

# The Life and Biological Sciences (LaBS) Facility: An Evolution in Space Station Design

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**This paper presents rationale, requirements and concepts for an advanced multipurpose, commercial LEO Life and Biological Sciences (“LaBS”) space station. The facility is proposed to support research and to act as a technology testbed in support of future exploration initiatives. The project has been undertaken by a team of advanced undergraduate and graduate architecture students along with MS-Space Architecture graduate students at the University of Houston’s Sasakawa International Center for Space Architecture (SICSA). The work has been guided by project definitions and operational requirements prepared by NASA astronaut, Dr. Bonnie Dunbar.**

**The LaBS plan combines current space station structural and hardware systems with new and emerging technologies that promise greater efficiencies and performance benefits. Historically, much of the US space program has advanced in bursts of technology and financial backing. This has inhibited steady evolutionary advancement and consistent experience that has been evidenced in the aviation transportation industry. Thus, a major intent of this project is to design a habitable platform which optimizes use of existing technology to control costs, yet which also supports development and testing of upgrades that will support the design of future space station platforms.**

**The LaBS design incorporates innovative concepts and applications that can provide a variety of important advantages. Included are the ability to attain permanent human operational status after only four launches and realize complete assembly after six launches; expandable modules that offer generous and economical habitable living and laboratory volumes; the use of RTG electrical power generation technologies; an integrated, centralized systems control architecture; ion propulsion offering a continuous reboost capability both to support economical orbit maintenance and to sustain a pristine microgravity test environment; and quarantine facilities for receiving and analyzing samples returned from extraterrestrial bodies such as the Moon and Mars.**

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## I. Introduction

Our short history of global space station experience draws upon four of primary design and operational developments. They include, in chronological order, the Salyut series, Skylab, MIR and the current International Space Station (ISS). This paper introduces the possibility of developing a “next generation” facility that will compliment and expand benefits offered by the most recent of these, the ISS, applying an architecture that utilizes new space materials, systems and power applications to optimize economy and vehicle operations. Our report presents conclusions of a two-semester research and design effort at the University of Houston’s Sasakawa International Center for Space Architecture (SICSA). Design drivers were established by NASA astronaut, Dr. Bonnie Dunbar, a review of previous NASA and commercial programs, and previous SICSA studies. Of special importance are requirements to achieve operational capabilities with the fewest possible delivery/assembly launches, minimize development/operational costs, and optimize use of currently available technologies, tooling and launch services.

In addition to supporting biological and physical sciences, LaBS will afford a place to test of subsystems, hardware and equipment that can be incorporated into future missions and exploration goals (e.g., Moon and Mars). Accordingly, an important programmatic intent is to use this facility as a flight test vehicle and research and development facility through a “plug-n-play” approach that will enable new systems to be added for upgrades and testing as the program evolves. Examples of existing systems that evolutionary knowledge could be incorporated are the Control Moment Gyros (CMGs) and a Carbon Dioxide Removal Assembly (CDRA). As an operational facility, the vehicle is designed to be outfitted with sensors and monitoring equipment to assess physical stresses on materials and structures in a “feed forward” manner that provides data to guide more advanced vehicle architectures and designs

## II. Key Elements Overview

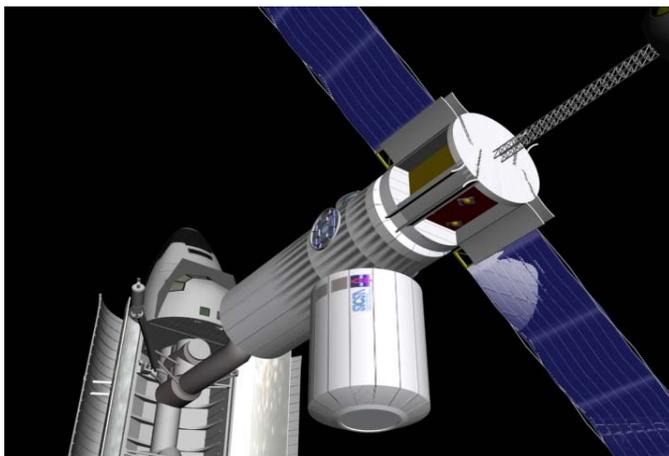
The section outlines high-level attributes of key LaBS elements that are presented in a launch and assembly sequence in Section III.

### A. Core Complex

The Core Complex at the heart of the LaBS vehicle and is comprised of the Core Module, Docklock and Vestibule, along with all ancillary nodes (e.g., Cupolas) and support equipment (including external EVA tool stowage, a robotic arm, and a Robonaut “dog house”).

