

DESIGN AND USE OF SPACE STATION EXPERIMENT MODULES

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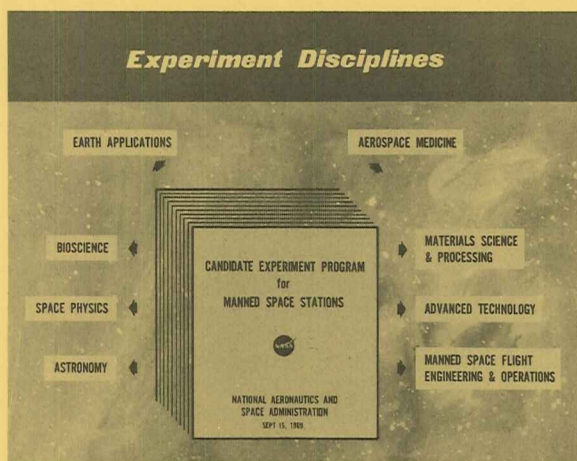


INTRODUCTION

The Space Station Program will provide a facility in space where the scientist or engineer, with little or no additional training, can actively participate in research and development activities on the Space Station. He will be able to do this directly on the Station or through the use of unmanned experiment modules.

This paper describes the results of a study performed by the GE Space Division under subcontract to North American Rockwell's Space Division for the NASA Manned Spacecraft Center. The prime contract was for a preliminary definition study of a manned space station. GE's role was to provide experiment and experiment module definition as well as the definition of the Space Station Information Subsystem.

Space Station studies, which have recently been concluded, have defined accommodation requirements for a set of typical experiments provided by NASA in their Candidate Experiment Program. More than 100 individual candidate earth-orbiting experiments were grouped into 26 categories, each placing similar needs on the accommodation requirements. These categories of experiments covered eight major disciplinary areas: astronomy, space physics, space biology, earth surveys, aerospace medicine, materials science and processing, advanced technology, and engineering and operations.



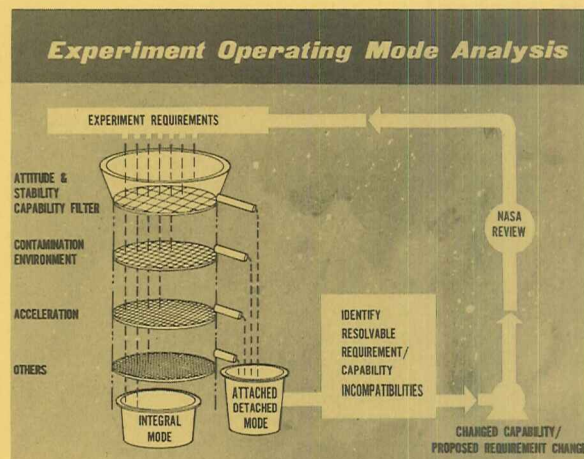
The major analyses effort that precedes any discussion of experiment modules is the determination of which experiments could be accommodated and operated within the Space Station. In other words, we had to determine which could operate integrally and which are forced to operate in

modules either attached to or remote from the Station. The latter situation is created by those experiments which, because of their special requirements unmatched to capabilities provided on the Station, cannot operate within the Station. This is also true in those cases where there are unique Space Station environments, natural or induced, that preclude operating the experiments on-board.

The analyses of the orbital operational modes required for the various experiments greatly influenced the groupings of experiments. Some experiments were grouped together since their function of taking measurements of the physical and behavioral performance of the crews required that they be operated integral to the Station. Other experiments which all look at the Earth might be mounted in modules attached to the Space Station. Some experiments will require precise pointing at the stars or, perhaps, the sun. These may require an experiment module which can operate in orbit detached from the Space Station, where it will not be perturbed by crew activities in the Space Station or by effluent contaminants in the immediate vicinity of the Station. Such contaminants include atmospheric leakage and reaction jet exhausts.

