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EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

SUMMARY REPORT

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

MCDONNELL DOUGLAS CORPORATION

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INTRODUCTION

Why on Earth is man in space? The question is not facetious. More and more people are legitimately asking it. Among those most concerned are those whose responsibility it is to allocate the funds, to determine objectives and schedules, and to plan space missions. These judgments are vitally important to the National Aeronautics and Space Administration, where the question of man's purpose and role in space is fundamental to the agency's functions.

The past 10 years have been directed primarily toward the exploration of space and the development of systems that can support man in this new realm. In September 1969, a summary of long-range goals and objectives suitable for NASA's activities during the 1970's and 1980's entitled, "America's Next Decades in Space," was published by NASA as a portion of a report for the President's Space Task Group. As noted in that document, the emphasis during the next 10 years in space may be expected to shift from exploration to utilization.

The study discussed in this report, the Earth Orbital Experiment Program and Requirements Study, was undertaken to translate the objectives described in the above mentioned NASA publication into specific experimental and engineering requirements. The purpose of this undertaking was to provide information which can assist mission planners in solving the difficult problems of apportioning limited resources among an almost unlimited number of candidate long-range projects under constraints that can be expected to change from time to time. Priorities depend on changing political, economic, social, and technological factors. Long-range planning is desirable, however. for the sound basis that it provides for ensuring that fiscal commitments are met and that required systems and components are available when needed. The course should be charted, but in such a way that modifications can be made along the way, and so that the impact that these changes have on the eventual accomplishments of the program can be realistically assessed. The study described in this report contributes to the information base required for the formulation of long-range plans, for the assessment of available choices, and for the examination of how these choices will affect the end result and reflect the original intent. By so doing, the study also contributes to the planning flexibility necessary for revision of specific research activities as constraints and objectives change.

The results of this study are available at a most appropriate time. They are the logical result of an incubation period that began with the first satellite flights. The exploratory developments of the past 10 years in space stimulated serious, realistic consideration of how best to utilize this new capability to man's advantage. The continuing growth of knowledge about actual conditions–knowledge collected through both manned and automated flights–has amended, shaped, and further developed that thinking. The advanced concepts for utilizing space that have resulted from that process have been documented in this study. The time is therefore ripe to reap the benefits of the first decade in space by using the fruits of that period in the effective planning of future missions.

This study delineates the substance of a comprehensive space research program to match the opportunities now present. It furnishes the key to the benefits to be derived from space. It does not decide what benefits should be pursued, or even which are most desirable; but it does say that there are benefits, it identifies the research required to pursue them, and it tells how to do this research. It sets out the specific elements for obtaining a substantial return from the investment of time, effort, and money.

BENEFITS TO BE DERIVED FROM SPACE

Economic benefits are already being accrued from automated Earth orbital spacecraft. Communication satellites are providing global networks at a substantial saving over ground-based equipment. Meteorology satellites are gathering cloud-cover data on a global scale in support of improvements in the accuracy and range of weather forecasts.

What other kind of benefits are available and what research will uncover them? Managing his resources has always been the key to man's progress, and today it is becoming dramatically apparent on a planet-wide scale that only the proper management of resources, including control of pollution, can ensure man's continued survival on Earth.

A crucial requirement in the proper management of Earth resources is a program to survey, inventory, and monitor the distribution and abundance of the world's natural resources. The discipline of Earth Observations offers techniques to permit man to survey the resources of the globe. The field of remote sensing can provide a technological capability to determine the properties of materials by optical rather than chemical analysis. Thus, man can locate and inventory potentially valuable sources of mineral wealth, range and timber resources, ocean fish, agricultural crops, and snow, ice, and other sources of fresh water. This knowledge can be put to work in new and unusual ways. For example, glaciers and the polar ice caps represent 75 percent of the Earth's fresh water resources. Manned spacecraft can perform rapid and frequent surveys of the areal extent, depth, and location of the continually changing glaciers and ice fields and, by using microwave imagery (which can penetrate cloud cover) and high-resolution photography, can keep an inventory of fresh-water resources. Relayed to Earth, this information will facilitate more-effective utilization of available water supplies.

Long-range planners are concerned with the rate of consumption of fossil fuels and the depletion of energy reserves. The identification of new energy sources is critical to man's long-term survival. One potential source promising high yield is geothermal energy. Natural hot springs in Iceland are used for heating; and Boise, Idaho, has natural hot water (170° F) available in an amount of one and a quarter million gallons a day. To date, however, there has been no really extensive use of geothermal energy, partly because no comprehensive survey of potential sources has been made. High-resolution photography from a space research facility can locate many such regions, and when conventional photographic interpretation is insufficient for geological understanding, it can be supplemented by infrared thermal imagery. It has been demonstrated that underground geothermal sources can be made clearly evident by the use of infrared photography augmented by artificial color enhancement techniques, even where the difference in surface temperature is a scarcely noticeable 1° C.

The spectra identified from space of the solar radiation reflected from the oceans can be used as a measure of chlorophyll concentration in the sea. Inasmuch as chlorophyll is associated with living plants (phytoplankton), development of this measuring technique will lead to a better understanding of the ecology of the oceans, from this to more accurate descriptions of ocean-population dynamics, and ultimately to more effective prediction and control of fish yield.

Besides offering potential for increasing the availability of natural resources, space research also promises to be extremely valuable in the fight against pollution. Pollution sources in the oceans, lakes, rivers, and streams can be located, and dispersal patterns can be charted and controlled. Pollution-related research is discussed later in more specific terms.

The need to communicate has been basic to man since prehistoric times, and significant improvements in global communications will provide immediate, identifiable benefits to hundreds of millions of people. Communication capabilities can be expanded and can be used both in normal business and in making important information developed in the applied and basic sciences almost immediately available to those who require it. This capability is important not only in the prediction of natural disasters, such as floods, earthquakes, and forest fires, but also in the rapid collection, analysis, and dissemination of information that can be vital in predicting crop yield and locating diseased crops, and other agricultural data.

Navigation and traffic-control systems incorporating Earth orbital spacecraft appear to be the best solution to the problem of controlling air and space traffic. Traffic control is required for vehicles, including ocean vessels and aircraft, operating in the terrestrial environment; vehicles orbiting the Earth; and space vehicles in the launch or reentry phase that pass through the zones of both the terrestrial and the orbiting vehicles. Navigation and traffic control systems that include spaceborne elements may also prove to be the only feasible way to bridge the gaps between the continental land masses in the efficient control of transocean air traffic.

Immediate returns to medical science may also be expected from research that may be undertaken initially in the interest of advancing our capability for manned spaceflight. Many bone diseases have their origin in poorly understood aspects of calcium metabolism and control. These diseases (e.g., osteoporosis and osteodystrophy) manifest themselves in brittleness, fragility, and faulty development. Decreases in bone density accompanied by an increase in urinary calcium have been observed in association with previous manned spaceflights. This subject is therefore a candidate for particular emphasis in future research programs in orbit. The information derived from such research, while directly applicable to manned spaceflight problems, is also expected to significantly increase our overall understanding of the complexities of calcium metabolism and may well produce a major advancement in the treatment of associated bone diseases.

Another class of benefits underlies man's welfare and provides the structure of his understanding of himself and his environment. These returns are derived from the furtherance of basic science. The practical application of any development of science for the sake of science is not always immediately evident. The influence of such development is usually subtle and often spread out over a long period. The two principal sources of these long-term returns are most likely to be the life sciences (Space Biology and Space Medicine) and the physical sciences (Space Phsyics and Space Astronomy).

The understanding of many basic life processes would be markedly increased if the roles of gravity and Earth-lunar periodicities in biological activities, particularly at the cellular level, could be more clearly defined. Unfortunately, from the point of view of experimental biology, these phenomena are always present in the terrestrial environment and consequently are not susceptible to experimental manipulation and control. It is only in the space environment, where biological organisms may be examined in the absence of gravity and terrestrial cycles, that the influence of these factors can be truly realized and meaningfully measured.

Most biological forms that have been studied show some type of rhythmic activities or cycles. The frequencies may be diurnal, in harmony with the terrestrial days and nights; circadian, repeating at about 24-hour intervals; or tidal or lunar, associated with 12.4- or 24.8-hour tides and showing monthly highs and lows. Man himself exhibits obvious diurnal temperature variations and more subtle variations that may be associated with susceptibility to disease and response to medication. The rhythms may be endogenous or they may require terrestrial cues; increased understanding must await extraterrestrial study.

The experimental organisms that are the subjects of biological research may seem rather exotic, even bizarre, to the layman. Such specimens as the fruit fly (*Drosophila melanogaster*), the fiddler crab (*Uca pugnax*), the mouse ear cress (*Arabidopsis*), parasitic wasps (*Hubrabracon*), and the like are usually quite outside the scope of lay knowledge, and the relationship and application of their biological processes to man is consequently unappreciated. Species such as these, however, may be selected as space research subjects because they manifest some biological phenomena in a manner that facilitates accurate experimentation and because they lend themselves well to the orbiting laboratory situation. Use of such specimens is feasible because there is a remarkable unity and constancy in the science of biology: a basic life process identified in a plant or lower animal is usually as applicable to man as it is to the organism in which it was studied.

Many of the phenomena suggested for study in weightlessness have a direct relationship to man's immediate terrestrial needs: an increased understanding of growth phenomena applicable to more precise nutritional requirements; the possible aberrancies in cell division in space, applicable to cancer research; a greater comprehension of the role of gravity in plant lignification, applicable to the development of stronger and more durable woods. Others have a less obvious but no less important long-term application. Advancements in basic knowledge are never wasted.

Although space medicine is directed primarily toward maintaining the health and performance capabilities of spacecraft crewmen, it will (by providing a better understanding of man's physiological responses to environmental stress and the improvements that can be realized with appropriate countermeasures) have a most direct and important application to man's terrestrial problems.

Three other research areas that will provide long-term benefits to man are Geodesy (Earth physics), Space Physics, and Space Astronomy. Systematic coverage of the Earth's land areas by cloud-free photography from space could produce a uniform series of geotectonic maps in a detail comparable to that of the lunar-orbital coverage of the moon. These maps would be of significant value to structural geology and geophysics by contributing to a basic understanding of Earth dynamics. The monitoring of active volcanoes is another activity that could be performed from space that would add to man's basic understanding of Earth physics.

Space Physics has potentially great practical application. Research in space not only permits study of the physics of space, in the sense of understanding the plasma sheath and the ionosphere, and their impact upon our terrestrial home, but it offers unusual opportunities for the development of physics. For example, research on the effect of surface tension on liquid behavior and other matters related to liquid-vapor interfaces in zero gravity will not only provide data needed for realistically designing propulsion systems and life support equipment for space applications but will also further the understanding of material behavior in space. This field of research could be particularly fruitful in its contribution to the eventual manufacture of special materials and extremely pure pharmaceuticals in space. Comparison of Earth-grown crystals with those grown in orbit, and other similar research, may result in the development of materials with very special characteristics that cannot be developed in the terrestrial environment.

Astronomy has, to date, been the most active scientific endeavor in space, chiefly because astronomical observations of many types can only be made above or at least high in the atmosphere. The list of space astronomy accomplishments during the 1960's is impressive; it includes discovery of discrete x-ray sources and diffuse x-ray and gamma-ray backgrounds, the first observations of ultraviolet stellar spectra, detailed observations of the Sun's spectrum from the ultraviolet to the hard x-ray region, high-resolution visible-wavelength imagery of the Moon and Mars, detection of intense far-infrared radiation from quasi-stellar radio sources (quasars) and certain galaxies, the first measurements of the diffuse low-frequency radio background of the sky with adequate resolution to distinguish the galactic halo and the galactic disc components, and detailed low-frequency-radio observations of the solar corona and of Jupiter's trapped-electron belt.

During the 1970's, Space Astronomy programs may be expected to include more and better observations of the types listed above, close-up (but still remote-sensing) observations of Mercury and some of the giant planets, and the first manned astronomical observations (Skylab). Traditionally, astronomers have not tended to rely on practical results as a basis for support, in spite of historical examples such as the calendar, celestial navigation, the discovery of helium in the Sun, and proof of the existence of sustained thermo-nuclear energy generation by the stars a process that has only been theoretically postulated on Earth. Although it is difficult to predict the practical applications of present or future astronomical investigations, one likely accomplishment is the development of solar flare theory in detail adequate to predict flare occurrences, thus warning space travelers of the health hazard and alerting Earth-based communications systems to anticipate increased noise and possible blackouts of some frequencies. Another possibility stemming from recent indications of powerful non-nuclear energy sources in galaxies and quasars involves the future harnessing of new energy mechanisms for man's use. If these prospects materialize, Space Astronomy observations will surely have provided vital contributions to man's welfare.

Man has a vital role to play in the development of the immediate and long-term benefits discussed above; but to be able to continue to explore the possibilities of utilizing space, he must develop new and better ways of functioning in space. Man himself, therefore, becomes one of the subjects of study. The research identified in the Manned Spaceflight Capability discipline will not only make it possible to develop equipment for life support systems and to aid man in performing useful functions in space, but will provide additional information on the interacting effects of such factors as weightlessness, isolation, sensory deprivation, boredom, monotony, restricted space, lack of privacy, and other psychological elements of a spacecraft environment. This kind of research will not only develop confidence that man will function efficiently over the span of long-duration missions, but will also provide design criteria directly useful in terrestrial facilities.

RESEARCH MISSION AND SPACE FACILITY PLANNING REQUIREMENTS

This study began with six NASA-assigned disciplines for research,* and through an organized overview analysis of each discipline, a total of 3,800 critical issues were derived. The term "critical issue" is used to denote especially important questions that are of crucial interest to the expert and to which answers are decisive in meeting a central objective within a pertinent theoretical or practical setting. These critical issues express the specific objectives required to fulfill the overall objectives within the discipline and are directly traceable to them. After screening to determine the applicability of the research required by any critical issue to manned Earth-orbital missions, the remaining critical issues (1,983 in number) were grouped into 136 "research clusters" on the basis of commonality of instrumentation and measurements.

Translation of NASA-assigned disciplines into relevant sets of research activities for man in space, however, is only one step in achieving NASA's goals. In addition to the determining of what research must be performed and how it can best be performed, it is also necessary to plan actual missions that will accommodate the research.

A number of vehicle concepts are currently available to be used singly or in combination as space research facilities. The configuration chosen for a particular mission must offer characteristics that are suitable to the desired mission. Some parameters that are necessary in some disciplines have little or no effect in others. For example, Space Astronomy (which uses telescopes in space) is different from other disciplines in that most of the research is better suited to free-flying modules that are periodically attended by man than to a continuously manned facility, because the presence of man may have adverse effects upon the stability of the telescope and therefore upon the measurements.

*Manned Spaceflight Capability, Space Biology, Space Astronomy, Space Physics, Communications and Navigation, and Earth Observations.

All research imposes certain requirements on both the mission and the research facility. The mission profile (altitude, inclination, pointing, duration), the volume required to house equipment, the weight of equipment carried, and the electrical power required to run the equipment are some of the more significant parameters. The number of crew members required to perform the planned research and the demands on their time will be a function of many factors, such as instrumentation, data management, type of research, and the versatility and skill levels of the crew. Crew size, in turn, will affect the configuration of the facility and the necessity for life support systems. Extravehicular activity, when required for some research, will likewise impose requirements on the mission, and research that involves calendar events (planetary activities or seasonal changes) will impose requirements in terms of mission timing. All of these parameters and many more interact with one another to influence mission planning.

Detailed descriptions of the research clusters were developed to define configuration requirements for space-research facilities, as well as for instrumentation and installation layouts; crew activities, skills, and schedules; data-acquisition elements; and interface of the spacecraft with the subsystems required to support the research. A summary of each of the 136 research clusters appears in the Appendix.

SUPPORTING TECHNOLOGY DEVELOPMENTS REQUIRED

Certain research activities identified in the study cannot be carried out with existing instrumentation and techniques. For example, classical techniques for microbial identification required in studying changes in the number and kinds of microorganisms existing in a closed spacecraft ecology are laborious and time consuming. To limit the demands upon the astronaut's time to an acceptable level, automated techniques need to be developed. As other examples, observations of faint astronomical objects will depend on development of a space-based system for acquisition of celestial targets; and the observation of natural resources from Earth orbit will require the continuing development of instruments, such as multispectral scanners and microwave radiometers, that can distinguish among surface features or conditions on the Earth. It is important that requirements for supporting technology development (STD) such as these be identified while a research program is in its formative stages, so that the activities necessary to improve or institute advanced technology programs to satisfy these requirements may be started at the most advantageous time. For this reason, the subject of STD was made an integral part of the study.

