Space Station Design and Operation

T. D. Smith* and D. E. Charhut†
McDonnell Douglas Astronautics Company, Huntington Beach, Calif.

A 12-man Earth-orbiting Space Station has been defined. Planned for launch in 1977 by a two-stage Saturn V, the Station is 111 ft long, 33 ft in diameter, weighs 187,000 lb, and consists of three two-deck common modules that allow for growth. An isotope/Brayton power system provides 37.5 kwe, with 20 kwe available for experiments. The Station has a closed-loop water system and a partially closed-loop, two-gas atmosphere at 14.7 psia. It normally operates in zero gravity, but also has provisions for artificial-gravity experiments. The Station is logistically supported by the Earth-to-orbit shuttle which provides for crew rotation, delivery of supplies and experiments, and return of hard-copy data to Earth. Experiment operations are conducted within the Station, in attached modules, and in free-flying modules that periodically return to the Station for servicing.

Introduction

THE NASA Space Station Program is planned to support Earth surveys and the sciences of astronomy, astrophysics, biomedicine, biology, and space physics—as well as the development of technology for space systems and operations by providing a long-lasting, general-purpose facility in Earth orbit. Dominating its design is the need to accommodate scientific personnel performing a broad spectrum of experimental activities that will change markedly over the years.

Studies of various space station concepts and their utilization potentials have been performed by the NASA/industry aerospace team during the past decade. These studies, e.g., the Manned Orbital Research Laboratory (MORL)[1,2] have provided NASA with a sound data base from which viable program objectives and design requirements were derived.

This paper presents a summary description of the Space Station design concept recently developed by the McDonnell Douglas Astronautics Company.[3,4] Illustrated are the modular approach of its configuration, subsystems, and experimental facilities. Those subsystems that exert primary influences on the configuration, i.e., electrical power and environmental control/life support (EC/LS), are emphasized. The Station has major operational interfaces with its logistics system, experiment modules, and the ground. The impact of these interfaces on the design of the Station are presented.

Space Station Design

The following guidelines have significant impacts on the design: 1) 1977 launch, 2) INT-21 (Saturn V) launch from Kennedy Space Center, 3) 55° inclination, 4) 12-man crew, 5) 10-year operational life, 6) 90-day resupply frequency, 7) 180-day capability without resupply, 8) Maximum onboard autonomy, 9) Accommodation for all candidate experiments, 10) Capability for artificial-gravity experiments for periods up to 30 days.

The selected launch vehicle permits a diameter of 33 ft, which allows a minimum-length station with maximum-payload potential. Achievement of a 10-yr life demands extensive mechanization for the test functions associated with onboard checkout, fault isolation, repair, and if necessary, system replacement. Maximum onboard autonomy minimizes the expense of sustained ground support operations and realizes the full potential of man's abilities.

Configuration

An inboard profile of the Space Station is presented in Fig. 1. The 33-ft-diam, 111-ft-long Station weighs 187,000 lb at launch. It consists of a 50-ft-long core module and an artificial-gravity module, which are separated by a cylindrical fairing that contains four communications antennas. The basic element of the Station is the common module. This module is a structural assembly fitted with equipment for environmental control, crew support, and power distribution. Its internal cylinder forms a tunnel 10 ft in diameter. The Station core module consists of two common modules connected by a 33-ft-diam skirt and a tunnel section, an outer meteoroid bumper and radiator shell, a power and equipment section located at the forward end, and a skirt at the aft end. Each common module is divided into two decks containing laboratory facilities on one deck and crew quarters for 6 men on the other. In an emergency, either module can accommodate the entire 12-man crew, as can the tunnel.

The central pressurized tunnel, which runs the length of the Station, is the main traffic artery. It can be entered through 5-ft-diam openings at each deck and at the extreme ends from docked modules. It also provides shelter during emergencies, reverse pressure capability, connections to environmental control systems in each compartment, radiation protection for film storage, a through passage for conduit, piping, and ducting, and convenient storage for food and pressure suits. The use of two separate pressurized modules or compartments with a common central tunnel is compatible with the concept of long-term refuge and repair, rather than abandonment in the event of a major emergency. Essential life support and control facilities are included in

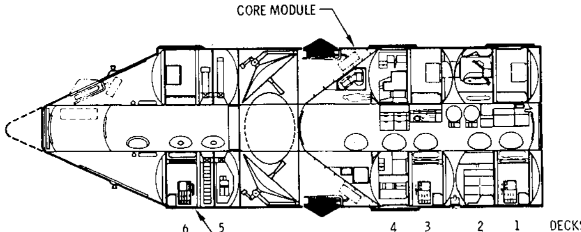

Fig. 1 Space Station inboard profile.

Presented as Paper 70-1299 at the AIAA 7th Annual Meeting and Technical Display, Houston, Texas, October 19–22, 1970; submitted October 30, 1970.

* Vice President, General Manager, Space Stations. Associate Fellow AIAA.

† Chief Designer, Space Station. Member AIAA.

