Space Station Requirements and Utilization

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This paper describes the approach being used to evolve basic systems and design requirements for the NASA Manned Space Station, based on a projected experiment program for applications and science, as well as from the operational demands that will be imposed on the station. In addition, some of the potential uses and anticipated benefits of the Space Station are discussed, concentrating on Earth surveys, and space manufacturing.

Introduction

THE NASA Space Station will be a self-contained orbital experiment facility with a minimum operating life of ten years and the capability of supporting a 12-man crew for an extended period. It will be available on a world-wide basis to members of the scientific community, Government agencies, private industry, and universities. For the preliminary definition study, NASA defined a representative set of experiments to be accommodated. The requirements analysis and design integration necessarily was conducted in a series of iterative steps. The first step was a cursory analysis of configuration concepts, subsystems and experiment characteristics, and operations requirements to establish guidelines describing baseline concepts and initial characteristics for experiments, operation, configurations, and subsystems. These guidelines were used to initiate the next cycle, after which an updated set of guidelines was prepared for the following integration cycle. The final iteration provided the requirements for the selected Space Station concept.

Definition of Requirements

Experiment Accommodation Requirements

The typical experiments defined for the Space Station fall into eight basic disciplines. The characteristics of their major requirements are summarized in Table 1. The mode for accommodating each experiment was determined by an iterative process which consisted of comparing experiment support requirements to Space Station capabilities, identifying incompatibilities and evaluating techniques to overcome them, and, finally, selecting one of the following three modes: 1) integral (within the Space Station, or in the airlock category wherein the experiments are deployed through booms or other structures for operation outside the mold line); 2) attached (outside the mold line of the Space Station but physically attached to it); or 3) detached (no physical linkage to the Space Station but within its command and control).

Analyses identified a number of experiments that are key station design drivers in terms of requirements for power volume, data, crew size, guidance and control, or station' caused external environment contamination (see Table 2), or program drivers in terms of station logistics requirements (consumables, etc.) and development funding. Sequencing of experiments with high requirements obviously is desirable, and three considerations provide insight into the influence of sequencing on station design: 1) the minimum station capability must exceed the requirement of each driving experiment individually; 2) an upper bound for station capability requirement for each parameter (power, volume, data, etc.) can be established by determining how many high-requirement experiments may be operated concurrently if limited only by available crew time; and 3) realistic "design-to" requirements will be established by multiple bounds and the resulting time-phased schedule, wherein maximum available power and volume constraints are added to the crew time limitation (Fig. 1).

Operational Requirements

The NASA guidelines established a mission flight envelope ranging in altitude from 200 to 300 naut miles at orbit inclinations from 28.5° to 55°. The operating altitude will be 200 naut miles for polar (90° inclination) and sun-synchronous (97° inclination) orbits. An evaluation of subsystem performance and logistics resupply requirements resulted in a design-to-altitude of 240 naut miles; this nominal altitude permits operation within all portions of the flight box, although operational resupply of consumables would be more frequent at lower altitudes and less frequent at higher altitudes.

The various experiment pointing requirements established the operational requirement of maintaining any flight attitude. However, all experiment attitude requirements can be satisfied with either the primary (Fig. 2) or the secondary flight-attitude mode. The primary mode (to minimize reaction control system resupply requirements) is X-POP Z-LV (i.e., X-axis perpendicular to the orbit plane and +Z-axis along the radius

Table 1 Major experiment requirement characteristics

Generic discipline	Requirements
Astronomy	High stability, uncontaminated view
Space physics	Moderate stability, large sensors
Bioscience	Long-term, low-acceleration centrifuge
Earth applications	Large sensor array, moderate stability
Aerospace medicine	Environments, large manned centrifuge
Materials science and processing	Low acceleration
Advanced technology	Controlled acceleration, external sensing of environment
Manned space flight engineering operations	Large volumes

Presented as Paper 70-1298 at the AIAA 7th Annual Meeting and Technical Display, Houston, Texas, October 19–22, 1970; submitted November 2, 1970; revision received June 1, 1971. This paper describes the results of a study, Solar Powered Space Station Definition Documents, SD 70-155 and SD 70-156, and the Space Station Program Phase B Definition, Third Quarterly Progress Report, SD 70-506, performed by the Space Division, North American Rockwell, in association with the Space Division, General Electric Company, for the NASA Manned Spacecraft Center under Contract NAS9-9953 for the preliminary definition of the manned space station.