- **Core Module**

The Core Module was designed as a completely self-contained space vehicle capable of supporting the attachment of up to six Common Berthing Mechanism (CBM)-compatible modules.



**Figure 1. Core Module.**

During initial man-tended operations it is attached to a Pressurized Mating Adapter (PMA) located in the Space Shuttle Orbiter External Systems Bay (ESB). The module’s pressure hull is a standard aluminum shell. Multilayer Insulation (MLI) will provide temperature and thermal shielding and thermostatic heaters will be used to provide surface and component heating as necessary. Additionally, to support the vehicle’s benefit serving as a flight test article, its exterior will be outfitted with a plethora of stress and strain sensors to continuously monitor thermal and mechanical health status. (See Figure 1.)

An External Systems Bay (ESB) attached to a deployable truss (similar to the ISS's Z1 truss) is protected within a micrometeoroid shell structure that provides four bay doors. The enclosed volume houses: ISS type Control Moment Gyros (CMGs), Rate Gyro Assemblies (RGAs) and Global Positioning System (GPS) receivers along with associated controllers. A thermal radiator with ammonia storage and heat exchangers for internal volume heat rejection is also provided, along with associated control and plumbing components.

An array of 600 DOE/NASA Radioisotope Thermal Generator (RTG)<sup>1</sup> units is proposed to provide the station with a 60 Kilowatt of continuous, uninterrupted power since no solar tracking is required. This LaBS power source assembly is located at the far end of a 9-meter (29.5 foot) telescoping retractable boom that spans a volume of 962.9 cu. cm. (58.76 cu. in.) and is connected at its base to the Core Module's ESB. A single collapsible solar array is proposed as a backup power system.

It should be noted that US Department of Energy the (DOE) provided a 100W RTG unit for NASA with a volume of 29.38 cu. in. (0.204 cu. ft.). Using RTGs instead of solar arrays for primary power enhances station efficiency by reducing the need for reboost as a result of decreased surface area and associated atmospheric drag. Nuclear power units like RTGs have been proven for space use in several manned and unmanned spacecraft for US and Russian space programs. These power sources are small in linear dimension per watt (i.e., as compared to photovoltaic arrays) and require shielding to protect astronauts and hardware from radiation. Several redundant antenna that support S-band, KU band, UHF and VHF will be deployed on the exterior to maximize communication coverage and to minimize multipath and structural interferences (e.g., KU-band communications coverage will be enhanced by not including large blocking structures such as the solar arrays and trusses.)

The ESB is mounted to one end of the Core Module with a 6 mm thick aluminum bulkhead and firewall which functions as the primary pass-through for all power, data handling, and thermal conditioning interfacing hardware. The firewall also serves as a unidirectional enhanced radiation shield. The Core Module is subdivided into two basic areas listed in order away from the ESB bulkhead: a 4-way atrium, and a Command and Control center. These two areas are bracketed by 16 lab rack-equivalent volumes containing primary control and utility interface components. Guidance, navigation, and control systems hardware are located at the end of the boom nearest the Core Module.

The concept of centralized control is exemplified by the merging of systems control interfaces and onboard operations. The Command and Control Center provides a centralized interface to subsystem computers, power routing networks (e.g., advanced RPCMs), internal thermal cooling loop pumps and controllers (e.g., upgraded low and moderate temperature ISS coolant systems), and environmental control subsystems. Emergency response and caution warning panels are also provided, along with and a dedicated robotic arm work station supported by external viewing through two cupolas (both clocked  $\pm 45$  degrees to the + x-axis).

Commonality, redundancy and standardization philosophies are typified by the distribution of emergency response equipment, fire suppression devices and medical treatment units, which are located in all LaBS modules. Fire suppression devices will make use of handheld pressurized vessels and inlet holes currently on ISS, and medical treatment for minor injuries, dental work, and light surgery will also be similar to those presently used on the ISS.

- **PMA, SSRMS and Robonaut/AERCam**

The Pressurized Mating Adapter (PMA) is a cylindrical tunnel structure, which, once connected to the Core Module, supports docking of a visiting vehicle (e.g., the Space Shuttle) to LaBS applying the Androgynous Peripheral docking mechanism (APAS) currently used on the ISS. This is a proven system that has been demonstrated on MIR and the ISS.