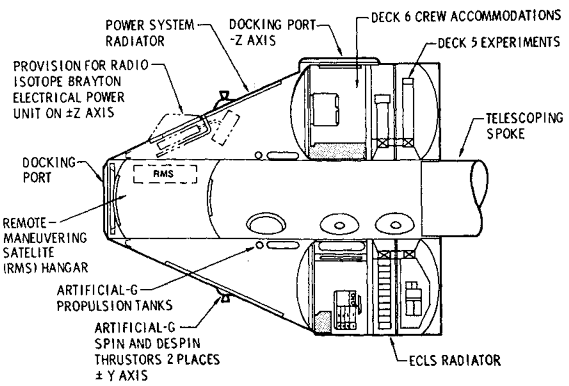

Fig. 2 Artificial-*g* module.

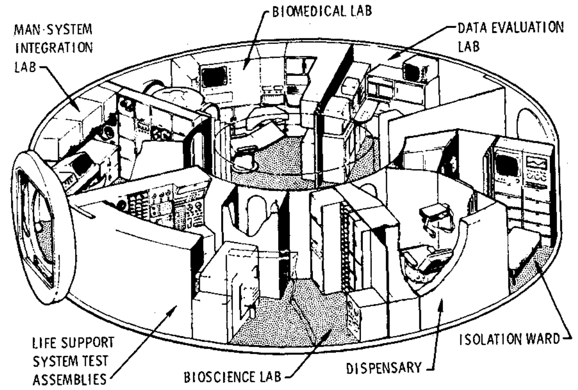

Fig. 4 Experiments (Deck 2).

both compartments to permit continuation of the mission if one compartment has to be evacuated for any reason. The time and distance required for a crewman in any area to travel to a safe area are minimal because there are two escape routes from each compartment: through the tunnel and through an airlock connecting the compartments. Each route terminates in a different location. Hatches are sized for free passage of pressure-suited crewmen.

A power and equipment section contains the primary electrical power system, two isotope/Brayton cycle power units furnishing a total of 25 kwe and 4 kwt for life support subsystem processing functions in the core module. A conical structure connects the outer pressure shell to the central tunnel, forming an additional pressurizable compartment that contains a suitable environment for the storage of propellants and other equipment.

The core module contains five docking ports on the cylindrical surface and one at the aft end of the Station. The docking mechanisms are of universal design in that any port may accept logistics (crew and cargo) modules or experiment modules. Each port has a 5-ft-diam access door and an atmospheric seal between the Station and the docking module.

The artificial-gravity module (Fig. 2), similar to the forward half of the core module, contains a two-deck common module and a conical section that houses the propulsion system used to spin the Station about its center of mass, thus producing an artificial-gravity environment, and provisions to increase the electrical power capability of the Station through the later addition of an isotope/Brayton power unit. The central tunnel extends the entire length of the module, serving as an airlock and satellite-hangar facility. Deck 5 of this module is devoted to experiment facilities. Deck 6 is initially configured as a crew and operations facility for the artificial-gravity experiment. When these operations are complete, Deck 6 can be converted to additional research facilities or to house more crewmen when needed. The artificial-gravity module is inverted (heads-down position) in the launch stack to obtain the correct orientation (floors-out) during the artificial-gravity operational mode.

Interior Arrangement

As shown in Fig. 3, one deck in each of the three common modules contains individual crew quarters for 6 crewmen, hygiene facilities, a galley, a multipurpose wardroom, and a Space Station control center, which varies in function and capability as required for each module. The wardroom is completely flexible in its configuration; it is used for eating and, when the tables are stowed, for recreation, exercise, as a theater and as a meeting hall.

On Deck 2 (Fig. 4) are located laboratory facilities, instruments, and equipment for research on small vertebrates, invertebrates, plants, and micro-organisms. Deck 2 also contains facilities for biomedical, bioscience, and man-system research. The dispensary and isolation ward are also located on this deck to allow common usage of facilities and equipment.

Centrally located, Deck 4 (Fig. 5) is the general-purpose laboratory (GPL), which supports the experiment activities and the Station's subsystems. Docking provisions for modules that most frequently require laboratory support are located on this deck.

Deck 5 configuration (Fig. 6) contains two separate and independent centrifuge systems—a man system and a specimen system. To minimize power loss to overcome aerodynamic flows and turbulence, and to provide an added measure of operational safety, the two centrifuges are separated by a divider panel. Both centrifuges are accessed at index positions through the centrifuge-support structure at the central tunnel.

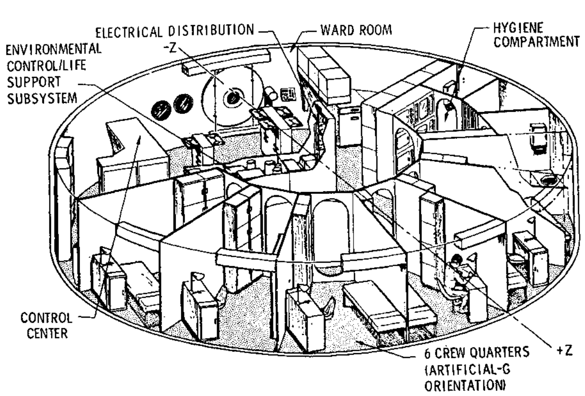

Fig. 3 Facilities and operations (Decks 1, 3, and 6).