Each of the 136 research cluster descriptions was examined, to determine STD requirements. From these requirements, specific activities studies, experiments, or development programs that will have to be carried out to satisfy the requirements were named. Studies were indicated for many new types of research equipment arising out of the prospect for research in the space environment, for example, a device capable of positioning or levitating molten metallic samples in a test chamber under zero-g conditions without distorting the surface geometry. Developments, on the other hand, are frequently required in connection with instruments that have been used in the terrestrial environment but need redesign for zero-g, such as blood-cell counters and tissue processors. Experiments, whether in space or not, are typically called for when specific physical information is needed for the design and development of new types of research apparatus. Such devices as condensers and liquid-gas phase separators suitable for operation in zero-g are examples of equipment requiring experimentation both in space and on Earth.

The STD activities were regrouped into STD work packages, each representing a logical combination of either studies, experiments, or developments in support of the STD requirements. For example, the studies identified from each of three STD requirements related to millimeter-wave research (MM-wave experiment plan, broadband modulators, and high-speed correlator) were combined into a single STD work package. Analysis of these work packages provides the data required to commit resources in a timely manner, and on any priority basis, for the development of operational capabilities in support of long-range mission objectives. In this area, as in the other areas of the study, traceability makes it possible to use the data in a meaningful way, and STD requirements and work packages can be related to the overall research objectives that they support.

RESULTS OF THE STUDY

This study details the manned research that can be performed in orbit to achieve NASA's objectives for the utilization of space for the good of mankind during the next decade. Six disciplines have been subjected to an overview analysis that resulted in the identifying of 3,800 critical issues timely and important research questions. Of these critical issues, 1,983 that were deemed suitable for near-term manned space research were grouped into 136 research clusters in accordance with commonality of instrumentation and measurements. These clusters were described at a level of detail that identifies the important aspects of the research and establishes the principal requirements that will be placed on the missions in accomplishing the research and on the space research facilities for these missions. Summaries of the space facility requirements and guidelines for mission planning were prepared. The supporting technology developments required to pursue the research were identified and grouped into 233 work packages. Critical issues, research activities, and supporting technology development requirements are all directly traceable back to the overall objectives within each of the six major disciplines.

The information derived in this study is a contribution to the formulation of a reference manual for planners of Earth-orbital research activities. The Study Final Report* provides an overview of NASA's orbital-research program objectives in six disciplines, with a continuous chain of traceable logic from the overall objectives in each discipline to the detailed descriptions of specific experimental activities necessary to consummate the research program.

*Earth Orbital Experiment Program and Requirements Study Final Report, MDC G0680, McDonnell Douglas Astronautics Co., December 1970.

Previous programs have addressed individual aspects of research planning, but the current program was the first to translate NASA's long-range objectives for man in space into a series of related specific research activities. Two major elements composed the research program thus derived: (1) the critical issues, which resulted from an overview analysis of assigned disciplines of scientific investigation and were an expression of the objectives in these disciplines, and (2) the research clusters, which resulted from an analysis of the critical issues and were an expression of the space-related research activities required to satisfy the objectives.

CRITICAL ISSUES FOR RESEARCH

NASA assigned six disciplines to the study team as areas for investigation: Manned Spaceflight Capability, Space Biology, Space Astronomy, Space Physics, Communications and Navigation, and Earth Observations. These categories approximate areas readily identifiable with recognized broad lines of scientific research activity. Within the discipline of Manned Spaceflight Capability, for example, are biomedicine, behavioral research, man-machine research, life support and protective systems, engineering experiments, and operations experiments. Earth Observations includes Earth physics, agriculture and forestry, geography and cartography, geology, hydrology and water resources, oceanography and marine resources, and meteorology. The approach to reducing each category to a series of definable, manageable packages of research activities was essentially the same for all of the disciplines, although individual disciplinary characteristics in some cases required differences in the details of the approach. The aim of the analysis was to identify (1) the important things to learn in each discipline during the next decade and (2) the research activities that should be pursued on manned space facilities in order to learn them.

To understand the analytic procedure followed, it is necessary to recognize the way in which science proceeds, and the inherent differences between "basic" and "applied" research. As illustrated in Figure 1, "normal science" proceeds in a closed cycle from observation to theory to observation and back to theory. That is to say, the scientist observes certain phenomena, thus developing "knowledge" which in turn, leads him to develop theories or an "understanding" of the phenomena; he then applies this understanding to a designed repetitive experiment or series of observations. Either his understanding is confirmed by the experiment, or the knowledge gained from it modifies his understanding. The cycle repeats itself, developing further detail or scope as it goes. Occasionally, however, an observation is so grossly contradictory of theory that a crisis situation develops and a revolutionary step is taken. It is at times like these, suggests T. S. Kuhn,* that science makes its most significant and dramatic forward movements. Among the six disciplines addressed in this study, those of Space Astronomy, Space Physics, and Space Biology proceed generally in the manner of "normal science." On the other hand, the applied sciences are concerned not only with theory and observation but with the application and utilization of knowledge. Typical of areas that must concern themselves with practical utilization are the disciplines of Earth Observations, Communications and Navigation, and Manned Spaceflight Capability. In

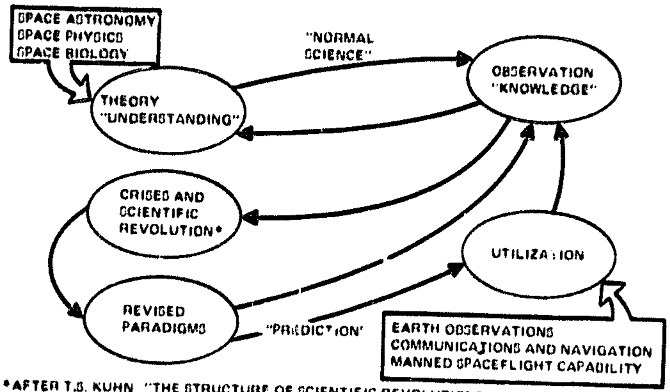

Figure 1. Philosophy of Research

*T.S. Kuhn, *The Structure of Scientific Revolutions*, University of Chicago Press, 1962.

implementing the analytic procedure, then, it was recognized that somewhat different approaches were required in each area, and this was reflected in the manner in which each of the subobjectives was treated in what was termed an "overview" analysis.

The method developed for dividing each discipline into performable research activities was called an overview analysis because it did indeed provide an overview of the entire discipline. An overall objective was identified for each discipline; a series of questions was then posed, and the answers constituted subobjectives. Figures 2 through 7 show the first level of categorization of the organized overviews for each of the six disciplines. Each subobjective was addressed by another series of questions, which in turn, defined further subobjectives at the next level of detail. The process was continued until a level was reached at which it was appropriate to pursue experimental means for answering the questions posed. A question at that level was called a critical issue. Figure 8 shows the flow of this analysis in one line of inquiry in the Earth Observations discipline (i.e., hydrology). From the overall hydrology research objective, a series of questions led to developing an understanding, among other things, of the effects of pollution on the utilization of water resources and the identification of such critical issues as the effect of chemical and biological pollutants on resources, the effect of stream flow and wastes on coastal waters, and the effect of saline intrusions on estuaries. These illustrations also suggest the traceability afforded by the overview analysis, traceability that makes it possible to identify critical issues with the overall objectives to which they relate, and to trace a major objective down to the research activities that must be accomplished. This traceability is one of the most important aspects of the study, and it contributes significantly to the planning of research missions that will satisfy NASA's long-range objectives for man in space.

During this analytical derivation procedure, scrutiny of the literature, personal discussions with recognized authorities in the various fields, and discussions by members of the study team with colleagues who were not directly involved in the program helped to validate the issues. This procedure made possible the derivation of a comprehensive and authoritative set of timely research questions traceable to original objectives. As a result of these overview analyses, a total of 3,800 critical issues were derived.

To determine whether these 3,800 critical issues were all suited for study by man in Earth orbit, new insight was required into the value of manned Earth-orbital research; and accordingly, the critical issues had to be screened. Three criteria were chosen against which every critical issue was measured. To remain a subject for study, a critical issue had to require research that could not be successfully performed on Earth but was suited to the Earth orbital environment (Figure 9); it had to be an area of study in which man's presence would contribute significantly to the conduct of the research (Figure 10); and it had to be a research problem that was not already a subject for study in an ongoing or firmly planned program. Most of the critical issues eliminated were dropped for the first reason inapplicability to Earth orbital research. The largest block rejected for other reasons was a group of 72 critical issues in the Manned Spaceflight Capability discipline that will be satisfied by Skylab experiments. The overall result of checking each critical issue against these three criteria was the reduction of the original 3,800 critical issues, to 1,983 that were considered suitable for further consideration in the study.

RESEARCH CLUSTERS

Analyzing six disciplines to identify 1,983 critical issues merely indicated the research activity required; it did not delineate the way to perform it. It was apparent that certain types of research problems could be solved by the same or similar instruments. The critical issues were therefore surveyed to determine where these commonalities existed; they were then grouped according to commonality of instruments and measurements. This process resulted in 136 such groupings, which were called "research clusters."

The 136 research clusters were examined in detail to describe the functional and operational characteristics of the associated experimental activities. This descriptive process translated scientific research requirements into engineering requirements in terms of a seven-part format that leads logically from scientific issues to the engineering details required to answer these issues. This format included the following information:

1. General characteristics of the research cluster: research objectives and experimental methodology.

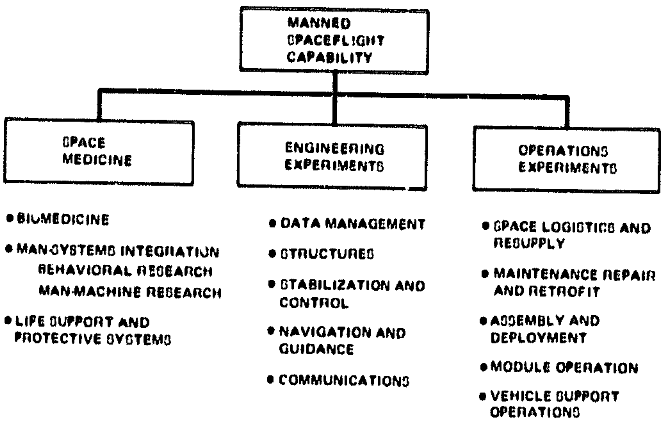

Figure 2. Organized Overview - Manned Spaceflight Capability

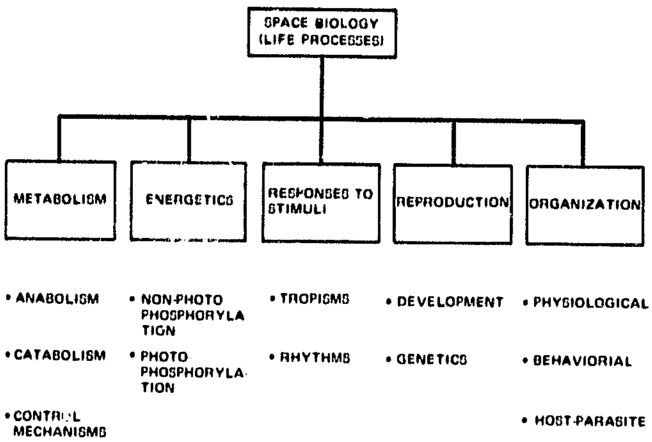

Figure 3. Organized Overview - Space Biology

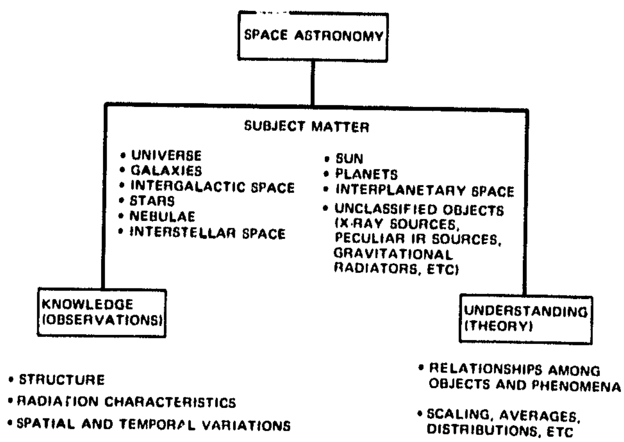

Figure 4. Organized Overview - Space Astronomy

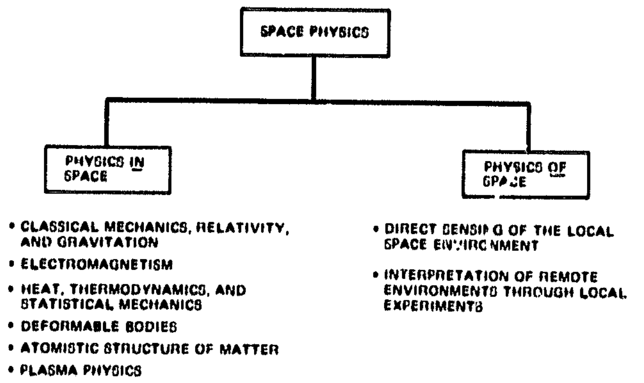

Figure 5. Organized Overview - Space Physics

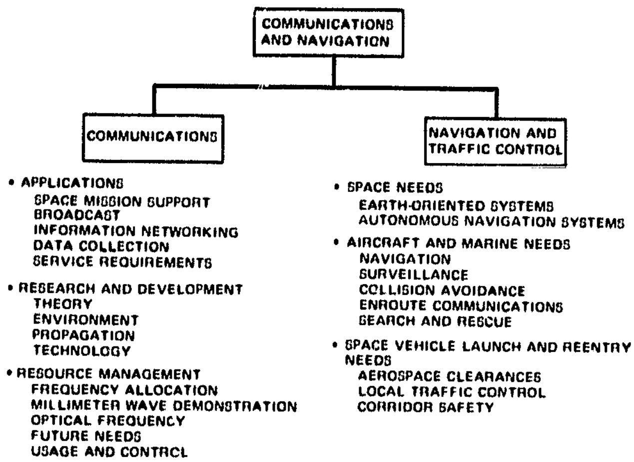

Figure 6. Organized Overview – Communications and Navigation

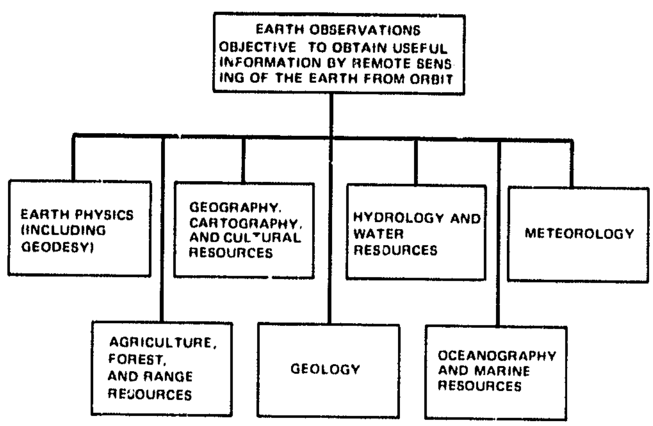

Figure 7. Organized Overview - Earth Observations

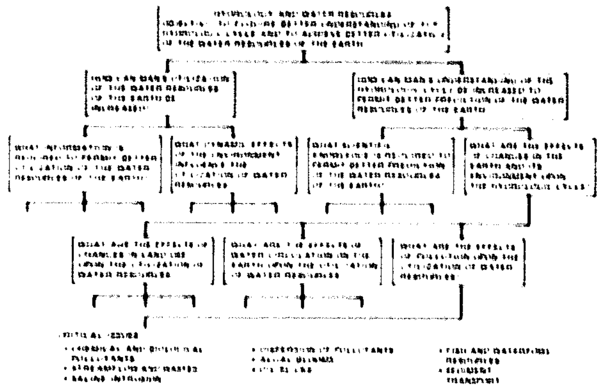

Figure 8. **Organized Overview - Hydrology and Water Resources**

2. Parameters to be measured: physical, temporal, and spatial characteristics.

3. Measurement techniques: physics of the measurement, instrumentation techniques, and potential sources of error.

4. Sequence of activities: preparations, operation of equipment, monitoring, and assessment of results.

5. Instruments required: type of instrument, general specifications, and functional description.

6. Support required from the orbital facility: volume and payload, electrical power, structural support, logistics, environment control and life support, propulsion and stabilization requirements, and crew-skill and manpower levels.