LaBS is proposed to be outfitted with a robotic arm to be used during assembly tasks, EVA-assisted maintenance and external science operations conducted on the station. Similar to the current 7 degree of freedom ISS Remote Manipulator System (SSRMS)<sup>2,3</sup>, the arm will have the capability of

self-collision avoidance and inchworm walk-off capability using Power/Data Grapple Fixtures (PDGFs). Using the “next generation” philosophy, new upgrades to the SSRMS can be added to enable command of the arm by EVA members to access hard to reach places, and a virtual reality graphical user interface can facilitate IVA arm operators. A Robotic Workstation (RWS), located within the command and control area of the Core Module and similar to that currently used on ISS has been incorporated in order to manipulate the LaBS robotic arm. This location will provide broad vista external viewing via dual Cupolas and support all external activities including EVAs.

To reduce, simplify, assist, or eliminate crew EVA time, Robonaut and AERCam systems<sup>4</sup> can be employed. They will be housed in a protected enclosure (dubbed the ‘dog-house’) attached outside the Core Module above Docklock EVA hatchways. This location provides for power connectivity and data system interfaces (including radio frequency control). The Robonaut and AERCam will be valuable for such uses as performing external systems and structural surveys, assisting with EVA preparations, and performing light repair and maintenance. The current NASA Robonaut design generally resembles a human EVA crewperson from the torso up, and has 5 independent digits with each “hand” on the arm. This allows Robonaut to perform dexterous tasks much like a human.

- **Docklock and Cupola**

The Docklock represents a hybrid or evolutionary module that is designed to support EVAs and docking of transfer and visiting vehicles such as Soyuz, Progress and HTV. The module is a conceptual mix of current ISS and Russian docking compartments, and supports the attachment of a single vehicle or an EVA airlock. The Docklock for the LaBS facility is larger than the current systems, and contains segregated, airtight interior volumes along with a spherical node with docking rings similar to those currently provided on the ISS’s Service Module (SM) and Functional Cargo Block (FCB) Module. This module is key to enabling permanent habitation of the station, involving long-term docking of a crew return/rescue vehicle, most probably a Soyuz or newer derivative.

- **Vestibule with attached MPLM**

The Vestibule is a separate module that affords a staging area for the quick transfer of the contents of an MPLM during the docked portion of a Shuttle flight. Once the MPLM is mated to the Vestibule, crews can quickly transfer logistical supplies, equipment, hardware and racks into the Vestibule, and later, return the MPLM to the Orbiter’s cargo bay. Once the Vestibule is loaded and the MPLM is returned to the Orbiter, the Shuttle is free to leave as scheduled or as needed in an emergency event. The LaBS crew will then have adequate time to accurately and efficiently remove and stow the newly transferred provisions to final locations. Additionally, the Vestibule may be used for storage of infrequently used equipment and hardware – much like a garage.

## **B. Expandable Modules**

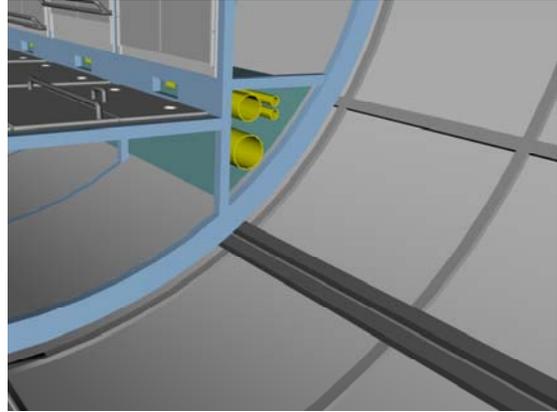
To extend limited internal volumes beyond those of current solid aluminum shelled ISS modules, two expandable modules concepts (see Figure 2) were proposed and studied. One type of the module utilizes a foldable “inflatable” section. The other applies a “telescoping” concept like two sections of a gelatin capsule with one part compactly encased within the other during launch. Both approaches are scaled to fit within the current Orbiter payload bay for launch and on orbit deployment. Each type of module is roughly the same size, both in the collapsed and expanded configurations. The interiors for both types of modules are modular, predefined and similar in layout and composition, and are virtually indistinguishable after assembly and outfitting.



**Figure 2. Expandable Modules in Deployed Configuration.**

- **Module Launch, Deployment and Outfitting**

Lab racks and hardware are preinstalled and secured in the hard portion of the inflatable module and in the extended section of the telescoping module prior to launch. After reaching orbit and docking with the LaBS Core Module, the collapsed modules are removed from the Orbiter's cargo bay by the SSRMS and are berthed to the station via the CBM interfaces. Both the LaBS and the Shuttle crews support expandable module expansion deployment and outfitting. The inflatable module is expanded/unfolded when atmospheric pressure is added, after attachment to the Core Module, whereas the telescoping module is extended using a mechanical track system. Following full module expansion, pressure leak testing is conducted and inter-module ventilation interfaces are verified before a crew can enter under "shirt sleeve" conditions to initiate final module outfitting.