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Table 2 Key parameters influencing station design

Consumables	Data
Cosmic-ray physics	Stellar astronomy
Earth surveys	Ionospheric plasma
Exposure experiments	Earth surveys
Space station guidance	Remote maneuvering satellite
Advanced EVA	Crew
Development	Biomedical and behavioral
Grazing incidence telescope	Biomedical centrifuge
Stellar astronomy	Life support protective system
Advanced solar astronomy	
High-Energy stellar astronomy	Cosmic-ray physics
	Small vertebrates
Cosmic-ray physics	Earth surveys
Earth surveys	Guidance and Control
Power	Grazing incidence telescope
Small vertebrates	
Plant specimens	Stellar astronomy
Earth surveys	Advanced solar astronomy
Components and sensor calibration	UV Schmidt telescope
	High-energy astronomy
Biomedical-behavioral	IR stellar survey
Materials and processing	Contamination
Volume	Advanced solar astronomy
Small vertebrates	UV stellar
Plant specimens	Cosmic-ray physics
Microbiology	Materials and processing
Invertebrates	Fluid physics
Biomedical centrifuge	
Operation—hangar	

vector and pointed to the ground). The Y-axis is in the direction of the velocity vector. Guidance and control sensors and certain experiments are located specifically for this flight mode. The secondary mode may be flown when astronomy observations are being conducted.

An analysis to determine the number of docking ports required to support and service experiments and cargo considered the manpower and electrical power availability. It resulted in the operational requirement for six docking ports: one for artificial gravity and power, two for cargo, two for attached experiment modules, and one for detached experiment modules.

Crew man-hour requirements were established in three categories: 1) station operation, 2) experiment, and 3) experiment support—to assure proper accounting of the total requirements and to clearly identify the types of crew activities. Figure 3 shows the requirements associated with routine experiment and experiment support operations for each of the generic experiment disciplines.

Assuming that a total of 120 man-hours are available daily from the 12-man crew, the distributions of the manpower requirements among the three basic categories of operations were determined for four classes of schedules of station activities. In all cases, ~20 man-hr/day are required for routine operations of the station, and 10 for routine experiment support; the other 90 are distributed as follows: 1) During periods of high routine experiment-support operations, ~15 more are required for them and ~20 for medicine experiments, leaving ~55 for other experiments. 2) During

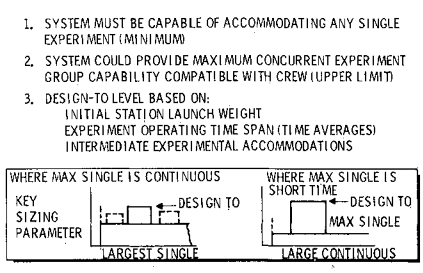

Fig. 1 Station sizing for experiment requirements.

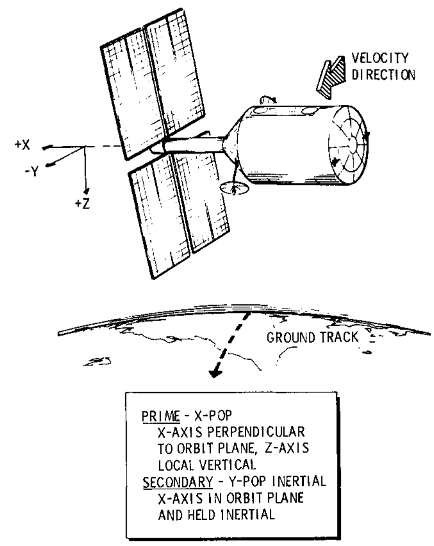

Fig. 2 Primary flight-attitude mode.

periods of high periodic station operations such as logistics resupply, an additional 20 are required for them leaving ~70 for routine experiment operations. Such periods are of relatively short duration. 3) During routine operating periods which constitute the major operational configuration, ~90 are left for routine experiment operations. 4) During periods of high periodic experiment operations, such as deployment and retrieval of detached experiment modules, an additional 10 are required for them, and an additional 20 are required for high periodic station operations as in 2), thus leaving ~60 for routine experiment operations.