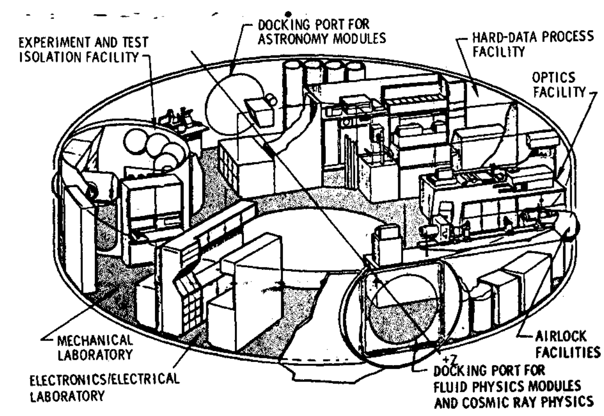

Fig. 5 General purpose laboratory (Deck 4).

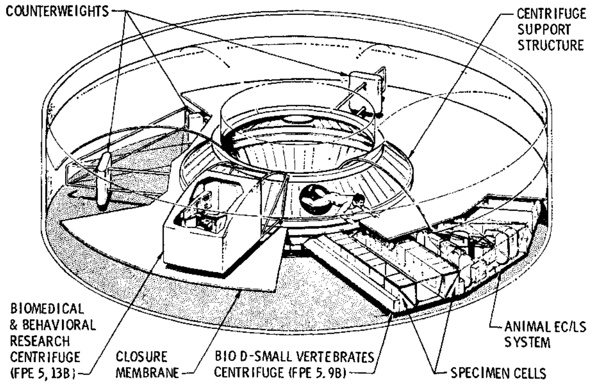

Fig. 6 Experiment centrifuge laboratory (Deck 5).

Following completion of artificial-gravity operations, Deck 6 is available for other experiments. One potential use of Deck 6 (Fig. 7) involves the accommodation of research facilities for study on primates. The primate life cells and other supporting equipment are installed following delivery to the Station by the logistics system.

Structural Design

The Space Station structural design concept resulted from considerations of multiple environments encountered during the launch phase and while on-orbit. The design goal was maximum structural efficiency to withstand aerodynamic and acoustic loads during boost, to provide a long-life pressure cabin, to resist meteoroid penetration, to provide a portion of the thermal protection system, and to provide radiation shielding for the crew and sensitive equipment. Figure 8 illustrates the selected design concept.

The pressure cabin consists of 33-ft-diam cylindrical sections and toroidal end domes. The cylinders are waffled 2219 aluminum alloy, function as the primary load-carrying members during the ascent mode, and are designed to withstand the 14.7-psia cabin pressure with a design factor of 2.0. The cabin is connected to the power and equipment section structure by a titanium isolation skirt, which contributes to the "thermos bottle" design concept selected for the Station.

Meteoroid protection is provided by a double-bumper structure, which when combined with the pressure shell significantly exceeds the design goal of 0.90 no-puncture probability in 10 yr. Radiator tubes are integrally contained in circumferential stiffening frames located between the outer and intermediate meteoroid bumpers. High-performance insulation is located beneath the intermediate bumper to

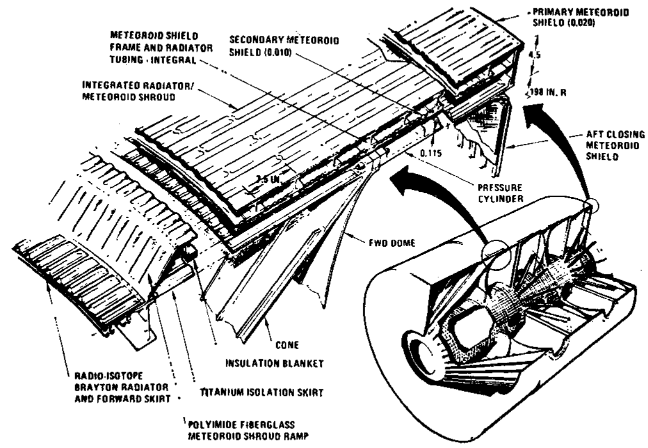

Fig. 8 Structural design concept.

complete the thermal protection system. For the low-altitude missions under consideration for the Station, no additional radiation protection is required for the safety of the crew or in the operation of equipment. Localized shielding is required for storing sensitive film.

Subsystem Design

The preliminary designs of the Space Station subsystems were selected on the basis of: 1) minimum total cost (including initial cost and cost required for extended operation) to perform the required functions; 2) indefinite operational life through balanced use of redundancy and replacement; 3) use of existing technology, except where an advanced capability could reasonably be expected through supporting research and technology programs.

The characteristics of the eight selected subsystems are shown in Table 1. Two 12.5-kwe isotope/Brayton power modules are located in the core module and a third unit is added to the artificial-gravity module when experiment loads increase after artificial-gravity operations. Environmental control and life support are modular within each common module design. Two such modules are located in the core module and a third in the artificial-gravity module. A normal Earth atmosphere is used with sufficient water and oxygen loop closure to eliminate the need for extensive resupply. The crew system features freedom of choice in food selection and use of free time. Emphasis is placed on providing a comfortable, pleasant environment for both work and recreation. The guidance, navigation, and control subsystem is configured to support the experiment program. Autonomous navigation eliminates the need for costly ground support operations.