**Figure 3. Utility runs.**

Utility cables and fluid lines are then connected (See Figure 3) to bulkhead pass-through panels near the CBM. Following system installation/checkout, the modules are ready for habitation and operation.

- **Interior Accommodations and Layouts Considerations**

The first expandable module is the Hab/Lab Module. It contains the crew habitation section (See Figure 4), which including living quarters, galley, exercise and hygiene areas. It also contains the first of three laboratories dedicated to human space and microgravity research (See Figure 5.) Similar laboratory facilities will also be provided by two both types of expandable modules following the completion of vehicle assembly. The Lab/Lab, which is the second expandable module to be attached, provides an additional two isolatable laboratories dedicated to biological life sciences. This portion of the module contains such accommodations as a bioreactor, plant and animal facilities, and microgravity research equipment.



**Figure 4. Hab Cross-section.**

The habitat portion of the Hab/Lab Module is arranged for maximum adaptability and utilization that allows living areas that can be reconfigured as needed by the crew. In order to create environments that are as comfortable and pleasant as possible during extended stays, a saturated earth-tone color scheme is proposed that provides vertical orientation queues to provide a familiar and easily adaptable setting. A combination of multi-color LED lighting and electro-luminescent panels is recommended to offer variety and adjustability through a range of illumination levels and provide simulated natural day-night diurnal cycles on Earth. The lighting systems must be power-efficient, minimize heat generation, and be adaptable to onboard living



**Figure 5. Lab and Endcone Cross-section.**

and task requirements. NADIR-oriented windows are strategically placed in appropriate locations to enable Earth viewing for operational and recreational purposes.

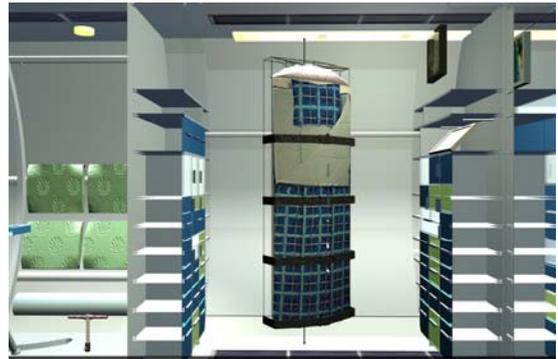
Module interiors are arranged to optimize crew habitability, usage, traffic flow, and correlations with related activities. A prime example is the exercise area, which is located next to the hygiene facility, a bioemergency and examination ward and the intermodule hatch that is immediately adjacent to the lab human sciences sample processing and refrigeration section.

- **Environmental Systems**

In all expandable modules, the end cone access way from the Core Module contains utility interface components. These include power routing, life support and ventilation systems (e.g., ECLSS), thermal control and data. The life support and ventilation systems provide continuous filtering (e.g., HEPA and microbial) and create an outboard pressure gradient. Environmental sensors record interior and exterior temperature, humidity, atmospheric toxicity, noise levels, electro-magnetic disturbances, airflow, biological contamination, and radiation levels. This data is used for real time health monitoring of the vehicle, and also as a database for evolutionary development of new vehicles, modules and systems.

- **Special Hab/Lab Module Design Features**

The crew habitation and living quarters portion of the Hab/Lab Module (either extendable or inflatable) can be isolated from the lab section by a pressure hatch in the event of a fire, smoke, chemical or biohazard emergency. Crews can then evacuate to the Core Module. The first block of the habitable area is comprised of crew quarters (Figure 6), which contain sleeping berths for three permanent crewmembers and additional space for one guest. This area can be configured for vertical or horizontal sleeping berths. Each crewmember has within their personal area a private communication work station that can access station LAN servers or entertainment libraries, and 10 cubic feet of personal storage. The sleeping area can be visually isolated from the rest of the module through the use of retractable folding screens. Individual crew compartments are separated by soft fabric covered panels. These quarters are encapsulated within a “radiation isolation area” surrounded with a blanket of interconnected water bladders for shielding. A central control station will be fully integrated with the core system functions to enable the crew to attend to necessary system functions without exposure to radiation during solar flare campout situations.



**Figure 6. Crew Quarters Cross-section.**

A galley adjacent to the sleeping quarters serves as a food preparation and dining area, and is also the module’s social and recreational center. This area provides primary food storage capacity for three crewmembers for up to 60 days. Supplemental food storage is provided in the Vestibule or MPLM when attached to the Core Module. Accommodations include cold storage facilities (refrigerator/freezer) for fresh foods, food preparation equipment, eating utensils, and a wash station. The dining area has retractable seating for up to 8 crewmembers that offers a place for group activities. Video monitors are attached to a ceiling stowage area to allow movie viewing and teleconferencing with large folding



**Figure 7. Long-View of Hab Section.**

separation screens mounted at each end of this volume as projection surfaces.

