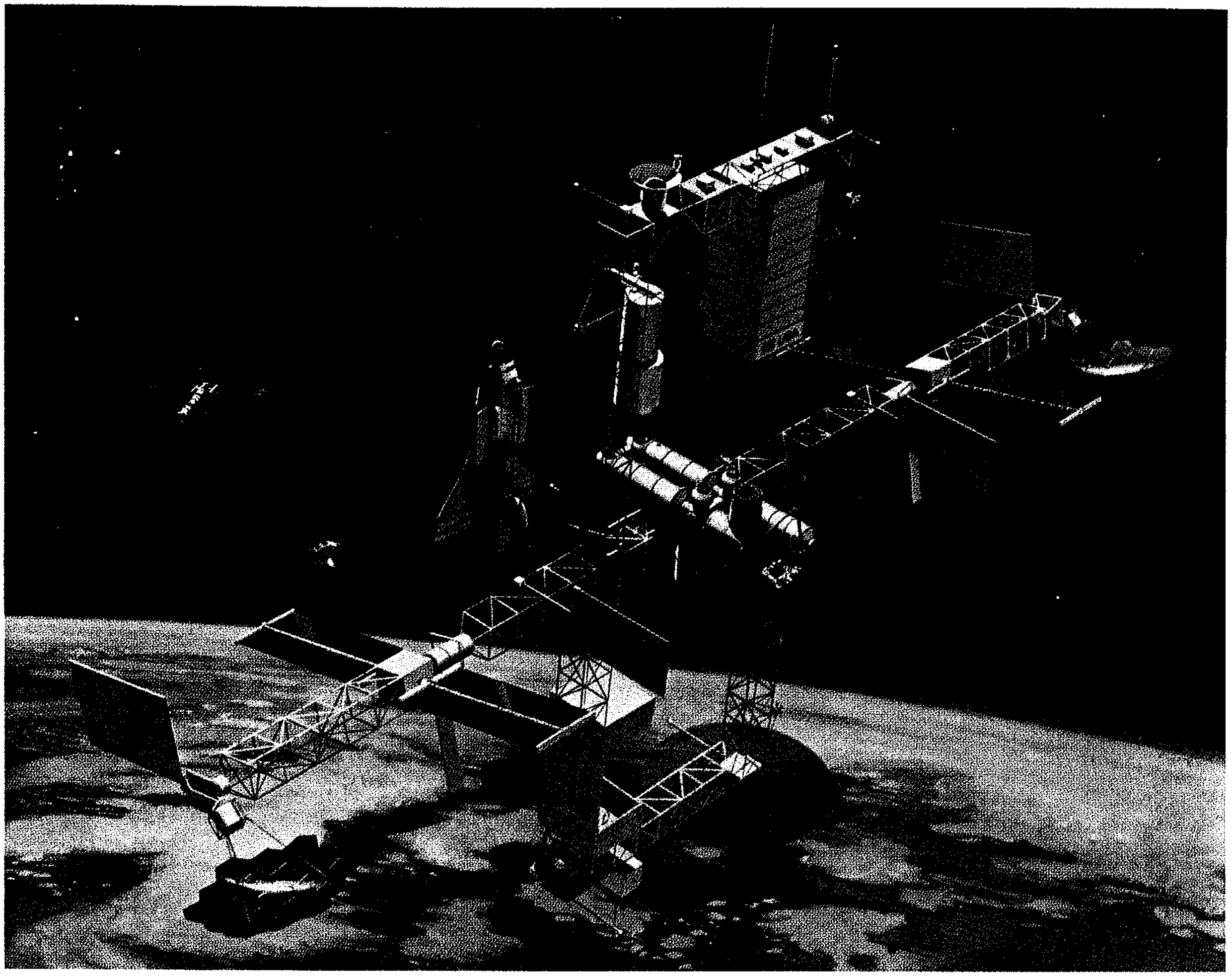
NASA
Space Station

THE SPACE STATION

A Description of the Configuration Established at the Systems Requirements Review (SRR)



Office of Space Station
NASA Headquarters
Washington, D.C. 20546

June 1986

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THE NEXT LOGICAL STEP

The Space Station continues to be the next logical step in this Nation's efforts to explore and use the environment of space. It represents a commitment by the United States to leadership in civil space activities. By providing a new capability for the conduct of science in space, the development of new technologies, and the promotion of business, the Space Station will retain American preeminence in space into the next century. As we reexamine the Space Shuttle program, we must at the same time look beyond the Challenger accident. Space has been and, with the Shuttle and the Space Station, will continue to be an arena of unparalleled American success. In space we have gained new knowledge and new technologies. The space program has provided a new dimension to the human adventure and it has instilled in Americans a deep sense of pride. In the 1990s the Space Station will continue and enhance this legacy. As a facility and laboratory in space, its value is extremely practical yet powerfully symbolic. As a program it is about to move into a critical stage. Now more than ever, the Space Station is important to our future and we must move forward as planned.

John D. Hodge, Acting Associate Administrator for Space Station,
testifying before the Subcommittee on Space Science and Applications,
U.S. House of Representatives,
April 10, 1986

PREFACE

In 1984, President Reagan committed the Nation to the goal of developing a permanently manned space station, and to doing so within a decade. He reaffirmed that commitment in his State of the Union addresses of 1985 and 1986. This document is a progress report to the American people on the status of the Space Station design in the spring of 1986.

In response to the President's directive, the National Aeronautics and Space Administration (NASA) undertook an examination of the many missions that a space station might carry out, and of the many ways in which a space station might be configured. This effort reached a major milestone called Systems Requirements Review (SRR) in March, 1986. The Systems Requirements Review is part of a long-established NASA decision making process used in many programs. For the Space Station Program, SRR marks the point at which the basic characteristics of the Space Station have been decided. These decisions were made by NASA scientists, engineers, and managers, working with partners in industry and from Canada, the European Space Agency (ESA), and Japan, and with representatives of the scientific and commercial customers worldwide who will use the space station.

SRR decisions establish the "baseline configuration"-- the overall configuration or floor plans -- for the Space Station. These include living and working accommodations, safety features, repair and maintenance capabilities, and such key matters as sources and levels of electrical power. SRR focused on technical decisions. The next step is to conduct Space Station preliminary design to improve our understanding of cost, schedule, and detailed engineering issues. During this period the baseline configuration will be subjected to vigorous review and challenge. NASA will then select through competition the industry teams that will prepare detailed specifications and build hardware for all elements and systems of the Station. (Detailed design and hardware development are scheduled to begin in FY 1987.)

Another important consequence of SRR is that NASA can now better estimate the cost of designing, constructing, and assembling the Space Station. Until the mission requirements and the baseline configuration were known, such cost estimating was little more than rough estimates. NASA is also able to analyze the likely costs of operations -- which are the costs most difficult to predict -- with greater confidence.

NASA has worked hard on Space Station planning, and has made significant progress in the past 2-1/2 years. The Agency has initiated a major advanced technology program to support Station design and operation; it has made a special effort to explore the uses of automation and robotics on board. It has developed a "man-tended" concept responsive to Congressional direction. It has developed an acquisition strategy for development activities, and it has begun refinement of work package assignments to the various NASA centers. In addition, NASA has developed an operations management concept and is reviewing operational requirements.

In the international area, and in coordination with the Department of State, NASA has reached "program level" agreement on preliminary design with Canada and Japan and continues discussions with ESA. We expect the Space Station to have a strong international dimension.

The Space Station Program is a large endeavor. It requires planning that integrates into a coherent whole a vast amount of subsystems engineering, technology development, cost analysis and budgetary projections, international cooperation, and managerial experience. The intensive definition phase completed with SRR has given NASA a good understanding of the technical issues and a better understanding of the managerial issues involved.

NASA also believes that a useful Space Station can be developed within the constrained budgetary outlook that both NASA and the Nation face. During SRR, NASA engineers and planners, along with their colleagues in industry, engaged in an intensive "scrub down" to bring the SRR baseline configuration within budget constraints. This goal was achieved largely by deferring some elements or capabilities and by eliminating desired advanced technologies that exceeded requirements or represented high technical risk. NASA made every effort to ensure that none of these deletions, reductions, or deferrals affected crew safety.

The Space Shuttle was -- and still is -- conceived as the principal means of transportation for the Space Station. The Shuttle will carry crews, supplies, and equipment to the Station. Equally important is the Shuttle's unique capability to bring payloads back to Earth. It will ferry new scientific and commercial materials made in space, as well as returning crews on rotation and equipment. Other vehicles currently in use cannot perform this round trip function; only Shuttle can. U.S. expendable launch vehicles -- as well as the European Ariane -- cannot make the return trip.

The loss of Challenger makes NASA acutely aware of the absolute requirement to ensure the safety of flight crews. Space Station will be safe and reliable. NASA is establishing a Space Station Safety Panel to ensure that planning fully and properly addresses safety issues. As an important example, the panel will examine NASA`s philosophy of crew rescue and the concept of "safe haven" that has been developed for the Space Station. This report covers several of these issues. Personal risk can never be entirely eliminated in space flight. But NASA is committed to minimizing it on Space Station, both in construction and operation, and to fully understanding what risks exist.

REPORT ON SRR

NASA plans on achieving an orbital capability with Space Station in 1994. Accomplishing that means that the Agency must stay on schedule with the design and development phases. The purpose of this report is to inform the American public on the configuration and capabilities of Space Station as it enters preliminary design

Space Station can and will become a reality within the next 8 years. As a permanent facility, with a crew of six to eight, the Space Station will provide the United States and its international partners with a truly remarkable workplace in space. Using both manned and unmanned systems, the Station will enjoy the advantages of both modes of space flight. It will be a research laboratory, an observatory, a place to develop and manufacture new products, a service facility for satellites, a storage depot for supplies, and an assembly point and staging base for missions to geosynchronous orbit, the planets, and beyond.

The Space Station offers a virtually limitless contribution to U.S. science, commerce, and technology. Space has become an important arena of human activity; one in which we must continue to excel. The Space Station will help us do so. It will ensure that the United States ends this century and begins the next as a leader on the frontiers of human knowledge and technology.

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June 1986

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June 1986

INTRODUCTION

The exploration and use of space are undertakings in which the United States has long excelled. Despite setbacks such as the Apollo fire of 1967 and the more recent tragic loss of the Shuttle Orbiter Challenger, space has been an American success story. The next logical step in ensuring U.S. leadership in space during the 1990s and beyond is to construct a space station. Only a permanently manned space station offers the kind of capability needed to reap the benefits of space -- in scientific research, technology development, and commercial enterprises. The United States plans to place a manned Space Station in orbit around the Earth within 8 years, and to evolve the Station over time to a more capable system.

Man has long dreamed of constructing such a facility, enabling scientists, astronomers, and other specialists to explore the nature of the universe from space and to exploit the unique features of near-zero gravity and near-perfect vacuum. The United States is not alone in this dream; the Soviet Union already has a space laboratory, having placed its latest upgraded version on orbit early in 1986. This accomplishment is worthy of considerable respect, and indicates the Russians' long-term commitment to the exploration of space and the development of manned space operations. The Europeans, through the European Space Agency (ESA), have also expressed strong interest in developing manned operations, and they -- like Canada and Japan -- are cooperating with the United States in developing the Space Station.

SPACE STATION TASK FORCE

The vast success of the Apollo and Skylab missions focused substantial interest on a space station. Development of the Space Shuttle in the late 1970s provided an incentive to further work on the idea, for the Shuttle would provide the essential transportation.

By late winter 1982, NASA decided that more rigorous analysis should be done on the space station concept. On May 20, 1982, James M. Beggs, the NASA Administrator, formed the Space Station Task Force to identify mission requirements for the program, to define an initial space station concept, and to coordinate the work of the many NASA offices and research centers that were interested in the concept.

In the summer of 1982, NASA contracted with eight U.S. aerospace firms to identify user requirements in space science and applications, technology development, commercial activities, and -- initially -- national security. Several foreign governments, including Canada, member nations of the European Space Agency, and Japan, conducted their own studies at their own expense, and informally exchanged their findings with the Americans.

NASA also initiated technical studies at its field centers. These took the form of working groups, formed in the summer of 1982, to examine mission requirements, operations systems requirements and program planning (for overall program management), as well as concept development. NASA offices took on studies of what technologies would have to be developed for a space station, including those needed for the Space Station platforms, an orbital transfer vehicle, an orbital maneuvering vehicle, and the like.

In April 1983, the President directed the Senior Interagency Group for Space (SIG(Space)) to study NASA's findings on the space station concept. SIG(Space) consists of representatives of Cabinet-level departments and agencies concerned with space. NASA's final briefing of SIG (Space) took place in August 1983, and the concept of a U.S. space station began to circulate at the highest levels of the Administration.

From this process there emerged, in the spring and summer of 1983, the general understanding within NASA and the Administration that a space station could serve a number of national uses. First, it would house scientific instruments to gather vital data on the Earth's environment and on the universe at large. Second, it would provide opportunities for commercial space endeavors. And as a permanent facility in space, it would be truly unique -- highly useful for both scientific and commercial activities. Skylab and the Shuttle had proved the concept of space manufacturing of medicines, rare materials, and such products as high-quality computer chips and precise optical fibers. But that prototype work also showed that continuous human attention was necessary for most experiments and that manufacturing required further research and development.

The Space Station would also serve as a repair base to maintain, upgrade, and fix a wide variety of spacecraft. In addition, the Space Station crew would be able to assemble, test, and calibrate satellites before they were deployed. Assembly was seen as a particularly important function, the Space Station would enable devices, much larger than can presently be launched, to be put together and placed in service.

It was also clear that a space station could provide a staging point for spacecraft of unprecedented size, which could return to the Moon, send a manned expedition to Mars, conduct a manned survey of the asteroids, build a manned scientific and communications facility in geosynchronous orbit, or build scientific and manufacturing facilities in low Earth orbit.

It is clear that the Space Station was seen from the very beginning as something whose benefits were diverse and substantial. The Space Station would be a new national scientific laboratory. It was also envisioned as something that would stimulate economic investment and commercial business activity in space, and would contribute to economic growth, productivity, and more jobs through national investment in high technology. Finally, the space station was seen as a method of generating international cooperation among nations friendly to the United States. As one observer, Col. Gilbert Rye, closely familiar with the SIG (Space) study put it, the President's "final decision was a recognition that ... a favorable space station decision would preserve the option to pursue more ambitious goals sometime in the future .... In the final analysis, the President felt deeply that we could preordain a pessimistic future by simply not providing the infrastructure necessary to ensure that optimistic estimates of space uses would actually materialize. These uses were primarily in the civilian applications of the Space Station."

The members of SIG (Space) presented their recommendations to the President in a Cabinet meeting late in 1983, at which the NASA Administrator presented the case for a permanently manned Space Station. No consensus among agencies had developed during the SIG (Space) study or at the Cabinet meeting. The President therefore sought additional advice and engaged in further deliberations. In his State of the Union message delivered on January 25, 1984, the President announced his decision: he directed NASA to develop a space station and to do so within a decade. He reaffirmed that decision in his State of the Union addresses in 1985 and 1986.

PHASED PROGRAM PLANNING

The work of the Space Station Task Force constituted the first of five stages of planning that NASA uses in managing large programs. The method is known as phased program planning and has evolved over the years from both NASA's experience and that of other agencies.

Phase A is called the Concept Phase. NASA sought in this phase to state mission requirements and objectives, gather information, and articulate concepts that met the objectives. Phase A addressed the questions: What would a space station do? And what might a space station be like that could do these things?

Phase B is called the Definition and Preliminary Design Phase and it began on April 19, 1985 after the President directed NASA to develop the Space Station. Phase B addressed the questions: How would the Space Station meet its mission requirements? What would it cost to accomplish that? What technical challenges are involved? How should key systems be defined and designed? The SRR milestone represents the point in Phase B at which NASA has selected from among many concepts the one that most satisfactorily meets mission requirements, within the constraints of cost, technology, and time. The remainder of Phase B will be devoted to preliminary design while preparing to competitively select contractors to undertake specific development assignments.

Phase C is scheduled to begin in the fall of 1986 although the Phase C contractors start work on or about May 1, 1987. Called the Detailed Design Phase, it extends Phase B to the point of preparing detailed engineering drawings and detailed specifications for the hardware, working and living quarters, electrical and fluid systems, data processing systems, and other elements of the Space Station. NASA may retain program management and the critical functions of systems engineering and integration (SE&I), which is the process for ensuring that all mechanical and electronic elements, systems, and subsystems function properly together. Phase C will last until the Critical Design Review process has frozen the design sometime in the fall of 1989.

Phase D is the Development Phase, in which NASA contracts with major U.S. aerospace firms to build and test the hardware. The competition for Phase C includes the Development Phase as well. Testing may be done in industrial facilities or in NASA testbeds. Crews will be selected and be trained extensively in the construction and operation of the Space Station.

The final phase, E, is the Operations Phase. The Space Station is scheduled to be assembled in space from early (first quarter) 1993 through 1995. It could be man tended during that period. The Space Station will become permanently manned by 1994 with mature operations beginning a year or two later as the systems and operations procedures are fully checked out and refined.

THE SRR PROCESS

Because of the size and complexity of the Space Station, NASA decided on an unusually long Phase B period -- first setting it at 18 months and later extending that to 21 months. A key element of the effort was to initially develop a "reference configuration," which is a best-guess design for the framework and systems of the Space Station. This reference configuration (known as the "power tower" for its single, vertical keel) was simply a common point of departure for engineering and other analyses. Throughout Phase B, NASA and the aerospace contractors narrowed the possibilities of each element of the reference configuration until the "baseline configuration" of SRR was reached.