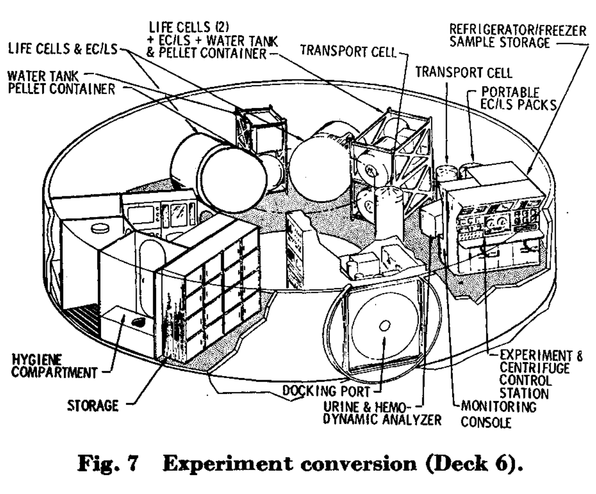

Fig. 7 Experiment conversion (Deck 6).

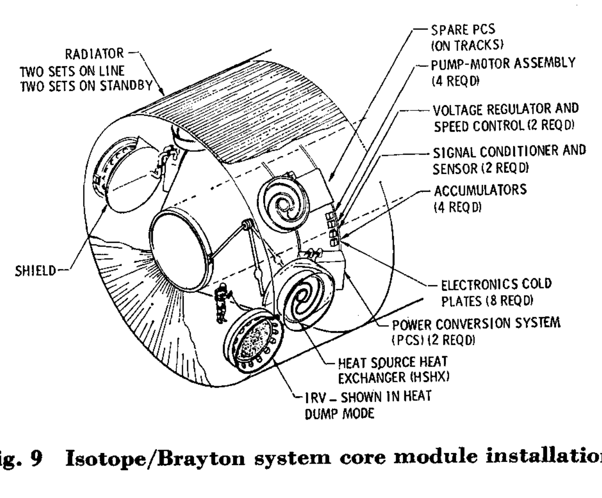

Fig. 9 Isotope/Brayton system core module installation.

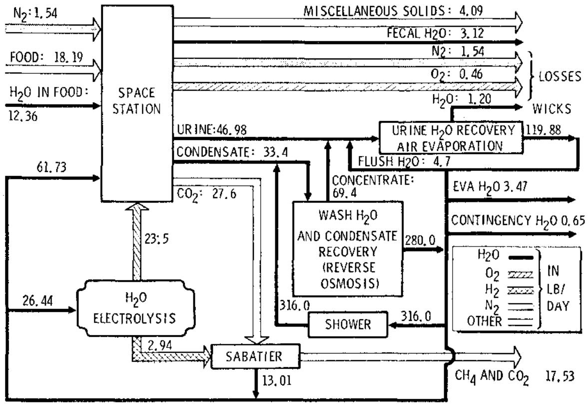

Fig. 10 Space Station mass balance.

The propulsion system emphasizes low contamination and use of biowaste environmental control and life support products. The onboard electronics are configured for collection and processing of experiment data for return by relay satellite or by Shuttle. Detection of failures and isolation to the replacement module level are performed with the onboard checkout subsystem providing the crew with the information they need to locate and replace the selected unit.

Electrical Power

The selection of a suitable electrical power system involved detailed evaluation of several alternate systems including solar array/batteries, isotope/Brayton cycle, and reactor heat sources with various conversion systems. A final decision is still pending but an isotope/Brayton cycle system has been selected for the purpose of completing a preliminary design of the Space Station.

The isotope/Brayton system consists of two independent 14.9-kwe (12.5-kwe of conditioned power at the load bus) power sources installed in the unpressurized region at the forward end of the core module. A third unit is delivered to the Station during the mission, using the Shuttle, for installation in the artificial-gravity module.

The electrical power requirements (Table 2) are indicated when the normal 12-man crew and 24-man overlap crew are onboard. Also shown are the options of normal closed-cycle EC/LS operation or a partially open EC/LS operation, which depends on a 10-lb/man day resupply of expendables. The thermal requirements in the artificial-gravity module will be supplied initially by electrical power from the core module, but will be derived from waste heat of the third isotope/Brayton assembly in the same manner as in the core module after the third isotope/Brayton assembly is installed.

Figure 9 illustrates the electrical power source assembly group installation in the unpressurized chamber located outside the forward thrust cone structure and inside the cylindrical radiator shell. Each power source consists of 52 kwt of plutonium-238, a replaceable Brayton cycle power conversion system, a shield assembly, and a parasitic load and control assembly to maintain constant turbine-alternator-compressor speed under all loading conditions. Power is generated and transmitted at 1200-Hz, 115/200 vac. Seven nickel-cadmium batteries are used to handle peak loads.