A personal hygiene area provides a place for grooming and wet-wipe cleansing in an isolatable watertight rack space. Adjacent to the hygiene area is the exercise area, providing resistive exercise devices and cycle ergometers that can be stowed. The main wall of the exercise area serves as a projection screen for any desired background image. Each station will have video and keyboard access to biostatistics monitoring equipment located in a health sciences station co-located into this area to support exercise physiological monitoring, research and emergency response (e.g., ECG, defibrillator, oxygen, LBNP, ect.).

After passing through the intermodule hatch, one enters the bio and human sciences laboratory. A pressure seal between the lab and hab sections provides isolation from biological or chemical contaminations. The laboratory is designed to support biological and human research, including effects of long-term microgravity exposure. Equipment includes centrifuge facilities, an end cone airlock for planetary sample analysis, and NADIR-oriented photo quality optical windows that enable Earth observations.

- **Special Lab/Lab Module Design Features**

This module is developed around a dual lab configuration and is primarily designed to support microgravity life sciences experiments and to serve as a systems and technology development/demonstration test bed (Figure 8). Each lab contains 38 racks as compared with 24 rack slots currently available on the ISS. In addition to these rack volumes, an airlock-glove box facility capable of supporting Mars sample return and biohazard level IV operations is provided in the module's end cone. Two Nadir-oriented optically clear viewing windows are also provided for Earth sciences and crew recreation.



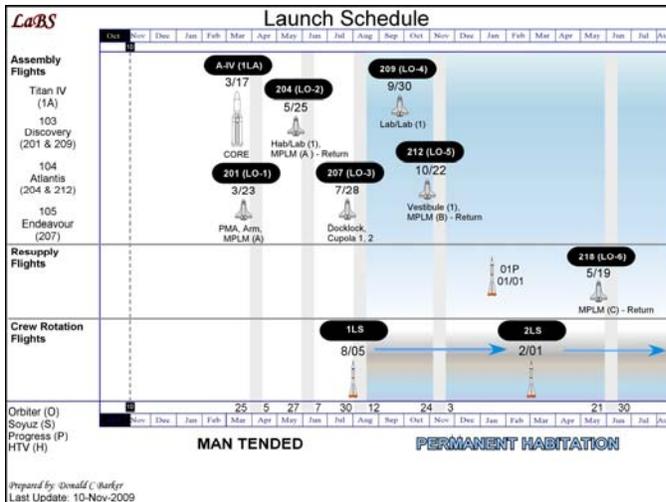
**Figure 8. Generic Lab Area.**

This two-in-one laboratory facility can be reconfigured over time to accommodate a variety of research functions. The inboard lab (i.e., the volume closest to the Core Module), is initially proposed to support hydroponics and environmental control testing. These studies might include fresh food production and harvesting experiments for long-duration space flight, volatiles recycling, and regenerative life support systems validation (e.g., phytoremediation of air and water supplies, solid waste reclamation, and carbon dioxide scrubbing and filtration), small centrifuges, and plant growth and mutation analysis.

The second lab might serve as a clinic and test bed for animal studies. To prevent fecal and other back contamination into the habitat environment, this volume is isolatable from the inboard lab via an intermodule hatch and pressure seal of the same type provided in the Hab/Lab Module. Additionally, air patterns, like those in the Hab/Lab, are planned to provide positive flow from lab 1 to lab 2 to keep airborne contaminants and odors within lab 2's filtration system. At the far outboard end of the lab 2 area is the second of the LaBS two end cone airlock/glove boxes.

### **III. LaBS Launch and Assembly Sequence**

This section proposes a timeline for vehicle assembly along with a description of critical systems that are activated or directly addressed during the on orbit assembly phase. (See Figure 9)



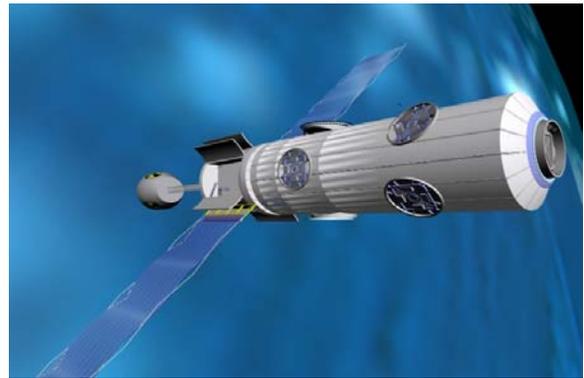
**Figure 9. Launch Sequence.**

pressurized module, the Core Module, weighs approximately 20,411-kilograms (45,000-pounds) and must be launched by a heavy lift vehicle. All other modules are sized to accommodate a launch in the Shuttle payload bay.