Another key effort was a technology review, conducted largely in-house by NASA personnel and initiated relatively early in the process (in 1981 with the formation of the Space Station Technology Steering Committee). At the outset of Phase B, it became clear to senior NASA managers that they needed to know which technologies could be used "off the shelf" -- that is, where the state of the art would suffice -- and which would have to be pushed to new limits if the program were to go forward with confidence and within the constraints of cost.

NASA offices identified about 70 areas (in 14 categories) where new technologies would be needed. Among these were several life support technologies. For example, both the air and the water that support Shuttle crews are used once and then expended as carbon dioxide (CO_2) and waste water. This is an inexpensive and simple way to support these crews during the comparatively short Shuttle missions.

On the Space Station, however, one-time use would require that prohibitively large amounts of air and water be brought up from the ground on logistics runs. A better way would be to "close the loop;" that is, to retrieve the basic elements of Oxygen, Hydrogen, and Carbon from the used air and water rather than to expel, expend, or otherwise use up these materials. Although these processes are well known, the technology to perform them in a small, reliable, closed system in space is not yet developed.

Another advanced technology that is related to both closing the environmental loop and propulsion is the selection of the thruster technology that will move and control the Space Station. At SRR, the decision was to utilize the existing thruster technology that uses Hydrazine as a propellant. However, shortly after SRR, the decision was made to capitalize on the Hydrogen and Oxygen available from the environmental system and push for low thrust Hydrogen and Oxygen engines from the available and proven large engine Shuttle technology. This would reduce the amount of consumables required on Space Station as well as reduce the amount of hazardous materials. At this point, both Hydrazine and Hydrogen/Oxygen thrusters are being examined.

Numerous technical issues emerged during Phase B. For example, Space Station will constitute a first in the use of a sealed atmosphere over a virtually indefinite period of time. What happens to air and materials in an atmosphere that has been closed for years? What biological activity takes place, and what are the acceptable levels of biological activity for human habitation? The answers at present are not clear.

Space construction and on-orbit maintenance also pose challenges. In construction, for example, experience on one Atlantis Shuttle flight demonstrated that crews were more proficient at structure assembly in space than in the Marshall Space Flight Center deep-water simulation tank. The longer the crews worked, the more efficient they became. Nonetheless, building a structure in space the size of a football field will pose both problems and risks. Likewise, on-orbit maintenance will require advanced technology and new skills. Normally, a system is shut down during maintenance -- but the Station must continue to function while under repair.

Phase B uncovered issues that are less susceptible to engineering response. For example, the sociology of the Space Station environment raises intriguing questions. How well will a crew of mixed nationals get along over extended periods of time? What law applies in case of conflict? What recreational patterns are necessary for extended durations in space? Answers to these and many other remaining questions will need to be provided.

DECISION-MAKING STRUCTURE

At the beginning of the Definition Phase NASA set up a decision-making structure designed to ensure two things. First, the structure had to accommodate a large number of elements and systems, each made up of many components. Second, if the full intellectual range of options and considerations was to be made accessible to NASA managers, then the structure had to accommodate and even encourage opposing and dissenting views.

The foundation of the Phase B decision-making structure was the Technical Integration Panels (TIPs). Members of a TIP were experts in their field and focused on one particular technical area. For example, among the subjects of study were the suits used in extravehicular activity, communications between the Shuttle and the Station, the data management system on board the Station, and crew safety.

Each panel developed options for addressing each element of the Space Station, and its chairman presented these to the next level of decision-making, which includes the following: the Systems Integration Board (SIB), the Operations Panel, the Mission Integration Panel, and the Technical and Management Information Systems Control Board. Members of the TIPs made presentations to the boards and panels, and could voice supporting, opposing, or dissenting views.

The SIB member represented major areas of interest, such as engineering, safety, operations, and customers. The SIB meets periodically to examine the panels' options and narrow them down to one or two. The SIB Chairman, who is also the head of the Systems Engineering and Integration organization for the Space Station Program Office at the Johnson Space Center, then presents the Board's recommendations to the Space Station Control Board (SSCB). Members of the SIB and, in many cases, members of the panels as well, prepare the SIB presentation and can voice supporting, opposing, or dissenting views.

The SSCB is headed by the Space Station Program Manager and consists of representatives of the other Level B organizations. ("Level B" is the Space Station organization responsible for program management and for integrating the individual work of the "Level C" project offices at various NASA Centers. "Level A" is responsible for overall program direction and is located at NASA Headquarters in Washington, D.C.). At SIB presentations, SSCB members ask questions that cut across functional lines and attempt to reach decisions that meet mission requirements, safety concerns, technical issues, and cost considerations.

The NASA decision making process during the various phases of development provides for minority and dissenting views as well as a forum for discussing the application of new approaches and ideas, and applications of advanced technology. These discussions may be at the TIP, SIB, or SSCB levels as previously described. The process drives toward a program or technical decision. Decisions do not end the inquiry, but they direct all activities. Engineers, scientists, and contractors, must follow the baselined and controlled documents that Levels A and B issue after the SRR decisions are made. This allows the program to go forward in an orderly manner. Similar control boards function within the Level C activities.

Even after controlled documents are issued, however, dissent and new ideas find a ready hearing. The process is called a Change Request (CR) which is a formal document that the requester fills out and sends to the SIB. The SIB must provide a hearing for and respond to every CR. A CR that is rejected by the SIB can be appealed to the SSCB, which is the final judge. In certain cases, further appeal can be made to the Level A Space Station Office.

The process of change continues through Phase C and even into Phase D, as design turns up new problems or possibilities, as testing discloses flaws and suggests new answers, and as construction confronts realities that never appeared on the drawing boards or even in the most sophisticated computer simulations. A document called The Program Definition Requirements Document contains all SSCB decisions, as modified by approved CRs. All program engineers, designers, contractors, and other personnel are required to adhere to the specifications in this document.

SPACE STATION UTILIZATION

The purpose of Space Station is to provide an orbiting facility to users and customers, referred to generically in this document as users. After a 4-year worldwide exploration of ideas with business and industry leaders, scientists, technology experts, and government officials, NASA believes that a user community exists and can be defined with considerable precision.

Users can be divided into three categories: science applications, technology development, and commercial. Science applications will likely be the largest users of the Station in its early years of operation. These users include universities, consortia of academic and research organizations, and foreign and U.S. government researchers. The U.S. science community, like those in other industrialized nations, is well-developed and is organized to generate well-considered projects frequently of large magnitude. The scientific community has informed NASA that it expects to make use of the Space Station base and platforms for observations, laboratory experiments, and a wide range of research. Many scientific projects will require the presence of a person to oversee the process and to make scientific observations.

Technology development users will be concerned with technology developed on Space Station. Clearly, man's capacity to live and work in space will benefit from technology developed for the Space Station. But the prime emphasis of users is expected to be on developing and testing new technologies such as methods of producing materials, and on advancing the state of the art of known technologies, such as telerobotics. NASA itself, in its role as a national leader in new technology development, will be an important user of the Space Station.

Commercial users comprise one of the largest pools of potential users, but their entrance into space-oriented activities early in the life of Space Station could be easily overstated. American business is often attuned to short-term profits from short-term investments. Space Station will be on the cutting edge of commercial activities in space, and is unlikely to offer capabilities that ensure quick profits. Some exceptions to that general observation certainly exist, particularly in telecommunications. But on the whole, a business or industry sending a manufacturing payload to the Station will be experimenting; the short-term return on investment may be quite uncertain, although the long-term payoff may well be immense.

An important consideration for NASA in regard to both scientific and commercial users is ease of access to the Station. Ideally, a commercial user would like to develop an experimental process, prepare it for flight, have the payload certified, accepted, and delivered to the Space Station, have it work, and receive the products back in a reasonable amount of time. Scientists also need an avenue of access that enables short-term research projects to utilize Space Station capabilities. NASA is sensitive to the need to keep payload procedures simple and timelines short. NASA also recognizes that costs -- particularly launch costs -- are critical and must be kept to the minimum consistent with crew safety and mission requirements.

Users in all categories will make use of the laboratory modules and free-flying platforms that orbit as part of the Station complex or circle Earth in orbits on their own. A man-tended platform or free flyer offers an ideal base for many users. The platform appears ideal for astronomy and microgravity science and offers promise for future commercial endeavors. It will be stable and can be serviced from the Station. In practice, a scientist or commercial company could place an experiment on-board a platform, put it into operation, let it produce data for a given period of time, recover the "products" for return to Earth, and then place a new instrument aboard.

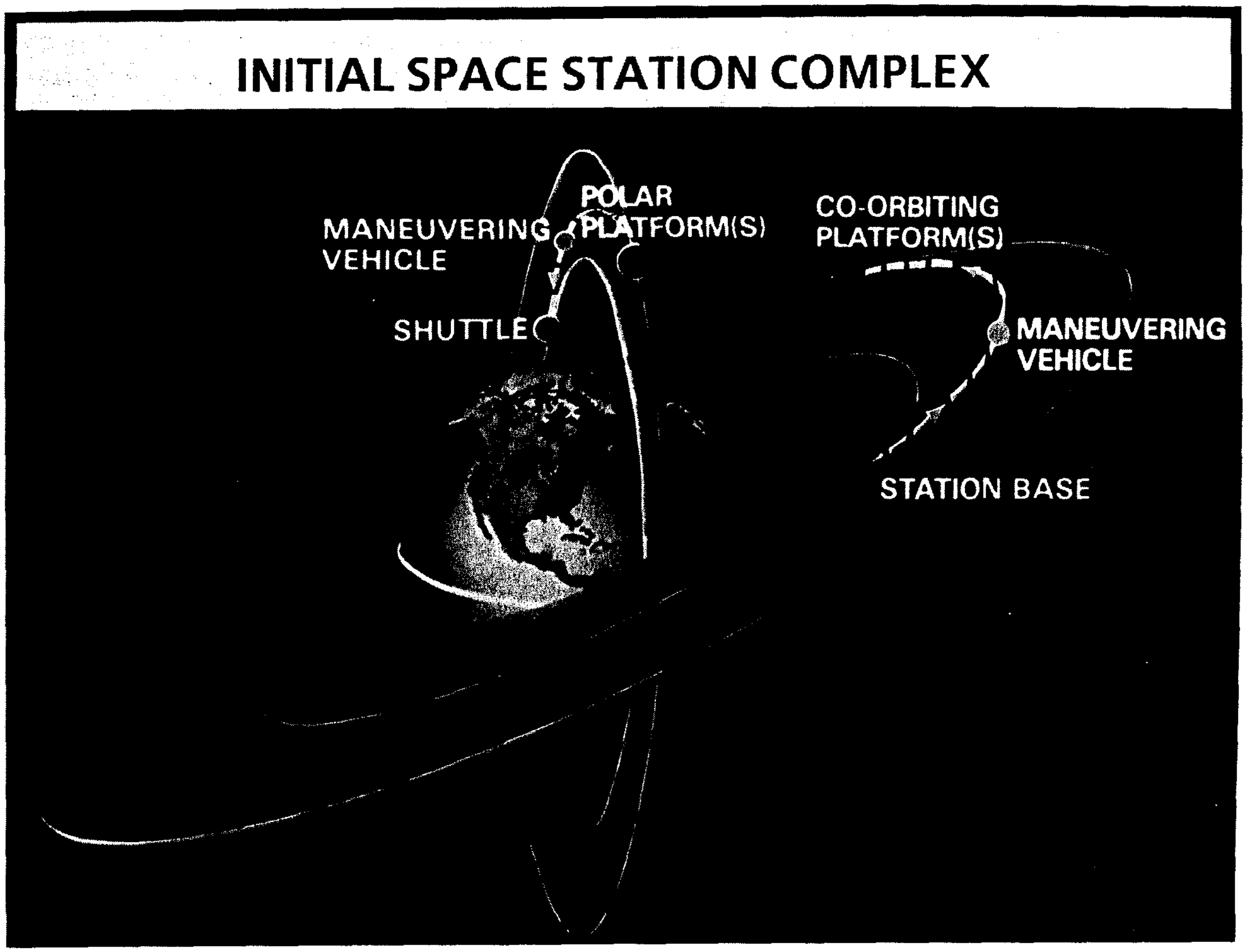
As approved by the President and established by NASA, the Space Station Program is a civil endeavor. Although the Department of Defense examined potential uses of a permanently manned Space Station through the early mission requirements studies and participated in the Administration's deliberations during the summer and fall of 1983, the Department concluded that such a station would serve no current requirements and -- initially -- opposed the concept. NASA has continually kept the Department of Defense informed of the progress of the Space Station Program and has informally solicited any design inputs the Department may wish to provide. Currently, the Department of Defense is reexamining the potential of utilizing the Space Station. Though based upon civil requirements, the Space Station will constitute a substantial national asset that, in the future, could be of value to the Department of Defense as a research tool.

NASA is exploring a number of important areas involving Space Station development. These include the possibility that some commercial organizations may want to provide elements of the Station itself, such as an auxiliary electrical power system, on a fee-for-use basis. Private sector, privately financed involvement in the building of the Space Station is an intriguing concept and is actively being explored at this time.

The Space Station has an important international flavor. When directing NASA to develop a permanently manned Space Station, President Reagan also invited our friends and allies to participate in the program. Canada, Europe, and Japan have done so and, while final agreements have not been reached, extensive discussions have taken place. Hopefully, these will lead to full cooperation and involvement in the Space Station Program.

Current management principles and planning emphasize that the international Space Station participants would share the benefits and the risks. The participants would obtain returns on their investments through a fair and reasonable allocation of the Space Station's resources and functional capabilities.

Against this background, a narrative description of the Space Station at SRR is presented. Descriptions of individual elements, systems, and other components are necessarily brief, but they provide in aggregate a reasonably comprehensive picture of this large and complex program.


INITIAL SPACE STATION COMPLEX

FLIGHT ELEMENTS

Flight elements are the major physical components that comprise the Space Station. They consist of: a central Station Base with its Habitation, Laboratory, Logistics and International Modules; nodes, airlocks, and tunnels connecting the modules; facilities attached to the main trusses; a servicing facility; a telerobotic servicer; accommodations for attached payloads; one U.S. and one ESA unmanned platform in orbit over the poles; one U.S. and one ESA unmanned platform that co-orbits with the Station Base; accommodations for storage, utilities, and servicing of future vehicles; and solar power and propulsion elements. For simplicity of discussion, the term Space Station "Base" will be used to describe the main assembly of elements. The following discussions describe the element categories.

CONFIGURATION

The physical structure of the Space Station Base resembles a large rectangle of metal trusses connected at their four corners. The framework consists of trusses approximately 94.5 meters (310 feet) long on the vertical side and 45.7 meters (150 feet) on the horizontal side. Across the middle of this rectangle is a truss that supports the modules, which are large cylinders in which crew members live and work.

NASA engineers arrived at this configuration during the Definition Phase prior to the SRR after lengthy analysis proved that the original reference configuration would not best fulfill the mission requirements for the Station. The reference configuration established at the beginning of Phase B had called for a single truss about 121.9 meters (400 feet) long with each truss bay approximately 2.7 by 2.7 by 2.7 meters (9 feet). The modules were located at the lower end of the truss. This configuration called for the concentration of mass to be toward one end in order to take advantage of what is called gravity gradient stabilization. Although the reference configuration may have been easier to design and construct, it suffered two drawbacks. First, the great length of the truss -- unsupported by cross-member trusses or other fixtures -- meant it would tend to wave and oscillate, causing problems for scientists who need to be able to point sensitive instruments at distant objects with great precision. More serious was the fact that this single-truss arrangement, which was called the "Power Tower," required placement of the modules some distance from the Station's center of gravity, which is the point closest to zero gravity. Much scientific and commercial work on the Station will make use of the low-gravity conditions. NASA engineers calculate the gravity on the Space Station Base at its center of mass as approximately 10^{-6}g or one millionth the gravity at sea level.

The Power Tower allowed placement of all upper modules at the limit of the 10^{-5}g zone but no modules within the 10^{-6}g zone. Furthermore, the Power Tower, although very large, had insufficient attachment area for positioning facilities, attaching payloads, or storing payloads or materials when not in use.

Instead of the Power Tower, NASA settled on the "Dual Keel" design. The Dual Keel is shorter than the Power Tower, but much more able to meet mission requirements. Its rectangular shape produces a stiffer frame; oscillation is no longer as great a concern. The Dual Keel allows for placement of all modules within the 10^{-6}g zone. Finally, the Dual Keel has ample room for positioning facilities, attaching payloads, and storage.

