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EARTH ORBITAL PROGRAM STRATEGY

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ABSTRACT

Through an examination of NASA functions and space program areas and their interrelationship, it is shown that the objectives of NASA earth orbital programs are: to develop space systems that will contribute to the solution of basic national problems by exploiting space for human welfare and knowledge, to exploit space for the advancement of science and technology, and to develop space capabilities precursor to planetary exploration. The role of a space station in the earth orbital program is that of a manned orbital research facility capable of exploiting the unique features of the space environment in combination with the capabilities of man as an onboard investigator to accomplish a broad spectrum of research and development in all areas of interest. Man's role in the orbiting research facility is similar to his role in a research laboratory on earth. His ability to observe and act upon unforeseen phenomena and events when coupled with the earth overview, the space environment, and the scientific instrumentation and equipment which can be available aboard an orbiting laboratory offers a unique opportunity. A manned orbiting research facility, however, should not be utilized to perform functions or programs which can be done economically and reliably by automated spacecraft.

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THE SPACE ACT OF 1958 CHARGED the National Aeronautics and Space Administration with the responsibility to conduct research into problems of flight within and outside the earth's atmosphere; to develop, construct, test, and operate aeronautical and space vehicles for research purposes; and to perform such other activities as may be required for the exploration of space. In fulfilling this responsibility, NASA earth orbital research activities have played a significant role through the utilization of both automated and manned satellites. Technological and operational capabilities have now progressed to the point where it is feasible to develop, construct, test, and operate a manned space station in earth orbit. In order to design properly and to utilize effectively such a spacecraft, it is mandatory that the role of a space station in the earth orbital program and the activities planned to be conducted aboard the station be well understood. The objective of this paper is to contribute to an understanding of the space-station role through a consideration of the functions of NASA in carrying out the nation's space program and through an effort to place the total earth orbital program in logical perspective. Additionally, some of the general features which an effective space station must include are defined.

SPACE PROGRAM PERSPECTIVE

A true understanding of the role of a space station in an earth orbital program can best be achieved by examining the total NASA space program in such a manner that earth orbital programs are placed in perspective. Once the total space program is in full perspective view, the potential contributions of a space station can be seen to influence all program areas. In order to achieve the perspective, it is necessary to review the functions of NASA in fulfilling the national space program objectives.

The national space program objectives were established within the Space Act of 1958, and the functions of NASA in fulfilling these objectives can be rather simply stated as follows: the exploration of space, the advancement of science, and the provision of services to the nation. The activities or program areas which support each of these functions are fairly straightforward for the first two functions. However, the service function is somewhat more complex and is dependent on the capabilities developed as a part of the other functions. It is for these reasons that by far the greater share of NASA effort has been expended to date in support of space exploration and science. These functions, their supporting program areas, and some examples of the related activities are illustrated in Table I.

TABLE I - NASA FUNCTIONS

(a) EXPLORATION OF SPACE

PROGRAM AREAS	ACTIVITIES/PROJECTS
LUNAR	RANGER SURVEYOR LUNAR ORBITER APOLLO
PLANETARY	MARINER
GALACTIC	OAO
ASTRONOMY	

Exploration of Space - The exploration of space as illustrated in Table I(a) involves earth orbital, lunar, solar, planetary, galactic, and intergalactic programs. Although the field of astronomy is generally classified as science, it represents man's first mode of space exploration and will continue to fulfill a significant role in space exploration for years to come. The major activities of NASA to date have been concentrated in these program areas and lunar exploration has received by far the greatest support. Since the moon is our nearest celestial neighbor, this support is very logical, but as our knowledge and understanding of the moon increases and as our technological capability grows, planetary exploration will receive increasing attention. This greater emphasis on the planets will ultimately lead to manned landings on the nearer planets. Feasibility studies of such missions have already been made and the technology requirements for such missions are well understood.

Scientific Advancement - Scientific advancement as illustrated in Table I(b) includes supporting programs in astrophysics, bioscience, physical science, earth science, and atmospheric science. Activities in these

TABLE I.- CONTINUED.