LaBS was designed to address the need to accomplish decking by a variety of current launch vehicles (e.g., Shuttle, Soyuz and Progress). The facility will operate in a Low-Earth Orbit (350-600 kilometers) at moderate inclination ( $\pm 40$  degrees). This low inclination orbit will optimize the number of potential users from multiple launch sites.

**A. First Launch**

The first element launch of the LaBS facility includes the Core Module (See Figure 10), which contains all of the on orbit support functions and systems required to operate autonomously. This 4.5-meter (15 feet) diameter, 16.74 meter (55 foot) long module uses an available expendable heavy launch vehicle for launch and orbit insertion. Currently, the US expendable launch vehicles that that are capable of supporting this size of payload include the Titan IV, Atlas or Delta. Though not all of these may be available in the future, several vehicles current systems could be modified to support the LaBS Core Module launch into an approximate 230 by 340 kilometer (142- by 211-statute mile) elliptical orbit. During launch, the Core Module's systems are in an idle mode to conserve battery power. After reaching the initial elliptical orbit and separating from the launch vehicle's upper stage, a set of preprogrammed commands automatically activate the Core Module's systems and deploy the RTG truss, thermal radiators and communications antennas.



**Figure 10. Core Module.**

Following several days of operational tests, including RTG power-up and atmospheric pressurization, the module will be commanded to fire its chemical engines and circularize its orbit at an altitude of about 390 kilometers (242 statute miles), the orbit at which an Orbiter will rendezvous and capture the module to perform the first assembly mission.

The LaBS facility is designed to fly in an attitude and orientation that maximizes economical and effective operations. The Core Module maintains attitude control through three systems listed in order of importance to maintain operations: Control Moment Gyros (CMG), ion thrusters and chemical thrusters. The chemical propulsion system consists of 6 large steering chemical jets and 12 small steering chemical jets along with a resuppliable propellant system with 0.5 metric tons (0.55 tons) of hypergolic fuel. This system is used initially to support Core Module orbit circularization and to hold an inertial rendezvous and orientation for vehicle docking. Eight ion

propulsive devices are arrayed for very gentle orbit maintenance and reboost with little or no impact on the quality of the microgravity environment. The five CMGs will sustain microgravity operations by flying an orbit-averaged Torque Equilibrium Attitude (TEA).

### **B. Second Launch**

This launch, the first assembly flight, is supported by the Space Shuttle (See Figure 11). The Shuttle approaches the Core Module from the zenith direction with the Shuttle Remote Manipulator System (SSRMS). Once grappled by the Orbiter's SSRMS, a Pressurized Mating Adaptor (PMA) which is docked to the Shuttle is attached to the Core Module via a Common Berthing Mechanism (CBM) interface.

Following successful mating and checkout of the PMA, the Orbiter crew ingresses the Core Module for the first time to perform systems checks and prepare for subsequent berthing of the Multipurpose Logistics Module (MPLM). The first Extravehicular activity (EVA) will also be conducted at this time in support of MPLM, Robonaut and EVA hardware dog-house installation. The dog-house is a simple EVA accessible enclosure which is mounted to the exterior of the Core Module just above the +y CMB port.

The MPLM, is a cylindrical logistics transfer module approximately 6.4 meters (21 feet) long and 4.6 meters (15 feet) in diameter, weighing about 4.1 metric tons (4.5 tons). It is capable of carrying up to 9.1 metric tons (10 tons) of cargo stowed in 16 ISS equipment racks. Five of these racks will be furnished with power, data and fluid to support refrigerator freezer equipment.

Following successful mating of a MPLM and limited logistical reorganization within the Core Module, the Orbiter undocks and returns with an empty cargo bay.

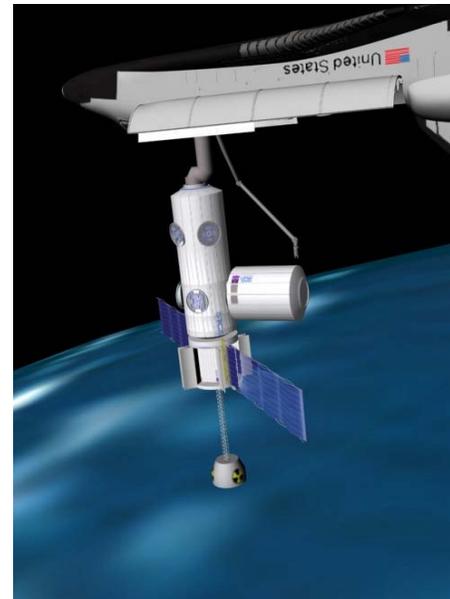
### **C. Third Launch**

The second Shuttle assembly flight lofts a Hab/Lab Module (See Figure 12), which occupies the entire volume of the Orbiter's payload bay.