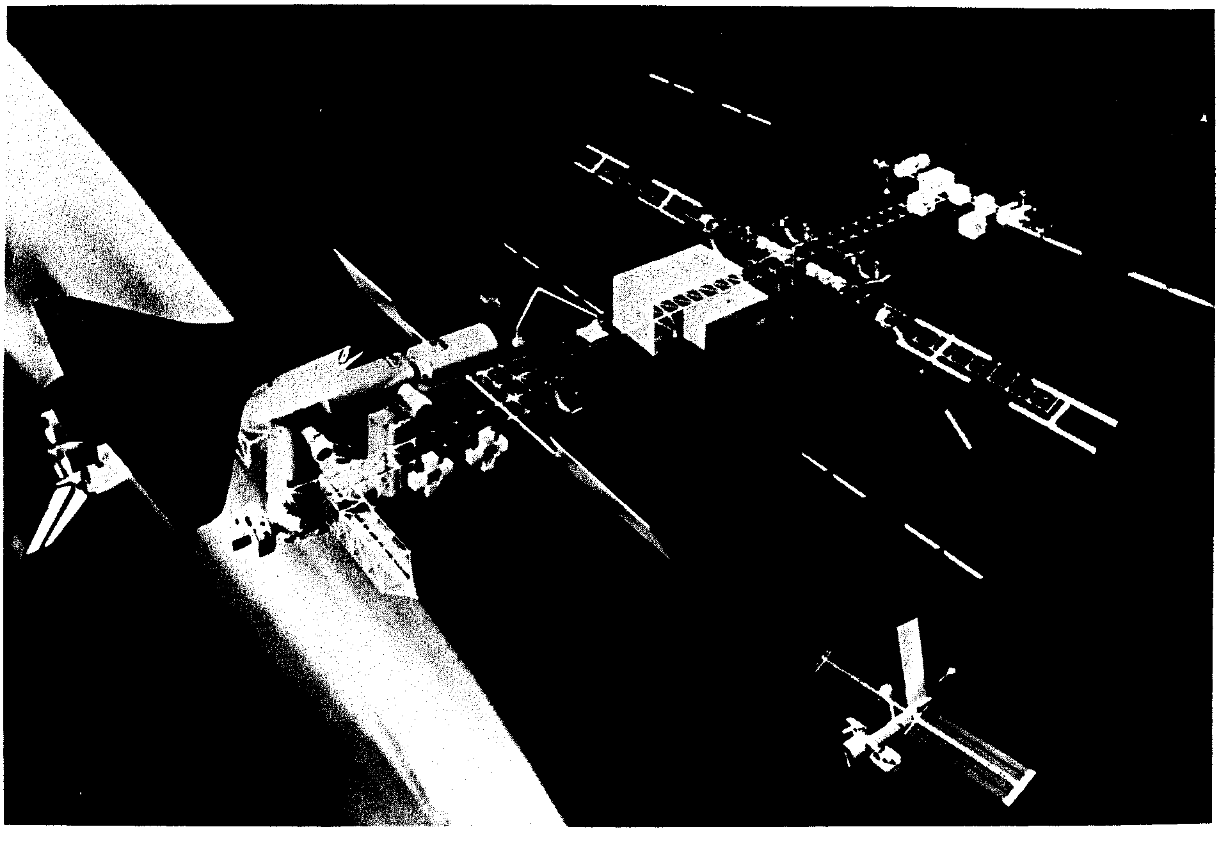
The major consideration that drove evolution of the Space Station configuration during phase B was the arrangement of the modules. In the reference configuration, the modules would be in a pattern that resembled a racetrack. Although seemingly efficient, this design suffered from two serious disadvantages. First, crew members could not easily move from one module to another without going all the way around the racetrack. Second, hatches along the module cylindrical section consumed room that could be better used for working or living quarters.

Instead, the SRR baseline configuration calls for the modules to be clustered in parallel, connected by nodes and tunnels that are exterior to the modules and thus consume little internal space. This arrangement permits ease of access and movement from one module to another, which is a key consideration in working and for safety in case of an emergency. It will accommodate additional modules as Space Station evolves over the years.

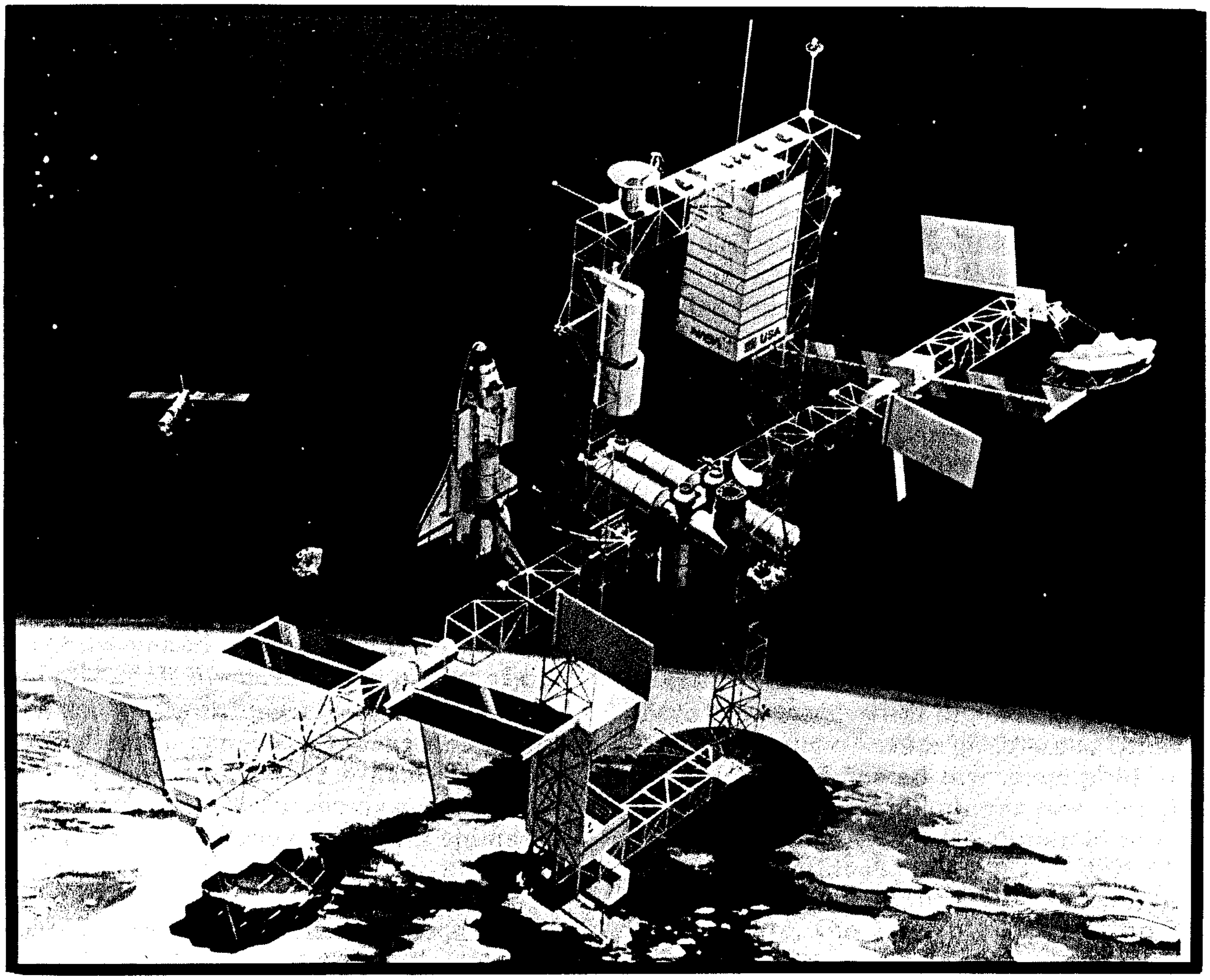
The SRR configuration calls for placement of the U.S. and ESA-provided Laboratory Modules directly on the flight line, near the center of gravity, in the prime position with regard to the 10^{-6}g zone. To one side, also in the 10^{-6}g zone, will be the U.S. Habitation Module and the Japanese-provided Experiment Module. All crew, from all nations, will live in the U.S.-provided Habitation Module.

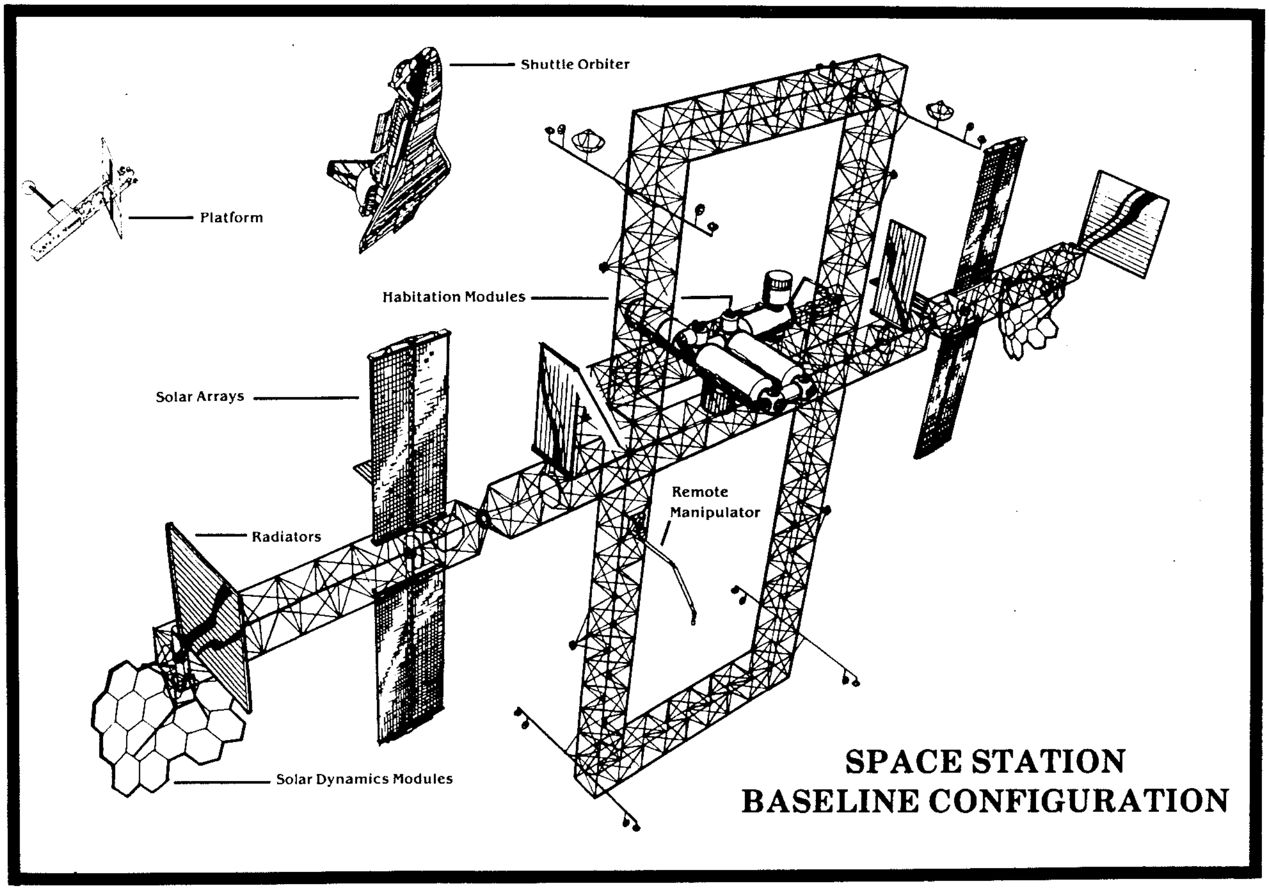
Construction of the Space Station represents a formidable undertaking, primarily because of its size. The materials and techniques to be used include comparatively little that is new. Trusses, for example, will be made of a composite material that NASA has used in space for some time. The elements of the composite react differently to heat and cold, with the net effect that the material does not change size as it heats in the sunshine and cools in the dark. The astronaut construction team will stack 5-meter (16.4 feet) cube trusses (the basic building block), gradually building the perimeter of a rectangle 94.5 meters (310 feet) by 45.7 meters (150 feet). Halfway across the rectangle, the astronauts will erect a transverse beam to which the manned modules will be attached.

NASA managers are planning extensive tests and practice sessions on Earth and in space to ensure that the assembly of the trusses goes smoothly. The goal here is to assemble the framework rapidly so that the three basic functional systems, electrical power, stabilization methods, and data links to Earth, can be installed. At that point, the foundation for Space Station will be in place.



POWER TOWER SPACE STATION REFERENCE CONFIGURATION





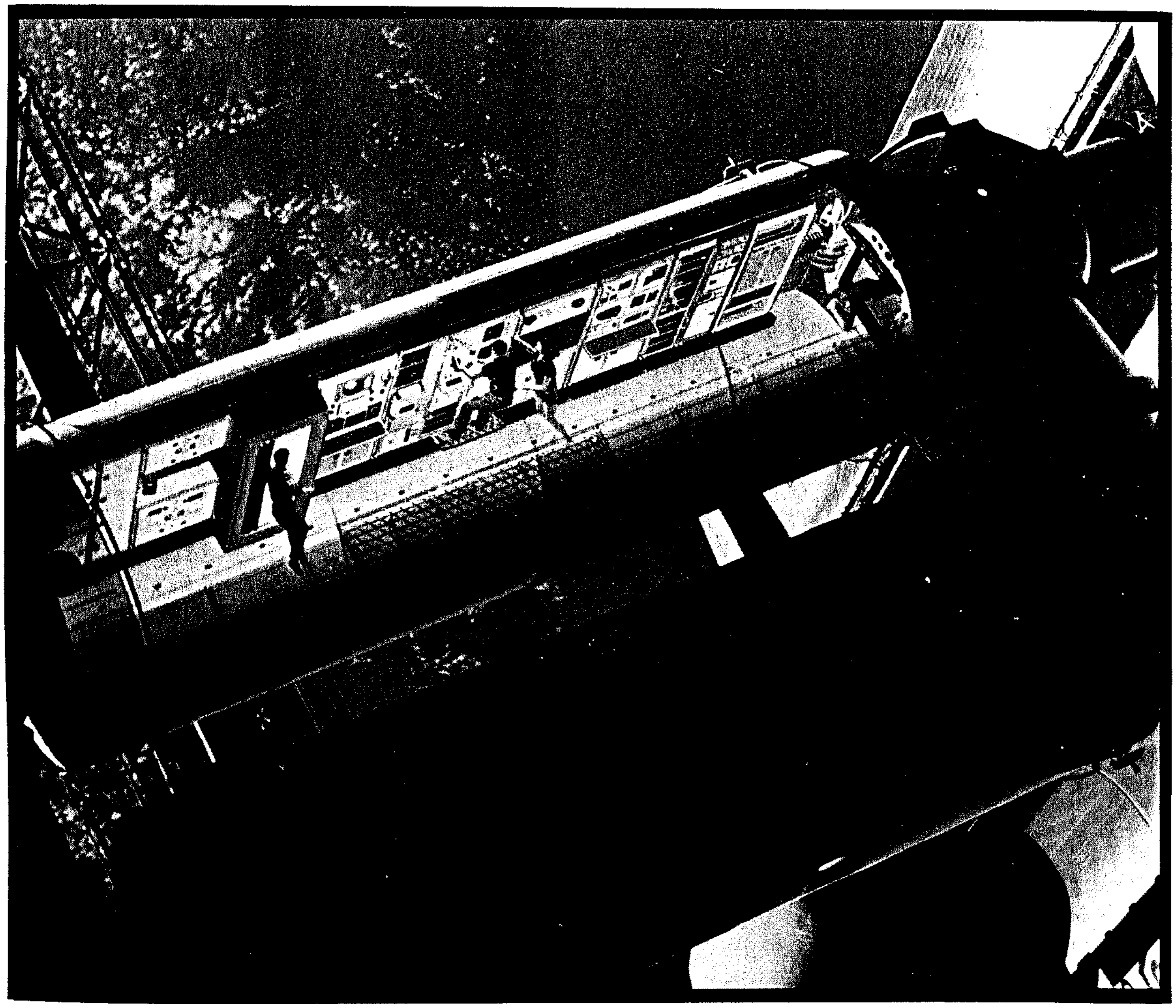
SPACE STATION
BASELINE CONFIGURATION

LABORATORY AND HABITATION MODULES

SRR established that the two U.S. modules will be 13.6 meters (44.5 feet) long and 4.45 meters (14.6 feet) outside diameter, with an interior diameter of 4.2 meters (13.8 feet). By comparison, the Skylab Orbital Workshop main living area was 8.2 meters (27 feet) long and 6.7 meters (22 feet) in diameter and was made from a modified Saturn SIVB rocket propellant tank which proved habitable for a crew of three for up to 84 days.

All modules will be pressurized to a sea level pressure of 14.7 pounds per square inch (psi). This decision has important implications. It will enable scientists and other users to conduct experiments under conditions that are easily replicable on Earth. This pressure will not require certification of experiment equipment and materials at a lower pressure, will allow use of off-the-shelf equipment, and will reduce flammability risks.

Sea level pressure also has a drawback. A crew member who intends to conduct an extravehicular activity (EVA) in the current Shuttle spacesuit must engage in extensive prebreathing before exiting the Shuttle for space. This suit maintains a pressure of 4.3 psi. In order to avoid the bends from the reduction in pressure from 14.7 to 4.3 psi, the Shuttle cabin pressure is maintained at 10.2 psi for 24 hours prior to the planned EVA. Then the crew member must breathe pure oxygen to purge all nitrogen from his or her blood.



NASA determined at SRR that the Space Station Program will use the Shuttle suit for the first phases of construction and operation. The Shuttle suit is currently available and its use ensures that assembly and early operation can go forward on schedule and for known costs. Construction crews will leave the Orbiter in the Shuttle suit and wear it during EVAs to assemble and tend the Station. In the meantime, NASA is exploring the engineering and cost considerations in designing and building a new suit that would maintain a pressure of about 8.4 psi. Such a high-pressure suit would require less prebreathing and, unlike the Shuttle suit, could be maintained on orbit.