One isotope/Brayton assembly (upper left) is shown in operating position. One isotope/Brayton (lower right) is shown in an inactive condition with the heat source dumping heat to the space sink. A third (spare) system is shown mounted on the positioning tracks in a spare storage location. The edge of the second spare system is visible near the top of the figure. The manipulator is shown in local operation by a spacesuited crewman; however, normal positioning is planned for remote manipulator control with a closed-circuit TV for observation, thus saving crew time and preventing exposure to heat, radiation, and operational hazards. The electrical power system radiator (1876 ft^2) is located on the cylindrical surface and end (not shown).

An alternative internal heat dumping mode is provided by retraction of the radiation shield, permitting the heat to pass through the heat source heat exchanger. The heat will be absorbed by the large internal area and thermal mass of the thrust cone and the radiator internal structures, conducted to the surface, and then radiated to space.

Isotope re-entry vehicles are removed from the outside for return to Earth by the Shuttle, while power conversion systems are handled through separate doors (not shown) between the operating positions for Shuttle return and resupply.

Environmental Control and Life Support

The primary characteristics of the EC/LS subsystem are as follows: 1) 14.7-psi O_2/N_2 atmosphere, 2) 12-man common EC/LS module per 2 decks, 3) full H_2O recovery (air evaporation, reverse osmosis), 4) partial O_2 recovery (Sabatier, electrolysis), 5) O_2 shortage makeup - H_2O in food, 6) biowaste for resistojets, 7) segmented radiator, integrated with structure.

The system is designed to operate in a variable atmosphere of 10.0 to 14.7 psi, with a partial pressure of O_2 constant at 3.1 psi, regardless of the total pressure. Three 12-man subsystems are provided, one for each common 2-deck module. The tunnel can be referenced to either subsystem. The subsystem has full H_2O recovery; that is, more water is recovered in the Space Station than is required for drinking and washing. It also has partial O_2 recovery, the shortage being made up by water contained in the food.

The EC/LS subsystem also provides methane (a by-product of the Sabatier reactor) and unreacted CO_2 to the propulsion subsystem, which uses these gases as propellants for orbit keeping and control moment gyro desaturation. The total heat generated in the Space Station is rejected to space through a segmented radiator (two 180-degree segments), integrated with the micro-meteoroid shield.

A total mass balance for the EC/LS subsystem is shown in Fig. 10. Inputs are nitrogen makeup, food, and water contained in food. Outputs are leakage O_2 and N_2, fecal and wick water, miscellaneous solids associated with the metabolic process (such as feces, hair, nails), methane, unreacted carbon dioxide, and a water surplus.

The reverse osmosis unit purifies 80% of the condensate and wash water; the 20-percent residue is cycled to the air evaporation unit. There, the residue, the urine, and the

Table 1 Space Station subsystem summary

Electrical power	Propulsion/reaction control
Three 12.5-kwe isotope/Braytons 115/200-vac transmission	High thrust (50 lbf)-N_2H_4 monopropellant
Environmental control/life support	Low thrust (0.025 lbf)-Biowaste resistojet
Three 12-man compartments	Onboard electronics
14.7-psia O_2/N_2	Data Management
Closed water loop	Multiprocessors
Partially closed O_2	Data bus
Thermal control—radiator and heat sink	Communications
Crew habitability and protection	Two synchronous relay satellites
Crew options	Four 15-ft-diam antennas
Palatable food	Onboard checkout
Showers	4,500 subsystem points
Guidance, navigation, and control	12,000 experiment points
Multiple orientations	Autonomous
All attitude reference	Lowest replacement level
Four control moment gyros	
Autonomous navigation	

Table 2 Space Station electrical load

Electrical load	12 Men	24 Men (1–5 days)	
		Δ[b]	
Subsystem loads[a]	17.22	19.58	23.40
Distribution loss 4%	0.69	0.78	0.94
Total for station operation	17.91[c]	20.36	24.34
Experiment load accommodation			
25 kwe initial EPS:	7.09	4.64	0.66
37.5 kwe design EPS:	20.79	17.14	3.16

[a] Plus 4 kwt for 12 men, 8 kwt for 24 men.
[b] Based on 10 lb/day/man of expendables.
[c] Reduced by 1.2 kw when 3rd I/Br unit is added (waste heat).

urine flush water are purified at a 99-percent efficiency. The only water lost is that contained in the replaceable wicks. The CO_2 is converted into water by the Sabatier reactor. The purified water from the water recovery units and the Sabatier water provide the water for electrolysis and the water consumed by the crew in excess of that provided in the food. The electrolysis assembly provides the oxygen required for breathing and for that lost through leakage. The CH_4 and unreacted CO_2 are transferred to the low-thrust (resistojet) propulsion system where they are used as biowaste propellants. The total system provides excess water, most of which is used for cooling during extravehicular activity (EVA) events. A smaller surplus provides a contingency, that can be used for experiments, an allowance for uneaten food or water lost in trash disposal, or as a biowaste propellant supplement.