7. Data requirements: type of data produced, rate of data production, time allowable until data are put to use, and characteristics of electrical data channels.

The Appendix contains summaries of all of the research clusters. The more detailed (seven-part) description of each cluster may be found in the Study Final Report (see Preface). These descriptions are definitive and functional portraits of each research cluster, and address the kinds of problems broadly discussed in the following paragraphs.

Manned Spaceflight Capability

As a research area, Manned Spaceflight Capability contains the studies necessary to qualify man and his equipment for extended spaceflight. It includes investigation of biomedical and behavioral tolerances to the stresses of spaceflight, determination of man's capabilities and limitations in performing useful work in space, verification of design data, and evaluation of operational manned spaceflight procedures.

For purposes of this study, the discipline was divided into six research categories: biomedicine, behavioral research, man-machine research, life support and protection systems, engineering experiments, and operations experiments. Research in these areas was eventually grouped into a total of 42 research clusters. Knowledge of how man reacts in space will be invaluable in helping to develop an understanding of the basic nature of his responses that will be readily applicable in any environment. It will uncover new relationships between man and the machines he uses and will help to develop aids to enhance his performance in using them. The research into life support and protective systems has application to waste management, water managemen, od processing in space, and similar problems on earth. Engineering experiments will contribute to the design of advanced data management, power, control, navigation and guidance, and communications subsystems

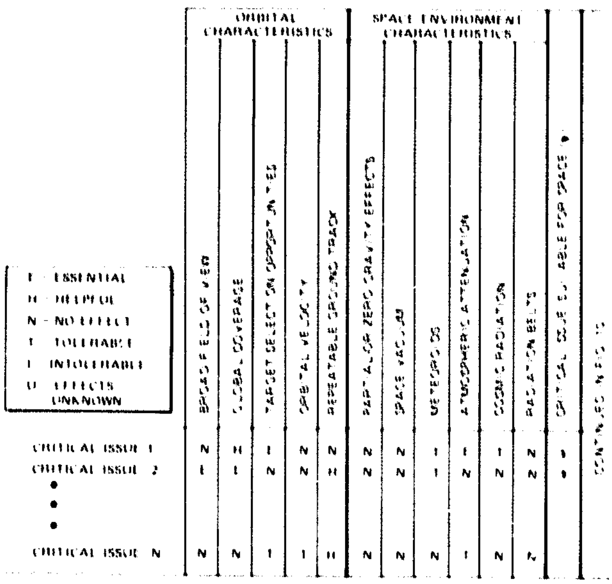

Figure 9. **Screening of Critical Issues for App!icability to Earth Orbital Research**

for manned space vehicles. Operations experiments will validate operational procedures developed and and tested in ground simulations.

Space Biology

To respond to NASA's long-range objectives in the field of Space Biology, three distinct areas were examined: life processes, taxonomy of life forms, and environmental factors. The five general life-process categories of metabolism, energetics, responses to stimuli, reproduction, and organization were further defined to more detailed levels. Taxonomy was divided into the phylogenetic groupings under plants, protists, and animals. The effect of environment on life processes is readily observable, and since weightlessness is the most unique characteristic of the space environment (besides being the one that most obviously affects living organisms), it was considered the prime independent variable to be applied in the analysis of this discipline.

Experiments in Space Biology were grouped under four major research areas corresponding to major taxonomical divisions suggested for study in space: vertebrates, invertebrates, protists and tissue cultures, and plants. This grouping was selected because of the commonality of equipment and techniques used in the experiments in any of the divisions and because it responds to the necessity for examining life functions in a variety of living organisms to ensure that a specific phenomenon is really a basic process common to many biological forms. For each taxonomical division, a preliminary, intermediate, and advanced research phase was described. Experiments in the preliminary phase are intended primarily to define and describe changes in gravity-dependent phenomena and terrestrial rhythms; those in the intermediate phase are intended to determine the components of the change and the various processes involved; and those in the advanced phase are intended to study the basic biological mechanisms responsible for the change.

Many of the suggested experiments are expected to increase our understanding of questions that have been incompletely answered over many decades of biological research. Consider for example, the pepper plants that orbited the Earth in Biosatellite II. Normally, the leaves and petioles of healthy pepper plants grow horizontally, relative to the Earth's surface; that is, to the side, relative to the plant's stem. In space, however, they curved downward on the pepper plants until the leaf tips almost touched the stem. This phenomenon, known as "epinasty,"

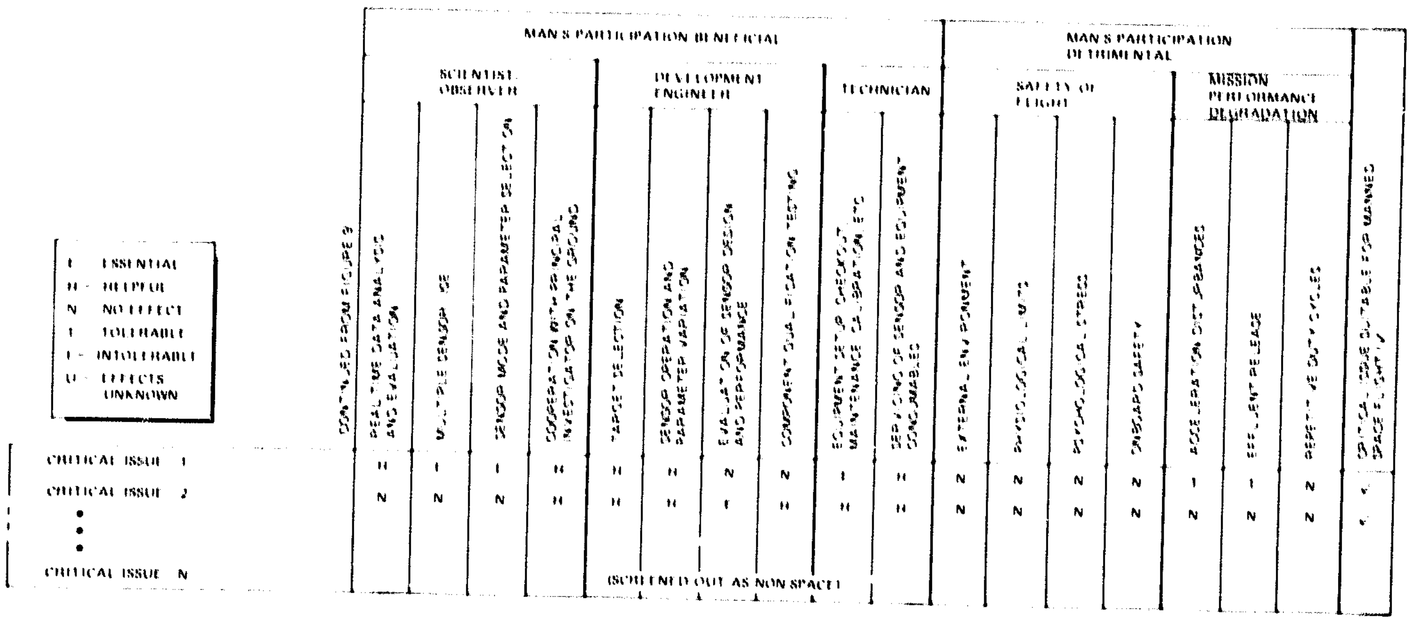

Figure 10. Screening of Critical Issues for Applicability of Manned Research in Earth Orbit

had been suspected because of clinostat (weightlessness simulation) experiments on the ground, but experiments in the actual space environment were required to confirm the suspicions. Similarly, the roots of wheat seedlings grew in a random directional pattern in space rather than in the highly restricted pattern recognized on Earth. This research was one of the most significant milestones in more than 150 years of experiments on the role of gravity in plant growth. Experiments performed on Earth since the flight of Biosatellite II have shown that when the plants are preconditioned to total darkness and grown in the dark on the clinostat, they fail to respond with epinastic curvatures. It appears, therefore, that light and weightlessness compete for a common functional element in the plant. This functional element is now believed to be the plant hormone auxin (indole-3-acetic acid). The mechanisms by which this hormone controls the plant's response is still not known and remains the subject of intensive study.

The flight of Biosatellite II also demonstrated that fruit fly (*Drosophila melanogaster*) larvae were disturbed by weightlessness, and abnormal chromosome transfers occurred in dividing cells. The frequency of this phenomenon is not seen in similar larvae produced and grown on Earth. Because of the Biosatellite experiments, it is now believed that radiation and weightlessness have a synergistic effect in regard to chromosome damage. Results of similar experiments with other forms of life indicate that synergism is most noticeable in the young, rapidly dividing cells. These kinds of questions, basic to biology itself, can be answered only by research in the space environment. The pioneering mission of Biosatellite II was (by design and necessity) restricted to the investigation of simple phenomena. Consequently, a minimum number of critical issues were examined. By pursuing the research clusters in Space Biology, divergent types of research can be combined for optimum data gain.

Space Astronomy

For near-term Earth-orbital astronomy, the full-time involvement of man is not required; as larger instruments evolve, however, manned activity will contribute more vitally in this discipline. The benefits of man's presence accrue primarily from his ability to evaluate instrument performance (permitting rapid response to equipment malfunction) and to exchange secondary instrument packages. However, negative factors are also associated with man's presence when Earth-orbital astronomical observations are being made. These factors are related to contamination of observations caused by spacecraft effluents and disturbances of instruments caused by crew motion. It was with these gross assessments in mind that the research for Space Astronomy was analyzed. The research clusters fall into three categories: optical,* x-ray, and low-frequency radio. One valuable research area would be an extremely sensitive sky survey of x-ray sources using a large-area detector array, and high-resolution imagery of strong discrete x-ray sources, using a large grazing-incidence telescope. The first program would reveal many more sources than any predecessor survey revealed, increasing chances of optical counterpart identification, and the second would improve knowledge of the structure and physical nature of individual sources. Another major area of research would be extragalactic studies using large optical telescopes, leading to an increase in the range of accurate galaxy distance determinations, an improved cosmological model, and better knowledge of the physical properties of quasi-stellar radio sources and galaxy nuclei.

Space Physics

The essential view of research in this discipline was that of using space platforms to assess the characteristics of the orbital environment and to utilize these environmental factors in conducting research in the setting of a physics laboratory. Several areas were omitted from the research clusters in Space Physics, because although they would normally be included in a comprehensive study of physics, they have either been researched satisfactorily in terrestrial laboratories or they are covered by other disciplines, notably astronomy, meteorology, and Earth physics.

The research clusters were developed in three general laboratory areas: physics and chemistry laboratory, plasma physics laboratory, and cosmic-ray laboratory. Within the concept of a physics and chemistry laboratory, the effect of zero-g on such phenomena as liquid-vapor interfaces and on the production of materials having superior physical characteristics is an

*Refers to wavelengths ranging from 900 Å to a few microns.

important area for study. Understanding these phenomena is basic to the possibility of producing, in space, materials that could not be produced on Earth but may have a wide range of applications.

In cosmic-ray physics, very little is known about the abundance and nature of cosmic rays that are of interstellar origin. The objectives of the cosmic-ray research clusters are to study properties of primary cosmic radiation in the 10^{10} to 10^{15} electron-volt energy range and to utilize the primary cosmic-ray energies that are available in space for interaction physics experiments. The envisaged cosmic-ray laboratory will contain basic instruments for the measurement and identification of cosmic particles at various energy levels and will be capable of being reconfigured as required to meet the needs of different experiments.

In the field of plasma physics, a primary requirement is to study the spatial extent of the region of perturbation that results from the introduction of any object into the space plasma. Perturbation caused by the research facility may handicap or preclude long-term study of environmental characteristics (e.g., electron density and temperature, ion temperature and species, and electric and magnetic fields over the facility orbit). Also, plasma physics measurements have some characteristics that are unique with respect to the remainder of the research program derived in the study. This is the only area in which the local environment of the space research facility will be sampled. Research and measurements are not being performed *in* the facility but rather *from* the facility and *in* the medium. Thus, plasma measurements depend critically on the orbital parameters, and, indeed, completely different sets of research activities can be defined for different sets of orbits.

Communications and Navigation

Unlike many disciplines in which increasing man's scientific understanding is the objective, Communications and Navigation is primarily concerned with providing new or expanded user services. For communications, the development of advanced space systems constitutes an extension of existing capabilities in providing customer services. The area of navigation involves position locations, surveillance, and control of high-speed transportation vehicles, as well as communications. The relation of rese rch in this discipline to research in other disciplines is most easily explained by the need for data. Whatever the research and whatever the measurement, the end result is data, and the management of that data is vitally affected by Communications and Navigation capabilities. The research clusters for this discipline are grouped into five areas: noise; propagation; test facilities for the deployment, calibration, demonstration, and testing of equipment in space; communications systems; and navigation systems.

Earth Observations

The discipline of Earth Observations was approached in seven areas. In Earth physics, the first, the research clusters are concerned with geodetic surveys, photographic coverage of the Earth, and the identification of such phenomena as volcanic activity. One of the objectives in the second area agriculture, forestry, and range resources is that of gathering data of higher quality, containing more information, and costing less money than the data used presently by the United States Department of Agriculture. These data are primarily photographs used extensively by agriculturists to classify, map, and measure vegetation, soils, and land use. Researchers have evidence to suggest that accurate yield predictions can be based on this kind of information; and disease and insect infestation of crops and soils, as well as areas of air and water pollution, can be located. Research concerned with forestry and range condition calls for collection of data on species, vigor, and yield of managed and unmanaged forest, range, and wild lands. Objectives for the third area, geography and cartography, involve questions about the Earth's surface (the answers to which will facilitate regional planning studies), the effective use of resources, and transportation activities, among others. In the field of geology, the fourth area, disaster avoidance, location of mineral and oil deposits, disposal of waste products, and use of geothermal energy sources for heating and power are among the items that receive particular emphasis. The fifth area, hydrology and water resources, has a number of areas of research that have immediate practical application, the most prominent of which is probably the identification of pollution. Several research clusters address the problem, not only from the necessary point of view of how and where supplies of fresh water are being wasted, but also from the more positive one of locating underground sources of fresh water and inventorying snow, ice, major lakes, and reservoirs. Research in the sixth area, oceanography and marine resources, also concerns itself with identification of pollution, and seeks information that will be of great benefit in the understanding of ocean population dynamics and fish resources as well as in developing greater understanding of ocean motions. Meteorology, the seventh area of Earth Observations research, concerns itself primarily with developing an understanding of the physics of the atmosphere, weather prediction, and establishment of a basis for weather modification and climate control.

TRACEABILITY OF RESEARCH CLUSTERS

The traceability concept initiated in the overview analysis and applicable to the resulting critical issues is carried one step further in the grouping of critical issues into research clusters. The fact that, in the study Final Report (see Preface), any research activity can be traced to the objectives to which it relates and, conversely, any objective can be traced to the research activities that it generates, facilitates the assessment of the effect of inclusion or deletion of research activities. The ability to make this assessment, by seeing directly what the overall effect would be, assists in the establishment of priorities at any level; it also enables a planner to make the most beneficial allocation of research effort in response to these priorities.

SUPPORTING TECHNOLOGY DEVELOPMENT REQUIREMENTS

Technology developments to support planned research must be identified early enough for them to be available when needed for a particular mission or research program. The forecasting of future technological capabilities and requirements, therefore, was an essential part of this study. Specific requirements for supporting technology development (STD) were identified whenever future requirements did not appear to be satisfied by present technology.

STD REQUIREMENTS DERIVED FROM RESEARCH CLUSTERS

Each research cluster description was analyzed by a member of the study team knowledgeable in the involved discipline. Whenever technology requirements in the cluster appeared to the analyst to exceed the known technology, he established a candidate STD requirement. When all such candidate requirements for a cluster had been compiled, the analyst consulted with the discipline specialist who had derived the cluster, to identify any additional candidate STD requirements considered relevant by the discipline specialist, and to ensure a consensus as to which candidates were valid STD requirements. An STD Requirement Description form was then filled out for each valid requirement. For the entire study, 238 STD requirements were identified; the description forms appear in the Study Final Report (see Preface), and summary data on the entire group are presented in Table 1.