EXPERIMENT OPERATIONAL MODE SELECTION

The analyses leading to the determination of operating modes were the prime factors in deciding the number of attached and detached modules that would be required if the entire set of Candidate Experiment Payloads were to be flown in the Space Station Program. These analyses reflect trades between the experiment requirements and the Space



Station accommodation capability. They cover such important factors as: attitude control and stability, contamination, acceleration, crew involvement, and data management.

Let me use one of these as an example: attitude control and stability. This considers the ability of the Station to provide the attitude accuracy and stability required by the experiment. With an inherent Station capability of about 0.3 degree pointing accuracy, various modes of accommodation could be obtained by adding progressively more complicated attached gimbal and feedback stabilization and control systems for accommodating the experiment requirements. Another way would be to detach the module and provide it with the attitude and control capabilities equivalent to the ATS-3 and OAO series. A trade-off would then be required to

determine which is the less complex or more cost effective.

The results of the analyses for the total candidate list are shown in the two tabulations in the preceding column. The total mode selection of experiment groups that are not integral to the Space Station resulted in 16 groupings to be accommodated in the attached and detached modules.

The integral and attached modules draw their required subsystem support (such as power, air, active thermal control) from the Space Station. The detached modules must be provided with the necessary support subsystems for them to function.

EXPERIMENT MODULE CONCEPTS

I would first like to discuss the methodology of the module design approach. A number of families of candidate module concepts was synthesized based upon the experiment operational mode requirements, and the experiment groupings for attached and detached operations. The intent was to satisfy the requirements for conducting the experiments while remaining compatible with the Space Station program, missions, and schedules. The two principal forcing factors that shaped these categories of candidate concepts were to provide: (1) effective solutions for minimum costs; and (2) maximum safety for the crew. The candidate concepts were evaluated first, based upon qualitative considerations. The results were then used to further define preliminary designs which would quantify the effects of the principal parameters upon each of the design approaches. The qualitative trade-offs were used together with such other programmatic selection criteria as launch capability, commonality, and operational flexibility to determine the design approach to be implemented for experiment modules. The design approach to be selected is the one that will provide maximum benefits for minimum costs consistent with all of the requirements.

In the qualitative analysis several seemingly simple concepts were identified and used to define the module design approaches. For instance, a unique module design satisfying all experiments will probably cost more than a design intended to satisfy only a single group of experiments.

On the other hand, the total research, development, test, and engineering cost for several such specialized designs, each for single groups of experiments, may well be more than the cost of one common design for all groups. As our detailed cost analysis later showed, this thesis turned out to be true.

Preferred Experiment Operating Modes

DISCIPLINE / EXPERIMENT	PREFERRED OPERATING MODE
ASTRONOMY	
▪ GRAZING INCIDENCE X-RAY TELESCOPE	ATTACHED
▪ ADVANCED STELLAR ASTRONOMY	DETACHED
▪ ADVANCED SOLAR ASTRONOMY	DETACHED
▪ UV STELLAR ASTRONOMY	DETACHED
▪ HIGH ENERGY STELLAR ASTRONOMY	ATTACHED
▪ IR STELLAR ASTRONOMY	DETACHED
SPACE PHYSICS	
▪ SPACE PHYSICS AIR LOCK EXPERIMENTS	INTEGRAL
▪ PLASMA PHYSICS & ENVIRONMENTAL PERTURB	DETACHED
▪ COSMIC RAY PHYSICS LABORATORY	DETACHED
BIOSCIENCE	
▪ SMALL VERTEBRATES	ATTACHED
▪ PLANT SPECIMENS	INTEGRAL
▪ MICROBIOLOGY	ATTACHED
▪ INVERTEBRATES	ATTACHED