Experiment Characteristics Summary

Four of the six decks of the Station are dedicated to conducting the experiment program, with adequate electrical power to support these activities. Initially, 7.1-kwe average and 20-kwe peak are available with growth to 20.8-kwe average and 38-kwe peak when the third isotope/Brayton unit is added. An all-attitude capability (inertial and Earth-centered data available) eliminates restrictions for sensor viewing. Vehicle capability is at 0.05 degree for pointing and 0.001 degree/second for hold. Use of a low-thrust propulsion system minimizes contamination and offsets the effects of aerodynamic drag, contributing to achieving a low-gravity environment necessary for bioscience experimentation. Checkout and fault isolation capability is provided for the experiments as well as the Station. The data management system provides quick-look capability and a two-way TV link with the Earth-based principal investigators. Data transmission capability through the data relay satellite systems is 10^{12} bits per day. An additional 20,000 lb per year of film and tape is returned to Earth via the Shuttle. The Station is complemented by a variety of experiment modules that use the Station's laboratory facilities in conducting their experiments and for maintaining their equipment.

Table 3 Space Station weight summary

Space Station	162,960 lb	
Structure		79,050
Electrical power		13,130
Environmental control/life support		17,400
Propulsion		5,360
Electronics		17,830
Interior and crew accommodations		13,160
Personal equipment		5,050
Fluids		10,840
Fairings (effective weight)		1,140
Experiments (at launch)	14,000	
Discretionary payload	10,040	
Total at launch	187,000 lb	

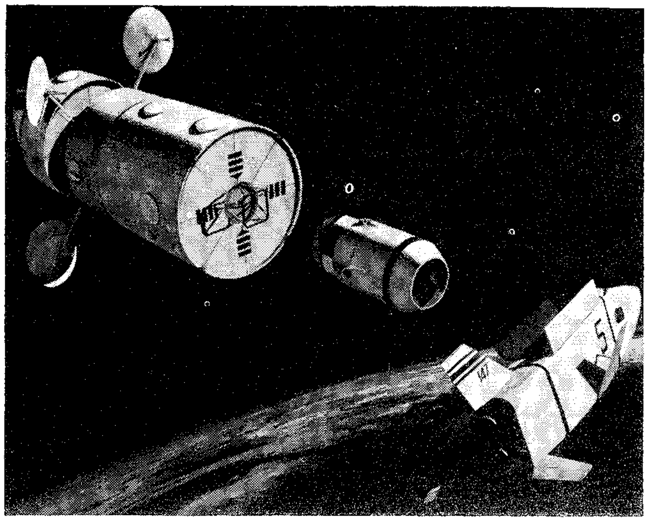

Fig. 11 Space Station logistic rendezvous.

Weight

Table 3 presents a summary weight statement for the Space Station at launch. The weights are arranged by function combining those for the core and artificial-gravity modules. Subsystem weights are for dry systems; the propellants and various life support liquids and gases being contained in the item fluids. The experiment weight is an allowance for equipment built into the Station. Actually, discretionary payload can be allocated for additional experiments if desired.

Operations

The Space Station Program represents a major departure from current space flight operations. Its long duration requires substantially new procedures so that operations can proceed efficiently in an environment of ever-changing emphasis in scientific goals and constant modification of program requirements. The concepts developed for Space Station operations will provide a high level of flexibility for conducting a dynamic scientific program with the necessary precision and in the most cost-effective manner.

Mission Description

The Space Station is launched, unmanned, on an Intermediate-21 launch vehicle (S-I and S-II stages) from the Kennedy Space Center. During the ascent trajectory, fairings located on the nose and on the cylindrical section between the core and artificial-gravity modules are discarded.

The Station is placed into a circular orbit at an altitude of 246 naut miles and an inclination of 55° by the launch vehicle. The orbital inclination was selected to provide maximum coverage for Earth-related experiments and to remain within range safety limits. The altitude selection involved consideration of experiment requirements, payload capability, orbitkeeping requirements, radiation environment, and launch-rendezvous compatibility.

The S-II second stage is separated and deorbited into a preselected deep-ocean area. The critical systems consisting of communications, life support, etc., are activated and Station readiness for manned occupancy is verified by ground monitoring before launching the logistics system that will carry the Space Station crew.

The logistics system, which consists of the orbiter and the crew/cargo module, is launched 24 hours after the Space Station. After the logistics system rendezvouses and docks to the Space Station, the crew enters the Station, activates the remaining systems, and advises the orbiter that Station

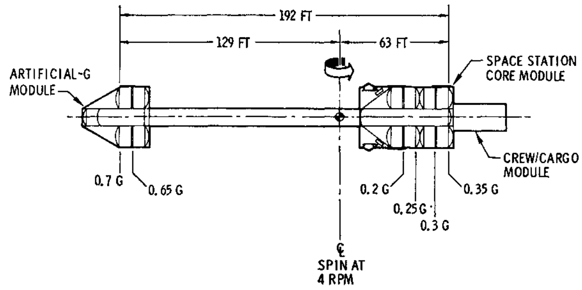

Fig. 12 Space Station artificial-*g* test configuration.