On the STD Requirements Description form, the technology gaps are described by indicating the needed technology and the present level of technology with respect to that need. The research clusters to which each STD requirement is relevant are noted on the forms, so that the traceability established in the overview analysis and carried through the critical issues and the research clusters is extended to include the STD requirements.

Implementation of the various STD requirements is anticipated by means of activities ranging from theoretical studies and research to development of equipment or instruments. Most of the experimental work can be accomplished on the ground, although some of it must be performed in the Earth orbit environment in order to obtain the data necessary to satisfy specific development requirements. On each STD Requirement Description form, therefore, one or more activities necessary to implement the STD requirement are identified under one of four headings: studies, experiments in space, experiments not in space, and developments. The programmatic aspects of each STD requirement are addressed in the description form by indicating (1) whether the STD requirement is judged to be critical or merely important to the related research; (2) other STD requirements derived in the study, or known from ongoing activities with which the activities indicated for STD requirement could be integrated; (3) any promising development approaches known to the study team; (4) special facilities required; (5) the estimated time and cost to achieve the required advancement; and (6) an estimate of the confidence that the desired advancement can be achieved. Trends observed in each study discipline are discussed in the following paragraphs.

Manned Spaceflight Capability

Fifty-three STD requirements were identified in the Manned Spaceflight Capability discipline. Of these, 46 were derived from the four areas related to space medicine: biomedicine, behavioral research, man-machine research, and life support and protective systems. Key items include the need for orbital facilities to support the animal research program in biomedicine, performance aids to support man-machine research, and techniques and instruments for gathering crew-behavioral data on a noninterference basis to determine group dynamics and personal adjustment in the space environment.

The research clusters derived from the engineering-experiment and operations-experiment areas of this discipline underscore the necessity for considering not merely an STD requirement that answers the specific needs of an individual cluster, but also for considering such a requirement in the broader context of the entire study. For example, one operations-experiments research cluster (1-OE-3) has a specific STD requirement (OE-1 in Table 1) for a study to define extravehicular-activity (EVA) techniques for assembling large antennas in space. Since many problems concerning EVA have yet to be solved, however, the description form for this STD requirement recommends an EVA study that is much broader in scope than that necessary merely for the research cluster in question.

Space Biology

Of the 21 STD requirements identified for Space Biology, only two (automated microbial identification system B-14, and advanced plethysmograph B19) identify equipment or techniques that are not presently available for ground-based research, and therefore require an advancement in current technology rather than a redesign for zero gravity. Seven of the remaining STD requirements are associated with equipment presently available for ground use, but whose functions involve gravity-dependent fluid-flow characteristics and would consequently require redesign for zero-gravity use. Similarly, five of the requirements are associated with equipment whose functions involve gravity-dependent mass effects and require modification on that basis. The remaining requirements are distributed among studies to redefine laboratory equipment that in its present form would have an unfavorable effect on the space research facility, and studies to define procedures and techniques.

A high degree of commonality exists across the various Space Biology research clusters in regard to STD requirements. Twelve requirements relate to more than one research cluster; of these, six fulfill needs from all research areas. Vertebrate research requirements are the most specialized and include six that relate to single research clusters. Protist and tissue culture research have three unique requirements, and plant research and invertebrate research have none.

Space Astronomy

Thirteen primary technology requirements were identified for Space Astronomy. The development of high-resolution optical telescopes for use in space will require many technological innovations. The assembly and alignment of large diffraction-limited telescopes in high orbits (possibly synchronous) will require some generally exotic concepts even for feasibility assessment (A-5). Such studies are imperative, not only because they affect any mission using this instrument but because they may affect the design of the instrument itself. Advancements in technology of Space Astronomy include such items as information-storage systems, spectrographic equipment, photometric devices, photographic films, and electronic sensors. Among the least-addressed subjects in Space Astronomy are target acquisition (A-10 and A-13) and the development of a practical celestial-coordinate reference system. The majority of Space Astronomy research cannot be effective without such a standardized reference system. Photographic film will likely play a very important role in this

Table 1 (Page 1 of 7)
SUPPORTING TECHNOLOGY DEVELOPMENT REQUIREMENTS

STD Requirement No.	STD Requirement Title	Critical or Important To Research	Types of STD Activities*	Confidence In Achieving Advancement	Estimated Times to Achieve (Months)
	Manned Spaceflight Capability				
BM-1	Body Fluid Analysis	I	S	High	24
BM-2	Non-Invasive Central Venous Pressure Measurement	I	S	Low	24
BM-3	Animal Toxiocological Chamber	C	D	High	24
BM-4	Manned Orbital Animal Research Facility	C	D	High	36
BM-5	Radiation Source	C	S	High	12
BM-6	Space Thermal Enclosure	C	NE	High	12
BM-7	Sensitive Quantitative Evaluation of Reflex Functions	I	NE	High	12
BM-8	Endoradiosonde	I	NE	High	12
BM-9	Animal Sensors	C	S,D	High	24
BM-10	Animal Modules	C	D	High	36
BM-11	Body Volumeter	C	D	Moderate	12
BM-12	Measurement of Transpulmanory Pressure	I	D	High	24
BR-1	Hearing	I	NE	High	12
BR-2	Audio Tone Source	I	D	High	12
BR-3	Psychomotor Tests in Simulated Zero-G	I	NE	High	12
BR-4	Cognitive Measurement Test Module	I	D	High	36
BR-5	Automated Behavior Data From Video and Audio Records	I	S,NE,D	High	36
BR-6	Verbal Behavior Assessment Program	C	NE,D	High	24
BR-7	Hazardous Complex Tasks	I	S,NE	High	24
BR-8	Training Problems and Equipment	I	S,NE,D	High	24
MM-1	Display/Control Computer Capability	C	D	High	36
MM-2	Display/Control Experimental Apparatus	C	D	High	24
MM-3	Dark Adaption Equipment and Techniques	I	SE,NE	High	18
MM-4	Portable Metabolic Analyzer	C	D	High	36
MM-5	Onbody Accelerometer	C	D	High	36
MM-6	Habitability Experiment Support Package	C	NE,D	High	36
MM-7	Emergency Reaction Time From Sleep	C	NE	High	24
MM-8	Equipment for Sleep Experiments	C	D	High	12
MM-9	Performance Aids	C	NE,D	High	60
LS-1	Multipurpose Fluid Physics Apparatus	C	S,D	High	24
LS-2	Zero-G Condenser	C	SE,NE,D	High	36
LS-3	Catalyst Bed Poisons	I	D	High	12
LS-4	Negative Pressure Device	I	NE,D	High	12
LS-5	Zero-G Phase Separator	C	SE,NE,D	High	24
LS-6	Automatic Potability Measure	C	S,D	High	60

*Activities: S – Studies SE – Experiments in Space NE – Experiments Not in Space D – Developments

Table 1 (Page 2 of 7)
SUPPORTING TECHNOLOGY DEVELOPMENT REQUIREMENTS

STD Requirement No.	STD Requirement Title	Critical or Important To Research	Types of STD Activities*	Confidence In Achieving Advancement	Estimated Times to Achieve (Months)
LS-7	Low-Flow Metering Device	I	D	High	24
LS-8	Separation of Effluent Gases From Electrolyte	C	NE,D	High	30
LS-9	Identification of Contaminants in Electrolysis Products	C	S,NE,D	High	24
LS-10	Evaluation of Hydrogenomonas Eutropha Reaction Chamber	C	D	High	12
LS-11	Integration of Hydrogenomonas Eutropha System Components	C	D	High	24
LS-12	Development of CO_2 Removal Methods	C	D	High	24
LS-13	Boiling and Condensing Steam	C	NE,D	High	24
LS-14	Waste Management Systems	C	D	High	24
LS-15	Microbial Detection and Suppression	C	S,NE,D	High	60 120
LS-16	Systems Integration of Sensors	I	D	High	24
LS-17	Waste Management System Concepts	I	S	High	12
FE-1	Biowaste Electrical Propulsion	C	S,NE,D	High	36
FE-2	Biowaste Resistojets	C	S,NE,D	High	21
FE-3	Biowaste Resistojet EVA	C	S,NE	High	0 12
FE-4	Laser Ranging System	C	S,D	High	36
FE-5	Landmark Tracker System	C	S,D	High	18 24
FE-6	Long-Range Optical Communications	C	S,D	High	36
OE-1	Assembly Techniques Study	C	S,NE	High	18
	Space Biology				
B-1	Amino Acid Analyzer	C	S,SE,D	High	48
B-2	-180°C Tissue Freezer	C	D	High	12 24
B-3	Zero-G Animal Cages	C	D	High	12 24
B-4	Animal Biocentrifuge	C	D	Moderate	60
B-5	Surgical Procedures	C	S,SE	High	12
B-6	Zero-G Autoclave	C	D	High	12
B-7	Zero-G Incubator	C	D	High	12
B-8	Tissue Processor	I	D	High	12 24
B-9	Activity Platform	I	S,D	High	12 24
B-10	Visual Cliff	I	S	High	12 24
B-11	Animal Maze	I	S,D	High	36
B-12	Bunsen Burner Substitute	I	S	High	6
B-13	Liquid Handling	C	S,SE,NE	High	24 36
B-14	Automated Microbial Identification	I	D	High	60
B-15	Zero-G Homogenizer	C	D	High	12
B-16	Dialysis Equipment	C	D	High	12
B-17	Blood Cell Counter	I	D	High	12 24
B-18	Fluid Electrolyte Analyzer	C	D	High	12 24

Table 1 (Page 3 of 7)
SUPPORTING TECHNOLOGY DEVELOPMENT REQUIREMENTS

STD Requirement No.	STD Requirement Title	Critical or Important To Research	Types of STD Activities*	Confidence In Achieving Advancement	Estimated Times to Achieve (Months)
B-19	Advanced Plethysmograph	I	D	High	6–12
B-20	Small Particle Mass Measurement	C	S,SE,NE,D	Moderate	36–60
B-21	Equipment Analysis and Integration	I	S	High	12–24
	Space Astronomy				
A-1	High-Resolution Optical Systems	C	S,SE,NE,D	Low	120
A-2	Electronic Image Intensifiers (Stellar Astronomy)	C	S,D	Moderate	12
A-3	Telescope Operation In Space	C	S,NE	Moderate	12–24
A-4	Orbit-To-Orbit Shuttle Requirements	I	S	High	12
A-5	Assembly and Alignment of High-Resolution Telescope In Space	C	S,SE,NE	Low	38
A-6	Developments for Use of High-Resolution Telescope	C	S,NE	Moderate	12–18
A-7	Development of Use of Photographic Film for Space Astronomy	C	S,SE,D	Moderate	23
A-8	High-Resolution Optical Telescopes	C	S,SE,NE,D	Low	120
A-9	Electronic Image Intensifiers (Planetary Astronomy)	I	S,D	Moderate	9
A-10	Acquisition of Celestial Targets	C	S,NE,D	Moderate	24
A-11	High-Precision Stellar Photometry	C	S,NE,D	Moderate	18–36
A-12	Cooling of Solar Astronomy Telescopes	C	S,NE,D	Moderate	30
A-13	Acquisition and Tracking of Solar Targets	C	S,SE,NE,D	Moderate	39
	Space Physics				
P-1	Mass Spectrometer	I	S	High	12
P-2	Gas Chromatograph	I	S	High	12
P-3	Pyrometer	C	D	High	12
P-4	Apparatus for Liquid/Vapor Studies	C	S,D	High	24
P-5	Low-G Accelerometer	C	S,SE	High	24
P-6	Low-G Isolation Mounts	C	S,SE,NE	High	12
P-7	Crystal Growing Apparatus	C	S,D	High	18
P-8	Zone Refining Apparatus	C	S	High	6
P-9	Production of Hard Vacuums	C	S,SE	High	24
P-10	Contamination by Physics Apparatus	I	S,NE	High	18
P-11	Melting Apparatus	C	S,D	High	24
P-12	Sample Centering Device	I	S	High	6
P-13	Film Drawing Experiments	C	SE	High	18
P-14	Optimum Material Heating	I	S	High	9
P-15	Cosmic Ray Experiment Package	C	S,D	High	33

Table 1 (Page 4 of 7)
SUPPORTING TECHNOLOGY DEVELOPMENT REQUIREMENTS

STD Requirement No.	STD Requirement Title	Critical or Important To Research	Types of STD Activities*	Confidence In Achieving Advancement	Estimated Times to Achieve (Months)
P-16	Laser Holography	I	S	High	12
P-17	Contaminant-Proof EC&LS System	C	S,NE,D	Moderate	48
P-18	Heat Transfer Chamber	C	D	High	12
P-19	Superconducting Magnets	I	S	High	12
P-20	Integrated Physics Apparatus	I	S	High	18
P-21	Wicking Apparatus	C	D	High	12
P-22	G-Level Control	C	S,D	Moderate	30
P-23	Heat Transfer Apparatus	C	D	High	24
P-24	Apparatus for Controlled Density Material Study	C	S,D	High	30
P-25	Film Video Tape Trade Study	I	S	High	12
P-26	Onboard Film Processing	I	D	Moderate	24
P-27	Transition Radiation Detector	I	S,NE,D	Moderate	36
P-28	Superconducting Materials	I	S,NE	Moderate	36
P-29	Cryogenic Systems	C	S,SE,NE	High	24
P-30	Plasma Physics Subsatellites	C	S,D	High	48
P-31	DC Electric Field Measurements	I	S,NE,D	Moderate	36
P-32	Plasma Diagnostics Techniques	I	S	High	9
P-33	Barium Cloud Apparatus	C	D	High	30
P-34	Intense Electron Sources	I	S,SE,D	High	24
P-35	Research in Plasma Physics	C	S,SE	High	60
P-36	Apparatus for Superfluidity Tests	C	S,D	High	36
P-37	Dewar Viewport Studies	C	S,D	High	9
P-38	Cryogenic Remote Handling	C	S,NE	High	12
P-39	Superfluid Research	C	S	High	36
	Communications and Navigation				
C-1	94-GHz Amplitude and Phase Measurement System	C	D	Moderate	36
C-2	MM-Wave Experiment Plan	C	S	High	12
C-3	MM-Wave Experiment Package	C	D	High	24
C-4	Broadband Modulators	C	S,D	High	33
C-5	High-Speed Correlator	I	S,D	High	24
C-6	Laser Telescope Alignment	I	S,SE,D	High	84
C-7	Improved Satellite Tracking	I	S,D	Moderate	36
C-8	Subsatellite for Navigation	C	D	High	36
C-9	Transponders for Navigation Satellites	I	D	High	24
C-10	Data Processing Software	C	S,D	High	36
C-11	Satellite Position Determination	I	S	High	12
C-12	Laser Radar Development	C	D	High	24
C-13	Autonomous Navigation Sensors	C	D	High	36
C-14	Improved Position Determination	I	S,D	High	36

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SUPPORTING TECHNOLOGY DEVELOPMENT REQUIREMENTS

STD Requirement No.	STD Requirement Title	Critical or Important To Research	Types of STD Activities*	Confidence In Achieving Advancement	Estimated Times to Achieve (Months)
C-15	Software Development for Autonomous Navigation	C	S,D	Moderate	24
C-16	Subsatellites for Surveillance	C	D	High	36
C-17	Transponders for Surveillance Systems	I	D	High	24
C-18	Traffic Control Computer Software	I	S,D	Moderate	36
C-19	Collision Avoidance Hardware	C	S,D	High	27
C-20	Emergency Location Signal Detectors	I	D	High	12
C-21	Software Development for Location Methods	I	S,D	High	24
C-22	Low Noise Receivers	C	S,D	Moderate	39
C-23	Computer Software for Noise Measurements	I	S,D	High	36
C-24	Noise Source Identification Plan	C	S	High	12
C-25	Digital Ionosonde	I	D	High	12
C-26	Higher Efficiency RF Transmitters	I	S,D	High	45
C-27	High Power RF Transmitters	C	D	Moderate	24
C-28	Computer Software for Propagation Experiments	I	S,D	High	18
C-29	Self-Steering Phased Array Antenna	I	S,NE,D	High	36
C-30	Optical Communications System	C	S,D	High	48
	Earth Observations				
EF-1	Vegetation Species Signature	C	SE,NE	High	36
EF-2	Soil Series Signature	C	SE,NE	Moderate	36
EF-3	Crop Yield Signature	I	SE,NE	High	36
EG-1	Quantification of Volcanic Morphology	C	NE	High	12
EG-2	Multispectral Signature of Rocks	C	NE	High	12
EG-3	Multispectral Signature of Rock and Soil Types	C	NE	High	12
EG-4	Waste Flow Pattern Determination	C	NE	High	24
EG-5	Multispectral Signature Waste Storage Sites	C	NE	High	36
EG-6	Laser Interferometer Relay System	C	NE,D	High	12 60
EG-7	Multispectral Signature of Geothermal Sources	C	NE	High	12
EG-8	Fourier Transform Analysis of Landforms	I	NE	High	12
EG-9	Thermal Sensing of Seamounts	I	NE	High	12
EH-1	Water Pollution Identification Techniques	C	NE	Moderate	24
EH-2	Snow/Ice Depth Measurement Techniques	I	NE	Moderate	12
EH-3	Model of Snow/Ice Depth Signature	I	S	Moderate	6
EH-4	Soil Moisture Measurement Techniques	C	NE	Moderate	12
EO-1	Ocean Pollution Identification Techniques	C	NE	Moderate	24
EO-2	Ocean Pollution Model	C	S	Moderate	24
EO-3	Heat Flow Measurement Techniques	C	NE	Moderate	12
EO-4	Sea Surface Heating Model	I	S	High	12
EO-5	Chlorophyll Concentration Model	I	S	Moderate	12
EO-6	Ocean Population Measurement Techniques	C	NE	Moderate	12