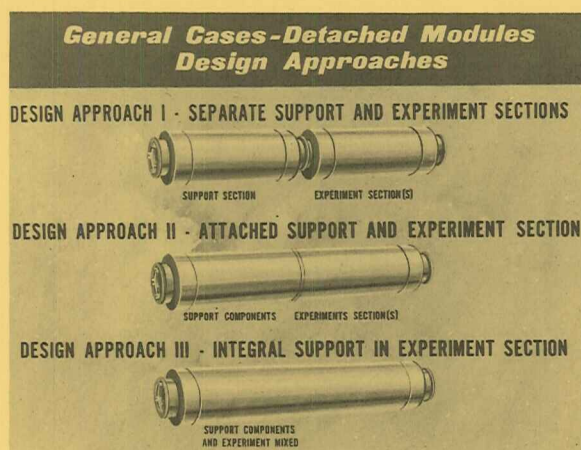
Preferred Experiment Operating Modes

DISCIPLINE / EXPERIMENT	PREFERRED OPERATING MODE
EARTH APPLICATIONS	
▪ EARTH SURVEYS	ATTACHED
▪ REMOTE MANEUVERING SUBSATELLITE	DETACHED
AEROSPACE MEDICINE	
▪ BIOMEDICAL & BEHAVIORAL RESEARCH	INTEGRAL
▪ MANNED CENTRIFUGE	ATTACHED
▪ MAN/SYSTEM INTEGRATION	INTEGRAL
▪ LIFE SUPPORT & PROTECTIVE SYSTEMS	INTEGRAL
MATERIALS SCIENCE AND PROCESSING	
▪ SPACE MANUFACTURING	INTEGRAL
ADVANCED TECHNOLOGY	
▪ CONTAMINATION MEASUREMENTS	INTEGRAL
▪ EXPOSURE EXPERIMENTS	INTEGRAL
▪ FLUID PHYSICS IN MICROGRAVITY	DETACHED
▪ COMPONENT TEST & SENSOR CALIBRATION	INTEGRAL
MANNED SPACE FLIGHT ENGINEERING	
▪ ENGINEERING & OPERATIONS	INTEGRAL & ATTACHED

The results of our qualitative analysis defined these critical factors forming the design approach:

- a. Commonality in design, manufacture, and usages
- b. Design, develop, test, and qualify a minimum number of elements
- c. Multiple production of a minimum number of common designs
- d. Design for economical launch vehicle and operations costs

These are modules designed (1) with separable support sections and experiment sections; (2) with attached support sections and experiment sections; or (3) with the support subsystems integrated within the experiment modules.



These three basic approaches were further delineated into a family of twelve designs varying only in the degree of standardization and commonality in the design of the support and experiment sections. Qualitative analyses were utilized to define three specific design approaches, the best of each type, which were subjected to an in-depth quantitative cost analysis. In each case the one selected was the most standardized.

A RECOMMENDED DESIGN APPROACH

The recommendation for a design approach for experiment modules for the Space Station program, based upon the previous work discussed, and the summation of additional criteria having program impact is Design Approach I: separable support sections and experiment sections made up of com-

mon 16-foot structural module elements.

The implementation of this design approach has been evaluated to yield least cost, with better capabilities, reliability, and more flexible operations than the other approaches. It is adaptable to accept changes and provide for future growth. Therefore, it is anticipated that the cost effectiveness for the program will be maximum. This result is further supported by a module launch analysis which indicated that only in Design Approach I could all of the detached modules be handled by the Space Shuttle.

The interfaces of the experiment modules with the Space Station are as varied as the experiments themselves. Simply stated, however, there are two general interface situations: first, for attached modules, where all supporting subsystem requirements of the experiments and modules are provided for by the Space Station, and second, where the free-flying module, with its own supporting subsystem section, docks to the Station for repair, normal refurbishment, or maintenance.

In either case, the Station, or the support section, provides the electrical power, environmental control, pointing and stability control, command and control, data handling, and life support, when crewmen have need to enter the module. Let me now trace in detail how the requirements for one such function, electrical power, have been generated and met, and indicate the capability provided for the other functions.