(b) SCIENTIFIC ADVANCEMENT

PROGRAM AREAS	ACTIVITIES/PROJECTS
ASTRONOMY/ASTROPHYSICS	OAO OSO PIONEER IMP EXPLORER ATM
BIOSCIENCE	BIOSATELLITE
PHYSICAL SCIENCE	EXPLORER
EARTH SCIENCE	OGO
ATMOSPHERIC SCIENCE	NIMBUS

areas involve comprehensive supporting research as well as space flight projects and these activities are aimed at achieving advancements in our understanding of fundamental physical processes and laws. Interest and earth orbital activity in these scientific areas will continue to grow as our technological capability to utilize space increases. Space conditions such as weightlessness, absence of atmosphere, and comprehensive overview of earth are unique research environments which have never before been available to scientists. Absence of atmosphere offers an unparalleled opportunity for advancement of astronomy, and weightlessness permits advances in bioscience which probably could be achieved in no other way. Continental land masses and weather systems can only be viewed as an entity from space. A significant increase in capability to capitalize on the usefulness of space will be realized when it becomes possible to make greater utility of man in space as a scientist equipped with the necessary instrumentation and support.

Service - The NASA service function, illustrated in Table I(c), is one which has yet to come into full prominence, but which offers great potential to the nation in terms of utilizing space for the benefit of human welfare. The service function has many facets and includes technology development programs for both space and aeronautics as well as programs in space operations and applications. Activities in these areas are rather broad, interwoven, and comprehensive; they also serve national interests, including NASA purposes. The distinct identification of NASA purposes within national interests is somewhat arbitrary and is intended to emphasize some of the varied aspects of the service function illustrated in the following material.

TABLE I - CONCLUDED

(c) SERVICES

PROGRAM AREAS	ACTIVITIES/PROJECTS
ADVANCED AERONAUTICS TECHNOLOGY	X - 15 M2 - F2 HL - 10
ADVANCED SPACE TECHNOLOGY	LAUNCH VEHICLES SPACECRAFT INSTRUMENTATION COMMUNICATION
SPACE OPERATIONS	LAUNCH TRACKING DATA PROCESSING MERCURY GEMINI
SPACE APPLICATIONS AND UTILIZATION	TIROS COMSAT ESSA ATS

Advanced space technology programs include a wide variety of activities necessary for the accomplishment of NASA purposes and to benefit the nation. For example, the rather extensive technology development activities in propulsion, space power, electronics, control, structures, materials, life support, and all spacecraft subsystem areas serve NASA needs in terms of increasing our technological capability to accomplish exploratory and scientific space flight missions. This increasing technological capability, however, simultaneously provides benefit to the nation in that it improves our ability to capitalize on the potential benefits to mankind of space utilization. A necessary adjunct to the technological capability and mandatory for space utilization is, of course, the simultaneous development of space operational capability. The development of launch vehicles, launch operations techniques, tracking and communications networks, and data handling systems and operations are all complex and necessary activities for the development of space operations capability. Probably the most significant operational capability for both NASA needs and national benefit is the development of our capability to utilize man in space properly. The Mercury and Gemini activities were the first steps in this direction.

The contribution of space applications and space utilization to the solution of today's problems is in an early stage of development. However, this activity appears to offer enormous benefits to the nation and to all mankind. SA activities in this area have been limited to technology utilization, the so-called technology spin-off, and to the communications and meteorological applications.