Table I (Page 6 of 7)
SUPPORTING TECHNOLOGY DEVELOPMENT REQUIREMENTS

STD Requirement No.	STD Requirement Title	Critical or Important To Research	Types of STD Activities*	Confidence In Achieving Advancement	Estimated Times to Achieve (Months)
EO-7	Fish-Chlorophyll Correlation Model	I	S	Moderate	12
EO-8	Radar Determination Sea Height	I	S	Moderate	24
EO-9	Ocean Current/Height Model	C	S	Moderate	12
EO-10	Ice Distribution Model	I	S	Moderate	24
EO-11	Ocean Salinity Measurement Techniques	I	NE	Moderate	12
EO-12	Ocean Physical Properties Model	C	S,NE	Moderate	24
EO-13	Ocean Depth Model	C	S,NE	Low	24
EO-14	Boundary Processes Measurement Techniques	I	NE	Moderate	24
EO-15	Sea Surface Roughness Measurement Techniques	C	NE	High	24
EO-16	Sea Surface Roughness Model	I	S	Moderate	24
EO-17	Active/Passive Microwave Radiometry	I	NE	High	24
EM-1	Atmospheric Boundary Layer Model	C	S	Moderate	24
EM-2	Atmospheric Effects by Surface Alterations	I	S,NE	Moderate	24
EM-3	Sferics Data Interpretation	I	NE	Moderate	36
EM-4	Stellar Scintillation Effects	I	SE	Moderate	24
EM-5	Atmospheric Density Applications	I	S	High	12
EM-6	Atmospheric Density by Dual Spacecraft	I	SE	Moderate	36
EM-7	Zero-G Cloud Physics Laboratory	C	S,D	High	36
EM-8	Aerosol Droplet Handling	I	SE	High	6
EM-9	Cloud Physics Experiment Priority	I	S	High	12
EM-10	Cloud Physics Laboratory, Related Uses	I	S	High	12
EM-11	Coherent Radiation Pollution Detection	I	NE	Moderate	12
EM-12	Atmosphere Pollution Signature Analysis	C	NE	Moderate	48
EM-13	Atmosphere Model of Pollution Effects	C	S	High	24
EM-14	Tropical Cloud Systems Model	C	NE	High	18
EI-1	Twin Metric Camera	C	D	High	24
EI-2	Multispectral Camera	C	D	High	24
EI-3	Ten-Band Multispectral Scanner	C	D	High	36
EI-4	Side-Looking Radar Imager	C	D	High	48
EI-5	UV-Visible Absorption Spectrometer	C	NE,D	Moderate	24
EI-6	Multi-Channel Ocean Color Sensor	C	D	High	18
EI-7	Radar Altimeter/Scatterometer	C	D	High	24
EI-8	Microwave Scanner Radiometer	C	D	Moderate	60
EI-9	UHF Sferics Detector	C	D	High	24
EI-10	Data Collection System	C	D	High	36
EI-11	Star Tracking Telescope	C	D	High	31
EI-12	Zero-G Cloud Physics Chamber	C	D	High	48
EI-13	Photo-Imaging Camera	C	D	High	36
EI-14	Infrared Interferometer Spectrometer	C	D	Moderate	24 36
EI-15	Multispectral Tracking Telescope	C	D	Moderate	48
EI-16	Infrared Selective Chopper Radiometer	C	D	High	30
EI-17	Infrared Filter Wedge Spectrometer	C	D	High	24

SUPPORTING TECHNOLOGY DEVELOPMENT REQUIREMENTS

STD Requirement No.	STD Requirement Title	Critical or Important To Research	Types of STD Activities*	Confidence In Achieving Advancement	Estimated Times to Achieve (Months)
FI-18	Infrared Temperature Sounder	C	D	Moderate	24
FI-19	Satellite Infrared Spectrometer	C	D	Moderate	12 24
FI-20	Temperature Profile Radiometer	C	D	Moderate	40
FI-21	Visible Wavelength Polarimeter	C	D	Moderate	36
FI-22	Ultraviolet Imager/Spectrometer	C	D	Moderate	48
FI-23	Laser Altimeter	C	SE,NE,D	High	48
FS-1	Ground Data Processing Center	C	D	High	36
FS-2	Automatic Data Transmission System	I	S,D	High	48
FS-3	Space Radiation Effects on Films	I	SE,NE	High	4
FS-4	Temperature-Humidity Effects on Films	I	NE	High	9
FS-5	Photographic Film Storage Vault	C	D	High	12
FS-6	EVA Instrument Maintenance	I	S,SE,NE	High	7
FS-7	EVA Antenna Deployment	I	S,SE,NE	High	7
FS-8	Earth Observations Crew Operations	I	S,SE,NE	High	10
FS-9	Photo-Processing System	C	S,D	High	18 36
FS-10	Photo-Interpretation System	C	S,D	High	22
FS-11	Spacecraft Effluent Effects	I	S,SE,NE	High	27 42
FS-12	Remote Data Degradation Effects	I	NE	High	12

discipline. About 60 percent of the observations in the ultraviolet and x-ray regions require Schumann-type film, which must be processed wet in zero gravity, a problem that has not yet been seriously addressed (A-7).

Space Physics

A total of 39 STD requirements were identified for Space Physics, consisting largely of new instruments and apparatus. However, some of the STD requirements are concerned with the interaction of instrumentation with the space environment. For example, a device is required to measure dc electric fields as low as 1 mv/m (P-31). This is a major development requirement in itself, but the effects of contact potentials and plasma coupling that arise from the space environment complicate the problem. Another example is the utilization of the hard vacuum of space in materials research at zero-g. Studies and research in space are required for the evaluation of alternative concepts to overcome the problem of insufficient vacuum in the immediate vicinity of the research facility due to the effluent cloud around it (P-9). Effluents emitted from various vehicle configurations must be measured, and the diffusion rates and electric-charge effects must be determined theoretically.

Communications and Navigation

The user-oriented nature of Communications and Navigation is reflected in the 30 STD requirements that were identified in this discipline; most call for development of specialized communication hardware or for systems studies related to such development. Development of a 94-GHz amplitude and phase measurement system (C-1), for example, is required for millimeter-wave experiments because present instruments are limited to 18 GHz for automatic systems. This requirement involves improvement in a current system as does the STD requirement on autonomous navigation sensors (C-13), which calls for improvements in star trackers, radar, and particularly in landmark trackers.

Earth Observations

Analysis of the 34 research clusters in Earth Observations led to the identification of 82 STD requirements. The general problem of processing the wealth of data obtainable by an orbital observation system and disseminating this information to user agencies in a usable form and within acceptable time constraints is probably the most imposing problem to be mastered before an operational system can become effective. Included in this problem is the determination of the amount of data to be processed in orbit for direct communicatio to users. An example of the implications of STD requirements is the need for spectral signature analysis of images of oceans, rivers, and lakes (e.g., EH-1, EO-1), to provide near-real-time identification and measurement of water-pollution sources.

ANALYSIS OF STD REQUIREMENTS

Figure 11 summarizes by discipline the percentage of studies, nonspace experiments, space experiments, and development activities identified. It may be noted that almost one-tenth of the activities (32 out of 371) are experiments in space. Table 2 lists the STD requirements that give rise to these 32 activities and shows their distribution over the six disciplines of the study. These activities are especially pertinent for consideration as the nucleus of a spaceborne advanced technology research facility.

Many examples can be cited from Table 2 of the value of space experimentation in achieving supporting technology developments. A definitive understanding of the degree to which man can function in zero-g in the deployment and operation of sensors and in the processing, interpretation, and dissemination of data is necessary for detailed instrument and support equipment design. The effect of the spacecraft environment on photographic film must be defined, particularly with regard to natural radiation. Data on radiation effects as well as on the effects of temperature and humidity during storage must be put into terms of image interpretability and information return to the experimenter.

Spacecraft effluent effects are another area of potentially major influence on the success of many research activities in space. The cloud of particulate debris and gasses that may result from thrustor operations and waste dumps, as well as the electromagnetic interference caused by spacecraft equipment operation, can severely degrade the quality of measurements. The spatial extent, dynamic characteristics, and physical constitutents of the near spacecraft region must be defined explicitly enough to enable subsequent research activities to be planned with assurance.

Knowledge of the limits of man's performance in extravehicular activities is essential in formulating plans to use him to erect, adjust, and monitor such equipment as antennas mounted outside the spacecraft, and this should be explored through space experimentation. Liquid handling—the transfer, mixing, agitation, and removal of bubbles from liquids in zero-gravity conditions—is another important area for which techniques should be developed. Similarly, animal tissues will require techniques for removing, separating, evaluating, and handling in the space environment. A better understanding of interactions of internal and external disturbances on optical instruments must be achieved, so that designs can accommodate these interactions. Storage and transfer of cryogenics in zero-g conditions are essential to the completion of sophisticated measurement programs, and techniques for these processes should be explored in space. Laser altimetry, aligning of laser telescopes, technology for measuring space plasma and the masses of small particles, recognition of agricultural spectral signatures from space, and stellar scintillation effects are other areas that should be investigated in space to contribute to the implementation of more-comprehensive research programs.

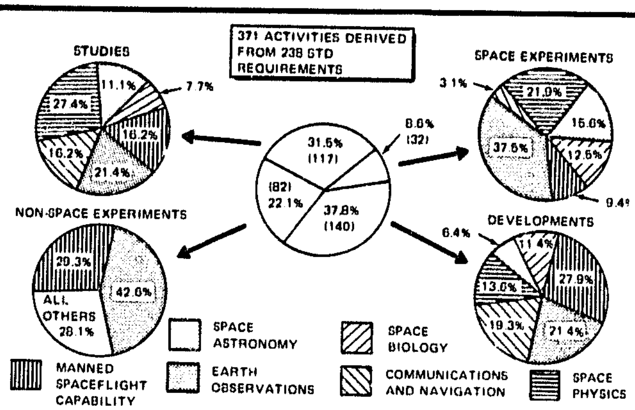

Figure 11. Distribution of Supporting Technology Development Activities

Table 2
STD SPACE EXPERIMENT DISTRIBUTION

STD Work Packages	STD Requirements: Manned Spaceflight Capability	Space Biology	Space Astronomy	Space Physics	Communications and Navigation	Earth Observations
Man's Participation in Earth Orbital Operations	MM-3		A-5	P-5,-6		ES-6,-7,-8
Optical Instrument Design Factors			A-1,-13	P-5,-6		
Effluent Effects			A-1,-8	P-9		ES-11
Cryogenic Systems			A-1,-8	P-29		
Photographic System Technology			A-7			ES-3
Fluid/Vapor Experiments	LS-2,-5					
Liquid Handling Techniques		B-13				
Amino Acid Analyzer		B-1				
Zero Gravity Surgical Procedures		B-5				
Small Particle Mass Measurement Technology		B-20				
Molten Film Drawing and Working Technology				P-13		
Space Plasma Measurement Technology				P-34,-35		
Laser Telescope Alignment					C-6	
Agriculture Signatures From Space						EF-1,-2,-3
Stellar Scintillation Effects						EM-4
Atmospheric Density Characteristics						EM-6
Aerosol Droplet Handling						EM-8
Laser Altimeter System						EI-23
Number of Space Experiments (Total 32)	3	4	5	7	1	12

PROGRAMMATIC APPLICATION OF SUPPORTING TECHNOLOGY DEVELOPMENT

To examine the programmatic aspects of accomplishing STD requirements, the individual STD activities (Table 1) were grouped into logical, cohesive work packages, some of which are shown in Table 2. STD activities of the same type (i.e., studies, experiments in space, experiments not in space, or developments) were grouped together into the same work package if the results derived from one activity were judged to influence another. Activities of a given type that appeared appropriate for a single contracted effort were also grouped into a single work package. Many of these STD work packages actually involved only one STD activity and hence only one STD requirement from Table 1. Others included as many as 12 STD activities. The total number of STD work packages was fairly close to the number of STD requirements and the number of STD activities.

Summarizing these statistics, there were 238 STD requirements, 371 STD activities, and 233 STD work packages.

Two types of STD work packages from each of the six disciplines were chosen for use as examples of how the STD data can be applied to actual planning of an STD program. Table 3 identifies the work packages chosen for this purpose. For each work package, the start time of each constitutent STD activity was determined, giving first consideration to the degree of dependence of that STD activity on such ongoing or potential NASA programs as Skylab and Space Station. Of secondary importance were the schedules of these programs and the experiments they support. Third in importance was the dependence of the STD activities upon the results of other STD activities in the work package. Based on these three factors, the start times were ordered and, considering the durations estimated for each activity, a sample schedule was made, and a funding curve was drawn using the cost estimates from the STD Requirements Description forms. Figure 12 shows the example program and presents the annual funding required to support these activities.

The example shown in Figure 12 should be viewed in terms of the limited analysis that it represents. It does not represent the only way to apply STD data to programming, but it does illustrate one way to use the information and one way to analyze the problem of scheduling. Although it was only an example, the schedule that was developed revealed some important facts about STD requirements: they impact early in relation to known programs, beginning with Skylab; they depend upon results from these programs; and they extend far into the future.