LOGISTICS MODULE AND ELEMENTS

The logistics elements consist of four types of carriers which would be used to satisfy the logistics requirements of the Space Station. The four carriers support the transport of the following four generic classes of cargo: (1) pressurized cargo; (2) unpressurized cargo; (3) propellants; and (4) fluids. The four logistics elements are the pressurized module, the unpressurized cargo pallet, the propellant pallet, and the fluids pallet.

The pressurized module is designed to accommodate the resupply and return of hardware and consumables and to provide ready on-orbit access without EVA. The pressurized module will maintain a habitable environment for crew activity while providing a benign storage facility for equipment. The unpressurized pallets provide a capability to transport both dry cargo and fluids. The fluids pallet provides for the transport of fluids including the resupply of consumables for the ECLSS system. The propellant pallet provides for the transport of propellants including propellants for the Space Station, OMV, and platform(s).

The logistics elements provide for the ground-to-orbit, on-orbit supply/storage, and return-to-ground logistics requirements for the Space Station.

The logistics elements will be carried to the Station in the Shuttle Orbiter cargo bay. Various combinations of elements may be used in each resupply flight depending upon the particular logistics resupply requirements for the flight. Upon reaching the Station, the logistics elements may be exchanged for logistics elements brought to the Station on a previous flight. Whenever elements are brought to the Station to replace elements already at the Station (i.e., an element providing propellants, ECLSS consumables, etc.), the newly arrived elements will be transferred to the Station, hooked up, and checked out before the returning element is removed from the Station.

SERVICING FACILITY

A U.S.-provided servicing facility will be positioned on the truss framework to allow maximum access to service payloads and free-flying vehicles. The facility will contain an in-bay manipulator system with effectors (hands) that is teleoperated from a control station. The operator will be able to grasp a payload or free flyer, draw it into the servicing facility, and position it for refueling, maintenance, or repair by EVA crew members.

The servicing facility will include necessary hardware and distributed systems to berth, store, assemble, repair, refuel gas/fluids, refurbish and checkout free flyers, attached payloads brought to the servicing facility, and other attached payloads as necessary to support Mobile Servicing Center (MSC) capabilities. Hydrazine refueling of free flyers will also be performed in the servicing facility after the Space Station is permanently manned.

TELEROBOTIC SERVICER

At SRR, a U.S. provided telerobotic servicer (and accommodations) was baselined. This system will interface with and be utilized on the OMV, with positioning devices on the MSC and at the satellite servicing facility. It will be used for Station assembly, maintenance, payload servicing, and remote payload servicing with the OMV. The hardware includes the telerobotic servicer, attachment fittings, interfaces for utilities, and provisions for controls. It will also include accommodations for later growth and capability for Orbital Replacement Units (ORUs) and fluid resupply.

MOBILE SERVICING CENTER

Canada is studying a Mobile Servicing Center (MSC) which will build on the capabilities and technologies developed for the Canadarm Shuttle Remote Manipulator System. NASA will supply a transporter which will be used to move the MSC along the Station truss structure.

During the "Shamrock Summit" in March of this year, President Reagan and Prime Minister Mulroney agreed that visible, meaningful Canadian participation in the Space Station Program is important. Indeed, the MSC is on what NASA terms the critical path; an element of the Space Station whose delivery and performance are necessary to assemble the Station on-orbit.

The MSC will consist of a base structure with accommodations for payloads, orbit replacement units, utilities, and thermal control. Included with this structure will be the Space Station Remote Manipulator System as well as special purpose dextrous manipulators, end effectors, and servicing tools. The MSC provides for external and internal control stations from which the crew can control its operation. To aid the crew, the MSC also provides astronaut positioning mechanisms. In the current configuration, both arms are identical seven degree of freedom devices. However, the Astronaut Positioning Arm configuration is still under review. As an adjunct to the MSC, Canada is studying an MSC maintenance depot.

Canada will be responsible for developing, constructing, and integrating the elements it provides. NASA will be responsible for the overall systems engineering and integration that incorporates Canada's contribution into the overall servicing, maintenance, and assembly functions on the Station.

The MSC will have the predominant role in assembling and maintaining external portions of the Station, externally servicing attached payloads, moving equipment and supplies around the Station, deploying and retrieving satellites and other payload items, and supporting astronauts during extravehicular activity with positioning arms and associated controls.

EUROPEAN PRESSURIZED MODULE

The European Space Agency (ESA) is studying an attached pressurized multi-purpose laboratory module for international utilization primarily in the fields of fluid physics, life sciences research, and materials research. It will also include storage volume and accommodations for crew safe haven capability. The ESA laboratory baseline configuration is a module comprised of four Spacelab segments with dimensions similar -- but not identical -- to the NASA modules. The diameter is 0.25 m (10 inches) less than the U.S. common module; however, experiment/equipment racks will be standardized.

Both ESA and NASA are studying polar-orbiting platforms which would accommodate payloads including Earth, ocean, solar, and atmospheric observation, plasma physics, remote measurements, and environmental effects monitoring. ESA has indicated its primary interest in the area of polar platforms is in Earth observations. It is likely that one of the polar platforms will be in a morning orbit and the other in an afternoon orbit to maximize overall observation capabilities.

In addition to the permanent attached laboratory and polar platform, a joint ESA-NASA study is currently underway on a Man-tended Free Flyer (MTFF) for international utilization primarily in the fields of material and life sciences and fluid physics. The MTFF configuration would be comprised of two Spacelab segment pressurized modules and a resource module. It is being designed to be placed in orbit with a single Ariane 5 launch.

The joint study is concentrating on user requirements for the MTFF, as well as its developmental and operational impacts on the Station. NASA and ESA will assess the results of this study and other factors such as cost impacts to determine whether the MTFF would be a mutually beneficial element to add to the Space Station.

In the area of co-orbiting platforms, while ESA is no longer studying the provision of a co-orbiting platform as part of the cooperative project, activity will continue in Europe on an enhanced Eureca which could be available in the 1990/1991 time frame. NASA has acknowledged, under the terms of the Phase B Memorandum of Understanding relative to advanced development activities, ESA's intention to study an enhanced Eureca with potential for precursor Space Station applications.

JAPANESE EXPERIMENT MODULE

On March 10, 1986, Japan's Minister of State for Science and Technology ratified Japan's proposal to conduct preliminary design activities on an attached multi-purpose research and development laboratory.

The laboratory, known as the Japanese Experiment Module (JEM), consists of a pressurized module, an exposed facility, a scientific/equipment airlock, a local remote manipulator and an experiment logistics module. The JEM will be equipped to accommodate general scientific and technology development research activities, including microgravity research. In addition, the module will contain a multipurpose workstation that could include controls for attached payloads, the Canadian-provided Mobile Servicing Center, and the Station's fixed Servicing Facility. Provisions for system storage and accommodations for crew safe haven capability are also under study.

The JEM's exposed facility will extend aft like a deck from one end of the module, providing users research opportunities in the near-perfect vacuum environment of space with accessibility from the safety of a pressurized module. Linking the module and the exposed facility will be a one-meter (39 inches) diameter airlock which will be used with the remotely operated local manipulator arm to transfer materials and experiments between the pressurized interior and external environment.

The Experiment Logistics Module (ELM) attaches to the laboratory and can be removed, returned to Earth to deliver experiments and products, refilled with new materials on the ground, and brought back to the Station for reattachment to the JEM. The JEM will accommodate provisions for both pressurized and unpressurized experiment resupply. The ELM diameter of 4.2 meters (13.78 feet) is designed for compatibility with the Japanese H-2 launch vehicle to be available in the mid-1990s.

USER PAYLOADS

Three kinds of payloads will be delivered to the Space Station for users. In most cases, the Shuttle will deliver these payloads, which will be off-loaded at the Station by the Canadian Mobile Servicing Center. Although not in the current baseline, it is possible for international partners to deliver their own payloads via Expendable Launch Vehicles (ELVs). The ELV could ascend to the proximity (outside of 32 kilometers) of the Space Station Base, separate from its payload, and fall back to Earth. Such vehicles are the European Ariane 5 and the Japanese H-2. The OMV would fetch the payload and bring it to the Station Base. However delivered, payloads will be used for work inside a module or on a platform, or will be attached to the Station truss framework.

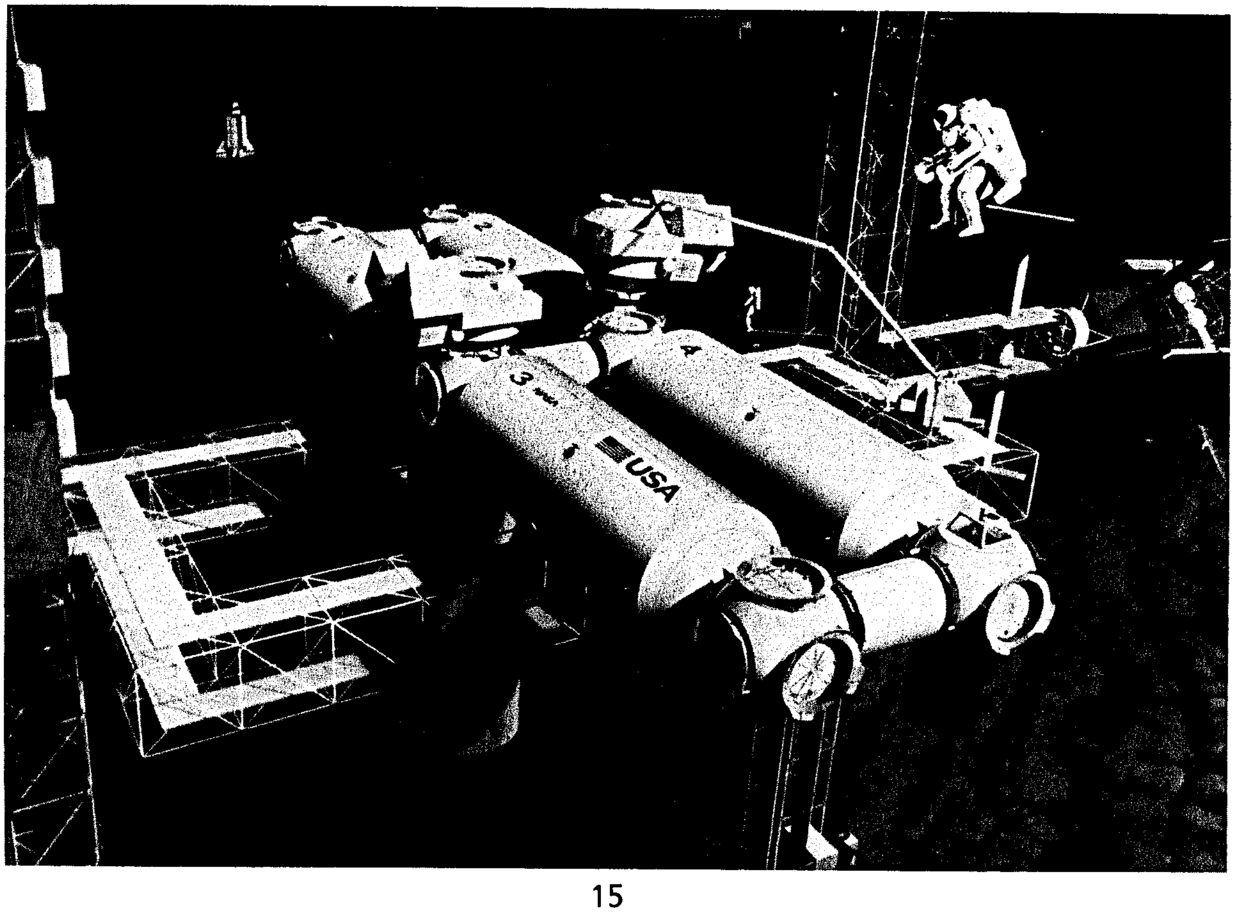
Payloads for use inside a module will be contained in racks and other packages that can pass through the 1.27 meter (50-inch) square hatches. Typically, these payloads would carry experiments or manufacturing materials for scientific or industrial use.

Payloads for use on a co-orbiting platform will be off-loaded at the Station Base. The OMV will then deliver the payload materials to the platform, or bring the platform to the Station where the payload materials will be transferred to it. These materials will typically include sensing devices that require extreme stability, or experimental or manufacturing processes that require an environment even closer to zero gravity than that available on the Station.

Finally, some payloads will be attached directly to any of the five locations on the truss framework of the Station, to the pressurized berthing ports on the nodes, or to the exposed facility on the Japanese Experiment Module. Electrical power and other utilities will be available. These packages might typically include a long-term physics experiment by an American or foreign university, devices to test a new communications system for a major U.S. telecommunications firm, or a self-contained processor to manufacture substances for an international pharmaceutical firm. Other packages might include telescopes, cosmic ray detectors, plasma physics experiments, tethers, and other diverse attached payloads. These payloads will make use of the low gravity conditions of the Station, and will be tended by crew members to ensure that they remain operational. Results of the work can be reported to Earth over the high-data-rate communications systems or as materials returned in the Shuttle.

PLATFORMS: POLAR AND CO-ORBITING

The Space Station also includes several associated, unmanned free-flying platforms. The United States and the European Space Agency (ESA) will each provide two platforms. The polar-orbiting platforms will be designed to accommodate various payloads primarily for Earth observation. They will be capable of carrying payloads for Earth and solar observations, plasma physics, remote measurements, and monitoring of environmental effects. The co-orbiting, general purpose platforms in low-inclination orbit are primarily for various space science and other compatible payloads, but will accommodate activities such as astrophysics and materials processing. The platforms will be self-powered with solar power and will be maintained and refueled *in situ* or by being brought back to the Space Station Base.



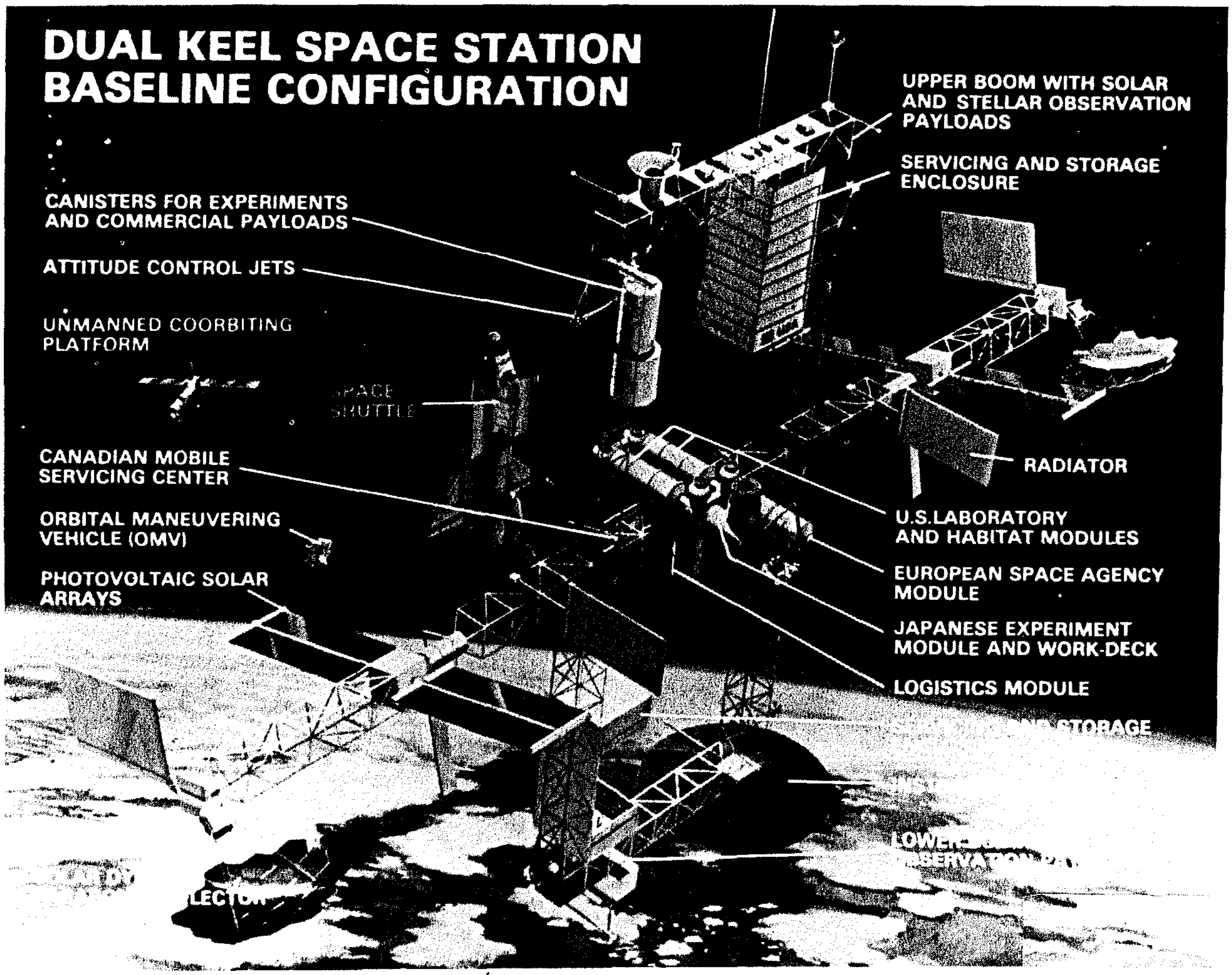
OTHER VEHICLE ACCOMMODATIONS

The capabilities of Space Station will be substantially enhanced by deployment of an Orbital Maneuvering Vehicle (OMV) now in competitive procurement. The OMV is a reusable, remotely controlled, free-flying vehicle capable of performing a wide range of on-orbit services in support of orbiting spacecraft. It is projected as an important element of the Space Transportation System (STS), designed to operate from either the Shuttle or the Space Station. SRR baselined only the servicing, storage, and utility accommodations for the OMV, not the OMV itself.