This limitation has resulted from limitations in our technological and operational capability and not from lack of interest, the fact being that recognition of the possible benefits of space utilization places greater emphasis and urgency on the need to develop the necessary technological and operational capability. Not only is it necessary to develop spacecraft subsystem technology and space flight operational capability, but also more important, it is necessary to develop the sensing instrumentation, data handling and interpretation techniques, and proper systems and methods for providing the ultimate user of information with information that is truly useful to him. The systems and techniques required to provide useful information in fields such as agriculture, forestry, oceanography, hydrology, and mineral resources may or may not be very similar, and these application areas probably have requirements very different from those needed for applications such as communications, meteorology, navigation, and traffic control. Much of the development activity needed to bring to fruition these application possibilities requires ground laboratory research, but a large part of the activity must also be accomplished in earth orbit. Earth orbit is the one single and certain space factor common to all these application areas. The role of man in space to meet the needs of these applications in an ultimate operational status presents a nebulous question; however, it would seem at this time that automated spacecraft will ultimately satisfy most requirements. In the meantime, man in earth orbit properly equipped with research instrumentation can accelerate development of the space systems, operations, and techniques required to achieve the benefits which space utility offers.

One other service function which cannot be overlooked, even though it would seem not too closely related to the subject of this paper, is the aeronautics technology program. Most of the activity in this program area is in support of national transportation needs; however, it also includes supporting research on atmospheric entry, both earth and planetary, and spacecraft recovery. Considerable emphasis has been given to lifting-entry technology leading to the ultimate development of economical earth-orbit manned logistics operations, for example, the M2-F2 and HL-10 lifting body flight projects. Economical logistic support is one of the key developments required for effective utilization of man in orbit.

In summary, the service function of NASA is very broad in scope and involves servicing the needs of NASA for space exploration and science as well as servicing the need of the nation to utilize space for the benefit of home and hearth. The prime role of NASA in meeting the space utilization needs involves developing the technical capability, proving the applicability, and furnishing the space operations necessary to support ultimate users.

After briefly examining a full spectrum of NASA functions and program areas, it is seen that earth orbital activities comprise most of the NASA space flight missions and that the development of technology and space operations capability are the primary activities in earth orbit.

EARTH ORBITAL PROGRAM

Within the total space program, those activities related to development of the capability to utilize space for human benefit are probably of greatest national interest. Man's existence and well being are strongly influenced by the availability and use of earth resources and these resources are being rapidly depleted both by growth in population and increase in individual demands. Adequate measurements of the quantitative and qualitative conditions that actually exist are fundamental to an understanding of the problems and to effective efforts to alleviate them. The acquisition of such measurements requires surveys of significant resources and conditions. Aircraft survey techniques have been utilized very successfully but in limited areas. There are critical needs for regular surveys in areas such as fresh water supplies and usage; land usage; soil and crop conditions; population trends; transportation status; marine life and wildlife distribution; fuel, ore, and mineral reserves; natural disaster surveillance; and pollution and waste disposal. The advantages of the comprehensive overview and long flight duration available through utilization of spacecraft for such surveys offer great potential to the nation for effective utilization of national resources. The meteorological satellite programs have already shown that surveys of global scope can be conducted on a routine basis with unexcelled cost effectiveness, and the utilization of communications satellites, as an example, has progressed into the realm of commercial interest. All these factors demand that special emphasis be given to the development of applicable space technology and space operations techniques which are a part of the service function of NASA and which are earth orbital activities.

The NASA science programs in atmospheric and earth science are inherently and intimately associated with the earth resources surveys just discussed. First, they also require earth orbital activity; second, most likely they require very similar orbital instrumentation and operations; and third, advancement of our knowledge of the earth and atmospheric sciences is inherent to the improvement of our understanding and use of natural resources. Table II illustrates the commonality of survey instrumentation for earth resources, earth science, and atmospheric science by listing the most common types of sensors. It is not intended to imply that any single type sensor will meet all requirements for that sensor type, but it is intended to show a high degree of commonality in sensor technology. Similarly, there can be expected to be a high degree of commonality in data format and handling requirements. Furthermore, the development of sensor technology and operational techniques for earth survey inherently increases our capability to perform meaningful space exploration. Sound knowledge and understanding of the earth, in the scientific sense, seem prerequisite to proper interpretation of planetary discoveries and to the understanding of planetology.