When more STD work packages are considered and when all the data are further analyzed, the example shown may well undergo change. Nevertheless, it demonstrates that STD programs can be used to help structure near-term NASA programs. The immediacy of the influence of these STD requirements, as

Table 3
STD WORK PACKAGES CHOSEN FOR PROGRAMMING EXAMPLE

Study Discipline	Work Packages	
	Studies	Space Experiments
Manned Spaceflight Capability	Potability and Microbial Detection (LS-6, -15)	Fluid-Vapor Experiments (LS-2, -5)
Space Biology	Methods of Handling Liquids in Zero-g (B-13)	Small Particle Mass Measurement (B-20)
Space Astronomy	Logistics and Control of Telescopes in Space (A-4, -5, -6)	Assembly and Deployment of Space Telescopes (A-1, -5, -8)
Space Physics	Plasma Physics Research (P-31, -32, -34, -35)	Low-g Measurement and Isolation Tests (P-5, -6)
Communications and Navigation	Millimeter-Wave Research (C-2, -4, -5)	Laser Telescope Alignment (C-6)
Earth Observations	Model of Ocean Dynamics (EO-2, -5, -8, -9, -12, -13, -16)	Laser Altimeter (EI-23)

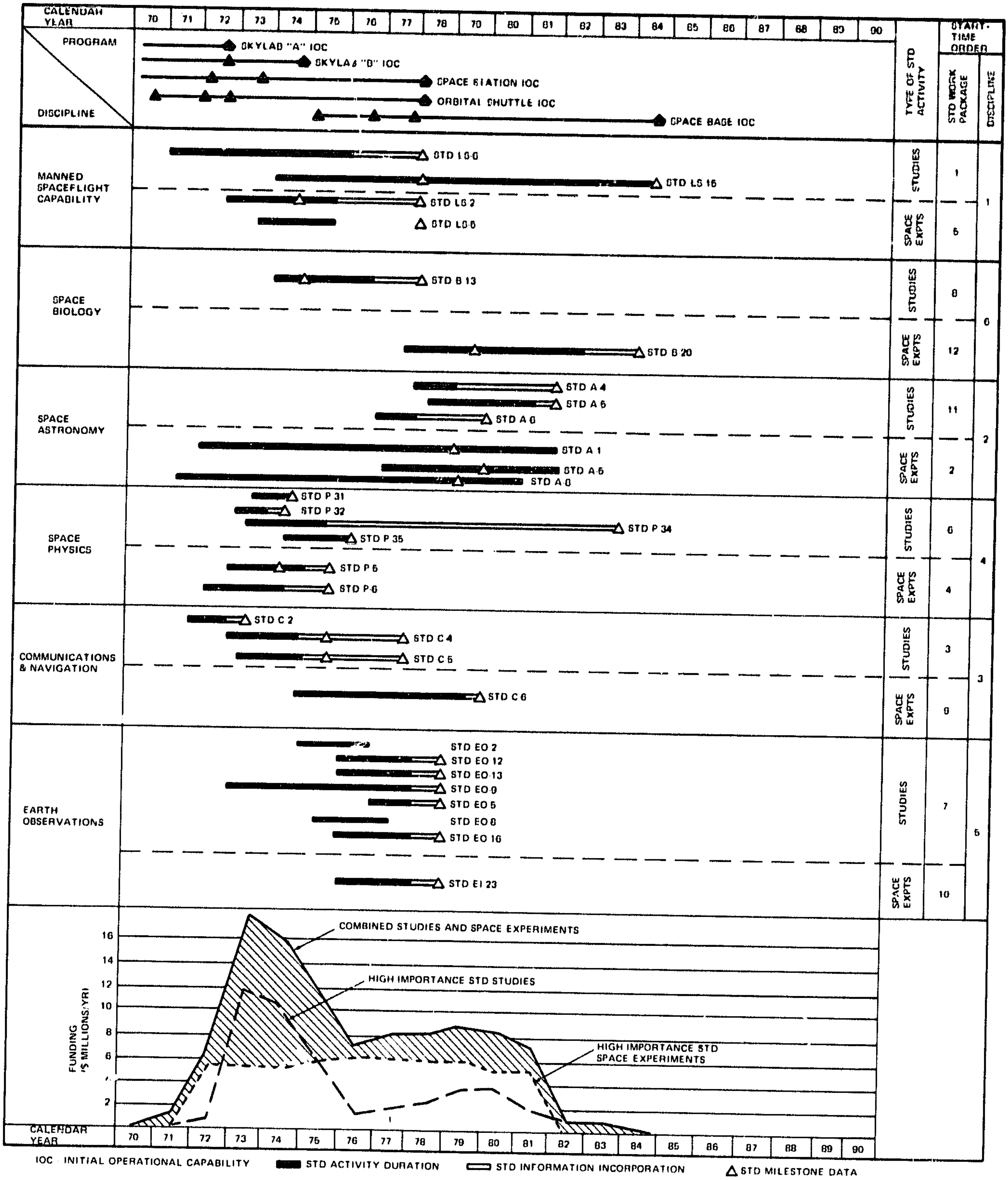

Figure 12. Example of Supporting Technology Development Program

demonstrated by the example, strongly indicates that this area should be considered for emphasis in the immediate future, for without the inclusion of supporting technology developments in the planning of research for the next decade in space, the program returns will undoubtedly suffer.

MISSION AND SPACE FACILITY PLANNING REQUIREMENTS

During the last decade, missions were planned to get man into space. Onboard experimental equipment often went along incidentally, simply because both it and the space were available. Such missions had a place in the past, but the aggregate of more than 10 years of experience in space has developed more-sophisticated ways of approaching mission planning, and the achievements in space during the next 10 years will depend largely on how effectively this sophistication is utilized.

Operating in space has become a sufficiently feasible undertaking that a planner generally has a variety of systems from which to choose. Programs for manned space research now in various stages of development include the Skylab, shuttle-and-module systems, and space stations in various configurations. Skylab, an orbiting laboratory, will sustain three periods of occupancy by 3-man crews for a total of 140 days over a span of approximately 8 months. Earth-to-orbit shuttle systems with either free-flying or shuttle-supported experiment modules will provide broad research capabilities. For the 1980's and beyond, space stations supporting 12-man crews for extended periods, and large permanent space facilities (known as the space base) capable of housing as many as 50 men have been under study. With the wide range of options that these programs offer (although methods for planning missions are still in their formative stages), it is already clear that for research missions to achieve maximum effectiveness, the requirements of the missions must shape the facilities, rather than vice versa.

For space research missions to shape the space research facilities, the parameters that govern mission planning must be thoroughly understood. One of the advantages offered by research conducted by man, as contrasted with purely automated research, is the possibility of simultaneously realizing a variety of related research objectives instead of pursuing a single experiment, as is usually the case with automated missions. This was emphasized during the current study, which uncovered numerous opportunities in which researchers in different disciplines could profit from the same or similar measurements. Thus, while all critical issues addressed in a given research cluster share, by definition, certain commonalities, it has been shown that other research clusters may also participate in this commonality. The missions of the next decade must be designed to fulfill research needs to as great an extent as possible, and at the same time to have the flexibility to change in response to the stimulus of new objectives that will develop as data are acquired. That being the case, the successful mission may be defined as the one that accomplishes the maximum amount of research with the minimum amount of investment.

The principal justification for research is to expand knowledge. The means by which this is done imposes certain requirements on the mission itself and on the space research facility. The nature of these requirements varies with the research activity, but many activities impose the same or similar requirements. The detailed information contained in the research cluster descriptions was therefore analyzed to identify research activities with compatible requirements.

The requirements placed on the mission and on the space research facility by any planned research activity are, in general, both operational and engineering in nature. The operational aspects concern parameters of the space environment in which the facility will operate. The engineering requirements concern the interface between the facility and the subsystems that support the research, man-machine relationships, and data acquisition and management.

REQUIREMENTS RELATED TO THE SPACE ENVIRONMENT

The major parameters to be considered in regard to the space environment are orbital altitude, inclination, spacecraft pointing orientation, pointing accuracy, and duration.

Orbital Altitude

Research activities for which orbital altitude considerations are important fall into two categories, those activities that should be performed in orbit at synchronous altitude or higher, and research that has to be performed in low Earth orbits. Analysis of this information from the 136 research clusters reveals that there are no specific requirements for orbits of intermediate altitudes and that 83 research clusters are insensitive to orbit altitude. Manned Spaceflight Capability and Space Biology investigations are essentially independent of orbital parameters, except as the orbit parameters influence the natural radiation exposure or impose logistical problems. Space Astronomy observations involving faint sources or high-resolution spectroscopy may require synchronous altitudes due to requirements for long exposure times. Some Space Physics investigations also pose special problems regarding orbit selection. In Earth Observations, the remote sensing requirements, allowable sun-target geometry, spacecraft-target geometry, and temporal and seasonal requirements represent orbit selection factors to consider. The orbit altitudes that fulfill most of the requirements of this discipline, however, lie in the 200- to 250-nmi range. Communications and Navigation experiments, in certain cases involving ground-site observations, require low orbital altitudes similar to those required by Earth Observations.

Altitude affects not only resolution and ground swath width, but also, together with inclination, the number of times the spacecraft passes over a particular area. The three parameters to consider in selecting an altitude for any given research activity, then, are resolution, swath width, and ground-track repeatability. Table 4 groups the various research clusters in accordance with altitude requirements.

Orbit Inclination

Most requirements for a particular orbit inclination are imposed by research that involves viewing a certain ground site, surface feature, surface area, or portion of the celestial sphere. For Earth Observations, the ground target of highest latitude defines the minimum adequate inclination. Other factors that must be considered include the look-angles and the angular fields-of-view of the sensors making the measurements.

A large number of truth sites and target locations are to be found in the Earth Observations research clusters. These targets can be separated into two categories: truth sites, which are involved in feasibility demonstration in which the sensor signal must be correlated with observations made from aircraft and from ground level; and sites that are observed in an operational (data-gathering) situation rather than in an instrument-development mode. In an analysis of the research clusters, 84 truth sites were identified, including existing instrumented field laboratories and projected requirements for new sites, as defined by principal investigators. Although these 84 sites are not all that would be necessary to accomplish the objectives for this discipline, the sample is large enough to permit the forming of conclusions about the latitude distribution of truth sites. To cover all the truth sites from low Earth orbit, inclinations up to polar are required. Analysis shows, however, that if an inclination of 55 degrees were selected, 75 of the 84 truth sites, or approximately 90 percent, would be visible from low orbit. Although 50 percent of the research clusters in Earth Observations require an inclination of at least 70 degrees, these operational requirements are not mandatory in all cases, as evidenced by several clusters (e.g. 6-II-1) where access to ground sites with latitudes of 60 to 70 degrees is desired but latitudes of 55 degrees are acceptable. Table 5 lists the inclination requirements for research clusters where the inclination is critical. For this study, inclinations are defined as low (below 30 degrees), medium (30 to 55 degrees) and high (above 55 degrees). While many research and development activities can be accomplished at lower inclinations, it can be expected that long-term, operationally oriented data-gathering systems will require inclinations approaching 90 degrees. Figure 13 compares these requirements as missions shift from research to operational modes

Pointing Orientation and Accuracy

The space facility may be required to point toward Earth or toward space, depending on the research activity. Some research activities impose strict limits

Table 4
ALTITUDE REQUIREMENTS FOR RESEARCH CLUSTERS

Synchronous or Higher	Low Earth Orbit (<300 nmi)	
1-EE-4*†	1-EE-2,-4	6-EP-1, -2
3-LF	3-OS	6-A/F-1 through -5
4-PP-2	3-XR	6-G/C-1
5-P-2	5-N-1, -2	6-G-1 through -5
	5-P-1,-3,-4	6-H-1 through -7
TOTAL: 4	5-NS-1,-3,-4	6-O-1 through -7
		6-M-1,-2,-3,-5,-6
While not a mandatory requirement, 3-OB and 3-OW would favor these altitudes	TOTAL: 44	

NOTE: Clusters not listed either have no altitude requirements or these requirements are yet to be identified.

*Translunar or interplanetary

†The index code numbers "1-EE-4", "3-LF", *et al.*, designate specific research clusters. More descriptive titles of these research clusters may be found in Table 6 and in the Appendix.

Table 5
INCLINATION REQUIREMENTS FOR RESEARCH CLUSTERS

Low (<30°)	Medium (30° ≤ i ≤ 55°)		High (>55°)
4-PP-2	5-N-2	6-G-1 through 6-G-5	4-PP-4
5-P-2	5-P-1, -3	6-H-1,-2,-3,-5,-6,-7	5-N-1
	5-NS-4, -5, -6	6-O-1 through 6-O-7	6-H-4
	6-EP-1, -2	6-M-1, -2, -3, -5, -6	
	6-A/F-1 through 6-A/F-5		
	6-G/C-1		

NOTE: Inclination requirements are associated with these research clusters. The remaining clusters have no specific inclination requirements, or they are yet to be identified.

on the research facility's pointing orientation and accuracy. The details of such requirements are discussed below under Guidance, Navigation, and Control, because the impact of these requirements makes itself felt in that area of subsystem interface. Figure 14 summarizes the pointing and rate requirements for the various research clusters.

Duration of Mission

Many research activities in Earth Observations and Space Astronomy, because of their viewing requirements, must be accommodated on long-term missions. Research in Space Physics on the behavior of liquid-gas interface phenomena in zero gravity, for

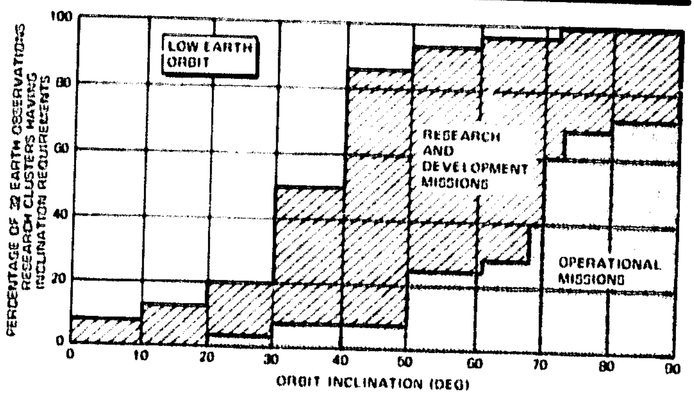

Figure 13. Inclination Requirements for Research and Operational Missions

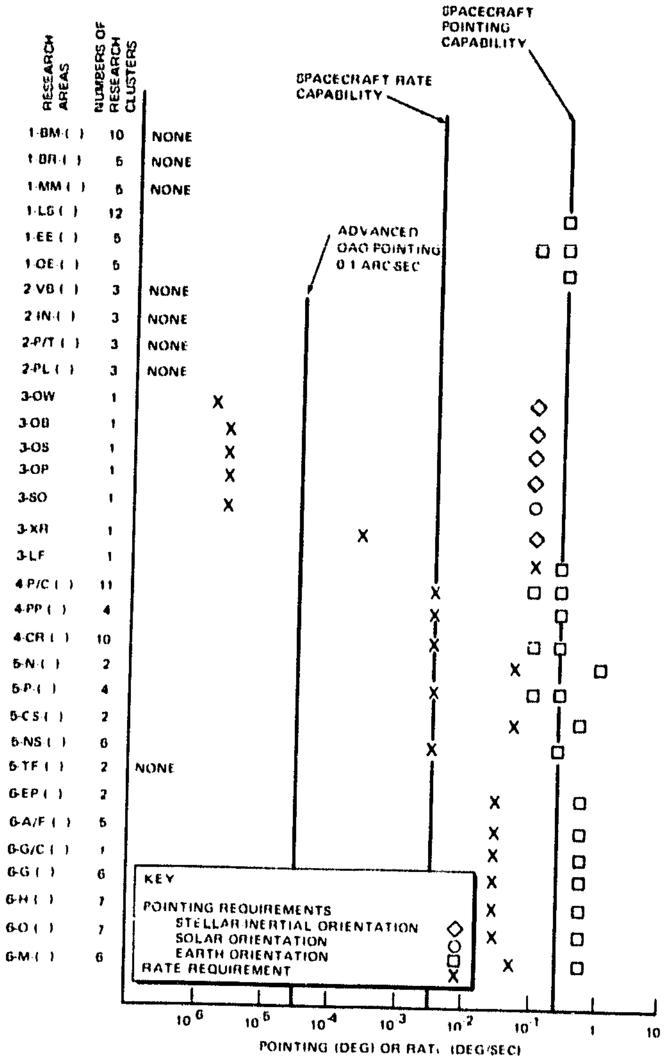

Figure 14. Summary of Research Cluster Stabilization Requirements

example, may require shorter periods of time in space. The duration of the mission, insofar as research requirements are concerned, is primarily a function of data acquisition and is mostly involved with the choice of the vehicle for the mission.

REQUIREMENTS RELATED TO FACILITY INTERFACE WITH SUBSYSTEMS

Before the problem of determing how a spacecraft will interface with subsystems required to support planned research can be addressed, a number of factors must be available for study. The configuration of the spacecraft must be at least loosely defined although this is not possible until the onboard instrumentation requirements have been determined. An instrumentation matrix was, therefore, prepared for each discipline, and from these matrices a summary was prepared to show which instruments can be used in common by research activities in all of the disciplines. It was then possible to consider the space vehicle subsystems to determine how the subsystems required to support a specific research activity would affect spacecraft sizing and how they could be integrated with the spacecraft. The volume the subsystems would occupy, the power they would require, and the weight they would add to the research facility had to be determined before these parameters could be meaningfully considered.

Each research cluster description was examined for requirements having a major influence on the resources of the host spacecraft. An interface summary chart (Table 6) identifies each research cluster and its requirements in terms of 12 important items. The data thus developed were used to determine requirements imposed by research activities on each of the subsystems individually. The individual requirements deal specifically with the subsystems for electrical power; environmental control; guidance, navigation, and control of the spacecraft; propulsion; logistics; and data acquisition.

Electrical Power Subsystem

From the data in Table 6 each research cluster was reviewed for average and peak power demands, and a summary of average power required for all instrumentation in each research cluster was prepared.

