Soyuz Upgrade	Operational Status	ISF-SOC Crew Return	CSF Crew Return	Fleet Expansion	Fleet Expansion
Shuttle Orbiter Passenger Pod (SOPP)	Design & Engineering	Development & Testing	Operational Status	Safe Haven Use	Fleet Expansion	Fleet Expansion
A.G. Science & Excurs. Vehicle (AGSEV)	Design & Engineering	Element Development	Orbital Assembly	Vehicle Testing	Lunar Rendezvous	Mars Rendezvous
Planetary Surface Systems		Design & Engineering	Design & Engineering	Lander Development	Lander Deployment	Surface Missions
Segment 3	**Space Operations Center (SOC)**					
Space Media Laboratory (SML)	Man-Tended Operations	Transhab Addition	Crew Training Application	Tourism Application	Mission Support	Mission Support
Hotel, Crew Base & Terminal	Design & Engineering	Development & Testing	Fully Manned Status	Assembly Completion	Transfer Terminal	Command Center
Segment 4	**Construction & Servicing Facility (CSF)**					
Const./Maint. Platform & Fuel Depot	Design & Engineering	Development & Testing	Man-Tended Operations	Fueling Capability	AGSEV Servicing	General Servicing
Crew Habitat & Maint. Laboratories		Design & Engineering	Development & Testing	Fully Manned Status	Crew Ops. Support	Crew Ops. Support

The Industrial Space Facility (ISF)

Space processing of materials can provide valuable products for use on Earth, in orbit, and beyond.

SICSA's proposed Industrial Space Facility will offer the earliest source of substantial business revenues by enabling the processing of extremely high value materials under the unique microgravity and vacuum conditions that characterize this environment. A large variety of Materials Processing in Space (MPS) experiments which have been conducted during the US Skylab Program (1969-1973), onboard the Russian Mir space station, and within the Spacehab laboratory (which has flown on the Space Shuttle), have all demonstrated the validity of these opportunities.

One of the most important near-term products may be knowledge about new ways to improve industrial processes on Earth.

The physical sizes and quantities of materials to be processed in orbit will be tiny compared with commercial production scales that characterize conventional industries. Only extremely precious substances, perhaps valued at millions of dollars per ounce, will offer the added revenue benefits necessary to offset enormous transportation and operations costs presently associated with space programs. In many cases, the most lucrative products will probably take the form of lessons from research experiments that can be applied to improve materials production on Earth. Examples include better understanding of ways to develop new and improved metal alloys, high quality exotic glasses for advanced optical devices, and ultra-pure hormonal extracts and other pharmaceuticals for expedient US Food and Drug Administration testing and approvals that will enable those products to rapidly enter the marketplace.

MPS will require a dedicated facility and reliable access to space.

Capitalizing on these opportunities will require that MPS facilities be continuously available to enable corporate users to sustain active programs. Implementation of a privately financed and operated ISF will respond to this need. Rapid, reliable, frequent, and efficient means of space transportation will also be essential to the success of commercial MPS programs.

Industrial Space Facility Lab

Representative MPS Processes and Products

- **Pharmaceutical Purification;** "Electrophoresis", a process to purify biological materials, is degraded by thermal convection. Microgravity processing avoids this problem.
- **Containerless Processing;** Molten materials can avoid touching walls of containers that introduce contaminants. Production of ultra-pure glasses and metals is possible.
- **New Alloys;** Sedimentation and buoyancy are absent in micro-gravity. Substances with different densities can fuse in solution.
- **Crystal Growth;** Very large, flawless protein and semiconductor crystals can be grown for Earth and space uses.

Microgravity Benefits: *Under "weightless" conditions, important effects of gravity upon physical processes are cancelled out.*

Advantages of the Space Environment

Vacuum Benefits: *Space offers an unlimited vacuum environment for a variety of laboratory experiments and production processes.*

- **Molecular Deposition Films;** A "Molecular Beam Epitaxy" (MBE) process which relies upon a high vacuum, can take advantage of the space environment to produce precious thin film materials for special applications.
- **Anhydrous Glass;** While glass is intrinsically one of the strongest known materials, its strength on Earth is severely degraded by atmospheric moisture. Such exposure hydrolyzes the silicon-oxygen bond with a hydrogen-bonded bridge that weakens the atomic network. Super-strength glasses (potential tensile strength of 2 million psi) are proposed to be produced on the ISF in space vacuum to create tethers for SICSA's AGSEV.

ISF Features and Operations

The Industrial Space Facility is a modular, pressurized materials research and processing laboratory that operates in LEO, approximately 300-500 nautical miles above the Earth's surface. It will provide a work space with accommodations for a variety of processing equipment and associated hardware and software systems, along with ample power and cooling capacities to support high MPS demands. At a mature stage, it will afford basic living quarters and environmental control systems to support a small crew of 4-6 technicians.

Operations can begin in an automated mode when the first Lab Module is in place.

The ISF is designed to generate early revenues in a "man-tended" operations mode immediately after the first Laboratory Module is put into operational status. During a typical mission sequence, the Space Shuttle Orbiter docks with the ISF and provides necessary living quarters and life support systems to sustain crew activities while the technicians resupply process materials, harvest finished products, maintain and replace equipment, and initiate new process operations. The crew then returns to Earth in the Shuttle Orbiter, leaving the ISF to function in an automated mode until the next visitation when this sequence is repeated.

Adding a Habitat Module will enable continuously manned operations.

The ISF's modular design provides for eventual incorporation of a Habitat Module and airlock that will enable continuously "manned" operations. At this stage, a Shuttle Orbiter or an Emergency Return Vehicle (ERV) will remain docked with the ISF as a vital safety feature. Additional Laboratory Modules can be attached, as needed, each providing additional power and cooling capacity.

Other modules can expand capabilities.

Logistics Modules will be provided to carry equipment, MPS materials, and crew consumables to the ISF, and to return products and wastes back to Earth. They will also serve as supplementary on-orbit stowage warehouses.

Emergency Return Vehicles (ERVs)

ERVs will serve as "lifeboats" to enable rapid evacuations of crews.

Emergency Return Vehicles must be made available to enable orbiting crews to rapidly return to Earth between scheduled Space Shuttle visits in the event that their spacecraft becomes endangered or dysfunctional, or when a medical emergency requires immediate evacuation and treatment. Such contingencies must be addressed by the time when the Industrial Space Facility commences operations in a continuously manned autonomous mode.

Modification of the Russian Soyuz vehicle can minimize new development costs.

To minimize new research and development requirements, time lines, and fabrication costs, SICSA proposes an ERV design that enlarges the Soyuz capsule that has been extensively used to support Russian Space Program missions. The SICSA version would expand the passenger capacity of this vehicle from four to six, but would retain its general configuration.