After Shuttle rendezvous and docking, the crew enters the Core Module and prepares for the assembly tasks. The SSRMS then unberths the Hab/Lab Module and moves it into position for final attachment to the Core Module via a CBM interface. Once installed, the Hab/Lab is inflated or extended to the final 27.43 meters (90 foot) length. Orbiter crewmembers then perform integrity checks and begin to outfit the pressurized volume with equipment stowed within a hard shell section (launch stowed) of the Hab/Lab or the MPLM, which had been berthed on the previous assembly flight. After all utility connections, outfitting and assembly tasks are complete, the Shuttle crew unmates the MPLM and stows it in the Orbiter's cargo bay for return to Earth.

### **D. Fourth Launch**

This assembly mission completes the initial phase of construction necessary for full time occupancy of the station. A third Shuttle mission carries a Docklock and two Cupolas. The Docklock provides the docking mechanism for attaching the crew transfer/rescue craft, which are proposed to be the Soyuz series spacecraft. Once unberthed from the Orbiter, the Docklock is connected by the SSRMS to the Core Module's 4-way atrium.



**Figure 11. Shuttle Docked.**



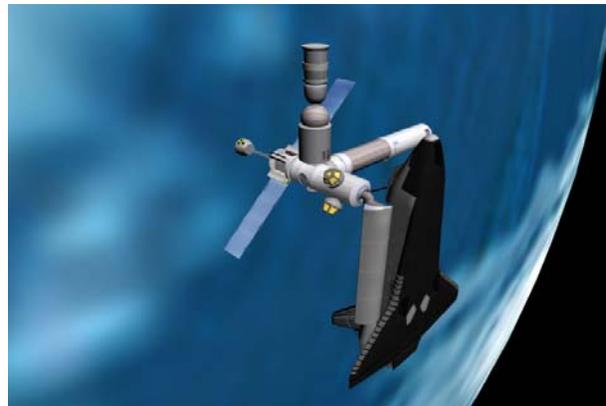
**Figure 12. Hab/Lab Installation.**

The Docklock is approximately 12.9 meters (40 feet) long and 4.5 meters (15 feet) in diameter. It is a derivative of the ISS's US Node, and Russian module docking spheres (e.g., the GA Transfer Compartment on the FGB or PHO on the Service Module) and Docking Compartment. The docking sphere contains two probe and cone docking mechanisms, one located along the module's axis, and one oriented NADIR when in nominal flight orientation. This allows for docking of Soyuz, Progress and HTV vehicles using automated and piloted rendezvous and docking procedures.

Following installation of the Docklock, the Shuttle crew will mate the two Cupolas onto the two "command area" portals on the Core Module. The Cupolas are oriented 90 degrees apart, and together their planes are clocked 45 degrees with respect to the Core Module's 4-way atrium (CBM mating ring) towards the Stations' +x axis. In normal flight, the Cupolas are oriented in the +VV direction of flight, allowing an unprecedented view of Earth in the forward direction. Their skewed orientation also allows a field of view of just over 180 degrees in support of SSRMS and Extra Vehicular Activity (EVA) operations.

**E. First Crew Launch**

Following the successful installation of the Docklock and before Orbiter undocking (See Figure 13), the first Soyuz launch, rendezvous and docking will occur. This Soyuz flight would carry the first LaBS crew and enable permanent habitation and operation of the facility for up to six months. After final middeck logistics transfers have been completed, the Orbiter undocks and heads for home.



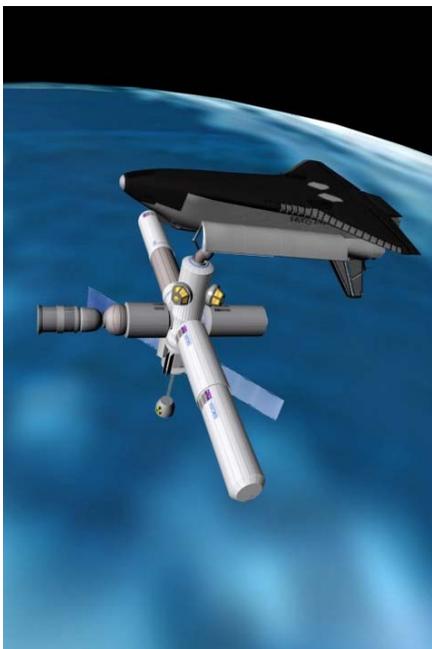
**Figure 13. First Station Crew and Soyuz.**

**F. Fifth Launch**

The fifth Shuttle assembly flight carries the Hab/Hab Module (Figure 14). Following Orbiter rendezvous and docking, assembly operations commence. The Shuttle crew undocks the Hab/Hab with the SSRMS and mates it with the CBM with the Core Module's 4-way atrium +x portal.