The multiple propulsion systems and onboard avionics enable the OMV to economically deliver and retrieve satellites at orbits not otherwise achievable. Precision maneuvering for proximity operations, including docking with an orbiting satellite, is accomplished by man-in-the-loop control of the OMV control station.

A corollary to the OMV is the Orbital Transfer Vehicle (OTV), which would be a larger, more powerful spacecraft capable of hauling large payloads up to high altitudes. For example, it could haul a platform or other device up to geosynchronous orbit at 22,300 miles. The OTV could carry an OMV with it to use for precise positioning of the payload, and as a tugboat in docking the OTV at the Space Station.

The OTV is currently under study, but is not scheduled for production at this time, nor is it part of the baseline configuration.


DUAL KEEL SPACE STATION BASELINE CONFIGURATION

SYSTEMS

An intricate network of pipes, cables, conduits, tubes, wires, and other components will carry the electricity, air, water, and other materials necessary for both Space Station and crew survival as well as smooth operations. Other systems will provide communications, propulsion, data management, and other capabilities that enable the crew to operate the base and the platforms and to serve user needs. Brief descriptions of the major systems follow.

ENVIRONMENTAL CONTROL AND LIFE SUPPORT

A permanently manned Space Station will require highly sophisticated and reliable systems to control air conditioning and pressure in the modules and to provide life-sustaining air and water. Because of its vital importance to crew safety, the Environmental Control and Life Support System (ECLSS) has received intense attention during Phase B.

The key characteristics of the ECLSS begin with cabin atmosphere. The modules will maintain a sea level pressure of 14.7 psi and the air will have the same mixture of Oxygen and Nitrogen as on Earth. Because the modules, nodes, and tunnels might leak slightly, and because air will be lost every time an airlock is opened, it will have to be replenished. The Oxygen for "new" air will come from an Oxygen generation option as yet undefined; possibly from the electrolysis of water. The Oxygen is blended with Nitrogen from an integrated Nitrogen system. The Nitrogen is resupplied via the Logistics Module.

When water (H_2O) is electrolyzed, Oxygen and Hydrogen will be recovered. The Oxygen will be released into the modules. The Hydrogen will be used to recover Carbon Dioxide (CO_2) from the air the crew has breathed; the Hydrogen will react with the Carbon to produce Methane (CH_4) and small quantities of water. The Methane will be disposed of, probably through venting to the outside in a careful manner that will not interfere with experiments. (NASA is also working on a way to break down CO_2 into Oxygen plus solid Carbon; the Carbon blocks could then be brought back to Earth.)

Water will be obtained from a dehumidifier from urine, and from waste water from experiments. A special phase change technology will be used for potable water. Various filter and membrane technologies are being considered for other water systems. Wash water will be used for crew handwashing and showers and for dishwashing (disposable plates and cups would produce too much trash on a long-duration flight).

Recycling air and water involves advanced technologies and will require development of sophisticated equipment. Other technologies involved in temperature and humidity control, ventilation, waste management (only solid waste will be returned to Earth), and other support systems also require advancement.

CREW

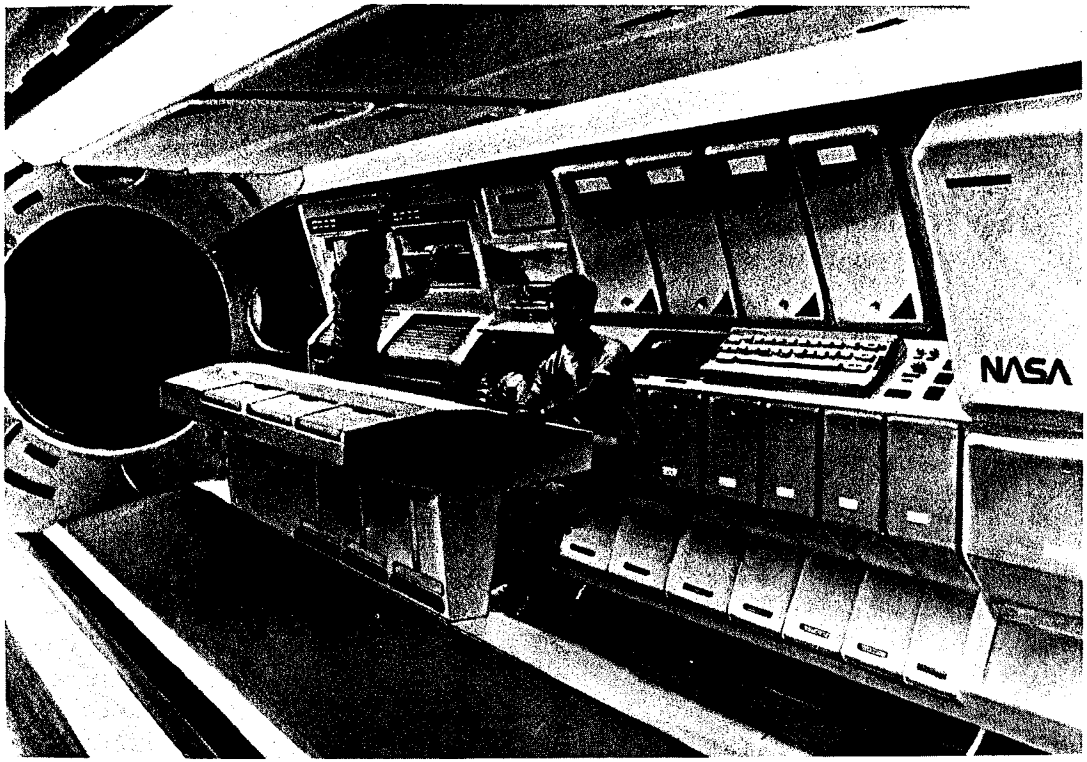
One major reason for assigning crew members to operate the Space Station is to ensure that facilities are available and functioning for the users. This requires that crew members be alert and productive. If the crew are to work productively for long periods of time (up to 180 days), they must have adequate sleep and exercise and enjoy some creature comforts.

NASA has studied the matter of productivity with some care. It is difficult to show that heightened habitability increases productivity, but the inverse certainly appears to be true. As a rule, where workers dislike their living or working conditions, they first lose creativity. On Space Station, NASA seeks to create a professional laboratory atmosphere and reasonably pleasant living quarters in the Habitation Module.

NASA is also aware that psychological problems can arise during long periods of duty in a confined place. Ample literature reports on behavior of scientists and other specialists who "winter over" at the Scott-Amundsen Base at the South Pole and other U.S. bases in Antarctica. Other experience has been gained from studies of Navy personnel who spend 90-day tours on nuclear submarines. Long flights by Soviet cosmonauts have added significant knowledge about living and working in space. NASA itself learned much from the duty tours on Skylab; the longest of which was 84 days. Based on these studies, NASA believes that the 90-day tour is realistic and will also minimize transportation costs of rotating crew.

The Space Station's manned systems will provide accommodations and comforts that are aimed at keeping the crew productive for at least 90 percent of the planned work schedule. That schedule currently calls for 6 hours of work with and for users per day for 5 days a week; in addition, each crew member will spend 2 hours per day on Space Station maintenance and about 2 hours exercising. Remaining time will be free.

Manned systems will provide accommodations such as a refrigerator, food storage and management, trash management (compacted trash will be returned to Earth via the Shuttle), showers and handwashers, a dishwasher, and laundry machines. Each crew member will have a private space in the crew quarters, and all crew will share a wardroom for meals, meetings, and recreation. In free time, the crew can rest, read, watch television, or simply gaze at the Earth below.



Food Preparation Area

EXTRAVEHICULAR ACTIVITY (EVA)

A great deal of Space Station activity will take place outside the pressurized modules. This extravehicular activity (EVA) will enable U.S. crew members to maintain the Space Station systems and to meet user needs as they arise. The crew operating the Canadian Mobile Servicing Center will also use EVA to work on payloads in the servicing bay. EVA will enable personnel to work on user payloads and to conduct experiments. At SRR, NASA established an upper limit of 1,800 to 2,000 manhours of EVA annually to support user needs and to maintain the Space Station.

The EVA necessary to assemble the Space Station will be conducted in the Shuttle suit, and the Shuttle will be the construction crew's base of operations. Communications, air supplies, and other support will come from the Shuttle as it stands by during assembly.

Once the Station is assembled and operational, EVA operations will transfer to the Space Station and a new Space Station suit will be used. Astronauts in the new suit will complete assembly, conduct on-orbit checkout of the Space Station, and prepare for user payloads and other user activities.

The two space suits are dramatically different in their characteristics and capabilities. The Shuttle suit's design heritage comes from the 1960's for the Apollo missions. It is a soft, low-pressure suit that maintains an internal pressure of 4.3 psi. The articulation is stiff, particularly in the arms and gloves; the wearer must exert considerable physical force to move and to perform such gestures as gripping or grasping a pipe or tool. The Space Station suit is to be a hard, high-pressure suit that maintains an internal pressure of 8.4 psi. It will be considerably more flexible in articulation and more comfortable. However, the hard suit also has fabric gloves and they become very stiff at high pressure. An advanced development program is underway to improve glove dexterity and tactility and to reduce hand fatigue. The use of the high pressure suit is critically dependent on this development.

With the Space Station suit, the wearer can decompress to 8.4 psi with no prebreathing. This shortened preparation time greatly adds to productivity by conserving the wearer's energy and by lengthening the time that the wearer can be conducting EVA.

GUIDANCE, NAVIGATION, AND CONTROL

The Space Station will fly at an operational altitude of 250 nautical miles at an orbital velocity of about 18,000 miles per hour on a course that will bring it directly over the Kennedy Space Center from where it was launched. The course was chosen for ease of Shuttle access for logistics resupply and, if necessary, rescue. The Station will circumnavigate the Earth about every 90 minutes and will be in the umbra (shadow) of Earth for up to 20 minutes per orbit. It will fly in the very hot sunshine and in the very cold of space.

Maintaining the correct altitude and a stable attitude is important for two reasons. First, without attitude control, the Space Station would drift from the sunline and significantly reduce the solar power system efficiency. In this state, it would also be difficult to maneuver for rendezvous with another vehicle. Second, users need to know exactly where the Space Station is, and many require a stable base for conducting experiments and precisely pointing observing instruments.

Orbit-keeping would be a comparatively simple matter were it not for several factors. Most importantly, Space Station will experience drag from the very small amount of atmosphere even at orbital altitudes and from solar wind. Second, it may experience tiny shocks from the impact of arriving spacecraft. Sensitive berthing mechanisms and shock absorbers will reduce this effect, but allowance must be made for an occasional jostling from an arriving Shuttle, OMV, or other spacecraft. Drag will cause the Station to slow down and lose altitude ("orbital decay"), while a jostling may cause it to pitch or sway at excessive amplitudes that cause equipment to deviate from specified performance.

The Guidance, Navigation, and Control (GN&C) system will control altitude as well as roll, pitch, and yaw attitudes. The system first establishes the Space Station position with respect to the stars (through use of star-trackers) or the Earth (through a limb-scanner). Once its position is fixed, the Station's GN&C system provides it three-axis control to defined requirements.

Orbital decay can be counteracted either by continuous firing of microthrusters with extremely small forces to maintain altitude, or by discrete firing of much larger thrusters to regain lost altitude every 90 days or so. At SRR, NASA decided on the latter approach. This allows the Station to drop in altitude periodically, timing the descent to approximately 220 nautical miles to coincide with logistics resupply trips by the Shuttle. It is more efficient to bring the Orbiter up to only 220 miles than to bring it up to the operational altitude of the Station since the Shuttle can carry a heavier payload to the lower altitude. After rendezvous and resupply, the Station will fire its onboard thrusters to regain operational altitude.

Space Station attitude (pitch, roll and yaw) deviations are automatically corrected by a device called a "control moment gyro" (CMG). A CMG works just like a toy gyro top. When you press on a gimbal of a gyro, the fundamental gyro principles (based on Newton's laws) creates a force equal to but in the opposite direction from the disturbing force. This principle maintains the spin axis fixed in inertial space but causes a displacement of the gyro gimbal. An equal and opposite force will bring the gyro gimbal back to its original position. When the gimbal reaches its stop (as far as it can mechanically go) the appropriate attitude control thrusters will fire bringing the gimbal back to its neutral position.

The GN&C system uses well-established technology. It will enable users to predict the exact orbit speed, attitude, and altitude at all times, and will provide users with a stable base from which they can fine-point their instruments.

PROPULSION

Atmosphere drag will cause the Station's orbit to come closer to the Earth. Calculations will be made to time the decay to coincide with Shuttle resupply every 90 days. At that point, orbit maneuvering thrusters positioned at the four corners of the Station will propel the entire Space Station Base back to its operational altitude.

These thrusters may use gaseous Hydrogen and Oxygen (as fuel and oxidizer) similar to the larger main engines of Shuttle but much smaller in size and power. Most attitude and orbit maneuvering thrusters have used Hydrazine and Nitrous Oxide (as fuel and oxidizer). This technology will continue to be evaluated along with the Hydrogen and Oxygen thruster technology.

POWER

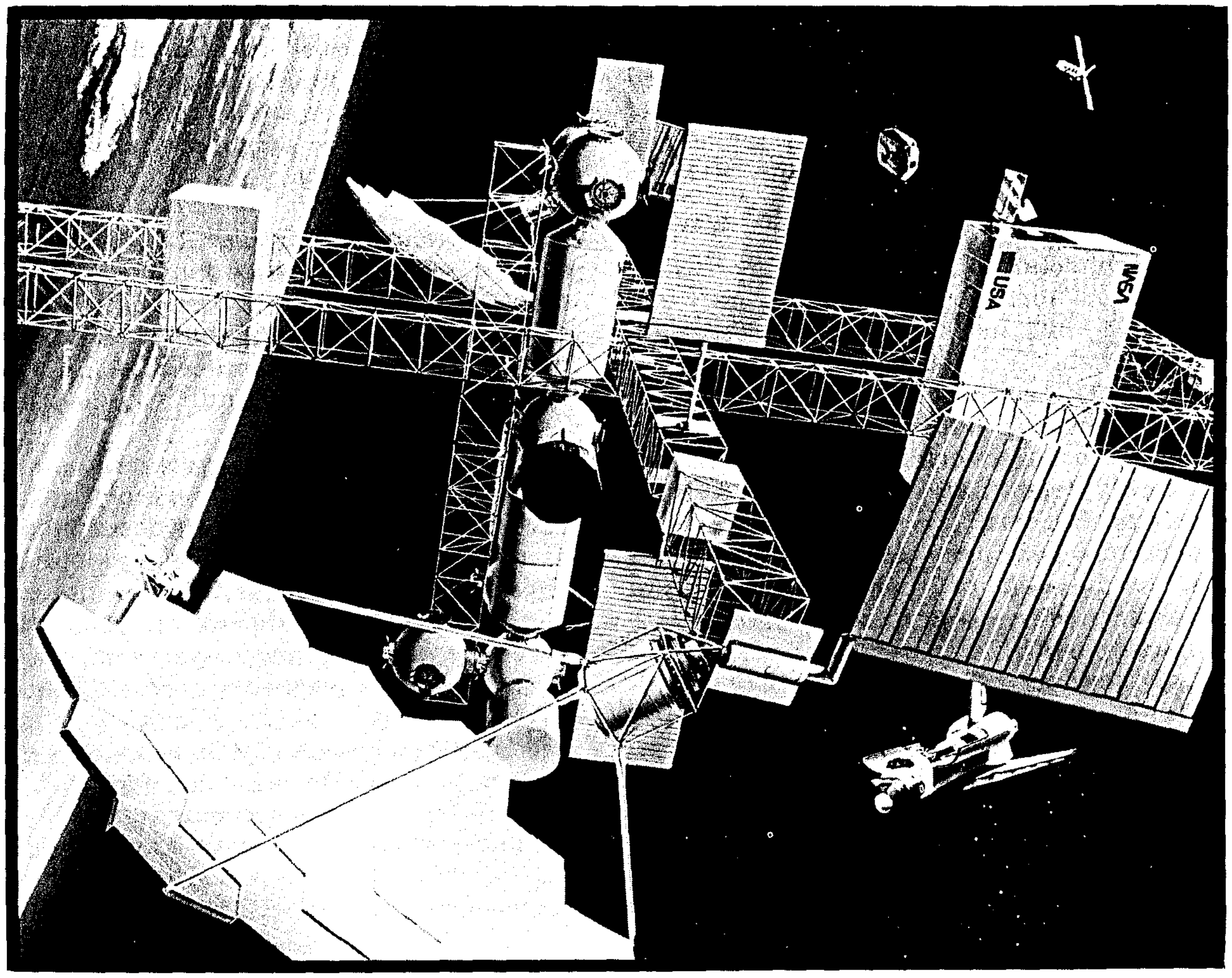
At SRR, NASA determined that the Space Station Base will provide 75 kilowatts (kw) of electrical power to operate and to feed power to users. This is an extremely high level of power compared to previous spacecraft. Some user activities, such as running high-temperature furnaces, will require substantial amounts of power.