LEGEND:

NR No Specific Requirement
N/A Item Not Applicable
TBD To Be Determined after Additional Analysis
UNK Relationship Unknown

Table 6 (Page 1 of 7)
SPACE RESEARCH FACILITY INTERFACE SUMMARY

Research Cluster		Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
Cluster No.	Short Title	(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degrees/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) B< (29) (degrees)	(12) Q (events/day)
1-BM-4	Cardiovascular	100	1,000	Film	Air	100 to 1,000 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-5	Medical Problems	240	1,200	NR	Air	1,200 + UNK	NR	NR	NR	NR	NR	N/A	N/A
1-BM-6	Stress Response	350(1)	870(1)	NR	Air	350 to 870 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-7	Nervous System	1	1	Film	Air	Metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-8	Gastrointestinal	40	45	NR	Air	40 to 45 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-10	Blood and Urine	200	300	NR	Air	200 to 300 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-12	Instrumented Animals	100	100	NR	Air	100 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-13	Pulmonary Function	50	55	NR	Air	50 to 55 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-14	Metabolism	20	27	NR	Air	20 to 27 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-15	Centrifuge Studies	280	5,300(2)	NR	Air	280 + metabolic	NR	NR	Ambient to 1.(2)	NR	NR	N/A	N/A
1-BR-1	Sensory Behavior(4)	180	400	NR	Air	180 to 400 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BR-2	Group Dynamics	50	100	NR	Air	50 to 100 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BR-3	Complex Tasks	47	187	NR	Air	2,187 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BR-4	Skill Retention	200	5,300(2)	NR	Air	200 to 5,300 + metabolic	NR	NR	Ambient to 1.(2)	NR	NR	N/A	N/A
1-BR-6	Performance Tests	50	100	NR	Air	50 to 100 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-MM-1	Controls and Displays(3)	50	1,000	NR	Air	50 to 1,000 + metabolic	NR	NR	Ambient	NR	NR	UNK	UNK
1-MM-2	Locomotion	40	50	NR	N/A	50	0.25	0.003	Ambient	NR	NR	N/A	N/A

NOTE: Numbers 1-BM-1, -2, -3, -9, -11 and 1-BR-5 were assigned to clusters that were later combined with others or eliminated.

Table 6 (Page 2 of 7)
SPACE RESEARCH FACILITY INTERFACE SUMMARY

Research Cluster		Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
Cluster No.	Short Title	(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degrees/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) B<(29) (degrees)	(12) Q (events/day)
1-MM-3	Habitability	40	50	Film	Air	40 to 50 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-MM-4	Activity Cycles	100	150	NR	Air	2 150	NR	NR	Ambient	NR	NR	N/A	N/A
1-MM-5	Performance Aid	345	425	NR	Air	Metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-1	Phase Change	200	1,500	NR	Air	1,500	0.25	0.003	10^{-6}(5)	NR	NR	N/A	N/A
1-LS-2	Material Transport	800	1,500	NR	Air	1,500	0.25	0.003	10^{-6}(6)	NR	NR	N/A	N/A
1-LS-3	Atmosphere Supply	1,000	1,200	NR	Air	1,000	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-4	Water Management	100	250	NR	NR	200	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-5	Water Electrolysis	630	700	NR	Air	200	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-6	Food Management	3,000	6,000	NR	Air	700	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-7	Atmosphere Purification	300	400	NR	Air	400	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-8	Life Support Monitoring	TBD(8)	TBD(8)	NR	Air	TBD(8)	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-9	Waste Management	500	900	NR	Air	400	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-10	Heat Transport	1000	1,200	NR	NR	800	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-11	Crew Systems	TBD(8)	TBD(8)	NR	Air	TBD(8)	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-12	Maintenance and Repair	TBD(8)	TBD(8)	NR	Air	TBD(8)	NR	NR	Ambient	NR	NR	N/A	N/A
1-EE-1	Data Management	100	250	Film	NR	250	NR	NR	Ambient	NR	NR	N/A	N/A
1-EE-2	Structures	550	1,000	NR	NR	NR	0.25	0.003	Ambient	NR	NR	UNK	UNK
1-EE-3	Stability and Control	530	765	NR	NR	100	0.1	0.003	Ambient	100 to 250	70	N/A	N/A
1-EE-4	Navigation and Guidance	100	TBD	NR	Cryo	100	0.25	0.003	Ambient(7)	NR	NR	UNK	UNK
1-EE-5	Communications	50	50	NR	NR	50	0.25	0.003	NR	NR	NR	TBD	TBD
1-OE-1	Logistics and Resupply	400	400	NR	Air	400	0.25	0.003	NR	NR	NR	TBD	TBD
1-OE-2	Maintenance and Repair	200	200	Film	NR	200	0.25	0.003	Ambient	NR	NR	N/A	N/A
1-OE-3	Assembly and Deployment	TBD	TBD	NR	Air	NR	0.25	0.003	Ambient	TBD(9)	TBD(9)	N/A	N/A
1-OE-4	Module Operations	TBD	TBD	NR	Air	NR	0.25	0.003	Ambient	NR	NR	N/A	N/A
1-OE-5	Vehicle Support	NIL	NIL	NR	Air	NR	0.25	0.003	Ambient	NR	NR	N/A	N/A
2-VB-1	Preliminary Vertebrates	450	2,200	Film	Air and Steam	Metabolic	NR	NR	Ambient	NR	NR	UNK	UNK
2-VB-2	Intermediate Vertebrates	450	2,200	Film	Air	Metabolic	NR	NR	10^{-5}(10,11)	NR	NR	N/A	N/A
2-VB-3	Advanced Vertebrates	450	2,220	Film	Air	Metabolic	NR	NR	10^{-5}(10,11)	NR	NR	N/A	N/A
2-IN-1	Preliminary Invertebrates	80	80	Film	Air	Metabolic	NR	NR	10^{-5}(10,11)	NR	NR	N/A	N/A
2-IN-2	Intermediate Invertebrates	80	80	Film	Air	Metabolic	NR	NR	10^{-4}	NR	NR	N/A	N/A
2-IN-3	Advanced Invertebrates	80	80	Film	Air	Metabolic	NR	NR	10^{-4}	NR	NR	N/A	N/A

Table 6 (Page 3 of 7)
SPACE RESEARCH FACILITY INTERFACE SUMMARY

Cluster No.	Research Cluster Short Title	Electrical (1) Average (watts)	Electrical (2) Peak (watts)	Logistics (3) Special Handling	Environment (4) Atmosphere (gases)	Environment (5) Cooling (watts)	Stabilization (6) Pointing (degrees)	Stabilization (7) Rate (degrees/sec)	Acceleration (8) Level (g's)	Orbit Parameters (9) H (nmi)	Orbit Parameters (10) i (degrees)	Viewing Restrictions (11) B<(29) (degrees)	Viewing Restrictions (12) Q (events/day)
2-P T-1	Preliminary Protists	440	2,400	Film	Air	Metabolic	NR	NR	10^{-4}	NR	NR	N A	N A
2-P T-2	Intermediate Protists	480	2,440	Film	Air	Metabolic	NR	NR	10^{-4}	NR	NR	N A	N A
2-P T-3	Advanced Protists	590	2,550	Film	Air	Metabolic	NR	NR	10^{-3}	NR	NR	N A	N A
2-PL-1	Preliminary Plants	265	915	Film	Air	Metabolic	NR	NR	10^{-5}(10,11)	NR	NR	N A	N A
2-PL-2	Intermediate Plants	265	915	Film	Air	Metabolic	NR	NR	10^{-5}(10,11)	NR	NR	N A	N A
2-PL-3	Advanced Plants	265	915	Film	Air	Metabolic	NR	NR	10^{-5}(10,11)	NR	NR	N A	N A
3-OW	Optical Structure	930	960	Film	Cryo	TBD	6×10^{-6}	1.4×10^{-6}	NR(12)	Sync	NR	NR(14)	NR
3-XR	X-ray Sources	406	960	TBD	NR	773	7×10^{-5}	7×10^{-6}	NR(12)	100 to 400	NR	NR	NR
3-LF	Low-Frequency Radio	366	400	NR	NR	400	TBD(13)	TBD(13)	NR(12)	Sync	NR	NR	NR
3-OB	Optical Planetary	1,100	1,920	Film	Cryo	TBD	7×10^{-4}	7×10^{-6}	NR(12)	Sync	NR	NR(14)	NR
3-OS	Optical Surveys	170	960	Film	Cryo	TBD	3×10^{-4}	3×10^{-6}	NR(12)	100 to 400	NR	NR(14)	NR
3-SO	Solar Optical	TBD	TBD	Film	Cryo	TBD	3×10^{-4}	3×10^{-6}	NR(12)	Low	Sun Sync	None	None
3-OP	Stellar Photometry	170	960	TBD	NR	TBD	3×10^{-4}	3×10^{-6}	NR(12)	100 to 400	NR	NR(14)	NR(14)
4-P C-1	Chemical Reactions	750	1,000	Film	TBD	TBD	0.25	0.003	10^{-3}	N A	N A	N A	N A
4-P C-2	Liquid-Vapor Interface	400	500	Film	TBD	1,500	0.1	0.003	10^{-5}, 10^{-6}(15)	N A	N A	N A	N A
4-P C-3	Heat Transfer in Zero-G	30	3,000	Film	Inert or Noble gas	3,300	0.1	0.003	10^{-2} to 10^{-5}(17)	N A	N A	N A	N A
4-P C-4	Controlled Density	5,000	20,000	Film	Various(16)	TBD	0.1	0.003	10^{-3} to 10^{-4}(17)	N A	N A	N A	N A
4-P C-5	E and M Fields	200	2,000	Film	TBD	2,000	0.1	0.003	10^{-3}	NR	NR	N A	N A
4-P C-6	Super Materials	5,000	20,000 (20)	Film	TBD	TBD (20,000)	0.25	0.003	10^{-2} to 10^{-5}(17)	NR	NR	N A	N A
4-P C-7	Levitation Melting	2,000	5,000	Film	TBD	TBD (5,000)	0.25	0.003	10^{-3}	NR	NR	N A	N A
4-P C-8	Films and Foils	5,000	20,000 (20)	Film	TBD	TBD (20,000)	0.25	0.003	10^{-3}	NR	NR	N A	N A
4-P C-9	Liquid Releases	175	200	Film	Air or He	Nominal	0.25	0.003	10^{-3}	NR	NR	N A	N A
4-P C-10	Capillary Flow	250	400	Film	Inert $+O_2$	400	0.25	0.003	10^{-2}, 10^{-4}, 10^{-6}(17)	NR	NR	N A	N A
4-P C-11	Superfluids	20	20	Film	NR	Nominal	0.25	0.003	10^{-2}, 10^{-4}, 10^{-6}(17)	NR	NR	N A	N A
4-CR-1	Nuclear Component	10,000 (18,20,4)	10,000 (18,20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-2	Primary e and e+	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK

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SPACE RESEARCH FACILITY INTERFACE SUMMARY

Research Cluster		Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
Cluster No.	Short Title	(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degrees/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) B<(29) (degrees)	(12) Q (events/day)
4-CR-3	Primary Gamma Rays	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-4	Heavy Isotopes	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-5	Antinuclei	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-6	Quarks	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-7	Unknown Particles	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-8	Albedo Particles	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-9	Differential p-p	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-10	Differential Spallation	10,000 (18,20)	10,000 (18,20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-PP-1	SS Environment Interaction	TBD	TBD	TBD	TBD	TBD	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-PP-2	Particle Dynamics	100	1,000	NR	NR	Nominal	0.25	0.003	NR	12,400	>55	UNK	UNK
4-PP-3	Thermal Plasma	TBD	TBD	NR	NR	Nominal	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-PP-4	Auroral Processes	100	1,000	NR	NR	Nominal	0.25	0.003	NR	12,400	>55	UNK	UNK
5-N-1	Terrestrial Noise	25	25	NR	NR (21)	Nominal	1.0	0.05	NR	200 to 1,000	90	NR	TBD
5-N-2	Noise Identification	25	25	Film	NR (21)	Nominal	0.25	0.003	NR	TBD	55	NR	TBD
5-P-1	Ionosphere Propagation	25	25	NR	NR (21)	Nominal	0.25	0.003	NR	100 to 200	90	N A	TBD
5-P-2	Troposphere Propagation	25	25	NR	NR (21)	Nominal	0.1	0.003	NR	Sync	0	N A	N A
5-P-3	Plasma Propagation	25	25	NR	NR (21)	Nominal	NR	NR	NR	100 to 200 (22)	40	N A	N A
5-P-4	Multipath Measurements	50	50	NR	NR (21)	Nominal	NR	NR	NR	100 to 1,000	NR	N A	TBD
5-TF-1	Laboratory Deployment	800	2,000	Film	NR (21)	2,000	NR	NR	NR	100 to Sync	NR	NR	TBD
5-TF-2	Demonstration and Test	800	2,000	Film	NR (21)	2,000	NR	NR	NR	100 to Sync	NR	NR	TBD
5-CS-1	MM Wave Demonstration	350	400	NR	NR (21)	400	0.5	0.05	NR	NR	NR	NR	TBD
5-CS-2	Optical Demonstration	500	1,500	Film	NR (21)	1,500	0.5	0.05	NR	200 to 1,000	TBD	NR	TBD

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SPACE RESEARCH FACILITY INTERFACE SUMMARY

Cluster No.	Research Cluster Short Title	Electrical (1) Average (watts)	Electrical (2) Peak (watts)	Logistics (3) Special Handling	Environment (4) Atmosphere (gases)	Environment (5) Cooling (watts)	Stabilization (6) Pointing (degrees)	Stabilization (7) Rate (degrees/sec)	Acceleration (8) Level (g's)	Orbit Parameters (9) H (nmi)	Orbit Parameters (10) i (degrees)	Viewing Restrictions (11) B<(29) (degrees)	Viewing Restrictions (14) Q (events/day)
5-NS-1	Navigation Techniques	50	100	NR	NR (21)	100	0.25	0.003	NR	100 to Sync (23)	55	NR	TBD
5-NS-2	Laser Ranging	500	1,500	Film	NR (21)	1,500	0.25	0.003	NR	TBD	TBD	NR	TBD
5-NS-3	Autonomous Navigation	50	100	NR	NR (21)	Nominal	0.25	0.003	NR	100 to Sync	NR	NR	TBD
5-NS-4	Surveillance Systems	25	50	NR	NR (21)	Nominal	0.25	0.003	NR	TBD	TBD	NR	TBD
5-NS-5	Collision Avoidance	25	50	NR	NR (21)	Nominal	0.25	0.003	NR	TBD	TBD	NR	TBD
5-NS-6	Search and Rescue	50	100	NR	NR (21)	Nominal	0.25	0.003	NR	TBD	TBD	NR	TBD
6-EP-1	Photographic Coverage	1,300	2,100	Film (24)	NR	NR	0.5	0.03	NR	100 to 300	30 to 90	30 to 90	1
6-EP-2	Volcanic Activity	4,000	4,700	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30	1 100
6-A F-1	Crop Inventory	4,800	5,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	220 to 270	45 to 60	30 to 90	1 8 and 1 30
6-A F-2	Soil Type Mapping	4,600	5,400	Film (24)	Cryo	TBD (25)	0.5	0.03 (26)	NR	220 to 270	45 to 60	60 to 90	1 8 and 1 30
6-A F-3	Crop Identification	4,600	5,500	Film (24)	Cryo	TBD (25)	0.5	0.03 (26)	NR	220 to 270	45 to 60	60 to 90	1 8
6-A F-4	Crop Vigor and Yield	4,600	5,400	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	220 to 270	45 to 60	60 to 90	1 or 1 8
6-A F-5	Wildfire Detection	2,200	3,000	Film (24)	Cryo	TBD (25)	0.5	0.03 (26)	NR	220 to 270	45 to 60	30 to 90	1 and 2
6-G C-1	Multisensor Mapping	1,300	2,100	Film (24)	NR	NR	0.5	0.03	NR	100 to 300	30 to 90	30 to 90	1
6-G-1	Rocks and Soils	3,900	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	73 to 107	30 to 90	1 10
6-G-2	Use of Earth's Crust	3,900	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30	1 10
6-G-3	Geologic Disasters	3,300	3,700	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	25 to 90	1 and 1 30
6-G-4	Geothermal Sources	4,000	4,700	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30	1 100
6-G-5	Minerals and Oils	3,900	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	15, 30, 60	1 190
6-G-6	Land Forms	3,900	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	73 to 107	30 to 90	1 10
6-H-1	Water Pollution	1,300	2,000	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30 to 90	1
6-H-2	Flood Warning	3,200	3,500	Film (24)	Cryo	TBD (25)	0.5	0.03 (26)	NR	125 to 275	55	30 to 90	1 and 1 8
6-H-3	Synoptic Lake Inventory	3,800	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30 to 90	1 90
6-H-4	Synoptic Ice Inventory	3,200	3,500	Film (24)	Cryo	TBD (25)	0.5	0.03 (3)	NR	125 to 275	55	30 to 90	1 90
6-H-5	Soil Moisture	700	1,000	Film (24)	Cryo	TBD (25)	0.5	0.03 (3)	NR	125 to 275	90	30 to 90	1 8
6-H-6	Underground Sources	600	1,000	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	50	0 and >50	1 180
6-H-7	Major River Basins	3,800	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 175	55 to 68	<30 and 0 to 90	1 90
6-M-1	Boundary Layer Exchange	600	900	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 300	30 to 70	NR	NR
6-M-2	UHF Sferics Detection	500	800	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 400	30 to 55	NR	NR
6-M-3	Atmospheric Density	65	100	Film (24)	NR	Nominal	0.02 (27)	0.05	NR	100 to 300	0 to 50	NR	NR