A detailed investigation of the power requirements of each proposed detached experiment module, including that to run the experiment and its supporting subsystems, was made. The results showed that except for the Cosmic Ray module, the average power required during full operation of any free-flying module varied between 1250-1930 watts. The Cosmic Ray module required 7500 watts, average. This range of requirement indicated that two separate categories of power modules should be considered, with modularity used to meet the larger requirement.

A detailed subsystem trade analysis was evaluated reflecting the various options of power subsystems and their components. The choices narrowed down to a 2000-watt and a 7500-watt subsystem. The final choice was for both to be solar array/battery subsystems rather than fuel cell, Radioisotope Thermoelectric Generator, or an Isotope Brayton. The key element for these subsystems is the roll-out solar array component, two in the 2KW and four for the 7.5KW subsystem. Other than the number of batteries required, it was determined that most other components of the power subsystem could be common or modular.

MODULE EXAMPLES

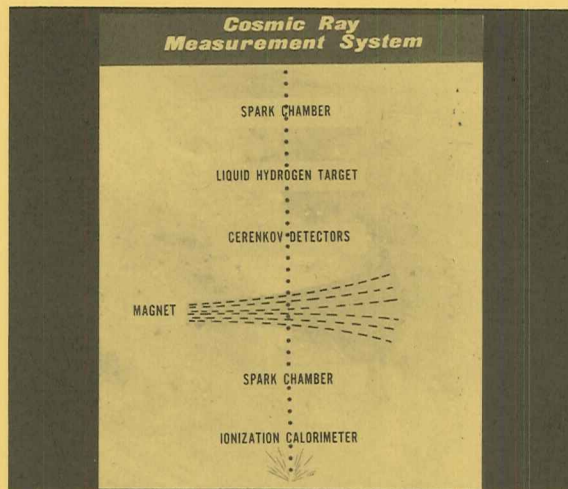
Cosmic Ray Laboratory

Now let me turn to several examples of modules that are of interest to the scientific community. The first one is the cosmic ray laboratory. The requirements that govern what this module will look like, what it will contain and how it will function, are all dictated by fundamental and simple scientific objectives. The first of these is to use cosmic rays as a tool for probing the dynamic structure of the universe so that we may understand its make-up and the role that cosmic rays play. A secondary objective is to study what happens when atoms collide with each other at fantastic energies up to 10^{20} eV that at present only cosmic rays provide. To intercept a sufficient number of these particles with such energies in a reasonable time requires instruments with very large and very wide-angle viewing ports.

Facilities and instruments that are capable of meeting these requirements may consist of large superconducting magnets to deflect particles, massive ionization calorimeters to measure their energies, photographic emulsion assemblies to record particle track ionization data, and many different kinds of detectors and arrays of detectors. Some of the detectors that will be used have not yet been developed but are bright on the horizon, such as transition detectors. Superconducting magnets are in their infancy and much is yet to be learned about their behavior and operation in space. The refrigeration power required to maintain such magnets would be large, of the order of several kilowatts.