Of the 75 kw, which is enough energy to run 25 all-electric homes, 50 kw will be allocated to users and 25 kw to the Space Station base itself for housekeeping requirements. The platforms will have their own separate power systems of approximately 8-12 kw. Users will consume some energy on-line; the Canadian Mobile Servicing Center, however, will store power in batteries and operate off the batteries. Power for the Space Station Base will be generated by a hybrid system employing both photovoltaic cells (25 kw) and solar dynamic heat engines (50 kw).

Photovoltaic, or solar array generation, converts sunlight directly to electricity and is the customary method of generating power in space. The large solar arrays cause drag, however, which contributes to orbital decay, which in turn requires more propellant to reboost the Space Station back to operational orbit. To generate 75 kw, for example, eight arrays measuring approximately 9.15 meters (30 feet) by 24.4 meters (80 feet) would be needed. The arrays must be large because the method is inefficient, converting only about 8 percent of the Sun's energy to power.

At SRR, NASA arrived at a compromise. Space Station will deploy 4 smaller arrays measuring 10.2 meters (33.5 feet) by 13.3 meters (43.6 feet) for photovoltaic conversion, and distribute the energy directly to Space Station operations or store it in nickel-hydrogen batteries (which are more efficient than the conventional nickel-cadmium batteries). This tried-and-true technology provides the Space Station with an easily deployable method of power generation. For assembly and early operational phases, photovoltaic arrays can be packaged into a very small volume in the Shuttle's cargo bay and can, therefore, be placed in orbit along with a large amount of Station structure on the first two assembly flights.

The second part of the hybrid system involves solar dynamic generators (heat engines). The Space Station Base will erect parabolic mirror segments to collect heat from the Sun's rays; that heat, which can reach temperatures of close to 2,000 degrees F, will drive turbines that generate electricity. Solar dynamic energy conversion is more efficient than photovoltaic; therefore, the mirror collectors can be one-fourth the size of the photovoltaic arrays. They cannot, however, be as compactly packaged in the Shuttle and will therefore require a dedicated Shuttle flight for their delivery to the Station.



A decision remains to be made on the kind of heat engine to be adopted; it will probably utilize either the Rankine or Brayton cycle. As the Space Station approaches the Earth's shadow, the system will store heat by melting a salt, which will give up its heat during passage across the dark side and thus continue to power the turbines. Solar dynamic generators will be used for Station evolution requirements.

At SRR, the electrical power system was baselined as providing 400 Hertz, 208/220 volt, 3-phase sine wave utility grade power to the user interface. The power system must, however, meet many user needs and therefore may be altered somewhat in its final form.

DATA MANAGEMENT

A capable and responsive Data Management System (DMS) is essential to safe and sound operations and to providing users with the kinds of services they need. NASA believes that the baseline configuration established at SRR identifies what is needed initially. The DMS is the onboard portion of the overall space and ground system called the Space Station Information System (SSIS).

The architecture of the DMS will consist of two global local area networks, network interface units, mass storage devices, and a family of standard data processors. One of the global networks will carry Space Station engineering and housekeeping data. The other global network will carry low rate (roughly less than 10 mbps) payload commands and data to and from user payloads. Separation of user and engineering data will help assure safe and interference-free operations. High rate payloads will be serviced by dedicated buses connecting them to the Communications and Tracking Systems.

These processors will run applications programs written primarily in ADA. Approximately 20 standard data processors will be distributed throughout the Space Station. As much equipment as possible will be standard; all keyboards and workstations will be identical or similar in order to reduce training time and to ease access for users.

The DMS will store sufficient engineering and payload data to provide adequate buffer during passage through the zone of exclusion (approximately 15 minutes per orbit) when the Space Station antennas cannot see a Tracking and Data Relay Satellite System (TDRSS) satellite or during temporary outages.

The SRR focused on DMS needs for onboard operations; work continues on the ground facilities that will support those operations.

COMMUNICATIONS AND TRACKING

The Space Station Program is comprised of many flight elements, many with different communications needs. It must also accommodate users from different nations and different industries. Communications requirements are thus diverse and extremely extensive and complicated. Communications must accommodate, among others, the following:

- Ground to Space Station.
- Space Station to space vehicles.
- Space Station Base to Station Platforms.
- Space Station to astronauts on EVA.
- EVA astronaut to another EVA astronaut and to ground.

The communications system must be capable of transmitting and receiving both audio and video, and it must accommodate user needs to transmit very large amounts of digital data. All of these functions must be performed within assigned, internationally agreed upon frequency spectrum allocations. Common hardware across the many flight elements would be ideal, but user needs differ so much that this goal probably cannot be met. During early Phase B, the cost of the optimal communications and tracking system rose well above budget limits, and those costs were the focus of attention during the SRR process.

The Communications and Tracking (C&T) System actually consists of many different subsystems; each designed to accomplish specific functions. Some of the C&T system, for example, enables communications to and from the ground via the TDRSS. Other portions permit communications with surrounding flight elements such as Orbital Maneuvering Vehicles, nearby satellites, and astronauts at work outside the Space Station. Still other C&T subsystems support position determination (to be accomplished from the signals emanating from the National Global Positioning System complex of satellites) and communications inside the modules (e.g., crewman to crewman).

The baseline configuration calls for a low-data rate S-band communications system through the TDRSS to be used during the assembly and checkout stage, and then to be put in a reserve as a backup to the main system. The main communication system is expected to be Ku-band, which provides substantially more bandwidth than the S-band and thus can carry video as well as high-rate engineering and payload data and experiences less interference from other users.

The Station will carry many antennas. One of these will be directed at TDRSS satellites; communications will break when, after leaving one satellite, the antenna is rotated to acquire the next satellite. TDRSS links are secure.

For the tracking system, SRR removed the radar system for tracking objects or vehicles within 20 miles of the Station; tracking will be performed through the use of a differential Global Positioning Satellite (GPS). SRR also reduced the number of television cameras (from 44 to 22) that will be located on the Station; these can zoom, pan, and tilt and will transmit their images to television monitors in the workstations in the modules and -- for both operations and safety reasons -- to screens in other modules.

STRUCTURES AND MECHANISMS

The framework of the Space Station will be an erectible truss latticework made of composite graphite tubes connected by aluminum fittings. The truss will consist of cubes five meters (16.4 feet) on a side; they will be made from 5 cm (2-inch) diameter tubing that is easy to grasp even with the heavy gloves of the Shuttle space suit. The cubes will be connected to create the keels and cross members. NASA considered, but decided against, spring-loaded structures that would deploy automatically, and chose the erectible structure advocated by the NASA Langley Research Center.

The 5-meter size of the cubical truss allows easy access to and storage of payloads from the Shuttle cargo bay. Also, the truss can easily accommodate new structural arms or extensions in any orthogonal direction during the evolution of the Space Station.

The pressurized module shell will consist of a single waffle pattern layer of aluminum. Outside of this will be a second layer, an aluminum shell called a bumper shield, which will be the first point of impact for incoming micrometeoroids and space debris. Between this sacrificial bumper shield and the outer shell will be many layers of insulation (for example, Mylar, Kapton, or Kevlar) which will break up and disperse the micrometeoroids that penetrate the bumper and also insulate the shell from the heat of the Sun and the cold of the umbra.

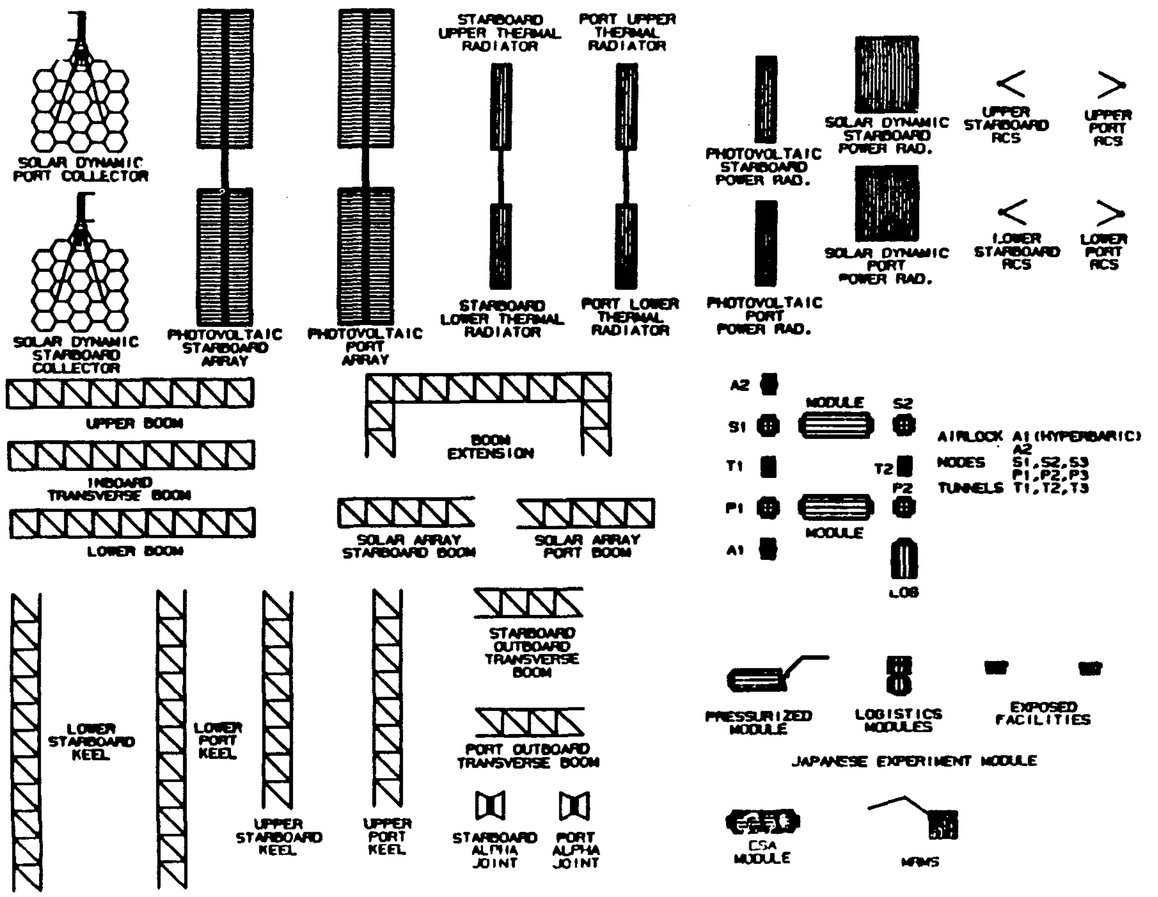
Micrometeoroids, which travel at many thousands of miles per hour, cannot be tracked on radar. They shower through space in predictable distributions, however. NASA uses tables showing the statistical probabilities of being struck by a micrometeoroid, which range in size from a few millimeters up to a centimeter in diameter, i.e., from the size of a grain of sand to larger than a ball bearing.

Large meteoroids are extremely rare in space -- fortunately, because they can reach the size of a car. The probability that the Station will be hit by such a large object is so small that it cannot be realistically calculated. No design or construction features take this event into account. Nonetheless, strategies such as radar detection and collision avoidance will be developed to protect the Station from large objects.

At each end of a module will be a hatch to which a node will be attached. The hatches in all pressurized compartments are 1.27 meters (50 inches) square with 30 cm (12-inch) radius corners; larger than any hatches on previous NASA spacecraft. These hatches allow users to move larger pieces of equipment into the modules than they otherwise could, and they allow for evolutionary growth.

Nodes and tunnels serve as the pressurized connections between modules. A node is a 3.2 meter (10.5 feet) diameter aluminum sphere providing six 1.98 meter (78 inches) ports for attachment of tunnels for access and permitting the module to grow in three dimensions. The tunnels will be of relatively unsophisticated construction, consisting of 1.98 meter (78 inches) diameter aluminum cylinders almost 6 meters (19.8 feet) long. They will be pressurized but will otherwise be austere.

BASIC SPACE STATION ELEMENTS



FLUIDS

Several fluids systems will serve housekeeping and user needs. They must accommodate substances ranging from drinking water to highly toxic or corrosive chemicals. NASA has adopted a guideline that substances that are not hazardous to the crew can be piped inside the modules, nodes, and tunnels; those that are hazardous must be piped outside.

The Station will provide special fluid systems to convey materials such as cryogenic Oxygen (which flows in liquid form at approximately -420 degree F.) and superfluid Helium (also super cold). These fluids are used for purposes such as cooling electronic equipment that gives off heat as it uses electrical energy. The fluid systems do not stand alone and must be viewed as part of other systems, such as ECLSS, propulsion, and thermal. Station designers will use common design pumps, piping, thermal systems, and other components to the extent possible. One problem being addressed by the advanced development program is how to transport fluids across the rotating joints that link the truss framework to the large photovoltaic arrays.

THERMAL MANAGEMENT

The current NASA design for a manned Space Station contains a baseline Thermal Management System (TMS) that uses components and subsystems never before used in manned spacecraft. The technology upon which this design is based is that of two-phase heat transport. The confidence necessary to baseline this change in system approach has come from the early results of a long-term TMS technology development activity that was initiated in 1979.

The Space Station TMS is functionally divided into three areas; heat rejection, heat acquisition and transport, and systems integration. In the area of heat rejection, efforts are underway to develop components and subsystem options for large, long-life heat pipe radiators. The options include: various high-capacity heat pipes; high-efficiency radiating fins; radiator to heat-transport-loop interface devices; and radiator gimbals that can allow orientation to the minimum thermal environment.

A further aspect of the TMS definition is related to the practical aspects of construction and erectability of the radiators on orbit and the packaging, delivery, initial setup, reliability, maintenance, and growth.

Thermal control requirements for future space applications are becoming increasingly more stringent with respect to temperature control, quantity of waste heat to be rejected, and transport distance. Conventional single-phase, pumped-liquid technologies, although known to be quite reliable and functional in current uses, are inadequate for the new missions in many ways. Two-phase loop concepts can potentially satisfy all currently identified operating requirements with good adaptability and versatility and with very low weight and power penalties to the overall system.

The central element of the system is a thermal bus, which provides the function of centralized heat acquisition and transport. The thermal bus is a two-phase loop which provides a uniform thermal control source for any user, interfaces for all heat loads and heat rejection elements, and transport potential from the heat sources to the heat rejection system.

Areas of interest in the systems integration category include: use of body-mounted versus deployed radiators; methods of fault detection; isolation and control; use of thermal storage devices or steerable radiators for minimization of radiator area and weight; determination of the desired temperature levels and quantity of thermal buses; methods of on-orbit repair or replacement of components; and accommodation of evolutionary growth requirements.

Many studies, flight experiments, and test bed activities are underway to define the total thermal system. An important aspect of this effort is to define any subsystems or components not currently available that offer significant improvement from an overall system point of view.

DESIGN CONSIDERATIONS

A number of concepts and considerations will guide managers and designers during the Phase C Design and Phase D Development stages of the Space Station Program. Brief descriptions of the major areas of interest follow.

SAFETY AND SAFE HAVEN

Alarm bells sound and emergency lights blink in all modules and at other key points on the Space Station. Alarms are simultaneously triggered on board and in the Mission Control Center at NASA's Johnson Space Center in Houston. Fire has broken out in a Laboratory Module on the Space Station!

In this hypothetical case, a planned response would instantly go into effect. In the afflicted module, the crew would seal a hatch electromechanically at one end and then escape through the other. As soon as they had exited and sealed the hatch, they would turn off electrical power and trigger release of a fire suppressant (Halon), and continue making their way to the designated safe haven point. Safe haven would be located in the remaining pressurized volume of the station, isolated from the flames. The crew members would gather to assess the situation and plan their next move.

If instruments indicated that the fire was out, the crew would prepare to reenter the module and repair the damage, clean up, and otherwise make ready to resume operations. If instruments indicated that the fire was still burning, the Station commander would probably order the module opened to the outside; interior pressure would push the air, fumes, smoke, and Halon out into the vacuum. Deprived of all air, the fire would be extinguished. Later, suited crew members would inspect the damage, close the vent, repressurize the module, and begin repair operations.

Fire is not the only possible danger; other dangers exist as well. A large meteroid could penetrate the hull of a module. Far more likely than that, a crew member could be injured or become seriously ill. In high inclination and polar orbits, the crew could be exposed to large doses of ionized radiation from an unpredictably large solar flare.

The Mission Control Center and other managers would monitor events on the Space Station by telemetry and by voice communications. Program managers would assess the readiness status of a Shuttle if rescue became necessary. Safe haven then, is a capability; not necessarily a specific place or module. This capability is planned to exist in at least two separate modules or isolated volumes.

For many years, space programs in the United States and other nations have searched for the best answer to safety in space. Two general options are available: safe haven and self-rescue (lifeboat). A third option is a combination of these two.

Safe haven calls for outfitting the spacecraft with places, provisions and procedures that enable the crew to retreat to a safe place, relying on life support systems for a given minimum length of time, and await rescue from the ground. Space programs selecting this option have normally invested financial and technological resources in increasing systems redundancy and in requiring very high levels of reliability. The idea is to make the overall operation of the spacecraft so reliable that the need to escape becomes a remote likelihood.