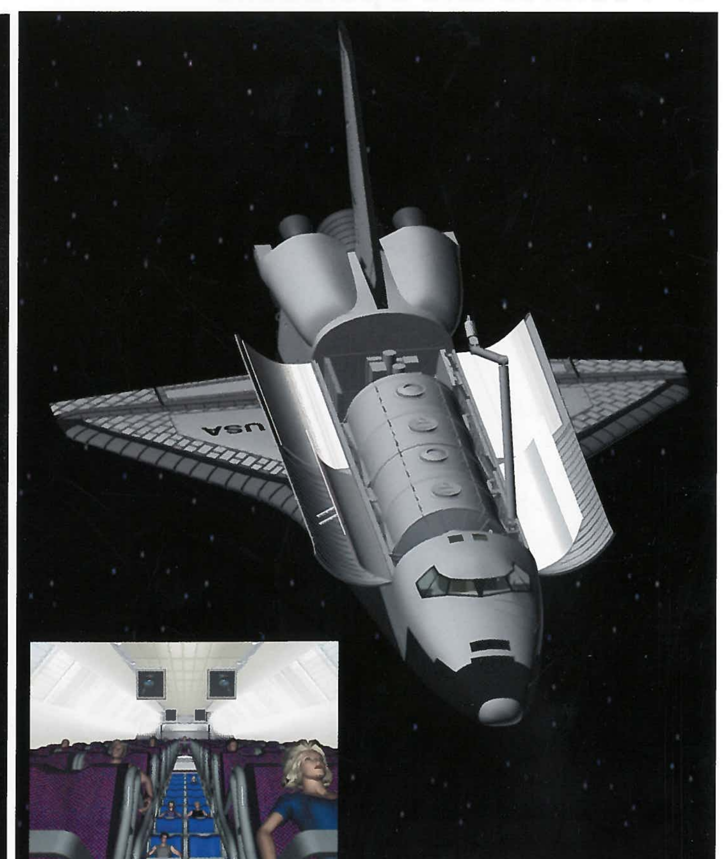
Shuttle Orbiter Passenger Pods (SOPPs)

SICSA's SOPP design enables the Shuttle Orbiter to carry up to 100 passengers to and from LEO.

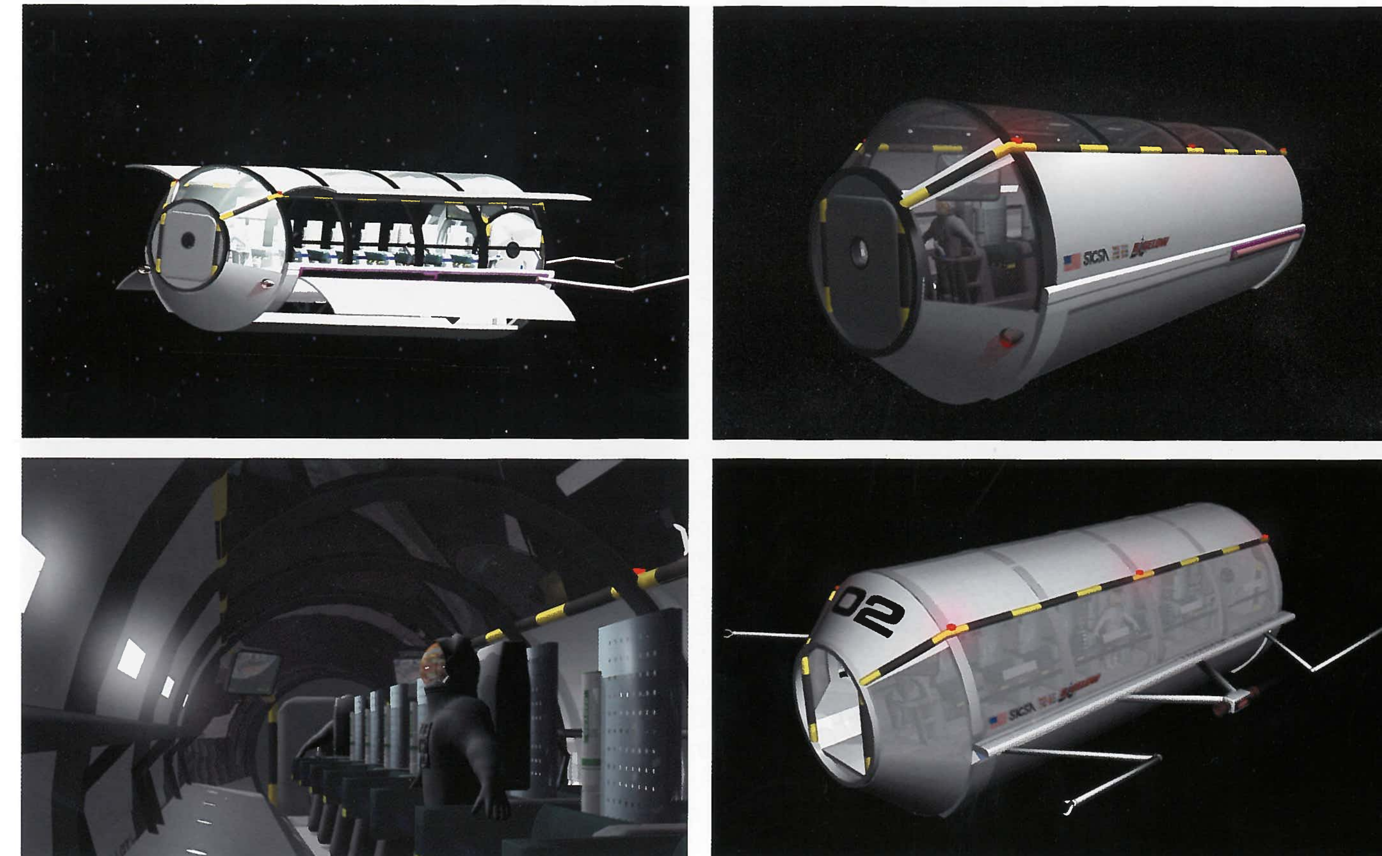
Future space tourism on a profitable scale will require expanded means to transfer significant numbers of passengers and huge amounts of logistic support materials to and from orbit on a frequent, reliable and reasonably cost-effective basis. Since the US Space Shuttle presently offers the only option for both delivering and returning relatively large payloads, SICSA's plan proposes that special pressurized pods with accommodations for 100 passengers and crew members be developed to be carried to space and back in the Shuttle Orbiter's payload bay.

The Shuttle Orbiter Passenger Pods will mate with docking ports on a proposed Space Operations Center (SOC). This will enable "shirt sleeve" transfers of personnel between the two pressurized environments.

Emergency Return Vehicle



Shuttle Orbiter Passenger Pod



Orbital Transfer Vehicles

Orbital Transfer Vehicles (OTVs)

OTVs will carry passengers and cargo between LEO facilities, and also serve as mobile servicing platforms.

Orbital Transfer Vehicles will be provided to transport people, equipment and materials between the various co-orbiting spacecraft. These interchanges will initially occur between the continuously manned ISF and the Space Operations Center. Later, they will link the SOC with a proposed Construction and Servicing Facility (CSF). A key OTV role at this stage will be to serve as a "space tug" to tow the large propulsion segment of a proposed Artificial Gravity Science and Rendezvous Vehicle (AGSEV) back and forth between the SOC and CSF for maintenance and refueling operations between lunar/planetary missions.

The unpressurized vehicles will provide supplementary life support supplies for EVA passengers.