Crew size, data system capacity, the number of docking ports, experiment power availability, and floor space are major constraints related to the scheduling of integral, attached, and detached experiments as well as cargo handling. In addition, each experiment discipline can be operated at a low, medium, or high level, depending on the availability of these major constraints.

A computer program was developed to define the possible combinations of generic experiment disciplines that could occur at any time in any feasible mission sequence plan, accounting for power, data rate, floor space, and docking port availability. Statistical distributions resulting from these analyses were obtained. This analysis process is shown in Fig. 4. The quantity "percent combinations" indicates the percentage of the total number of possible combinations of disciplines satisfied by the existing station capability shown below. Crew size was not varied—full utilization of a 12-man crew was assumed: on this basis, the following parameter values produced the percentage of possible and feasible combinations of experiment disciplines; average power, 6 kw;

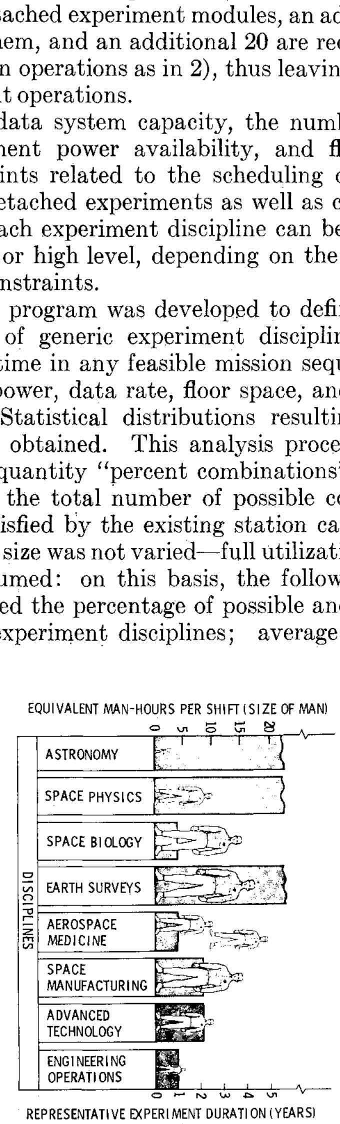

Fig. 3 Typical experiment manpower requirements.

experiment data rate, 158×10^9 bits/day, floor space for integral experiments, $1\frac{1}{2}$ decks, experiments-dedicated docking ports, 3.

A mission sequence plan based on the generic discipline approach is illustrated in Fig. 5. It has four major phases: 1) activation and artificial-gravity assessment period (3–6 mo); 2) experimental facility buildup and crew-duration qualification (6–18 mo); 3) nominal operation period (5 yr); and 4) matured capability period (3 yr). Earth surveys and engineering operations are conducted continuously throughout the mission. Aeromedicine and space processing disciplines, although planned initially for short duration, may continue through the program. Other disciplines are scheduled in accordance with various operational requirements and constraints; significant variations in generic discipline scheduling can be accommodated in the present configuration design.

Requirements Summary

The established operational and experiment support requirements are summarized in Table 3. Daily crew-scheduling options include single-shift, duty-watch, and random-shift operations. On the single-shift operations, all crewmen are on the same basic work/rest cycle, and only eating and recretional activities are staggered to reduce the number of personnel utilizing the dining, exercise, and personal-hygiene facilities concurrently. In the duty-watch concept, at least one crewman is awake at all times, and the others are scheduled on a single-, staggered-, or random-shift basis. The work/rest cycles are scheduled on the basis of the demands of the individual experiments for the random-shift mode of operation.

Single-shift operation is preferred, e.g., during periods of a high aerospace medicine experiment activity, or periodic operations requiring several men per task. Random-shift scheduling is more desirable for periods when experiments constrained by time or geometric considerations are operating, e.g., Earth surveys and astronomy. The experiments associated with space physics, space biology, space manufacturing, advanced technology, and engineering operations apparently can be performed utilizing any basic scheduling concept. If it is possible to avoid constraining the station design by any specific scheduling concept, then the scheduling concept is deferrable and can be changed during the actual operations of the Space Station.