TABLE II.-
COMMONALITY OF SURVEY INSTRUMENTATION FOR EARTH RESOURCES, EARTH SCIENCE, AND ATMOSPHERIC SCIENCE

SERVICES		SCIENCE	COMMON INSTRUMENTS
CULTURAL RESOURCES	NATURAL RESOURCES	ATMOSPHERE AND EARTH SCIENCE	SENSORS
SOILS	FRESH WATER	CARTOGRAPH	METRIC CAMERA
CROPS	FORESTRY	GEODESY	PANORAMIC CAMERA
LAND USE	MARINE LIFE	GEOLOGY	TRACKING TELESCOPE
POPULATION TRENDS	WILDLIFE	GEOPHYSICS	SPECTRAL SCANNER
TRANSPORTATION	MINERALS	OCEANOGRAPH	RADIOMETER
		METEOROLOGY	

Earth orbit is not uniquely required for the astronomy, bioscience, or physical science program areas, but absence of atmosphere, weightlessness, and long flight duration are required. Earth orbit represents the most convenient and economical means of meeting these requirements.

Most of the activity and accomplishment to date in these earth-orbital program areas has involved the use of automated spacecraft systems. As has already been indicated, automated spacecraft may very adequately serve the operational needs of the applications missions once the space applications capability has been fully demonstrated, and they may very well satisfy a significant portion of the science program area needs. However, the advantage of man in space is found in his capability to observe and act upon unforeseen phenomena and events and his capabilities have not yet been fully applied. Research is inherently oriented to the discovery of the unknown and unanticipated and requires the active participation of a staff possessing the necessary judgment, experience, and skills. Research and development, as has already been discussed, will comprise the major earth orbital activity for all program areas at least until such time as the technological and operational capability exists to capitalize materially on the usefulness of space for earth-related applications. The utilization of man in space permits experiments and tasks to be undertaken that would otherwise be impossible or are so complex that the probability of successful completion with an automatic system is low. For example, man's potential ability to erect and assemble large equipment in orbit and maintain it for long periods of time affords a flexibility and reliability that is beyond reasonable attainment for an automated system. The ability to conduct experiments and correlate inputs from ground-based specialists with results from many observations and sensor measurements affords an opportunity for an onboard scientific specialist to adapt experimental procedures to real time and possibly to edit and select the most appropriate data for transmission to the ground. Furthermore, automated systems are constrained to perform those functions for which the technology either exists or can be developed with reasonable certainty and for which the tasks can be defined in complete detail and are not so complex or intricate that the probability of successful completion is unattractive.

Man hours in space are inherently associated with high costs and it is therefore mandatory that every possible means be utilized to obtain maximum effectiveness of man.

Systems, experiments, and instrumentation should not be designed in such a way that they require man to perform simple or routine tasks which can be automated and perhaps commanded from the ground. If the potentials of man's involvement in space activities are to be fully exploited, however, it is necessary to proceed far beyond the Mercury and Gemini activities to develop the necessary supporting systems and operational techniques required. This development activity must also be a significant element of the earth orbital program.

In summary then, the earth orbital program encompasses: (1) the development of technology and operational techniques for earth resources survey, for other space applications in addition to communications, for the utilization of space to conduct activities in all the science program areas, and for the effective utilization of man in space; (2) the conduct of the atmospheric and earth science programs; and (3) the conduct of the astronomy, bioscience, and physical science programs.

THE ROLE OF A SPACE STATION

As has already been implied the role of a space station in the earth-orbital program is that of a manned orbital research facility capable of exploiting the unique features of the space environment in combination with the capabilities of man as an onboard investigator to accomplish a broad spectrum of research and development. A space station can provide accelerated development of space systems that will contribute to the solution of basic national and world problems. It can provide an unequaled opportunity for the study of crucial scientific questions. It also can provide the required facility for developing advanced technology and operations procedure for proper utilization of man in space systems and as a future explorer of the near planets. These capabilities of a space station then represent the objectives for any space station program. It must be noted, however, that a manned space station should not be planned to perform functions or execute programs that can be done better and more economically by automated satellites or by any other means. A manned space station utilized as a research laboratory can furnish the needed insight into the kind of meaningful measurements and observations that are required before automated satellites can be employed to provide large amounts of data on a routine basis.