SICSA's OTV concept is an "open cockpit" non-pressurized vehicle that is designed to optimize versatility, simplicity and cost minimization. Each vehicle can perform multiple functions: ferrying space-suited passengers between the co-orbiting facilities; transporting large equipment items and attached payload capsules; serving as a work platform to secure and manipulate structures and components during on-orbit spacecraft assembly and maintenance operations; and performing a variety of spacecraft checkout, extra-vehicular activity (EVA) monitoring, and numerous other support roles.

Operations can either be piloted onboard or controlled through teleoperated guidance.

The OTVs are conceived to operate with dual manual and remote control systems. Manual controls are similar to those currently used for US and Russian Manned Maneuvering Units (MMUs) which can be manipulated by astronauts with pressurized suits and gloves which severely limit dexterity. Vehicles would incorporate "plug-in" life support supplies and controls for the suited passengers. OTV guidance and operations involving such devices as attached remote manipulator systems and video cameras could alternatively be controllable from command stations incorporated into all orbiting facilities.

The Space Media Laboratory (SML)

The SML will be the first element of a Space Operations Center.

"Inflatable" flexible wall construction will enable the 40 ft. diameter module to be launched in the Orbiter's 15 ft. diameter payload bay.

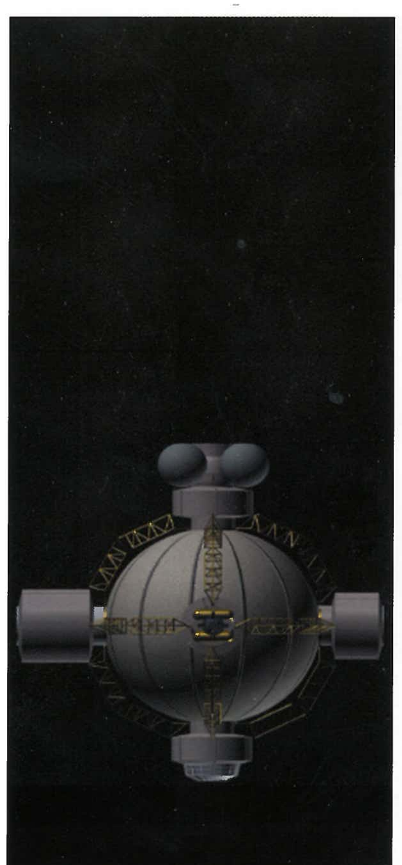
Various layers of the laminated wall will offer durability in the space environment, thermal insulation, and interior fire resistance.

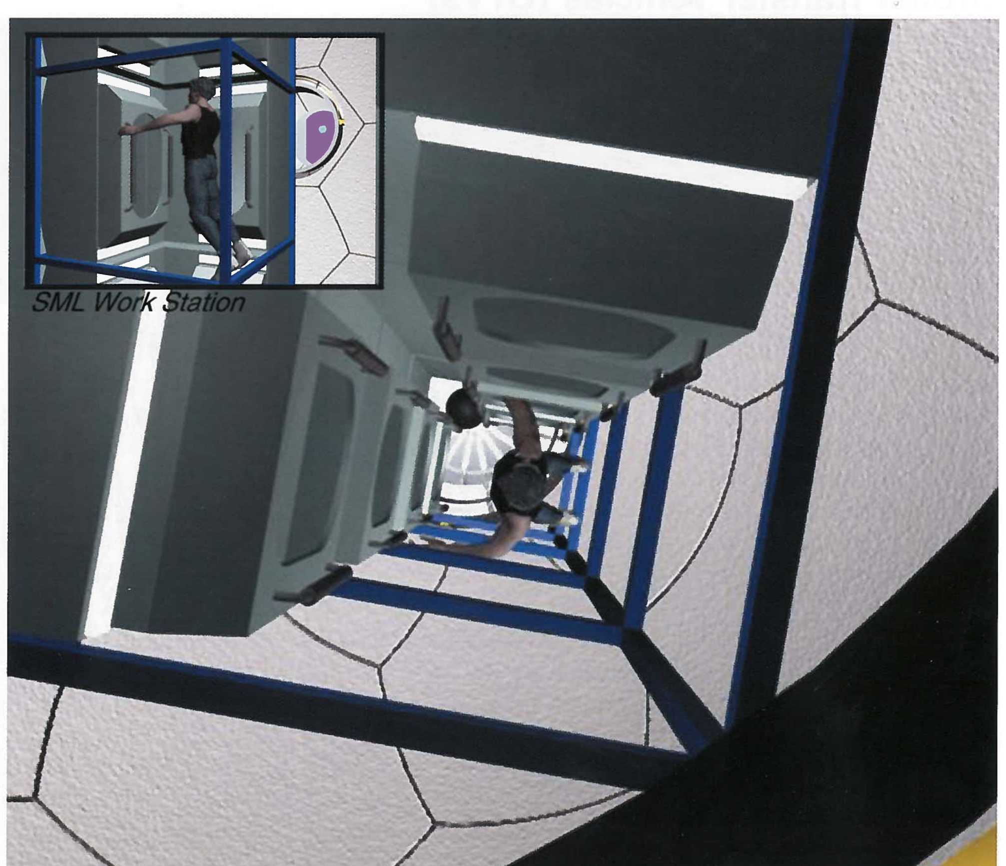
SICSA's proposed Space Media Laboratory responds to commercial business opportunities advocated by several advertising communications and educational organizations that desire to establish film and video studios in space. Prospective markets include:

- Motion picture and TV program producers who wish to portray realistic weightless action sequences.
- News and scientific organizations who desire a vantage point in space to observe weather conditions, environmental changes and other features on Earth.
- Companies that wish to sponsor and stage special promotional events in space to publicize their organizations and products.

The SML is comprised of one large 40 ft. diameter inflatable module and four attached "hard" elements. The hard elements include a viewing cupola; an EVA/OTV airlock; a berthing fixture for evolutionary SOC expansion; and a docking port for Shuttle Orbiters and other spacecraft.