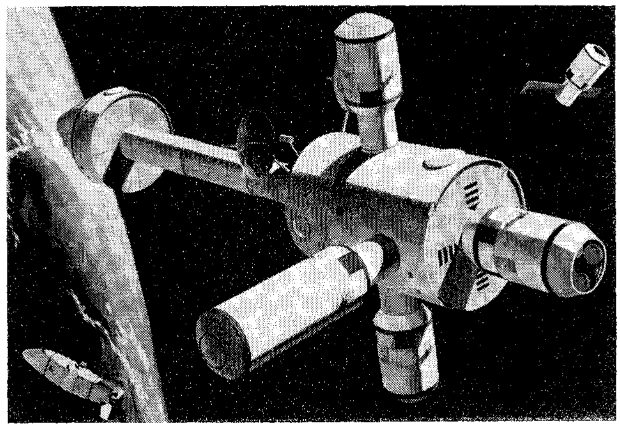

Fig. 13 Space Station zero-*g* mode.

operations can begin. Approximately 25 hr after initial manning, the orbiter begins its return flight to Earth.

Figure 11 illustrates a logistics system rendezvous with the Space Station. With the exception of the initial manning operation; which is to an unmanned Space Station, thus, requiring a docking controlled by the orbiter; logistics appointments will be carried out as shown. The crew/cargo module separates from the logistics spacecraft, propels itself toward the Space Station, and performs a docking maneuver with the Space Station. This docking mode is preferable to hard-docking the orbiter to the Space Station for subsequent appointments as it minimizes the impact on Station operations.

During the first month, the crew activates all systems and readies the Station for artificial-gravity test operations. The artificial-gravity module is deployed on a telescoping spoke as shown in Fig. 12. The combined mass of the artificial-gravity module and the Station rotates about its center of gravity, and the resulting centrifugal force produces a simulated gravity environment. The Space Station, while rotating at 4 rpm, produces an artificial-gravity environment as shown. Furthermore, a wide range of gravity levels is simultaneously available to the experimenters. A 2-man facility in the connecting spoke at the center of rotation is counter-rotated to maintain a zero-gravity environment. This enables the crew to directly compare task results between environments, and provides the capability to investigate the effect on man in transferring from a zero- to artificial-gravity environment.

Figure 13 shows the Space Station in its sustained zero-gravity mode. When the artificial-gravity operations are completed, the zero-gravity experiment program is accelerated. The logistics system delivers additional experiments for installation in the Space Station and the experiment modules. The Space Station may have three or four docked modules and three or four other modules orbiting in the vicinity of the Station.

Program Operations

The Space Station has been designed to achieve a high degree of on-orbit autonomy, with the on-orbit crew controlling the day-to-day operations and minimal schedule coordination with the ground. However, to maintain the program over a 10-yr period, ground and on-orbit operations must be coordinated to optimize the probability of accomplishing over-all program objectives.

Experiments are performed onboard the Space Station, although real-time control from the ground can be provided. The ground support function is primarily long-range planning, development of experiment procedures for future flights, and ground experiment data handling and dissemination. The remaining functions—flight operations support, mission analysis and planning, and logistics support—provide periodic real-time support but are also responsible for coordination of future mission activities.

In the program there are three separate types of modules that can be used with the Station.

1) Free-flying experiment modules controlled from the Space Station that send data to the Space Station. These modules have been developed because experiments that have unusual pointing requirements or contamination sensitivities must be operated remotely.

2) Attached modules provide flexibility in that experiments that are too large or have unusual requirements with respect to such things as safety can be operated from but not as an integral part of the Space Station.

3) Crew/cargo modules act as an on-orbit storeroom because they remain attached to the Station. As the program progresses and new and unusual requirements for cargo resupply occur, the Station need not be modified. Instead, the crew/cargo module is modified—an activity that can be performed on the ground.

Crew/Cargo Module

The crew/cargo module (Fig. 14) delivered by the logistics system carries a full replacement crew of 12 men and sufficient cargo to permit resupply every 90 days. The cargo consists of experiments, spare parts, and such expendables as propellant, food, clothing, and miscellaneous equipment. The passenger compartment is pressurized to 14.7 psia permitting direct shirtsleeve transfer into the Station after docking.

Added flexibility in Station operations is achieved by retaining the crew/cargo module in an attached mode for the 90-day interval between resupply appointments. Operation in this mode provides an increase in total usable volume in orbit, reduces the requirement for Station warehouse volume and interim cargo handling, permits obtaining logistics supplies directly when needed, and provides a convenient storage space for wastes. An added measure of crew safety is also obtained because the crew/cargo module can serve as a lifeboat, should Station abandonment be necessary. The module's self-propulsion capability minimizes the impact on Station design by simplifying the interface with the massive Shuttle orbiter, thus reducing docking loads, the number of docking operations, and stability and control requirements.

Experiment Modules

To complement the research facilities contained within the Space Station, a number of separate experiment modules are required to satisfy unique operational requirements and to add greater flexibility to the program.

The Space Station provides physical resources and operational services (Table 4) in support of experiment module operations.