In the interim before a full capability space station becomes available, there obviously will be considerable activity in all areas of interest utilizing automated spacecraft to the limit of our capability. Similarly, the Apollo program will provide valuable information relative to the provision of proper support for man in space and on methods for effectively utilizing man's skills. Advantage must be taken of every opportunity to gain experience in and improve our capability for manned space operations.

SPACE STATION BROAD REQUIREMENTS

Crew Requirements - The crew requirements for a space station are necessarily as varied and complex as the space experiment program itself. The crew size is a function of (1) the size of the spacecraft laboratory, (2) the degree to which the space station and the experiments are automated, (3) the frequency at which crew members may be rotated from earth, (4) the size and the displinary content of the experiment program, and (5) the skill level required and degree of cross training achievable in the crew. Of these five factors, the degree of automation of the experimental equipment and of station management and maintenance has the greatest effect on the crew size required by a given experiment program. Figure 1 shows that the effect of reducing the station-keeping task from 36 hours per day to 12 hours per day increases the experimental man hours actually accomplished in a computer simulated space station mission. Both curves reach a maximum at 60 hours per day because the assumed experiments and the crew skills were optimum at that point.

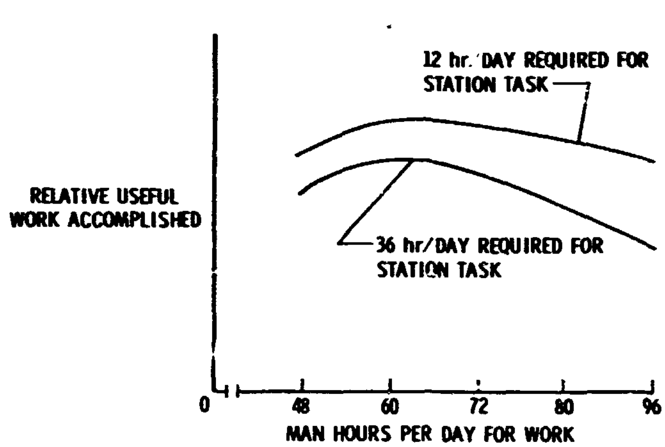

Fig. 1 - Effect of station automation on man hours available for experiment work - six-man crew.

The space-station-staff primary skills required to accomplish most of the programs are summarized in Table III. Those six skills for which there is the greatest demand are indicated to be basic skills and may be required on a continuous basis. It is recognized that these skills are also the basic skills required to operate the space station. The remaining skills mostly represent scientific specialties which are not necessarily required on a continuous basis and may be phased or shared in accordance with program scheduling and demand.

TABLE III-SPACE-STATION STAFF REQUIREMENTS

PROGRAM AREAS	SKILLS REQUIRED: BASIC						SPECIAL								
	ELECTRONICS TECHNICIAN	PHOTOGRAPHER OPTICAL TECHNICIAN	ELECTRICAL/MECHANICAL TECHNICIAN	ELECTRONICS ENGINEER	MECHANICAL ENGINEER	MEDICAL DOCTOR	AGRICULTURIST	ASTRONOMER	BIOLOGIST	CHEMICAL ENGINEER	GEOLOGIST	MEDICAL TECHNICIAN	METEOROLOGIST	OCEANOGRAPHER	PHYSICIST/PHYSICAL SCIENTIST
SERVICE	X	X					X				X		X	X	X
SPACE EXPLORATION	X	X	X	X	X	X				X		X			-
SCIENCE	X	X		X				X	X						X

The technician skills are in greatest demand and these skills together with the engineering and medical skills plus two scientific skills would dictate a minimum station staff of eight men. The numerous conflicting program requirements such as those cited previously would limit the maximum number of scientific specialists to about six men for effective utilization of staff time. These six men together with the six men having basic skills and required continuously then indicate the maximum necessary single station staff might be about six to nine men.