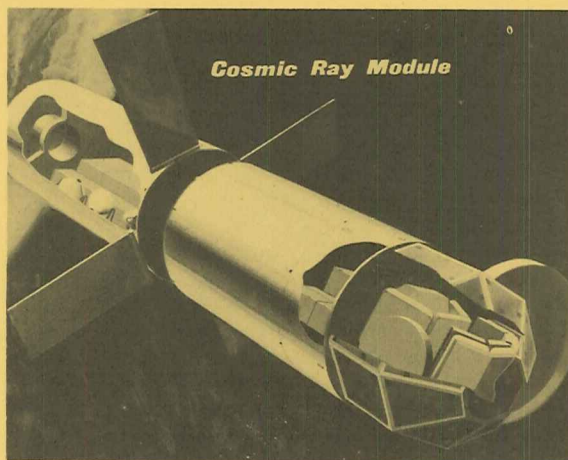
Design

The design that we have developed can best be described functionally by following the trajectory of a cosmic ray particle through a block diagram, beginning at the spark chamber which measures the entrance coordinates of the particle. The particle then passes through a tank that contains liquid hydrogen as a target material. Next is a hemispherical array of Cerenkov detectors which measure the particle charge state. Next a magnetic field generated by the superconducting magnet deflects the particle, thereby measuring its momentum. The next detector is another wire spark chamber which, together with the first spark chamber, measures the deflection of the particle by the magnetic field. Finally, the particle enters an ionization calorimeter where heavy slabs of tungsten and iron slow it down. They produce ionization cascades whose energy is measured from



the light that they generate in passing through a gas between adjacent slabs.

This system is contained in a 14-foot diameter module comprised of a standard 16-foot support section. Two standard 16-foot shell sections make up the experiment section. The experiment package slides forward on rails to expose the experiment directly to the cosmic ray environment. Power is supplied by the support section. This also contains the information management interface electronics together with functional equipment that is common to all support sections.



The required cryogenic temperatures for the superconducting magnet are obtained by the use of cryogenic refrigerators, which, in turn, define the

major requirement for high power. The power is met by utilizing four sets of roll-up solar array components as previously described. The primary items which led to the decision to make this module a free-flying module are the torque between the magnetic field of the Earth and that of the experiment section and the electromagnetic interference. The predicted value of 800 ft-lb torque is 8 times the capability of the Station. Other than the power and the torque requirements, all other supporting subsystem requirements are met by the common subsystems.

Earth Surveys Module

As a second example I would like to discuss the Earth Surveys Module. It will provide a facility for obtaining simultaneous images and measurements of the Earth's surface, using many different kinds of sensors, including microwave, infrared, and multi-spectral visible wavelengths. It will be contained in an experiment module which will operate attached to the Space Station.

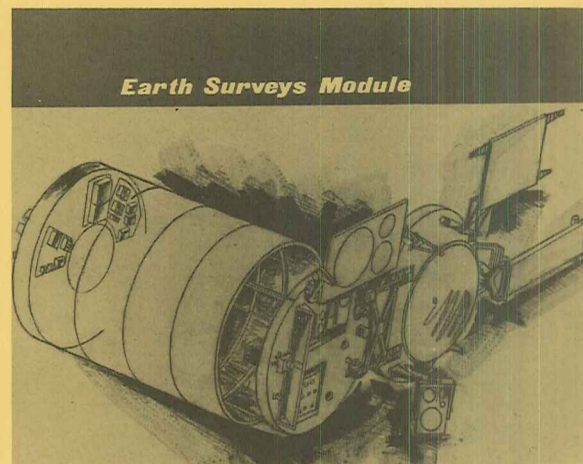
The objectives of this Experiment Group are: (1) to test a variety of complementary earth surveys sensors and other sensing hardware in orbit; (2) develop and verify on-board data gathering procedures and techniques; and (3) to develop and verify on-board data handling procedures and techniques for the return of large quantities of information to Earth.

These objectives will be accomplished by employing multiple sensors to obtain data on specific phenomena and for sites on and above the Earth's surface. The disciplinary groups served by the laboratory will include the following:

1. Forestry/Agriculture/Geography
2. Geology/Minerology
3. Hydrology/Water Resources
4. Meteorology
5. Oceanography

Here are presented the results of the General Electric preliminary design effort where in-depth accommodation analyses resulted in the configuration shown in its operating mode.

The prime considerations which led to this attached module configuration are the requirements for 440 square feet of nadir viewing area, and the ability to point at Earth with an accuracy of ± 0.25 degree with only a movement of 0.05 degree/second for over one hour. These requirements led to the unique design incorporating sensors located on both single-and-double-degree-of-freedom platforms. A unique feature is the calibration and alignment monitoring of the sensor platform by a light beam from the Station guidance and navigation base



through the docking port to the platform.