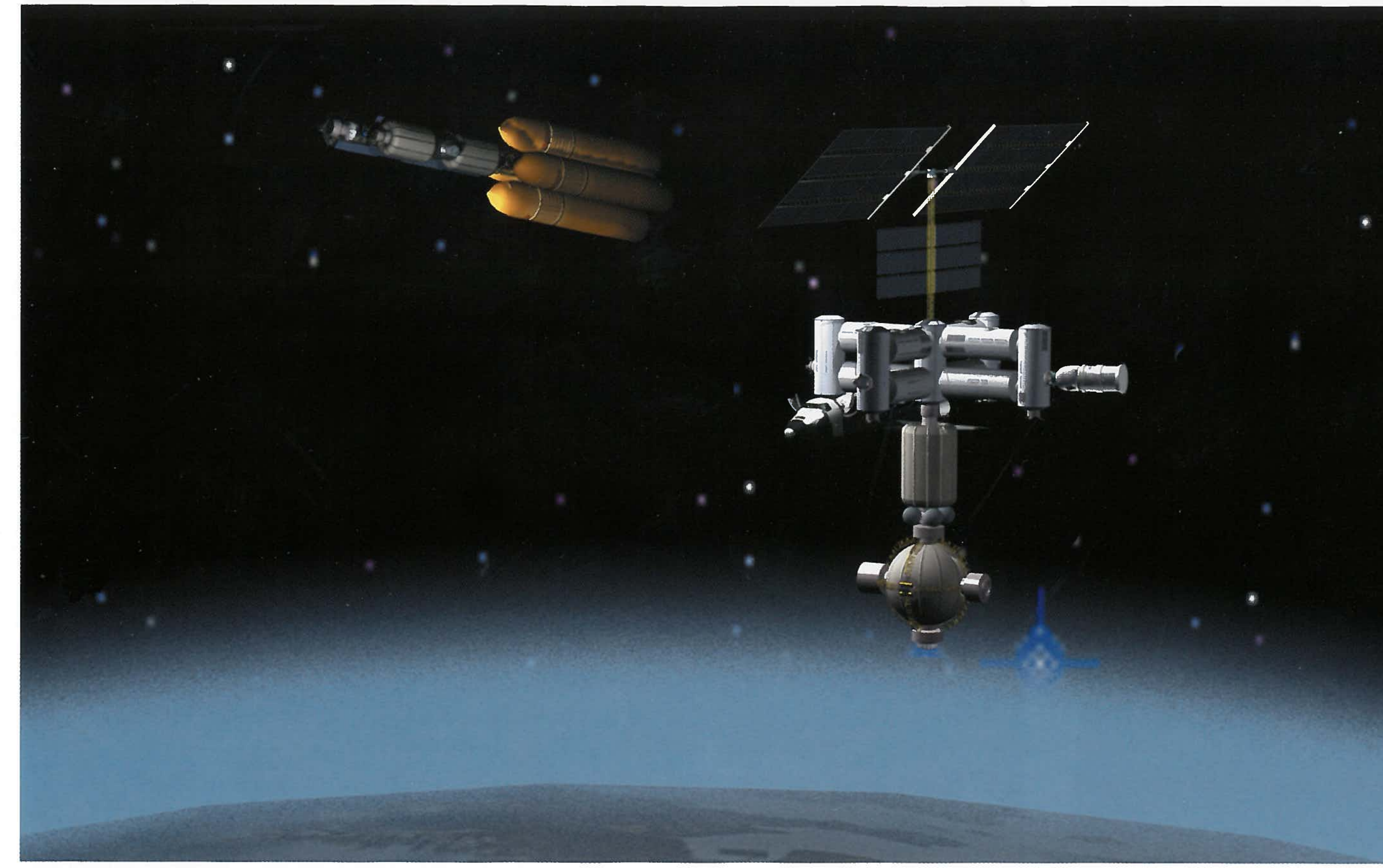
Initial SML operations will be restricted to a man-tended mode, occurring only when an Orbiter is present to provide power to the facility, basic living accommodations for the crew, and constant access to Earth return opportunities. As SOC evolution continues to add other modules and accommodations, the SML will support these expanded functions as part of a permanently manned and autonomous facility for weightless recreation and for crew maintenance task training.





SML Work Station

SML Interior



The SOC Space Hotel and Crew Base

Budget Suites of America (BSA) and other hotel corporations have expressed interest in pursuing space tourism.

Other modular elements will be added to the Space Media Laboratory before continuously manned operations are possible. At minimum, these will include a Transhab Module, a Berthing Module, and a Power System. When complete, the mature complex will accommodate approximately 100 people, including about 75 paying tourists and about 25 crew personnel. Onboard tourist stay time is estimated to be about two weeks or less, while crews will be in rotation cycles that may last many months.

During early stages of operation, the facility will primarily serve lodging, education, training, and recreation functions that extend use of the SML's open volume for tourist activities. The facility will also act as a "rest and recuperation center" for crews on the co-orbiting Industrial Space Facility and Construction and Servicing Facility that lack comparable amenities.

The SOC Test Lab, Transfer Terminal and Command Center

SICSA's commercial space development planning has been supported by a financial gift provided by BSA's owner, Robert Bigelow.

As the commercial space development program matures, the Space Hotel and Crew Base will take on additional roles to support lunar/planetary rendezvous, exploration and surface settlement missions. These ambitious initiatives will utilize the Artificial Gravity Science and Excursion Vehicle to transfer people, equipment and supplies between LEO and lunar or Mars orbits.

The Space Hotel and Crew Base will support AGSEV construction, testing and operations in vital ways. Key roles will be first to serve as an orbiting Science and Engineering Test Laboratory, then as an AGSEV Transfer Terminal, and ultimately as an Orbital Command Center for all activities in LEO and beyond.

The Transhab Module

SICSA's Transhab design modifies an inflatable concept developed by NASA.

As the evolution to a permanently occupied Space Hotel and Crew Base progresses, a second inflatable module that is based upon a NASA "Transhab" design will be attached to the Space Media Laboratory. This 27 ft. diameter by 40 ft. long element will house a galley and wardroom area for dining and general assembly. It will accommodate about 50 people at one time after the SOC is fully operational.

Orientation of the floor plane along the long axis optimizes usable volume.

In addition to dining, the wardroom area will also serve as a place for recreation and various other group events. Special foot restraints designed by SICSA are provided to anchor people so that they do not float away under weightless conditions. Similarly, dining trays that attach to deployable tables are designed to secure food containers in place.

Substantial stowage capacity is provided.

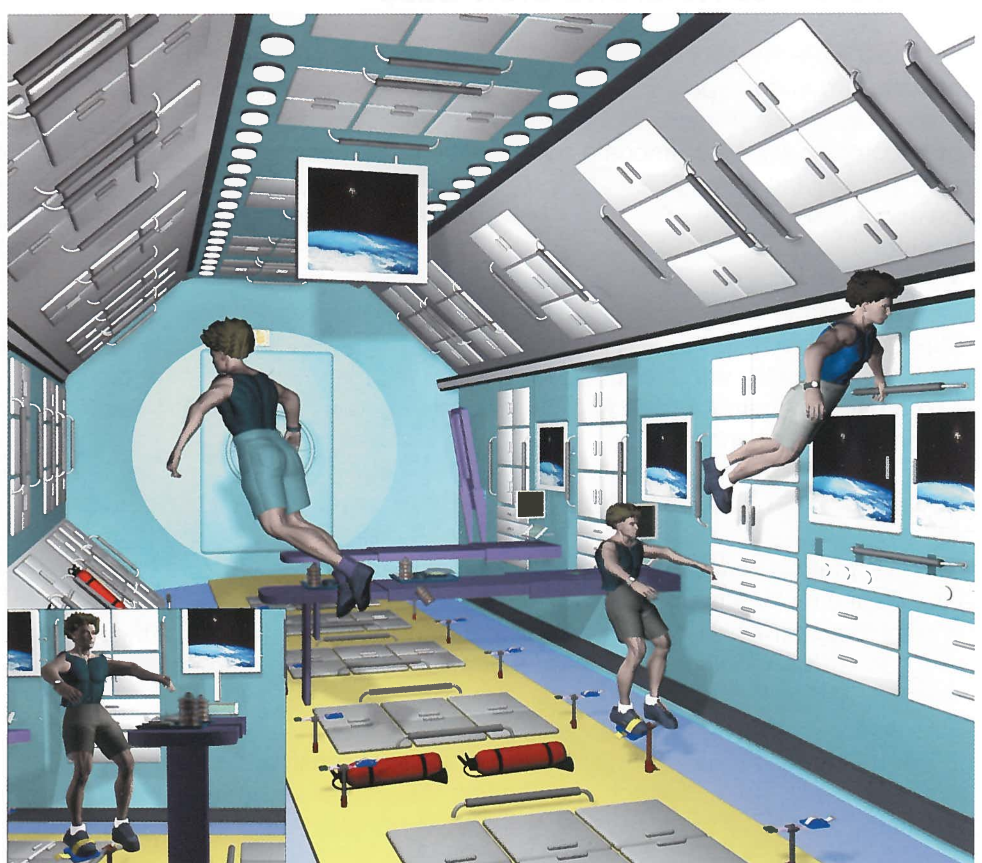
The galley area will incorporate stowage areas and equipment for consumables, including water supplies and treatment systems, refrigeration units, and trash management facilities. It will also provide work areas and equipment for food preparation.