The self-rescue or lifeboat principle calls for immediate departure from the spacecraft to return to Earth. The lifeboat would be capable of carrying all crew members with minimum life support systems for just a few hours; enough time to come home. It would have retropropulsion rockets and a heat shield. Although the lifeboat sounds simple, it would have to be a full-fledged reentry vehicle that stood by in full readiness at all times, to be used on a moment's notice. It must not fail, and it must itself not cause a problem, such as a fire or explosion while attached to the orbiting Station.

The U.S. space program has applied, at one time or another, various safety concepts and principles. For example, the Apollo Command and Service Module (CSM) was able to descend to a somewhat lower lunar orbit to rendezvous with the two Lunar Module astronauts in the case of an abnormal ascent situation but was no help for astronauts stranded on the moon for some reason. On Apollo 13, the Lunar Module acted as a safe haven for the disabled CSM. In Skylab, on the other hand, the crew launched into orbit in an Apollo CSM, and docked the CSM to Skylab. The CSM remained attached to Skylab and could have brought the crew home in an emergency. The CSM was the only way home for the Skylab astronauts; emergency or normal return. Consequently, this is not considered a lifeboat. The Soviet Union uses a Salyut spacecraft for the Mir Space Station as the normal and emergency return vehicle, and earlier this year utilized that vehicle in an emergency situation when a Cosmonaut became ill and a rapid unplanned return to Earth became necessary. Again this safety method is not considered a lifeboat because it is the planned and only way of crew return.

At SRR, NASA managers have decided to design the Space Station for optimum safety and reliability, and have designed into the structure and systems the characteristics of the safe haven principle. The development of distributed systems and redundancy for critical systems is important to this concept. They have not, however, ruled out eventual inclusion of a lifeboat.

Safe haven design characteristics are many, and most of them make sense as safety precautions no matter what the rescue philosophy. They begin with the positioning of the modules. The current agreement eases movement from one module to another, and shortens the time needed to move to any particular one. The Laboratory and Habitation Modules have dual egress capability, meaning that the crew can escape from either end. Neither the ESA Laboratory Module nor the Japanese Experimental Module, which ends with a platform instead of a node and tunnel, will have dual egress capability. They are both connected to the raft-like truss structure, but each has one end unattached to another module or tunnel.

In the unlikely event of an emergency in the node adjacent to the ESA or JEM modules that traps the crew inside, current safety planning calls for moving the ESA module or JEM Logistics Module to the unaffected portion of the module pattern using the Canadian MSC. The MSC would swing the module over to attach it to a node, allowing the crew to enter the main complex of modules. This would be a hazardous rescue. Most emergencies in the module pattern would allow enough time for crew egress and isolation of the affected volume so as not to require removal and transfer.

Another design consideration is that experiments and other uses of the Space Station must comply with NASA safety requirements. For example, NASA requirements might state that during certain hazardous activities, crew members must leave the Laboratory Module and conduct the experiment by remote control. This is an important area in which agreement among NASA, its international partners, and other users is essential. Discussions in this area are continuing.

Thus, Space Station at SRR is configured for application of the safe haven principle, but it also could accommodate a lifeboat. A preliminary cost estimate of a lifeboat shows that it can not be included in the initial $8 billion Space Station budget. Because the safe haven principle relies on rescue from the ground via the Orbiter, the Challenger accident raises serious concerns about the readiness of the Shuttle for rescue. In light of the grounding of the Shuttle fleet following the accident, NASA has decided to reconsider application of the lifeboat principle for Space Station and has appointed a special committee to reexamine this issue.

REDUNDANCY AND RELIABILITY

No matter what principle of rescue is applied to a space operation, and what resources are poured into rescue capability, there is no substitute for reliable vehicles and systems that enable the crew to operate the spacecraft safely. NASA has long believed that safe and sound operations begin with redundant and reliable equipment and systems.

Standards of safety for manned and unmanned vehicles obviously differ, with those for manned vehicles much higher. However, since crew members in manned vehicles can usually repair and restore failed systems, redundancy and reliability considerations can take this possibility into account.

At SRR, two key decisions affect redundancy and reliability. First, the entire Space Station will be used as a reference in applying safety standards. That is, the entire complex of trusses, modules, and other elements will be taken into consideration in determining whether a system meets the failure tolerances established for the Station.

The "Fail Operational - Fail Safe" philosophy of previous manned spaceflight programs needed to be changed for spaceflight missions that are almost continuous operations over years. On Space Station, systems can be repaired whereas on Shuttle, Skylab, Apollo and previous shorter duration missions, servicing, repair and replacement were not well developed nor were routine maintenance concepts. Repairs were made by necessity not by design.

Since the Space Station will have an indefinite lifetime and will be in a remote environment, Space Station reliability is driven by both safety and the need to provide a productive work environment within set constraints. Constraints on a productive work environment for the Space Station include: Shuttle weight and volume uplift capabilities, crew time available for maintenance, on-orbit spares provisioning, on-orbit maintenance philosophy, and the cost of success versus the cost of failure. These constraints will drive the functional redundancy to levels well in excess of those required for safety. The basic minimum functional redundancy requirements driven by safety are expressed in the following table.

FUNCTIONAL FAILURE TOLERANCE

FUNCTIONAL CRITICALITY	FAILURE TOLERANCE	FUNCTIONAL REDUNDANCY*
Crew Safety and Station Survival	2-Failure Tolerant	3 minimum
Critical Mission Support	1-Failure Tolerant	2 minimum
Noncritical Functions	0-Failure Tolerant	1 minimum

* Number of ways to accomplish the functions

The current safety philosophy for criticality 1 system functions requires that immediate maintenance actions will be initiated to restore a redundant path in the event the system's redundancy drops below that prescribed in the preceding table. If after dropping one level below the required 2-failure tolerance a second failure occurs (leaving only one functional path to maintain crew safety and Station survival), a "safe haven" status exists. A safe haven status prescribes that only those systems necessary to maintain crew safety and Station survival will require active crew support until the crew/Station is rescued.

RACKS

Space in the modules for equipment and storage of materials will be at a premium. Every cubic centimeter of interior space will be accounted for, consistent with providing the open areas necessary for crew work and freedom of movement.

SRR established that the Habitation and Laboratory Modules will be taken up to the assembly point only partially outfitted; to be completed on orbit. Equipment and hardware will be taken up in racks, which are metal frames that are form-fitted to the contours of the module hull and that contain equipment for communications, the galley, sleeping places, and other uses. Racks in the Laboratory Module will contain scientific equipment such as electronic measurement devices and furnaces.

Two sizes of racks will be used: equipment racks and functional units. The experiment racks will be interchangeable with those of international partners, while the functional units will be sized to fill the available rack space of the larger diameter U.S. modules. The functional units are large enough to accommodate the 95th percentile American crew in individual crew compartments, showers, toilet facilities, etc.

Racks will be taken up in clusters in the cargo bay of the Orbiter, or in the U.S. Logistics Module and will be sized to fit through the 1.27 meter (50 inches) square hatch of the modules.

COMMAND AND CONTROL ZONE OPERATIONS

Safety is the paramount concern in the zone immediately surrounding the Space Station. NASA has established a control zone (currently 32 kilometers or 20 miles) in the fore and aft, up and down directions, similar to airports on the ground. This zone is called the Command and Control Zone (CCZ). The CCZ is of critical concern because vehicles will be arriving at and departing from the Station regularly; they will include small unmanned free flyers, large orbiting platforms, the Orbital Maneuvering Vehicle (OMV), and the Space Shuttle. These must not be allowed to collide with the Space Station Base. Even a minor collision could cause the Station to shake and oscillate slightly, which might disrupt user experiments or processes. A slightly harder docking could cause the Station attitude control problems, which would require expenditure of thruster fuel to correct. A more violent collision could cause structural damage to the Station and may be life threatening.

Thus, Flight Rules are under development that will guide and direct CCZ operations. For example, the Station Commander will have final say in all cases about whether an arriving vehicle will be permitted to enter the CCZ. Second, within the CCZ, an arriving unmanned vehicle will be baselined to be commanded from the Station with monitoring and backup command from the ground. Third, free flyers without their own propulsion system will be guided to the Station by the OMV. Finally, only one vehicle will be allowed to move in the CCZ at a time. When the Shuttle is at the Station arrivals or departures will be strictly controlled.

A typical scenario would unfold as follows: A major manufacturer of electronic equipment has had a manufacturing process at work for several months on a large orbiting platform; the process is now completed and the payload is ready for delivery back to Earth. The Station sends the OMV to fetch the Space Station platform (outside the CCZ) and bring it to the Station Base. As it approaches, the OMV brings the platform within range of the Mobile Remote Manipulator System, which grasps the OMV/payload. EVA astronauts may then detach the payload from the platform and the robotic arm lifts it into the servicing bay. The OMV returns the serviced and resupplied platform to a parked position outside the CCZ, where it begins its next assignment. The OMV returns to the Space Station. Later, the Shuttle arrives and, after off-loading its cargo, takes on the payload from the servicing bay for return to Earth.

As a rule, arrivals will be berthed rather than docked. Docking is accomplished when the arriving vehicle propels itself up to the Station, including the final few inches and makes contact (as was done on Gemini and Apollo); this technique usually involves some bumping. Berthing calls for the arriving vehicle to bring itself to within a few inches of the port; a Station mechanism then reaches out, grasps the vehicle, and draws it slowly to the port. Berthing helps to eliminate bumping.

Communications within the CCZ will include radio contact between the Station and any arriving vehicle (sometimes direct, sometimes through a ground station); television viewing of arriving and departing vehicles; and radar. During Phase C, designers will pay attention to sight lines and will position equipment such as antennas to give maximum clear viewing from the berthing positions.

ALTITUDE

Selection of the operational altitude for Space Station involves weighing the benefits and disadvantages of various altitudes. The disadvantages relate to the hostile environment of space, i.e. debris from other satellites, micrometeroids, and radiation from the sun. The lower the Station is positioned, the less it will face these hazards. Shuttle performance is increased because less weight needs to be allocated to fuel to reach the lower altitude which increases payload weights and decreases costs of assembly and logistics runs.

On the other hand, the higher the Station, the lower the atmosphere drag (even at over 200 miles) and the easier it is to: control the Station, control vehicles maneuvering around the Station, achieve optimum microgravity conditions, and make up the altitude losses due to drag.

Another environmental factor, atomic oxygen, provides an argument for a higher Station altitude. The higher the Station the less the corrosion on surfaces exposed to these oxygen atoms.

After weighing these and other factors during SRR, NASA decided that the Space Station will be assembled at an altitude of 220 nautical miles and will operate at altitudes ranging from 250 to 270 nautical miles.

COMMONALITY

Commonality of functions and hardware for the Space Station elements was established by NASA as a major design and development goal. A plan is in place to achieve this goal to the greatest extent possible.

Commonality has many advantages. It enables NASA to depreciate the cost of design, development, testing, and evaluation of new subsystems over more units constructed. Commonality shortens the learning curve for the crew by requiring training in fewer subsystems. Most importantly, it lowers the cost of logistics support by requiring fewer kinds of units and parts.

Over the longer term, commonality can save money by permitting volume buying and certification of replacement parts; for a Station that could be operational for 30 years, it makes no sense to have five variations of a kind where one would do. The long-term saving from commonality, then, would be in maintenance of the Station over its useful life.

An example of commonality is the microprocessors for onboard computers. It is desirable to have only one kind of keyboard, standard types of displays, and one kind of storage capability. SRR established that Space Station should strive for commonality to the extent possible.

MAINTAINABILITY

Maintenance of the Station refers to the operational activity that ensures or restores subsystem elements to a nominal or normal operational state. Maintainability, on the other hand, is an aspect of design that facilitates maintenance. Maintenance is performed by crew members; maintainability is defined by design engineers and built in by manufacturers.

It is difficult to design systems for a Space Station required to operate continuously 20-30 years when the spacecraft life requirement exceeds the expected life of many of the spacecraft parts. In previous programs, redundancy techniques were used to meet the requirements. This solution is impractical for the long Space Station design life. The design philosophy used on the Space Station is to provide for dual paths for all functions that can fail. In the event of a failure, the system will be switched to the second path and the off line, failed system will be repaired and tested before being switched back to operation.

This mantainability approach presents many system design challenges. For example, the designer must consider how to perform the following:

- Monitoring operations to sense a failure
- Isolate the failure and switch off line with no interruption in operation
- Repair the failed system (or subsystem or component) within a minimum time
- Test the system before switching back on line
- Provide the proper spares and testing equipment onboard

These challenges can be met with known techniques. NASA will ask the contractors to propose the best and most efficient methods for satisfying these requirements in the upcoming Phase C/D RFPs.

INFORMATION SYSTEM AND SOFTWARE

A comprehensive network of communications, data and information management will be necessary to provide users and Space Station operators with the information capacity they need and to ensure safety of operations and security of transmission. The Space Station Information Systems (SSIS) is conceptualized as the comprehensive system that will accomplish these objectives.

The SSIS is defined as the end-to-end information system comprised of the data and communications capabilities of the flight elements, the communications system connecting space and ground, and all of the ground-located data handling, processing, and storage facilities including those of the ultimate data users. The SSIS thus encompasses facilities as far ranging as the Space Station Support Center at the Johnson Space Center, the Platforms Control Center at the Goddard Space Flight Center, The Integrated Logistics System at the Kennedy Space Center, and one or more Customer Coordination Centers at, as yet undetermined, locations. The SSIS will enable users to interact from their home locations with data archives, other Space Station users, and their payloads. Users in home laboratories will be able to work with their experiments from initial conceptualization through payload development, integration, on-orbit installation, commanding and data gathering operations, and on into refurbishment, reuse, and eventual experiment/payload retirement.

A key element of the SSIS is the establishment and application of a common set of software development and maintenance policies, procedures, and tools. This capability to develop, check-out, integrate, and maintain Space Station Program software of all kinds is called the Software Support Environment (SSE). The driver behind the SSE concept is the very real need to assure sufficient commonality in the software products delivered from the many diverse contractors. Another concern is to assure that the software products will be able to be integrated into a larger system and that they will be cost-effective to maintain. These strong motivations have prompted the definition of the SSE in advance of the rest of the program so that the "tools and rules" will be both available and common ahead of the time they are needed for software work.

The major components of the SSE are:

a) Software development tools such as compilers, debuggers, and documentation aids;

b) Policies and standards;

c) Simulations and models of the many and various Space Station systems; and

d) Flight system software (specifically, the on-board operating system, user interface, and database management system)

The Space Station Program will strive to use existing facilities and software where possible. It is also to the Program's advantage to capitalize on state-of-the-art technology advances, particularly those that will be widely used in other endeavors and programs. Thus, the new DOD software language, ADA, and its associated software engineering methodology have been baselined for use with all new software and will therefore be the heart of the SSE.

Software is an exceptionally costly part of any electronic data system. NASA's experience shows that the cost of software for space programs has dropped relative to the size of onboard software. The cost of software during the Apollo program was high while the amount of onboard software was low; that relationship will be reversed on the Space Station because of dramatic improvements in microprocessors, chip technology, and software development over the past 15 years. In addition, NASA will purchase as much software off-the-shelf as possible in order to contain costs.

UNITS OF MEASURE

SRR established that a rule for units of measure for the design and construction of Space Station will be necessary. NASA is now considering the degree to which the Program will adopt the metric system. The working rule at SRR is "hard metric with waivers." This rule translates as follows: During design and construction, NASA and its contractors will use the metric system unless such use proves expensive or impractical. In those cases, a waiver will be obtained and some other system of measure will be used.

Most nations in the world use the metric system, as do many U.S. industries. NASA's decision to adopt the metric system demonstrates the Agency's desire to cooperate with its international partners and to make the Space Station as compatible as possible with as large a potential user community as is feasible.

POINTING

Some users will operate instruments for observing Earth or celestial bodies. They require that the Station remain stable or fixed in attitude to a precise specification to ensure precision pointing of the instruments. To meet this requirement, the Station will operate a guidance, navigation, and control system to ensure stability during orbit. When sensors indicate that the Station is veering slightly from its proper attitude, the stability and control system control moment gyros will react to keep the Station in position.

For attached payloads requiring a high degree of pointing accuracy, the Space Station will provide a gimballed course pointing system. The course pointing system will be capable of pointing a payload with an accuracy of 60 arc sec. The stability of this system is 30 arc sec for 1800 sec exclusive of Orbiter docking, Station reboost and Mobile Servicing Center activities. In addition, the course pointing system will be capable of providing the slew capability to enable payloads to track celestial and Earth fixed targets. The capability for higher pointing accuracy on the order of 1-2 arc sec is the responsibility of the users, who will also have the option of flying aboard one of the Space Station platforms.

AUTOMATION AND ROBOTICS

In providing funds for NASA to undertake the Phase B definition work, the Congress instructed the Agency to use the Space Station Program to push the state of the art of automation and robotics (A&R) technology by employing machine intelligence, robotics, and advanced automation to lower life cycle costs and increase productivity.

NASA has long been interested in both automation and robotics, and has been a leader in automation for many years in such areas as computer fault detection, isolation, and correction of problems. Many NASA vehicles, including the Shuttle, are highly automated. The emerging and promising field of robotics also interests NASA and has clear uses in space; advances in space use should lead to advances in corresponding terrestrial technologies.

In response to the Congressional mandate, NASA commissioned a group of university and industry experts to examine potential areas where NASA could use automation and robotics on the Space Station and where NASA needed to push the state of the art. In addition, NASA initiated a study to recommend policy and make specific suggestions for all areas of the Space Station Program related to general purpose automation and robotics. NASA periodically reports the results of Phase B automation and robotics definition and design to the Congress.