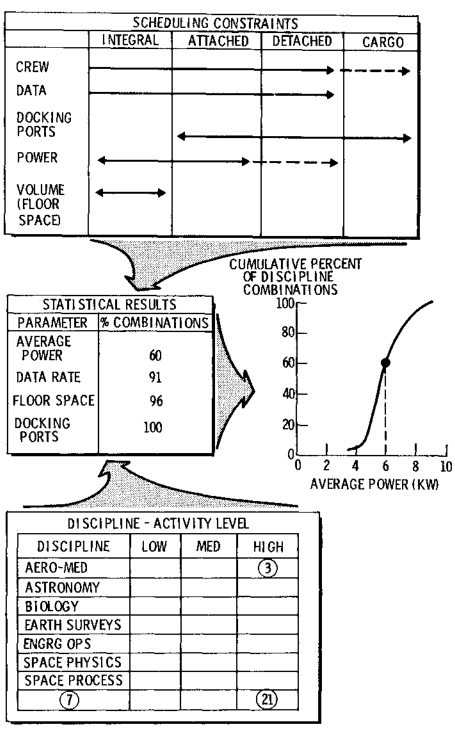

Fig. 4 Operations scheduling influences.

Table 4 illustrates some of the features incorporated in the Space Station concept and the options they provide. For example, use of nonload-carrying partitions permits rearrangement of the station on-orbit. The concept of always exchanging cargo modules when the logistics vehicle delivers cargo provides minimum interface problems and flexibility in loading and unloading cargo from a crew workload viewpoint. The flexibility provided by the power-boom concept and the general installation philosophy of ample access to subsystems will permit station modification for growth or technology reasons.

Earth Applications

The Space Station will have the potential to make major contributions toward solving the growing ecological problems. Much valuable information was gleaned from the Gemini and Apollo photographs and observations of the Earth from space. Extensions and refinements of sensing techniques now developed or under development for aircraft and unmanned satellite programs will be employed.

For example, the Forest Service of the U.S. Department of Agriculture keeps a continuing inventory of this country's timber to provide volume, growth, and drainage statistics to local and national planners and legislators, but some of the data are nine years old when finally reported. In many other countries, much less is known about the current condition of forest resources. The Space Station, with an attached earth surveys module, will use proven multispectral photography techniques to obtain up-to-date information about timber and forage crops in remote regions: the type and vigor of vegetation on each physiographic unit, the identity of damaging organisms or agents, the yield obtainable per acre, and the total area of various physiographic units. The crew would only acquire pictures of the specific areas of interest, and the film would be returned to earth in the logistics vehicle rather than transmitted electronically. Gemini and Apollo flights have shown that forest fires can be readily spotted from space; knowledge of fires in remote areas will be of great value.

Statistical agricultural data in many developing countries are sketchy and unreliable. Access to crop-producing regions, both existing and potential, is often difficult because of terrain barriers and the absence of all-weather roads, even in the United States. Future managers of cultivated vegetational resources will require greater knowledge of the foods and fibers growing in the world's major agricultural basins: the type, size, vigor, and probable yield of the crop in each field, and the identity of any damaging agents. With re-

Table 3 Operational and experiment-dedicated characteristics

Stability		
Attitude hold, deg	$\leq$0.25 (0.1 for 30 min)	
Angular rates, deg/sec	$\leq$0.0 (0.01 for 30 min)	
Accelerations, $10^{-3}\, g$		
Nominal (crew movement)	0.04	
Worst-case (ALS dock)	35	
Periodic (solar-array pointing case)	0.25	
	Operations	Experiments
Power, 24-hr integrated average, kw	19	6
IMS bits		
Storage, 10^6 words	1.5	1
Data rate, 10^9 bits/day	22	158
Integral area, ft^2	3,320[a]	1135
Integral volume, ft^3	17,460[a]	7700

[a] Includes toroids.