It will be necessary in the interest of assuring a well-coordinated and integrated station staff to train the specialists to perform certain other functions other than their specialty, especially for emergency operations. Computer simulations of a 5-year space station mission indicate that for efficient scheduling of experimental tasks, the crew should be as versatile as practical, and that the experiments should be scheduled so as to reduce the number of skills required during any given flight period in which the crew is fixed. For these simulations, the amount of the experimental program completed varied as much as 25 percent, depending on the relative cross training of the crew.

Performance Requirements - The most critical unknown relative to space station utilization is the requirement for, and the effectiveness of, artificial gravity. Table IV shows the stabilization and gravity requirements for a balanced experiment program. It is generally conceded that most of the experiments either require zero gravity (biology, fluids, behavior, etc.) or are complicated by spacecraft rotation (Astronomical pointing 0.1 - 0.01 sec and earth resources 0.1 deg). Only those experiments having to do with artificial gravity require it. The serious question remaining is whether the crew requires artificial gravity either from a physiological or a habitability point of view. In any event, the space station crew must learn to operate in a zero-gravity environment in order to carry out most of the crew tasks associated with the research and development programs.

TABLE IV - SPACE-STATION PROGRAM REQUIRMENTS

PROGRAM AREA	SENSING ORIENTATION	INSTRUMENT STABILIZATION ACCURACY, DEG	GRAVITY	ALTITUDE, n. mi	INCLINATION, DEG
SERVICE	INERTIAL AND EARTH	0.05	NO INSTRUMENT ROTATION	125 TO 200	50 TO 70
SPACE EXPLORATION	INDEPENDENT	INDEPENDENT	NOMINAL ZERO AND CENTRIFUGE	INDEPENDENT	INDEPENDENT
SCIENCE	INERTIAL AND EARTH	0.001	10^{-5} AND SMALL CENTRIFUGE	200 TO 200	< 60

The attitude and stability and control of the space station are related to the gravity question and represent the area of most frequent space station performance requirements conflicts. For example, the highly stable inertial astronomical requirement is in total conflict with the earth slewing requirement for earth resources and meteorology. In either case, however, the pointing and stability requirements are rigorous and suggest that the space-station attitude reference system and experiment sensor mounting and drive systems must be linked with a structure of suitable stiffness. The sensors that work together in the earth resources program should be mounted in a hangar area so that they may be boresighted and alined without incurring large extravehicular activity requirements. Figure 2 summarizes the more significant space station necessary features. The space station design obviously must meet the requirements of the crew as well as the experiment program. The cabin will have a comfortable shirt-sleeve environment which is as normal as practical, and a pressure commensurate with crew denitrogenation requirements before extravehicular activity can be accomplished. The crew support equipment must provide the crewman with adequate physical conditioning, recreation, rest, food, and personal hygiene without incumbering the crewman with time-consuming and trivial tasks.

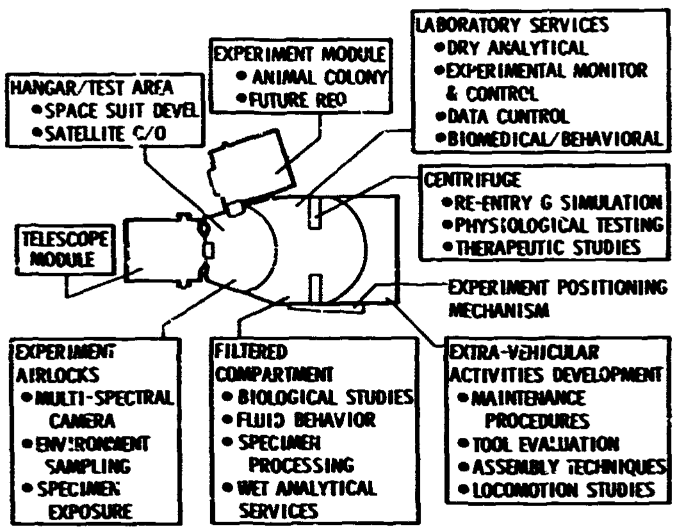

Fig. 2 - Space-station features.