As I previously explained, attached modules draw their subsystem support from the Space Station. The following indicates how the module requirements are satisfied by the Station utilities.

Earth Surveys Module Space Station Interface

UTILITY	QUANTITY AVAILABLE FOR ALL EXPERIMENTS	QUANTITY CURRENTLY REQUIRED BY EARTH SURVEYS MODULE
ELECTRICAL POWER	6 KW AVERAGE 9 KW MAXIMUM 10 KW PEAK	1.3 KW AVERAGE 5.1 KW MAXIMUM 6.5 KW PEAK
ATMOSPHERE CONTROL	3415 BTU/HOUR PLUS HUMIDITY & CO ₂ REMOVAL FOR FIVE MEN	1740 BTU/HOUR PLUS HUMIDITY & CO ₂ REMOVAL FOR TWO MEN
CLOSED-LOOP COOLING	20,490 BTU/HOUR	NONE
INFORMATION MANAGEMENT	5 X 10 ⁶ BITS/SEC MAX 150 X 10 ⁹ BITS/DAY MAX 4.5 MEGA Hz TV	3 X 10 ⁶ BITS/SEC MAX 130 X 10 ⁹ BITS/DAY MAX 4.5 MEGA Hz TV

Once the Earth Survey Module has been launched into space and docked to the Space Station, the sensors will be checked out and calibrated. The module will be ready, with all sensors deployed, to obtain correlated data on selected portions of the Earth's surface using simultaneous measurements and recorded images in many wavelengths. A few seconds operation, over a site such as the Great Lakes, can provide an immense amount of data. Such data include topographical locations, air and water pollution measurements, urban land use, transportation

routes, crop status, soil moisture, air temperatures, wind directions and velocities, plant distributions, geological formations, fresh water storage levels, and stream flows. For the first time, man will begin to see his environment as a unit, where all the interrelated parameters can be measured at a given instant of time.

Space Processing Laboratory

One important aspect of the utilization of manned space flight is to take advantage of the unique characteristics of the space environment, i.e., microgravity, vacuum, low temperatures, and radiation. My last example deals with the processing of materials in space to degrees of perfection and purity higher than can be accomplished on Earth.

One application, for instance, might be for melting, shaping and casting metals and ceramics, including glasses, of reactive or heterogeneous compositions. These materials will benefit from being processed in a buoyant manner without being in contact with a crucible that could cause contamination.

Another application might be for preparing large single crystals of semiconductor or other electronic materials. The processing has certain features, e.g., heating, that are common to the melting and casting facility just described.

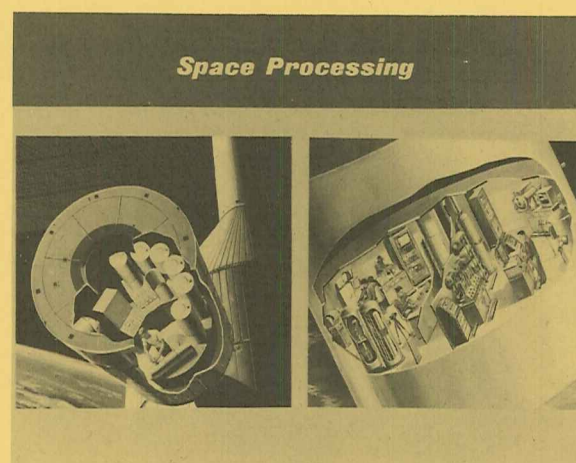
A facility might be devoted to the preparation of certain vaccines or pesticides. For safety and toxicity reasons this may well have to eventually be a separate module. Initial ideas for the improvement of processes by using microgravity can be suitably evaluated with innocuous substances, however. The principal concepts are centered around purification steps where thermal convection and mechanical vibrations are believed to be prime causes for not being able to further purify many biological and chemical substances. It is, in turn, these remaining impurities which are believed to be the cause of side effects in some patients who receive them in medications.