Table 4 Station concept flexibility

Features → Provides	→ Options
Configuration	
Movable partitions	Modify arrangement, inter-, intradeck
Standard utilities and outlets	Function relocation
50% launch-weight margin and 35% volume margin	Weight growth, development, payload
Artificial *g*, initial launch	Weight growth and program scheduling
Operations	
Multiple-, split-, single-crew shift	Program scheduling, scientific desires
Exchange cargo module	Crew transfer scheduling
Common docking port provisions	Module arrangement
Data record/and or transmit and PI air/ground	Conduct experiment program
Subsystems	
Power-boom concept	Add-on power growth, replacement
Access and location approach	Maintenance, modification update, growth
Capability to open system, logistics resupply	Power utilization, short periods

gional and global inventories and yield forecasts, steps can be taken to keep essential supplys and demands in balance. Using multispectral photography, color photography, multichannel optical mechanical scanners, and radar-type imaging systems, the Space Station crew will be able to obtain such data, as well as much needed information about potential agricultural areas (scope, aspect, soil depth, texture, chemical composition, moisture content, and susceptibility to erosion).

Geologists urgently need more knowledge on both a regional and global basis about the extent and location of mineral and petroleum deposits. Global observations made year after year from the Space Station would enhance the geologist's understanding of the dynamics of the Earth and, at the same time, help the prospectors now industriously examining the earth's continents and sea floors. Such an inventory is essential to the formulation of wise policies governing the use of natural resources.

A long-range Earth surveys program supported by the Space Station would provide similar benefits in geography, hydrology, oceanography, cartography, and other sciences still not envisioned.

Materials Science and Processing

A foam-type material with the strength and rigidity of solid steel but the weight of balsa wood might be formed by introducing gas into molten steel under zero gravity in the Space Station's materials processing laboratory. (On Earth, the gas-formed bubbles would float to the surface before cooling could occur, but in space they would remain entrapped.)

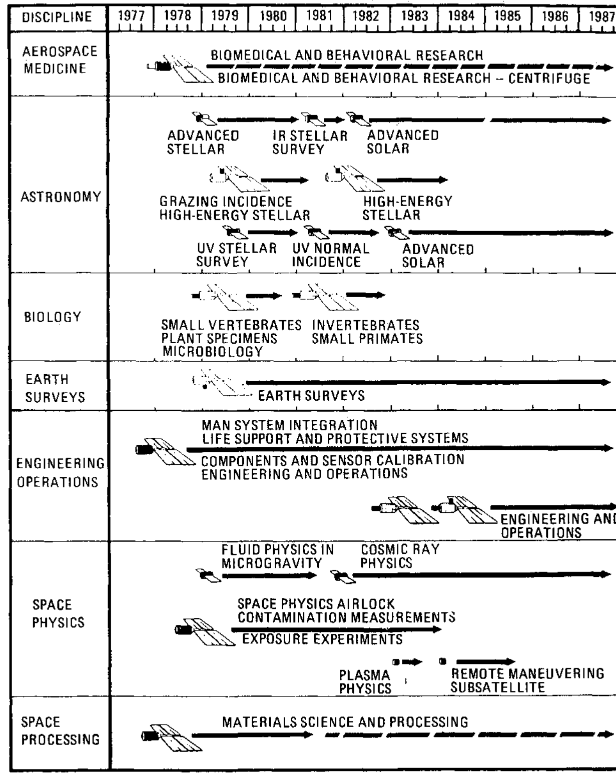

Fig. 5 Typical operational sequences.

Perfect ball bearings would be formed by a similar process. The controlled heating and cooling of metals by radiant or induction techniques under clean, zero-gravity conditions result in contamination-free, totally uniform alloys of almost any desired constituent mix. Other processes difficult to perform in the atmosphere or in Earth's gravity are also being studied for conduct in space.

Other Disciplines

The Space Station will permit astronomers to move their instruments into space, where they will be above atmospheric interference, turbulence, light-ray scattering, sky brightness, cloud cover, and pollution; they will be able to make full use of the inherent capabilities of the instruments. For the physics discipline, space offers the presence of phenomenon not available on Earth, that is, high-energy charged particles. For the life sciences discipline, space offers the absence of earth phenomena, such as gravity, periodicities, and phenomena not yet recognized. The Space Station also will serve as an excellent facility for supporting the development of technologies, techniques, and operations required for man's further exploration and exploitation of space, the solar system, and the universe.