Food preparation and cleanup must be simplified.

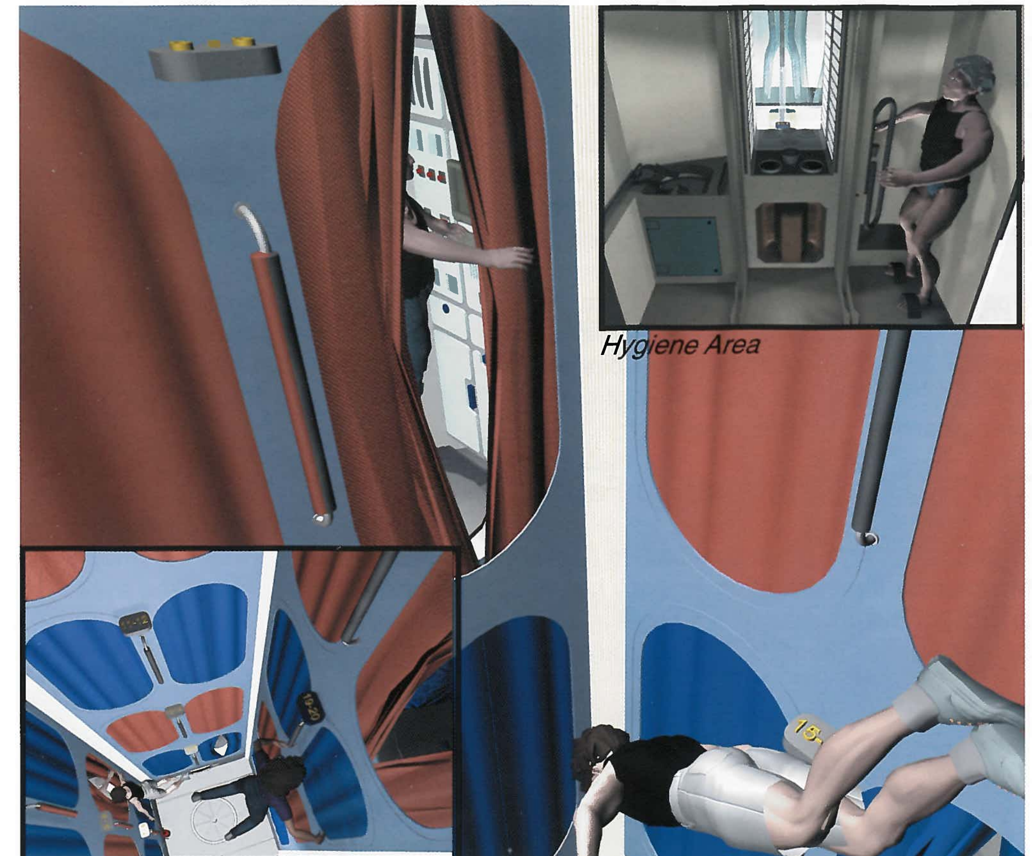
Since the cooking staff will be very limited, there will be a heavy reliance on menus that can be prepared quickly and easily. Microwave ovens will be used for heating because convection devices will not function in microgravity. Most probably, disposable plates will be utilized to minimize water consumption associated with dish and utensil washing, although this will add to trash management requirements.

Recycling of all water is essential.

Gray water and atmospheric humidity produced by human respiration and perspiration will be collected, purified, and recycled. This is essential to minimize the water mass that must be transported at great expense to orbit.

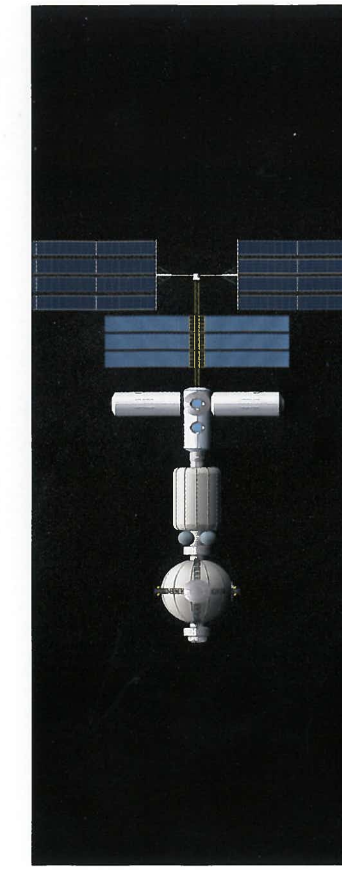


Galley Area



Hygiene Area

Bedroom Module



The Berthing Module and Power System

Attachment of these elements will complete the first fully operational stage of SOC development.

A Berthing Module and a Power System must be added to the SML and Transhab Module assembly before the SOC can operate in an autonomous service mode. The standard 15 ft. diameter, 40 ft. long aluminum alloy Berthing Module attaches to the upper end of the Transhab Module. Two sets of berthing ports located at 90 degree increments on four sides offer future attachment points for other modules. The Berthing Module will ultimately serve as a central passageway for people, supplies and equipment, and will also function as the primary utility corridor. In addition, the module will contain the SOC's command center and maintenance facility for onboard repairs. A photovoltaic Power System attached to the upper end will supply electrical energy and incorporate radiators to remove heat.

The Bedroom Modules

Sleeping bags attached to walls secure occupants in place.

Four standard hard modules, each providing personal quarters and shared bathroom accommodations for 25 people, are attached to the Berthing Module (one at each of four sides). These Bedroom Modules provide the only entirely private places onboard the SOC where individuals who wish to spend some time alone can quietly pursue personal leisure activities.

Special toilets and hygiene facilities are required under weightless conditions.

Toilets are specifically designed to function without water or gravity flush. Directed airflows assist defecation processes, and fecal materials are dried, compressed and sealed for contamination control. Body-fitted male and female urinal receptacles prevent leakage of fluids into surrounding interior areas. Similarly, closed handwash devices with arm cuffs prevent spillage during routine hygiene activities. Wet wipes will be used as an alternative to showers for bathing in the interest of reducing water consumption and purification requirements for recycling.

The Group Assembly Modules

Four pairs of Bedroom/ Group Assembly Modules enable occupants of each to have different sleep-activity schedules.