A prime consideration for the accommodation of this laboratory is the method by which we handle the large amounts of RF energy generated during the heating and sample material suspension operations. Another significant consideration is the requirement for large volume available for vacuum float of samples. Countermeasures for the RF energy include shielding (approximately 25 lbs) and proper location of the laboratory within the Station envelope.

The use of radiation countermeasures and the ability to withstand the range, frequency, and dura-

tion of normal Station acceleration levels allow this experiment group to be accommodated either integrally or in an attached mode. Final resolution is dependent on the available internal Station volume and the time availability of an airlock when needed for the processing.

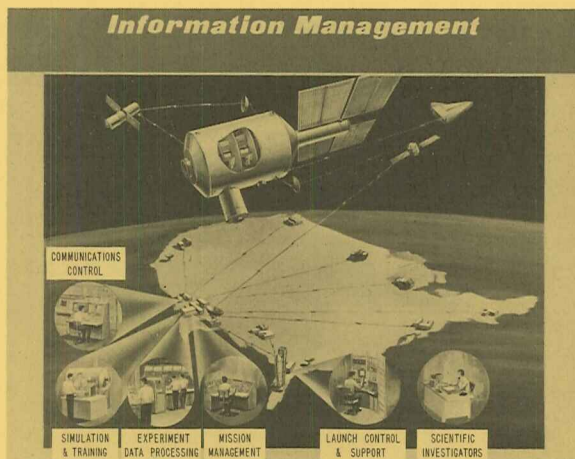
Examples of the accommodation as a laboratory integral to the Space Station or, if required, as an attached module are shown here.



MODULE OPERATIONS — INFORMATION MANAGEMENT SYSTEM

At this point, I would like to touch briefly on the Information Management System. During the operation of all experiment modules, situations and problems will continually arise that will exceed all attempts to anticipate them. Such activities as the acquisition of data from targets of opportunity, the unplanned performance of experiments, and the screening and filtering of acquired data, will continually require resolution utilizing the flexibility of man to resolve these situations as they occur. This will not only result in the collection of data that is definitely required, but the use of man will also serve to eliminate and reduce undesirable or unwanted data. More about that shortly; first, let me describe the facilities and operations that will allow man to exercise control over the experiment modules. This is accomplished by means of the Information Management System.

The Space Station Information Management System (IMS) has been designed to collect the raw experiment data, convert it into scientific informa-



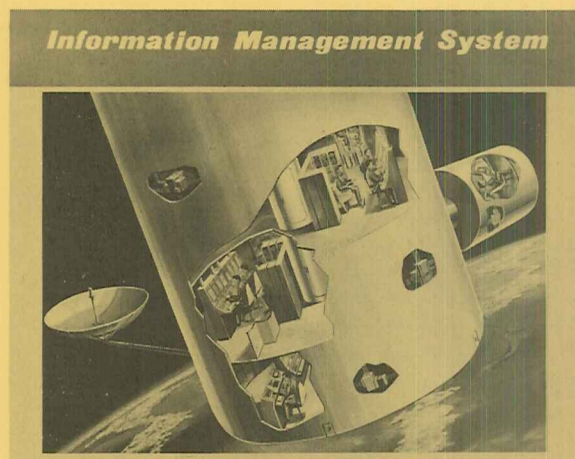
tion and transport it to its point of use on-board the Space Station and on the ground. In addition, it will provide the command capability which will permit the flight crew to control the Space Station, as well as the experiment modules, and the experiments themselves.

That portion of the IMS located on the experiment modules, the Information Management Subsystem (IMS/S) serves to acquire, store and transmit the experiment data. It will also provide the necessary equipment to utilize and carry out Space Station generated commands.

The Information Management Subsystem (IMS/S) functions are required to: (1) control the modules and their experiments; (2) monitor the existence of a suitable environment for the experiments; (3) place experiment data in appropriate hands in a timely manner; and (4) monitor the operating condition of the experiments and the modules.