The spacecraft structure must provide adequate volume, thermal, meteoroid and radiation protection for the crew and the experiment equipment. It must also contain sufficient optical and vision windows, airlocks, and hatches to accommodate the experiment program, logistic spacecraft docking, crew and cargo transfer, and modular experiment concepts. The interior structure must accommodate the equipment and spacecraft subsystems and provide a means for earth checkout and orbital maintenance. The power system should supply adequate continuous power without interfering with the experiment program pointing and viewing requirements. The data management and communications system must be flexible enough to accommodate onboard displays, high data rates such as are associated with TV and radar, and at the same time respond to high data rate random events such as a micrometeoroid velocity measurement.

Reliability studies indicate that a maintainable logistically supported station with a probability of mission success of 0.95 for a 1-year mission can be expected to operate for a period of 5 years with 0.80 probability of success. Therefore, it is reasonable to assume that a 5-year experimental program could be profitably planned for a single station.

The size of the space station is largely determined by the requirements of the experiment program, but it is also a strong function of the launch-vehicle capability and the requirement of the space station to meet future requirements. A space station with a 260-inch diameter sized to fit a Saturn IV-B stage is an eminently logical choice on this basis because it can be launched into low-altitude low-inclination orbit with a Saturn I, or it can be placed in low polar and synchronous orbit by a Saturn V and, lastly, it is dimensionally compatible with the nuclear stage development currently in its early stages. Therefore, such a spacecraft design would seem to have the potential for considerable longevity beyond the initial space station mission, if required.

Considerations of habitability volume requirements, space-station size, and crew support indicate that a reasonable space-station staff of six to nine men would be desirable. The space-station designer should be mindful that the space station is an evolutionary step of the type that will be required for future manned earth orbital operational systems and potentially for manned exploration of the solar system.

Logistics Requirements - A dynamic experiment program will require the flexibility of a periodic change of crewmen, additional experiment equipment and supplies, and the return of data and samples from orbit. For practical reasons, the crew stay time should probably be 180 days or less. A typical logistics system payload might consist of approximately 6000 pounds of crew support expendables, reaction control propellant and spares, and an additional 3000 to 4000 pounds of experiments and experiment support equipment. The ability to add major experiments in the form of complete experiment modules to the space station is highly desirable. It is unwise to attempt to place all experiments on board at launch because some experiments could not be started until months or years after they were placed in orbit and the equipment would therefore have been stored in space for long periods and might even become obsolete.

CONCLUDING REMARKS

The function of NASA in fulfilling the objectives of the Space Act of 1958 are the exploration of space, the advancement of science, and the provision of services to the nation. The greater share of NASA effort to date has been expended in support of space exploration and science, but as the technological and operational capability increase, the service function will come into full prominence through the exploitation of space for human and national benefit.

The role of NASA in meeting the space-utilization needs involves developing the technical capability, proving the applicability, and furnishing the space operations necessary to support the ultimate users of space. Earth orbital activities comprise most of the space flight missions and they primarily involve the development of technology and space operations capability, including the effective utilization of man, to satisfy the exploration, science, and service functions. In addition, most of the space flight service activity, earth resources survey, and the science activity will be performed in earth orbit.

The role of a space station in the earth orbital program is that of a manned orbital research facility which can provide accelerated development of space systems that will contribute to the solution of basic national problems, provide an unequaled opportunity for the study of crucial scientific questions, and provide the required facility for developing technology and procedures for proper utilization of man in space systems and as a future explorer of the planets. Some of the significant general features which such a space station must include are the following: a station module sized so as to serve the basic needs of the program; a staff of six to nine men supported by flexible laboratory facilities; and a versatile logistics support system to provide for dynamic programs in each area.

NASA-Langley, 1968