**Figure 14. Hab/Hab Installation.**

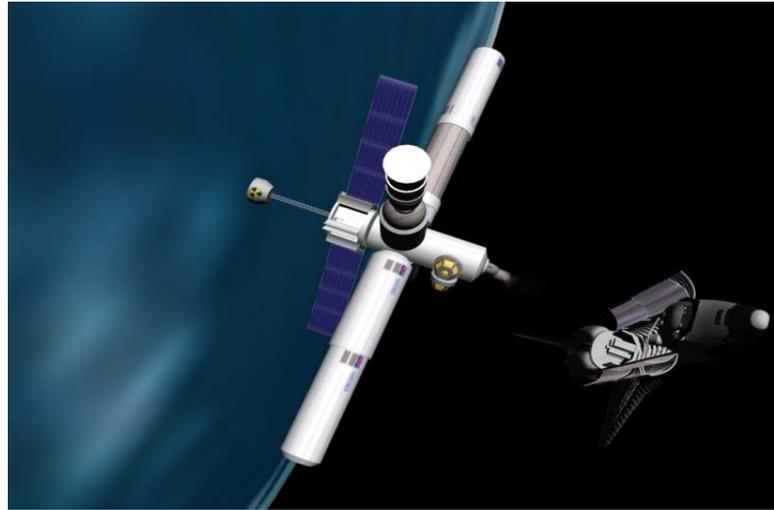


**Figure 15. Vestibule Installation.**

**G. Sixth Launch**

This flight marks the final Shuttle assembly launch for completion of the LaBS facility. It delivers and connects a 4.5 meter (15 foot) long Vestibule and a second MPLM (See Figure 15). The MPLM is launched and attached to an outboard CBM on the Vestibule, making the combined length roughly 9.45 meters (36 feet). The Vestibule is then attached to the final unused CBM on the Core Module's 4-way atrium mating ring.

In a leapfrog manner, racks, equipment and logistical supplies are moved from the MPLM to the Vestibule and from the Vestibule to the appropriate operational location within the LaBS. After the MPLM is completely unstowed, it is unberthed and placed into the Orbiter's cargo bay for return to Earth. At this point, the Shuttle itself may undock from the station (Figure 16) leaving the station crew to finish unpacking and arranging the remaining supplies now temporarily stowed in the Vestibule. The Vestibule will now act as a "garage", thus alleviating the necessity for the Orbiter to remain on orbit until all items are permanently stowed on the station. All subsequent launches will be either for crew rotations or supply and logistics outfitting.



**Figure 16. LaBS Free Flight (+XVV).**

#### **IV. Conclusions**

Exploring and investigating the highest-level requirements and considerations for the development of next generation space platforms provided this team with insight into the complex and highly integrated requirements necessary for safe, efficient and economic human space flight design and operations. This project was completed by the collaboration of a diverse group of engineering and architecture students who demonstrated that a large-scale space structures might be designed for rapid implementation and deployment. The most important educational lessons gained from this project include the importance of an integrated and informed team, establishing well-founded achievable project goals, and the introduction of novel means (i.e., via extreme environmental constraints) of thinking about architectural constraints and problems.

The primary technical lesson gained showed was that efficient evolutionary designs may only be achieved by incorporating historical lessons learned. Since the majority of space human rated facilities must initially perform as operational bases, space vehicle developers do not have the luxury of performing extensive evolutionary vehicle testing as done in the aviation sectors. Therefore, economic efficiency can only be achieved by designing; developing and testing integrated systems in a streamline manner. In this light, the SICSA team was able to adopt and explore novel approaches to module and vehicle systems design, configuration and operations.

As humans continue to venture out into space, new and evolving facilities will need to be developed and rigorously tested to insure continued and safe exploration. This can only be done efficiently by establishing a forward-looking program of incrementally advancing technologies and facilities developed to cull the necessary functional and historical operational data and information. Space is a harsh and unforgiving environment, and provides a challenging and rewarding venue within which to apply our terrestrial architectural knowledge and understanding for the betterment and advancement of all humanity.

#### **Acknowledgments**

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