Command and control is the activity associated with the manipulation of the equipment, both experiment and support, to accomplish the purposes of the experiments. This includes control of experiment equipment, providing communications, and controlling all supporting activities, such as providing power, vehicle orientation, data processing, control, and environmental controls.

To permit man to carry out his role as experimenter, it will be necessary to provide him with the tools and facilities to make decisions and to be assured that they will be carried out. Such operations as assessing performance of experiment modules, scheduling operations and determining the usefulness and quality of the collected experiment data, require



the use of general purpose interactive displays. They also require that man be made constantly aware of the activities taking place at a given time on an experiment module. To satisfy man's decision-making role and provide for visual alignment and experiment monitoring, real time TV between the station and the experiment module will be provided.

Most of this information will be viewed in the displays area with only about nine hours per month requested for ground viewing. Any or all of the TV images may be stored on video tape and shipped to the ground via the shuttle.

A total of over 200 giga bits of experiment digital data will be generated per day. Of all the data acquired by the experiment modules, one particular experiment group, Earth Surveys, will generate about 100 giga bits per day, plus about 800 photos. By utilizing man in his capacity of an on-line experiment director, this can be reduced to about three giga bits per day. One giga bit will be returned to Earth via RF and two giga bits via shuttle. This will be in addition to about 13 pounds of film and hard copy.

INTERNATIONAL COOPERATION

Before summarizing, I want to note the opportunity for international cooperation. The cosmic ray laboratory we have discussed will provide facilities and opportunities for scientists from many different nations and parts of the world. Its large size associated with many possible detector configurations -- its ability to "look" directly into space without the obscuration of any atmosphere and its flexibility as a result of man's presence -- all represent a quantum jump from today's balloon facilities and pay-

load-restricted satellites. Through such international sponsoring organizations as ESRO (European Space Research Organization), ELDO (European Launcher Development Organization), and COSPAR (Committee on Space Research, part of the International Council of Scientific Unions), the opportunities for participating in this exciting new facility can bring together scientists from all nations involved with space research.

Similar elements of cooperation can be envisioned for many of the other modules proposed for the Space Station program.

SUMMARY AND CONCLUSIONS

In summary, the guidelines for experiments installations required that all possible experiments be mounted integral to the Space Station. This applied also to many experiments which will be launched later and transferred to the Space Station in orbit. For those experiments groups which will require operations detached from the Space Station, because of ultra-precise pointing and stabilization requirements, or to assure freedom from the contamination of jet exhausts or atmosphere leakage expected near the Station, experiment modules capable of co-orbital operations were defined.

The design of modules emphasized compatibility for launch on the reusable shuttle vehicle because of the possibilities for reduced costs. It also emphasized use of common structural elements and common subsystems and components to the maximum extent practical. This would reduce total costs and assure that most hardware would be previously flight proven at launch. The manufacture of multiple units of a common design will provide the usual cost savings associated with mass production and will reduce other costs by limiting the types of training aids required. It will also reduce the types and quantities of spares required and the kinds of tooling, jigs, fixtures, and ground support equipments needed.

The recommended approach for experiment modules will use a common 14-foot diameter structural element in multiple lengths of 16, 32 or 48 feet to house most of the experiment groups which will be operated outside of the Space Station.

The detached modules will use a common-design, separable support section which will contain all of the subsystems required to support any of the detached experiment groups for limited duration co-orbital flights. These detached modules will rendezvous and dock with the Space Station periodically for maintenance, repair, and resupply. The attached modules will draw upon the Space Station for all of

their subsystem support requirements. The cosmic ray detached module, the earth survey attached module, and the space processing laboratory which I have described for you today are prime examples of how science and man will make progress through the Space Station. The overwhelming influence of information management in the acquisition, operation and dissemination of experiment data cannot be over-emphasized. How well man will interact with these new laboratories will determine the extent of the benefits to be derived from the experiment program.