Four standard modules attached to the Berthing Module immediately below the Bedroom Modules provide "living rooms" for each 25 person quadrant. Hotel residents will probably spend much of their active time in these areas, where they can engage in various educational, social and recreational pursuits. While relatively compact and confining in comparison with conventional lodging standards on Earth, these group activity volumes are very generous relative to the provisions that will be afforded aboard the International Space Station.

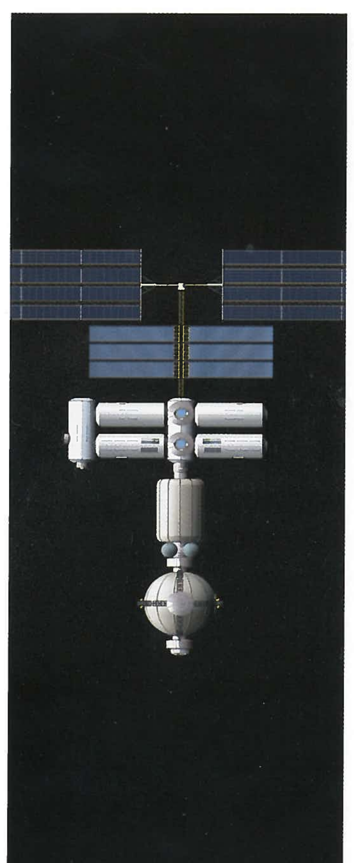
Opportunities to view the Earth have proven to be the preferred primary recreation for astronauts and cosmonauts. Direct Earth viewing is optimized by two relatively large 30 inch diameter viewpoints located in each Group Assembly Module. The overall number of viewpoints throughout the SOC is limited to minimize weight and maintenance.

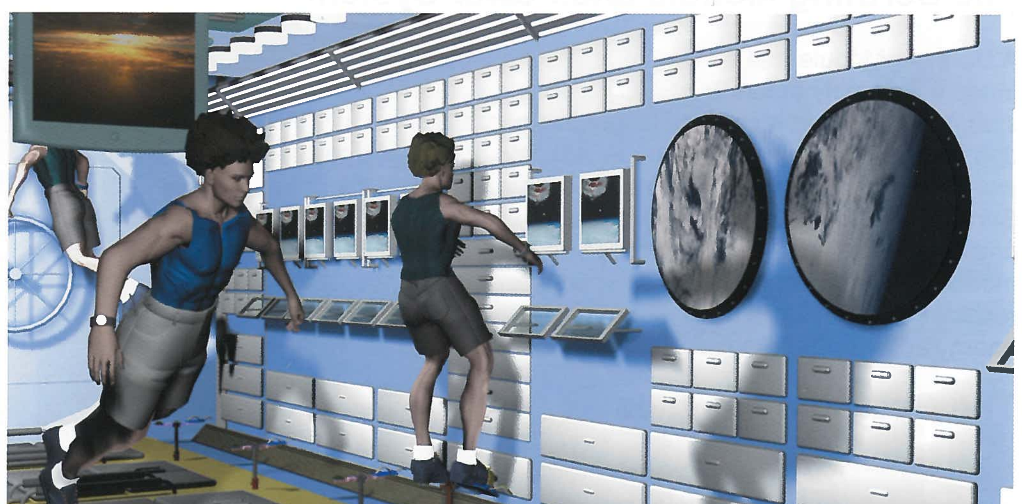
The Health Maintenance Facility (HMF)

Health monitoring, preventative medicine, and routine/emergency treatment are provided.

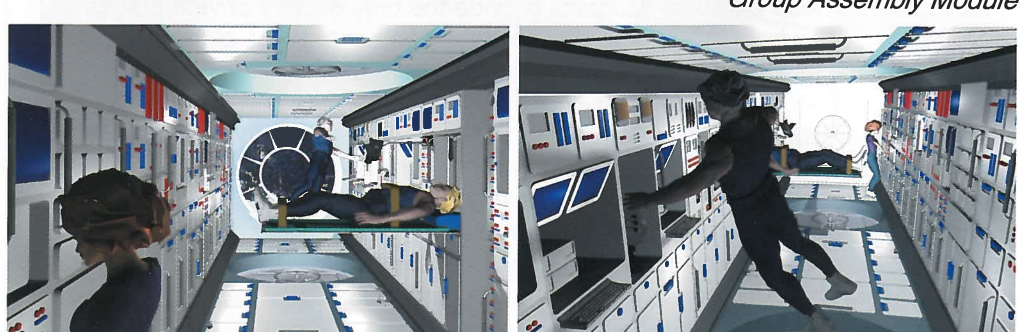
A dedicated module will be attached to one set of Bedroom and Group Assembly Modules for routine and emergency health care needs. Medical staff will be available to monitor the physical and psychological condition of commercial SOC clients and crew members, diagnose illnesses and injuries, and respond to basic remedial needs.

Since staff and resources will be limited, individuals requiring complex surgical interventions will be prepared for rapid return to Earth via an ERV or Shuttle Orbiter which will dock directly with the module. Simpler procedures, such as abscessed tooth extractions and treatment for abrasions and lacerations, will be conducted onboard.