Automation and robotics are, philosophically, a major objective of the Space Station Program. NASA's goal is to design the Station to accommodate future advances in machine intelligence and robotics, use general purpose automation and robotics to the fullest extent possible, both to provide user services directly and to relieve crew from Station tending tasks to be free to serve users. Automation can, for example, increase productivity by monitoring an astrophysics experiment or by keeping a materials processing operation within specified limits. Robotics may be of benefit, for example, by assisting with assembly of the Station and maintenance of the Station, satellites and platforms. The data management system will have automated self-check and correction capability. This system will be designed to accommodate advances in the state of the art of automation and robotics in coming years, such as major advances expected in symbolic processors and other elements of intelligent systems.

In robotics, NASA is aggressively pursuing a Space Station Telerobotics System, which involves such subsystems as vision, force feedback, and multiple robotic arms in a mixed human and robotic system. The Orbital Maneuvering Vehicle will also have a telerobotic capability.

Another thrust is in systems automation using knowledge-based systems software approaches to achieve high reliability and systems autonomy (i.e., systems that are autonomous in the sense that they can perform flexibly without human operation). All subsystems of the Space Station are being studied for possible A&R applications with the data management and operations management systems being important due to their central roles.

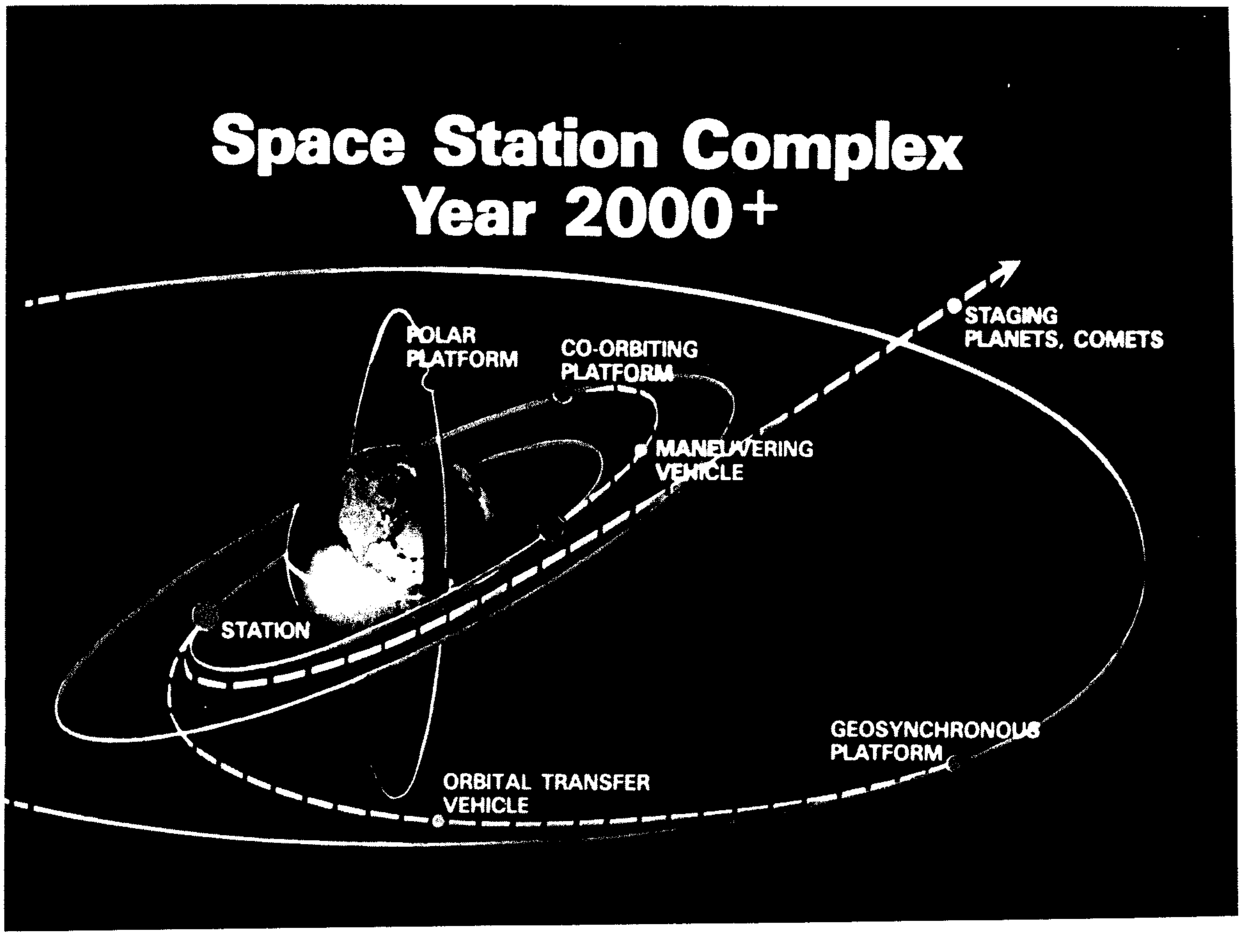
The types of design accommodations for advances and the level of use of automation and robotics for Space Station are being studied in Phase B and specifics will soon be decided. Certainly the Station will be highly automated, which is in keeping with NASA's heritage. Telerobotics will be used in very critical areas such as assembly and maintenance. Clearly, automation and robotics will be subjects of great interest at the Space Station evolves.

EVOLUTION

With a useful life of up to 30 years, the Space Station will experience many changes. Commercial, scientific, and academic users will discover the long-term effects of microgravity on experiments and manufacturing processes, and likely will change their requirements for Station capabilities. Some user needs may diminish, others will increase, and still others may be entirely new.

In examining this process during Phase B definition work, NASA concluded that the Space Station must be designed and constructed in a manner that allows response to changing user needs. NASA defines evolution of the Station as relating to anything that increases its capability to meet user needs. This increase can occur in physical growth of the structure -- more modules, more laboratory space, more framework for attached payloads -- or it can emerge in the form of improved systems, techniques, and procedures in research and manufacturing.

In the baseline configuration of the Station, NASA engineers have provided for a wide range of changes that will accommodate greater and different capabilities for users in the future. These provisions consist of what engineers call "scars and hooks". A scar involves built in hardware that can accommodate increased capacity. For example, the electrical circuitry at the time the Station is permanently manned will provide 75 kilowatts, but is designed and built to expand up to 175 kilowatts. Similarly, the latticework of trusses has a position designated for a servicing facility for the Orbital Maneuvering Vehicle, although no such facility will be available in 1994. A hook is similar to a scar, but refers to software; Station software will be written to accommodate additional programming and coding without extensive rewriting.



ASSEMBLY SEQUENCE

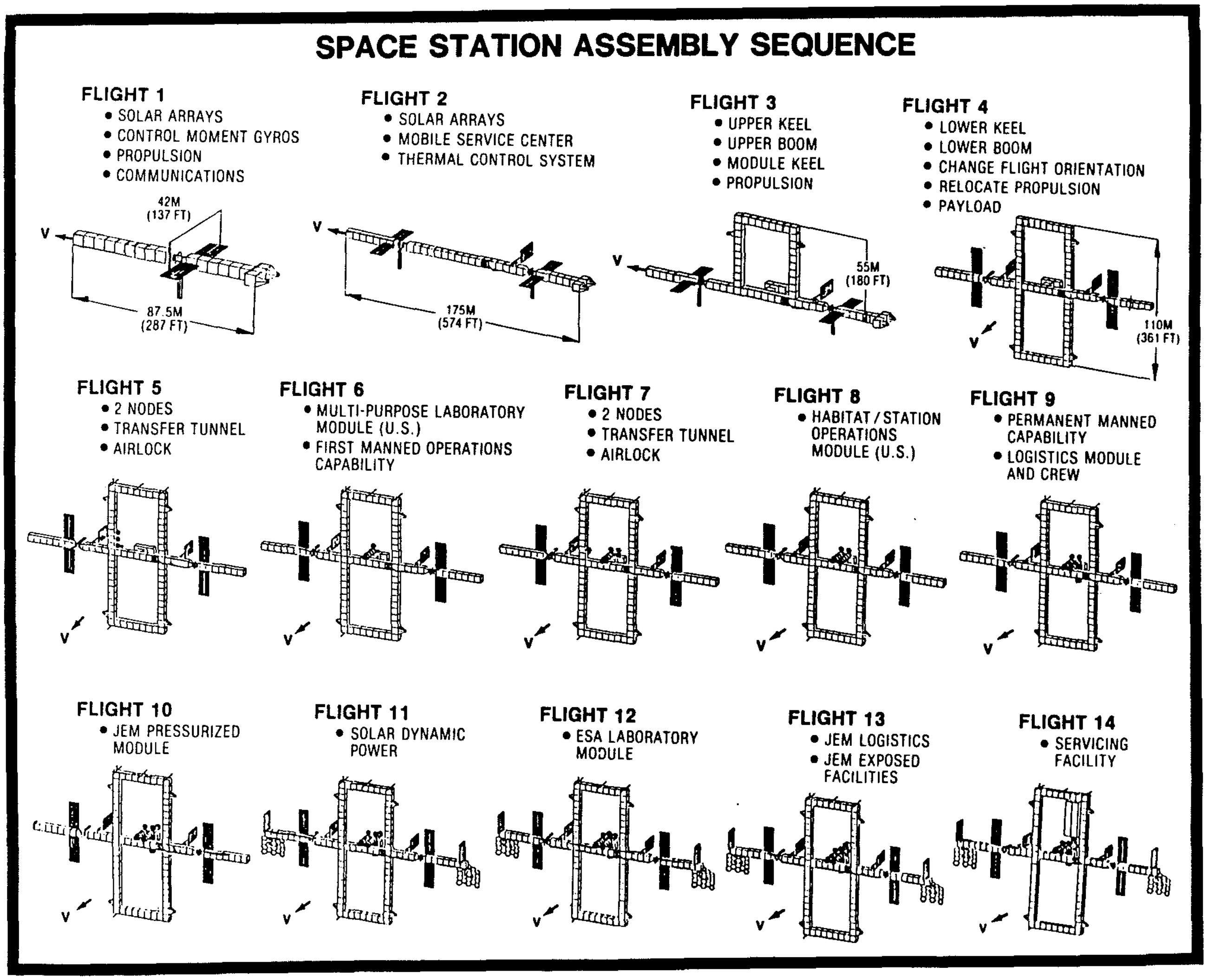
NASA is determining the order in which materials and systems will be ferried to the assembly point, the manifests for individual Shuttle trips, the techniques for assembly and check-out of the Station structure, and the sequence in which Station capabilities will become operational.

The Station can become man-tended within about 8 months of the initial assembly flight, and will be permanently manned by the end of the second year of flights.

Current baseline planning calls for flights approximately every 45 days during the assembly sequence. The Shuttle will arrive at the orbit assembly point. The crew will assemble elements of the Station in the cargo bay and swing those elements out into space with the Canadian Mobile Servicing Center arm mounted on the Shuttle. Early flights will concentrate on the truss framework, electrical power, and communications and guidance equipment. At the end of each of the early flights, Shuttle crews will leave the partially built Station literally hanging in space, and return to Earth.

Assembly is scheduled to begin in January 1993 with the Shuttle lifting off from Kennedy Space Center in the first of 14 flights needed to complete assembly of the Station manned base. The following graphic portrays the current assembly sequence. Other flights will place the Space Station platforms in polar orbit and in co-orbit with the Station Base. All elements could be in place by November, 1995.

SPACE STATION ASSEMBLY SEQUENCE



SPACE STATION AND THE FUTURE

The United States entered the 20th century already a world leader in science and industry. In 1903, with the dawn of flight, the Nation began an age using the airplane to extend human knowledge of land masses, the oceans, and the atmosphere. This new dimension in human knowledge has proven to be of value to the United States and to the world far beyond anything the early pioneers in aviation might have dreamed.

The Space Age has added an important chapter to our successes in science and in industry. We have learned much about the environs of space -- the Sun, the planets, and the galaxies beyond. We have also learned how to utilize space as a place of business, and both industry and science have benefitted from our investments in space technology.

As the Nation approaches the final decade of the 20th century, it is in a position to prepare for future national efforts in the 21st century. The Space Station can be among the Nation's most significant preparations for the next century. It follows in the steps of the early pioneering space flights, lunar landings, deep-space probes, and the Space Shuttle. It is the next logical step in extending American presence in space and in ensuring that the United States maintains a position of leadership as we enter the 21st century.

The Space Station Program now enters a period of preliminary design and detailed cost estimating, which are necessary preludes to the development of the physical elements of the Station.

NASA believes that the baseline configuration for the Space Station, as it emerged from the Systems Requirements Review described in this document, will enable the United States to develop a permanently manned Space Station, attractive to users, that is affordable and versatile. By 1994, a decade after President Reagan's directive, a permanently manned Station will be in orbit. Completion of all elements of the Station, of the full baseline configuration with mature operational capability, is planned for 1996. That event will mark an important national milestone. It will ensure that the United States has the tools it needs to enter the 21st century with confidence in its capacity to live and work in space, and with resolve to continue its leadership in science, technology and commerce -- each now linked to space.

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HISTORY OF THE SPACE STATION CONCEPT

The modern space station concept dates back to 1923, when the Romanian-born Hermann Oberth published his serious theoretical treatise on the possibilities of large, liquid-fueled rockets. Die Rakete zu den Planetenraumen (The Rocket to Interplanetary Space) was the opening shot in a debate about the meaning of the space station that was to last for more than six decades. Oberth envisioned a voyage to Mars, and perceived that a refueling depot in outer space (or "weltraumstation") would serve as a staging point for the journey. He quickly realized that a station in space could do many other things, which would further justify its construction.

In the twenties, other visionaries, mostly Germans, joined Oberth in his advocacy of this unheard-of technology. A space station was, at this time, symbolic of a wide range of Earth-orbital activity, such as astronomy, meteorology, cartography, and military reconnaissance. The word "weltraumstation" was a shorthand description for the entire gamut of orbital spaceflight technology.

Wernher von Braun was one such young enthusiast. A protege of Oberth, he rose in the thirties to become the premier rocket designer-engineer of his time. Unfortunately, the cost of building a rocket -- the first logical step into space -- was so high that the only patron available was the state of Nazi Germany. Von Braun saw the V2 as an intermediate step towards the much grander vision of a manned mission to Mars. He and other visionaries such as Krafft Ehricke left Germany at war's end to work for the United States. Thus, serious space station thinking came to the United States in 1945.

In the fifties, many groups began to think of the immediate and practical uses of space -- both civilian and military. Von Braun was in the forefront of the space race, but he dreamed of a space station in permanent Earth-orbit that would satisfy a wide range of scientific, economic, and political objectives -- and serve as a base for future missions to the Moon and to Mars. He postulated that to get to that step, the United States should first build a small test bed orbital laboratory. Others agreed in principle, and the debate continued: how long should such an orbital laboratory last? What was its primary function -- to test man, or technology, or both? How many crew? Would it be resupplied? What altitude and inclination? Should it be built in space, or on the ground and deployed in space?

NASA, created in 1958, became the forum for the space station debate. In 1960, space station advocates from every part of the fledgling space industry gathered in Los Angeles for a Manned Space Station Symposium, where they agreed that the space station was a logical goal but disagreed on what it was, where it should be put, and how to build it.

In 1961, President Kennedy decided that the Moon was a target worthy of the American spirit and heritage. A lunar landing had an advantage over a space station: everyone could agree on the definition of landing on the Moon, but few could agree on the definition of a space station. This disagreement was healthy. It forced station designers and advocates to think about what they could do, the cost of design, and what was necessary. What were the requirements for a space station How could they best be met? The requirements review process started informally in 1963 and continued for 23 years. NASA officials asked the scientific, engineering, and business communities over and over again -- what would you want? What do you need? The answers flowed in, and NASA scientists and engineers puzzled over how to organize these wants and needs into an orderly, logical sequence of activity. Was the station a laboratory, observatory, industrial plant, launching platform, or drydock? If it was all of these things, how much crew time should be devoted to each?

In the sixties, working quietly in the shadow of the gigantic Apollo/Saturn program, space station designers and planners began to come to grips with the tough questions of safety, hardware, money, and manpower. Working from 1964 through 1966, they settled on the modular approach: a pay-as-you-go program that offered something to everyone. With incremental funding, NASA managers could provide an incremental space station. Yet cost remained a problem. Design costs were always eclipsed by operations costs. The longer a station stayed up in space, the more it would cost to operate and resupply. In 1967 and 1968, NASA planners started looking at an advanced logistics vehicle concept for the space station. They already had a dependable transportation system (Saturn) to launch station modules. What they needed was a relatively inexpensive way to resupply the station. This reuseable spacecraft would shuttle between Earth and the space station. Hence, the word "shuttle "was selected in the summer of 1968.

NASA officials felt that the station/shuttle combination served everybody's needs well. The station had always been a logical step into space. The problem was that not everyone in the country agreed that developing space technology was a logical thing to do. The station program was caught in the shifting tides of politics and culture. Furthermore, the station and the shuttle were perceived as two separate entities, which had not been anyone's original intention. In 1970, plans to launch modules via Saturn technology were canceled, and station designers were told to scale down their modules to fit inside the shuttle, which would now do double duty as launch and resupply vehicle.

Thus, in 1972, in approving a reusable space transportation system, the Space Station concept itself was approved. The transportation segment, called the Space Shuttle, would be developed first. The Space Station itself would await the future.