Space Station provisioning of consumables, such as propellants and film, has allowed simplification of experiment module design while providing the program with a more flexible base facility. In addition to physical resources, the ex-

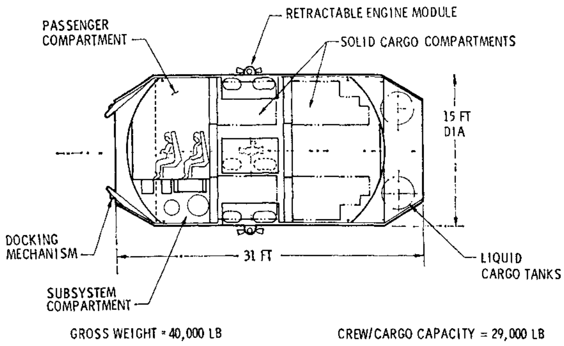

Fig. 14 Crew/cargo module.

periment module program has made maximum use of the operational services inherent in the Station design. The maintenance and modification service, in particular, is a basic ingredient in experiment module operational capabilities. This use of the Space Station resources has also resulted in a great simplification of the experiment module designs.

A typical experiment module that operates in the vicinity of the Station and returns to the Station periodically contains a 3-m, diffraction-limited UV telescope. The module provides all the physical and functional needs of the experiment as well as those for operating in a detached mode from the Space Station. The module is unmanned in the detached mode, but subsystem and telescope detector chambers can be pressurized for manned access when docked to the Space Station. The over-all size of the module is 15-ft diam (telescope detector chamber) by 60 ft long and has a lift-off weight of 19,535 lb. This makes the configuration compatible for launch in the Shuttle. The module can operate in station-keeping loops adjacent to the Space Station of up to 1,000 naut miles from the Station using the 4-ft-diam Ku-band high-gain antennas for communication of experiment and subsystem data and commands to and from the Space Station.

The basic configuration of the free-flying module provides subsystem and telescope detector chambers that will be pressurized to 14.7 psia during the docked mode to provide a shirtsleeve environment in which checkout, calibration, servicing, and modification of the subsystem or telescope detector assemblies can be performed by the crew. Because of the Shuttle limitation of a 15-ft-diam cargo envelope, a pressure shell could not be provided with adequate crew clearances around the telescope; however, only a small number of the operating assemblies are located in this forward portion.

Table 4 Station support functions for experiment modules

Physical resources	Services
Power	Data processing
Propellants	Data storage and transmission
Atmosphere makeup	Maintenance and modification
Film and tape	Atmosphere storage
Gases and other consumables	Operational control
Interchangeable batteries	Tracking and navigation update
	Onboard checkout control
	Calibration

Crew Operations

The Space Station is designed to be operated normally by a two-man flight crew and never to require more than three men for its operation. Thus, in a two-shift operation, the 12-man crew can include eight experimenters. It is envisioned that the research crew will be represented by a principal scientist who will provide the main interface with the flight crew commander. The crew commander has overall responsibility for the safety of the entire complement in orbit.

Additional flexibility has been provided by the crew scheduling approach. Statistical analyses[4] have revealed that simultaneous demands for resources and equipment often result in crewmen not being able to work because they have to wait for some item that someone else is using. Because of this, the Space Station day was divided into two 12-hr periods in which the crewmen have a 12-hr "tour of responsibility" instead of having one of three specifically scheduled 8-hour shifts for work activities. The advantage of the 12-hr tour of responsibility (an individual crewman is only expected to work 8 hr) is that the work periods of the crewmen can be adjusted with respect to each other to eliminate, or at least to minimize, conflicts such as simultaneous demand for specific resources.

Conclusions

In summary, a Space Station design concept has been developed to provide a low-cost, flexible research facility. Its design is based on sound technology and can meet NASA's goals for launch in 1977. The preliminary design studies recently completed have demonstrated that: a) known technology is adequate for Space Station; b) Space Station can grow with the experiment program; c) mix of integral and modular experiment accommodations ensures program flexibility; d) concept is adaptable to future applications.

The basic elements of the Space Station become the building blocks for subsequent missions, ranging from alternative Earth orbit missions to lunar and planetary missions.[3] The two-deck common module, which contains complete provisions for 6 men, is the basic unit. Advancements in technology can be accommodated in the module design approach so that when the country is ready for a Space Base or a Mars mission, the uprated common module can provide the framework for these installations through its basic structure.

References

[1] "Optimization of the Manned Orbital Research Laboratory (MORL) System Concept—Summary Report," SM-46071, Sept. 1964, Douglas Aircraft Co., Santa Monica, Calif.

[2] Starns, C. E., "Development of the Manned Orbital Research Laboratory (MORL) System Utilization Potential—Final Report," SM-48821, Jan. 1966, Douglas Aircraft Co., Santa Monica, Calif.

[3] "Executive Summary," Space Station Program MSFC-DRL-160, Line Item 4, MDC G0639, Aug. 1970, McDonnell Douglas Astronautics Co., Huntington Beach, Calif.

[4] "Space Station Definition," Space Station Program MSFC-DRL-160, Line Item 8, Vol. III, Analysis of Operations; Vol. IV, Configuration Analysis; Vol. V, Subsystems; Vol. VI, Payload Accommodation and Integration; Vol. VII, Expanded Capability Space Station Study, MDC G0605, July 1970, McDonnell Douglas Astronautics Co., Huntington Beach, Calif.