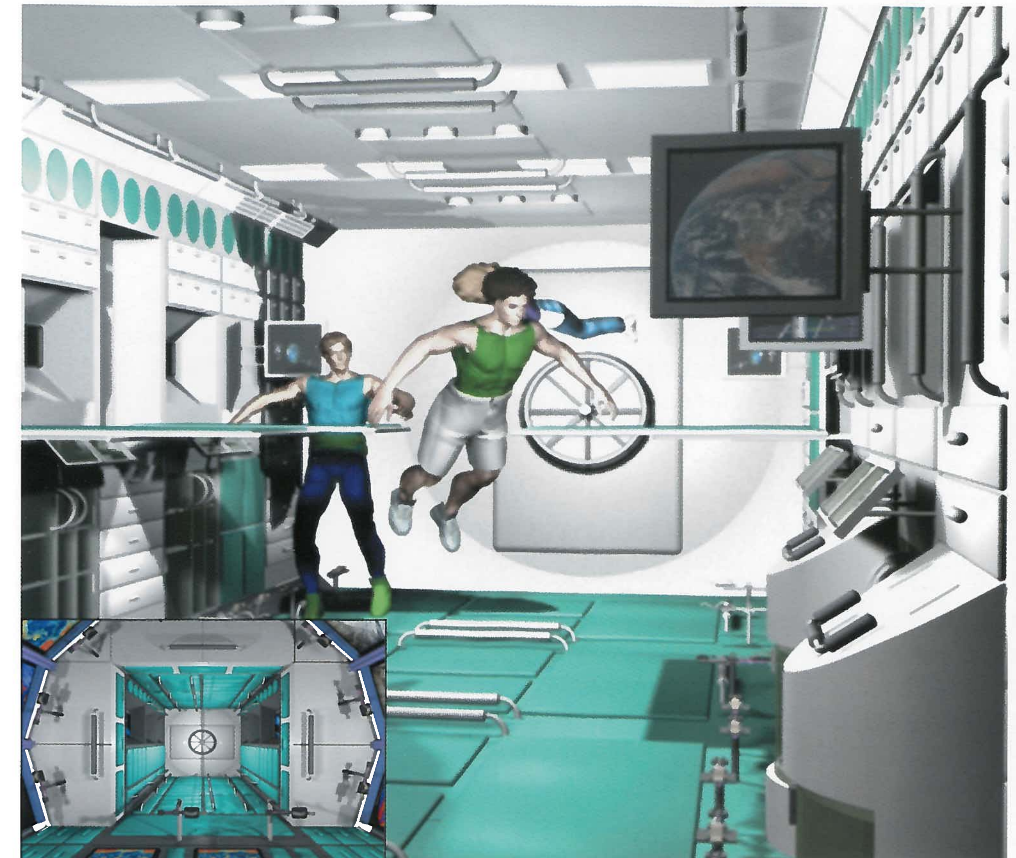


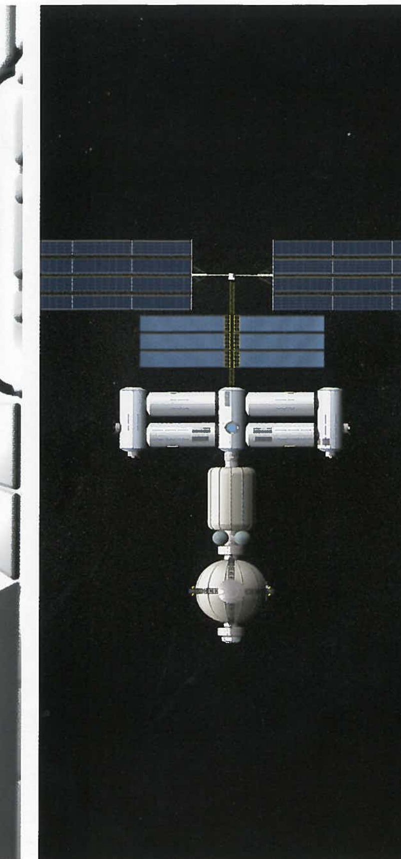


Group Assembly Module



Health Maintenance Facility





Logistics Module *Science and Engineering Test Lab*

The Logistics Modules

SOC and AGSEV operations will require means to replenish and store substantial quantities of food and other supplies.

A large volume and variety of replacement parts and supplies must be made immediately available to maintain SOC operations at mature stages of development and operations. Space hotel functions alone will impose large logistics demands, and support for the Artificial Gravity Science and Excursion Vehicle missions beyond Earth orbit will produce a multiplying effect.

Two standard Logistics Modules, each providing docking ports for an AGSEV and for Shuttle Orbiters, will be attached to paired Bedroom and Group Assembly Modules to accommodate on-orbit logistics stowage. The modules will also serve as important auxiliary passageways between the Bedroom and Group Assembly modules to offer "dual egress" benefits in the event that rapid evacuation should become necessary under emergency conditions.

The Science and Engineering Test Laboratory Module

A dedicated facility for on-orbit research and technology support will complete the SOC configuration. This laboratory module will provide scientific instruments, computing systems and diagnostic equipment to undertake a wide variety of technical tasks.

Advanced SOC activities will include space research and equipment tests for planetary missions.

Scientific support roles will include analyses of impacts of the space environment upon materials processing and biological functions. Engineering and test roles will include monitoring and performance verification of hardware and software systems and electro-mechanical devices that must be proven effective and reliable prior to being put into service for spacecraft operations. Such functions will be vital in readying the AGSEV for lunar/planetary voyages.

The Artificial Gravity Science and Excursion Vehicle (AGSEV)

Fuel budgets for the Moon and Mars are about the same.

SICSA's proposed Artificial Gravity Science and Excursion Vehicle (AGSEV) will enable human voyages to the Moon and Mars. Lunar round-trip excursions would be about 9 days in duration. Mars expeditions will be much longer, but would expend approximately the same amount of propulsive fuel.

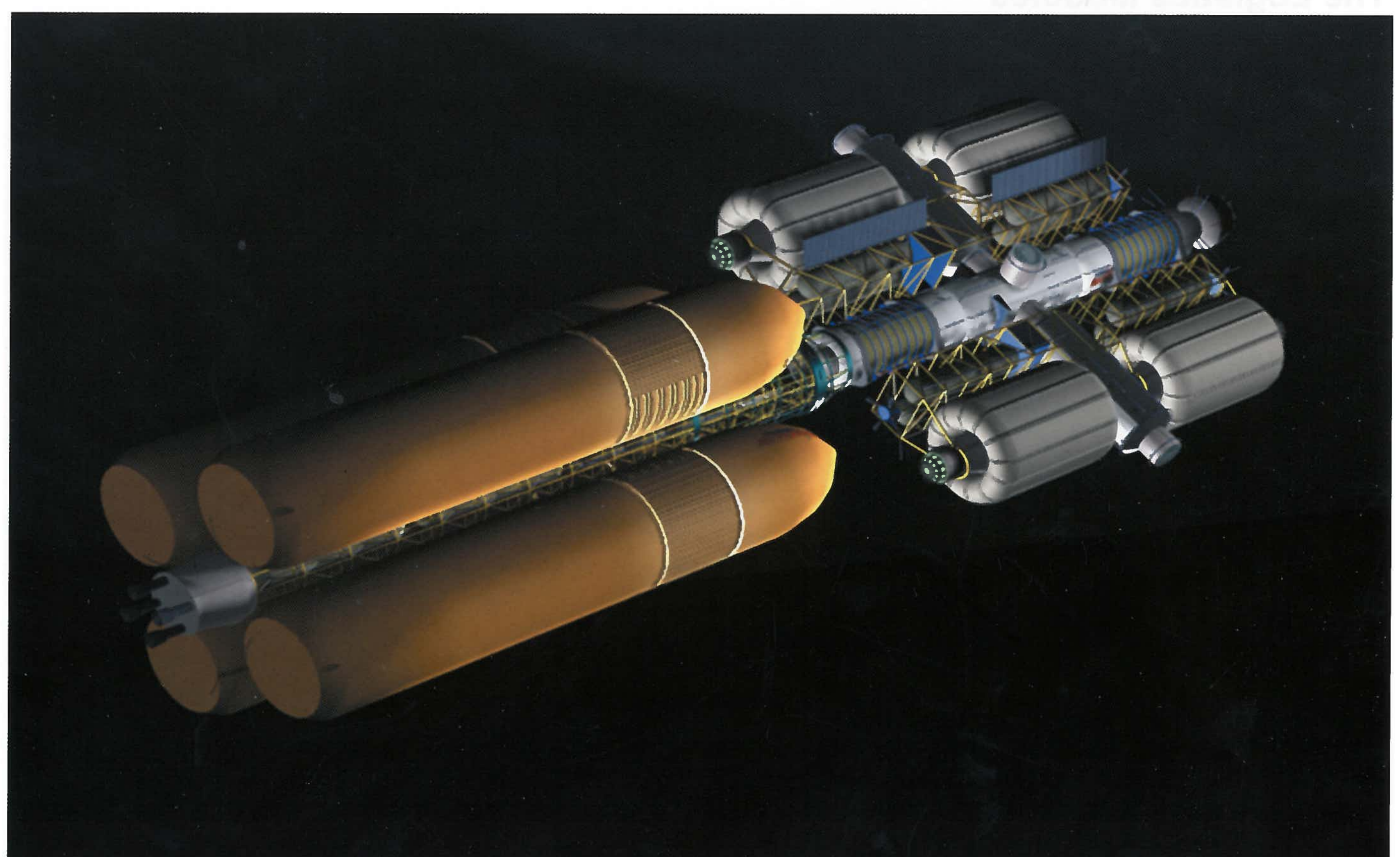
The time requirements for missions to Mars will depend upon the position of the planet relative to Earth when the spacecraft is scheduled to depart and arrive, and upon the trajectory route that is selected:

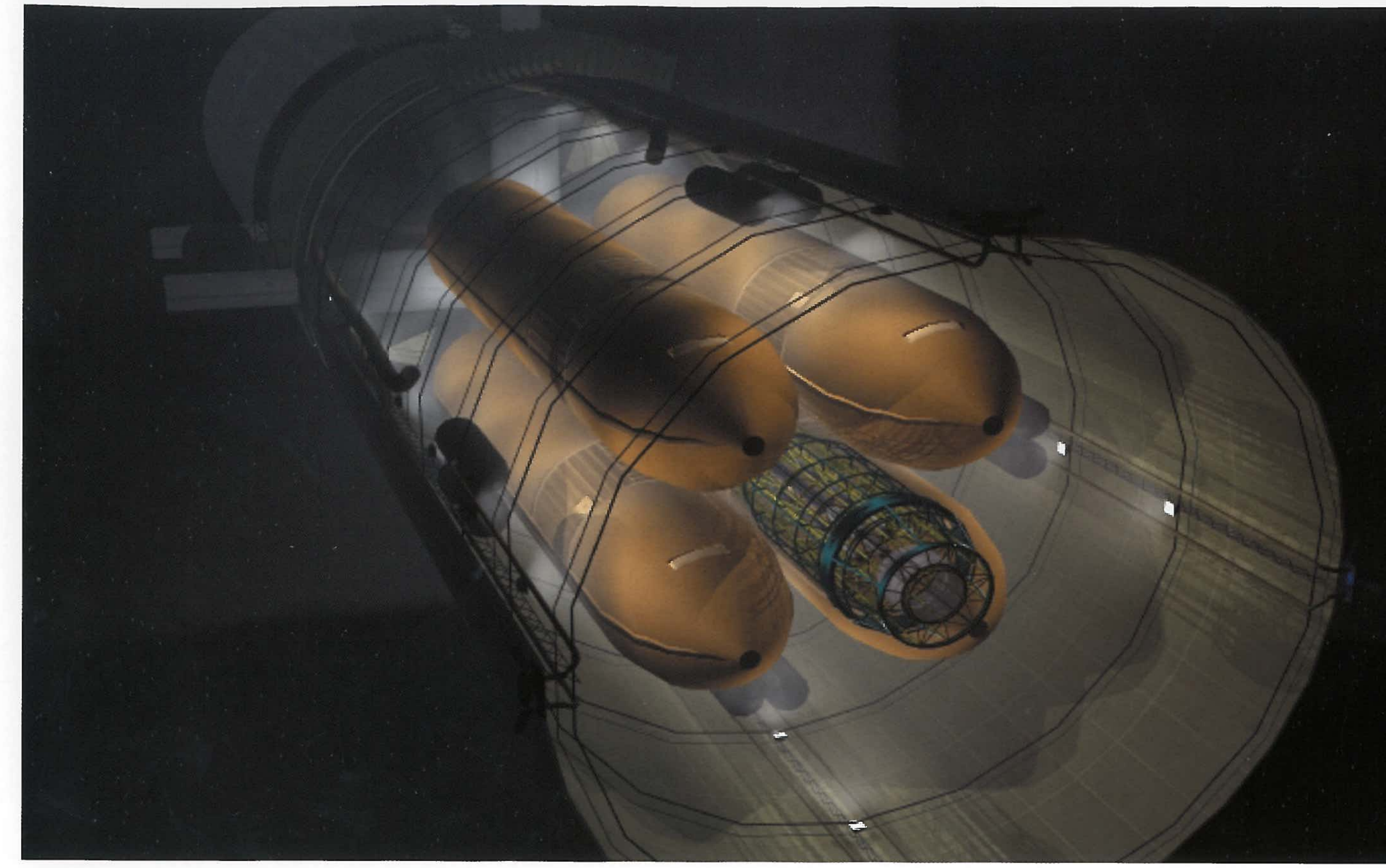
"Artificial gravity" produced by the AGSEV's rotation can help maintain the strength and health of Mars voyagers.

- If a mission's schedule coincides with "Opposition Class" positioning between the Earth and Mars, the total flight time will be about 1.6 years, with 30-60 days spent in the vicinity of the planet. Adjusting the trajectory to fly past Venus could reduce the energy requirements, but would increase trip time to about 1.9 years.
- The lowest energy route called, a "Conjunction Class Mission", would require about 270 days outbound, 1-1.5 years near Mars, and 209 days for return, resulting in a trip of about 2.8 years.

Opposing sets of Habitat Assemblies attached to deployable tethers provide a long spin axis.

The AGSEV Mars mission plan anticipates a crew population of about 8-12 people, in comparison with approximately 100 passengers and crew for the much shorter duration lunar rendezvous missions. AGSEV modules rotate at one revolution per minute on 1,140 ft. tethers to provide 40% of Earth gravity (similar to conditions on Mars). This "artificial gravity", which is created by centripetal force, will help to keep occupants healthy and fit during long Mars voyages. Without gravity, muscles atrophy over time due to inadequate exercise, and unstressed bones tend to leach out calcium and become brittle.





The Construction and Servicing Facility (CSF)

Economically practical and sustainable human missions beyond Earth will require the development of a large orbital infrastructure for spacecraft assembly, checkout, refueling and maintenance. Vehicles such as AGSEVs that carry passengers and equipment to Mars, for example, will be much too large to be launched fully assembled from Earth.

Upon return from each lunar/planetary mission, the AGSEV's propulsion unit will be transferred by OTV to the CSF for refueling and engine servicing.

The Construction and Servicing Facility will offer an orbiting manned platform where smaller components of large vehicles and structures can be warehoused, integrated into functioning systems, prepared for service, and repaired or refurbished following use. The platform will also incorporate a propellant storage tank farm with rocket fueling capabilities. Orbiter-compatible tanks will be used as fuel storage vessels. Since the facility is vulnerable to certain hazards, such as possible tank punctures by space debris, it will fly in an independent co-orbit away from the SOC.

Preparations for two AGSEV missions can take place simultaneously.

After an AGSEV returns from a lunar or planetary mission and docks with the SOC, its propulsion unit is separated and transferred via OTV to the CSF for maintenance and refueling. Dual AGSEV propulsion system servicing capabilities will enable preparations for two missions to occur simultaneously so that missions can be scheduled with short turnaround periods. This plan also offers a backup contingency in the event that servicing for an AGSEV mission exceeds the time allocated.

The CSF will provide basic living accommodations and emergency evacuation means for its crew. ERVs or Shuttle Orbiters will remain on standby at all times. The CSF will also incorporate facilities for electronic systems repair, mechanical equipment maintenance and storage, onboard operations management, and viewing and control of teleoperated servicing functions.

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