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SPACE RESEARCH FACILITY INTERFACE SUMMARY

Cluster No.	Research Cluster: Short Title	Electrical (1) Average (watts)	Electrical (8) Peak (watts)	Logistics (3) Special Handling	Environment (4) Atmosphere (gases)	Environment (5) Cooling (watts)	Stabilization (6) Pointing (degrees)	Stabilization (7) Rate (degrees/sec)	Acceleration (8) Level (g's)	Orbit Parameters (9) H (nmi)	Orbit Parameters (10) i (degrees)	Viewing Restrictions (11) B<(29) (degrees)	Viewing Restrictions (12) Q (events/day)
6-M-4	Zero-G Cloud Physics	200	200	Film (24)	N_2, O_2, CO_2, H_2O	Nominal	NR	NR	10^{-5}	N/A	N/A	N/A	N/A
6-M-5	Atmospheric Pollutants	500	800	Film (24)	Cryo	TBD (25)	0.5	0.05	NR	200 to 300	30 to 55	30 to 90	NR
6-M-6	Special Area Studies	600	1,000	Film (24)	Cryo	TBD (25)	0.5	0.05	NR	100 to 300	20 to 30	TBD	TBD
6-O-1	Ocean Pollution	700	1,000	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	30 to 60	1
6-O-2	Solar Energy Partition	800	1,100	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	30 to 60	1
6-O-3	Ocean Population Dynamics	700	1,000	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	30 to 60	1
6-O-4	Currents and Tides	3,100	3,300	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	NR	1
6-O-5	Ocean Physical Properties	3,000	3,300	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 200	55	NR	1
6-O-6	Ocean Solid Boundary	1,500	2,200	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	NR	1
6-O-7	Ocean Surface Activity	700	900	Film (24)	Cryo	TBD (25)	0.5	0.03 (28)	NR	100 to 250	55	NR	1

REMARKS:

(1) Power levels required for thermal enclosure; when not used power levels reduced to 40 to 45 watts.

(2) Onboard manned centrifuge required. High starting and run up power requirements may require secondary batteries. Stabilization and control distrubances need to be noted.

(3) Research may be accommodated by coordination of design of onboard stabilization and control subsystem.

(4) Recommends Space Station rotation and/or centrifuge.

(5) Investigations require this acceleration level for periods of 1 hour.

(6) Investigations require this acceleration level for periods of 5 hours.

(7) Some of the functions performed by onboard investigators and members of the crew produce significant disturbances. The effect of these disturbances on the spacecraft could be measured to obtain important data concerning disturbance torques and accelerations.

(8) Research data may be derived from other experiments; unique requirements need to be determined when experiment groupings are resolved.

(9) Orbit must be selected so as to be safe for EVA.

(10) Some investigators may settle for 10^{-4}g.

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SPACE RESEARCH FACILITY INTERFACE SUMMARY

(11) Some experiments require onboard centrifuge.

(12) The optical instruments need to be isolated from vibration and torque disturbances produced in the spacecraft.

(13) Scanning required at a 6-degree/second rate.

(14) Protection required to prevent instruments from inadvertently pointing toward the sun.

(15) Level required for periods of 2 hours.

(16) Gases required include N_2, O_2, He, A, and others.

(17) May require onboard centrifuge or Space Station rotation.

(18) Power levels required for cooling superconducting magnet by closed system. For passive resupply of cryogen total power would be about 3,000 watts.

(19) Periodic major reconfiguration of experimental apparatus may be required at 1- to 3-month intervals.

(20) Depending on duty cycle, high-power level demands may require secondary batteries.

(21) No specific atmosphere requirements except for no corrosive components.

(22) Orientation of sensors is critical during reentry in order to make measurements of spacecraft perturbations or plasma.

(23) Surface and airborne targets required to 100,000-foot altitude.

(24) Retrieval and resupply of photographic material considerations may result in onboard processing requirements.

(25) Amount of cooling for infrared detectors depends on details of open or closed loop refrigeration installation.

(26) Spacecraft roll maneuvers required to calibrate microwave radiometer.

(27) For target acquisition 1 arc-min, for target tracking 2 arc-sec.

(28) Spacecraft yaw maneuvers required to calibrate radar altimeter/scatterometer.

(29) Angle between spacecraft-sun line and orbit plane.

Electrical power requirements for most of the Manned Spaceflight Capability research are generally below an average of 500 watts, with most averages being less than 200 watts. The peak power demands are usually less than 1 kw and of short duration. Inclusion of a manned centrifuge onboard (required by two clusters in this discipline) means that the electrical subsystem must supply a high-torque starting power of about 5.3 kw for about 1 minute, or proportionally less for longer starting periods, and an operating power of about 200 watts. In some research for Space Biology, which generally makes moderate demands on the electrical power supply (average demand between 80 and 600 watts), the use of a smaller centrifuge for animals may mean a peak power requirement as high as 2.5 kw.

The five optical-region clusters in Space Astronomy use common equipment, and average loads vary up to 1,100 watts with peak demands as high as 1,920 watts. Less electrical power is required for the x-ray and low-frequency-radio clusters in this discipline. Most research activities for Space Astronomy will be conducted in an autonomous vehicle, and provisions must therefore be made for self-contained power supplies.

For Space Physics, the research clusters exhibit average power demands from about 50 watts to 10 kw, with peaks ranging from 200 watts to 20 kw. Special power-source provisions will be necessary for the 20-kw peak power required for high-temperature and high-pressure processing. These requirements could call for the shutdown of all other research and even absorb the several kilowatts of power intended for housekeeping loads. However, these power requirements are predicated on an active cooling system for the superconducting magnet required by the cosmic-ray laboratory. A substantial reduction in power demand could result if use was made of passive techniques that relied on a logistic resupply of cryogens.

Communications and Navigation research clusters have no special electrical power requirements, their average being from 25 to 800 watts with peaks up to 2 kw.

In the area of Earth Observations, it was found possible to accommodate the applicable research objectives without placing unusual requirements on the electric power subsystem.

Environmental Control Subsystem

Most of the electrical energy demanded by individual instruments will be converted to thermal energy that will have to be dissipated at a rate sufficient to keep the equipment within safe operating temperature limits (Figure 15), which represents a cooling load on the environmental subsystem. An estimate of this load is included in the projection of electrical power requirements, so that the electrical power data discussed above will reflect the probable cooling load presented to the environmental control system when the duty cycle of the equipment is factored in.

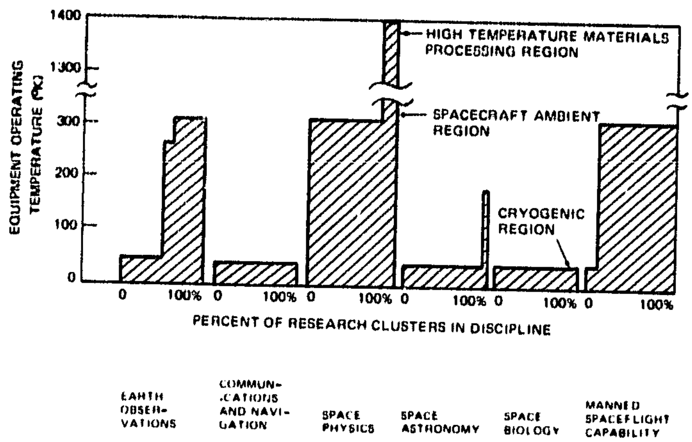


Figure 15. Distribution of Operating Temperatures of Research Cluster Equipment

The onboard apparatus must be protected from outside sources of contamination, and hazardous experiments must be isolated from other elements of the spacecraft. The biological materials and chemical reagents used in the Manned Spaceflight Capability and Space Biology disciplines and the materials used in the physics and chemistry laboratory investigations represent two groups of potential contaminants whose presence onboard imposes requirements on the environmental control subsystem.

Guidance, Navigation, and Control Subsystem

Three types of requirements are generally imposed on the guidance, navigation, and control subsystem. The first concerns acceleration. Some research requires that extremely low acceleration levels be maintained for extended periods of time (10^{-6} g for hours). The ambient acceleration level on a nominally zero-g space research facility approaches 10^{-4} g. Disturbances normally present include gravity gradient torques, aerodynamic drag, reaction-control-system thrustor firing, logistics vehicle docking, crew motion, and control-moment-gyroscope torques. During experiments requiring low acceleration levels, sensitivity is such that crew motion must be limited to console operation and similar duties. Sustained gravity levels of 10^{-5} appear possible with passive or active devices to attenuate crew motion and other short-period disturbances. Sustained gravity levels of less than 10^{-6} do not presently appear feasible for manned space research facilities.

The second type of requirement for this subsystem is derived from the need, in Earth-oriented research, for determing ground-site position. Most Earth Observations research has ground-site position accuracy requirements of 3,000 and 6,000 feet, and several have requirements down to 1,500, or 500, or even 100 feet as shown in Figure 16, which summarizes these requirements and indicates the capabilities of various systems to fulfill them.

The third set of requirements imposed on the guidance, navigation, and control subsystem is that of pointing stabilization. The requirements for telescopes are so stringent in some Space Astronomy research that conventional attitude sensors cannot provide the necessary accuracy, and the experiment sensor must provide its own attitude information (for example, the 3-meter diffraction-limited telescope with attitude-sensing capabilities, for research cluster 3-OW). There are experiments (high-precision photometry, for instance), where viewing is through a diaphragm subtending an angle as small as 1 arc-second. For these cases, acquisition becomes a significant problem for which techniques must be developed. The simple approach of rigidly attaching the telescope to an experiment module or space vehicle and providing attitude control with control moment gyroscopes is rendered impractical in most cases by the disturbances acting on the module, such as solar panel rotation, fans, and camera shutters. Since the amplitude and frequency of such internal disturbances are not well defined, the question of pointing stability for this type of telescope must undergo more study.

Propulsion Subsystem

Two areas of potential effect on the propulsion subsystem are identified within the reaction control system; they are thrust limitations due to acceleration constraints, and plume contamination effects. Space Physics requirements will be imposed on the reaction control syste to limit accelerations to levels ranging from 10^{-3} t. 10^{-6} g, and Earth Observations and

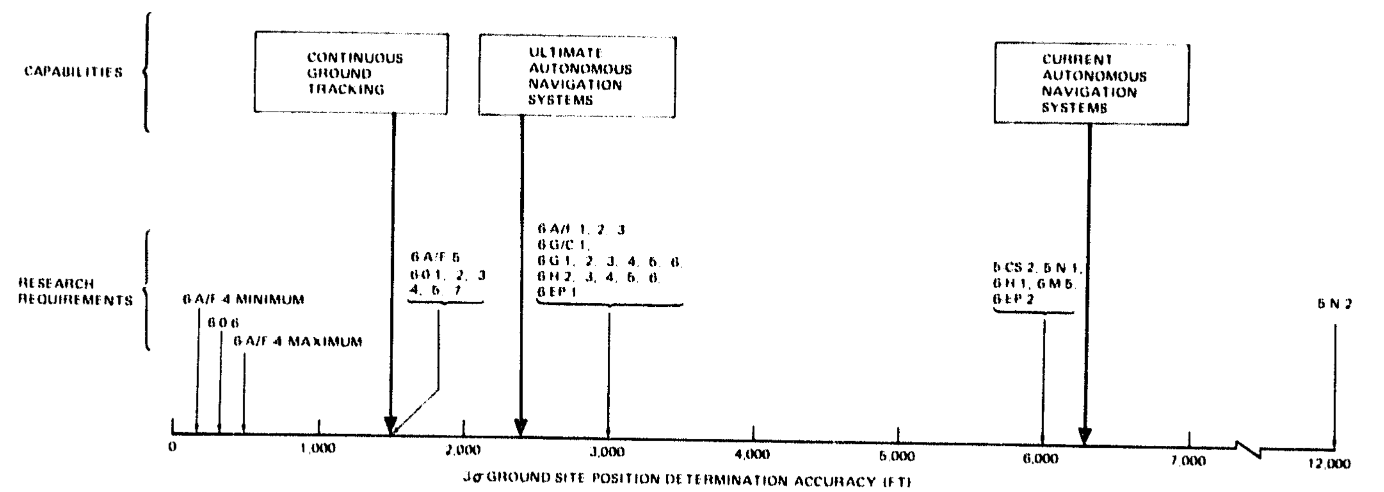


Figure 16. Ground Site Position Determination Requirements and Limitations

Space Astronomy experiments can be degraded if effluents contaminate sensors or optical surfaces or interfere with transmission of radiation in the vicinity of the camera or telescope. Manned Spaceflight Capability investigations do not impose any specific restrictions on the reaction control system. In Space Biology, many investigations require gravity levels in the range of 10^{-5} to 10^{-4} for extended periods. These requirements influence the mechanization and selection of reaction control system components.

The low-acceleration-level requirements impose thrust-level constraints on the propulsion system, the severity of which is a function of vehicle weight and mission operations. Zero-gravity investigations in Space Physics and in meteorological cloud-chamber research require a low level of acceleration disturbance (10^{-5} g) for extended periods of time. These research activities would benefit from a propulsion subsystem using low-thrust techniques, such as the resistojet.

The extent of propulsion-subsystem-plume contamination is one of the least-understood of the important phenomena associated with spacecraft design. It is known, however, that contamination of critical surfaces and the degradation in transmission of radiation due to scattering and absorption are unacceptable. Space research facilities must be designed to minimize the contamination of the sensitive instruments called for in the research clusters.

Logistics Subsystem

With regard to the logistics subsystem, the influence of research requirements can be fully appreciated only when missions are synthesized; however, study of the individual research clusters did reveal certain trends.

The most severe demands for resupply and handling of materials involve onboard photographic processes. Sixty percent of the research clusters describe a need for photographic film or other photosensitive materials. The packaging, thermal and radiation protection, handling, storage, onboard processing, retrieval, and resupply of these materials will be critical to the success of the research.

Other logistical problems may be encountered when cryogenic fluids need to be resupplied on a periodic basis. Certain Earth Observations instruments that function in the infrared region of the spectrum have detectors that must be cooled to cryogenic temperatures (4° to 170° K); communications radiometric receivers require cryogenic cooling of the first few RF amplification stages to reduce internal noise to a level where the incoming low-level radiometric signals are not masked. The Space Physics cosmic-ray experiments use a supercooled magnet assembly that would require a sizeable supply of cryogens if it is cooled by passive means.

REQUIREMENTS RELATED TO MAN

Among the most limiting constraints that manned space research can place upon a space research facility are those imposed because of the presence of man himself. In addition to his requirement for a life support system inside the facility, systems for extravehicular activity are also needed. Crew size imposes volume, weight, and power requirements; these are in addition to requirements inherent to man's presence. The extent of crew participation required in each research area was identified, and relevant crew data were included in the research cluster descriptions.

Each experimental task was analyzed to determine the type and level of skill required to perform the task. Skill type was divided into the 20 categories shown in Figure 17, each type representing the range of skills normally associated with a particular discipline. Three skill levels were identified, and the specialized education or training required for task performance was determined. The highest skill level, (I) requires extensive education and training in a professional discipline, usually representing a Master's or higher degree in the discipline. The intermediate, or technician, level (II) requires several years of training in the discipline, but not necessarily a formal degree. Skill level III can be achieved through cross-training in 3 months or less by crew members not having specific background in the discipline. The distribution of skills for each of the three levels is shown in Figure 17, along with the number of research clusters involved. The general level of crew involvement in each research area is discussed below.

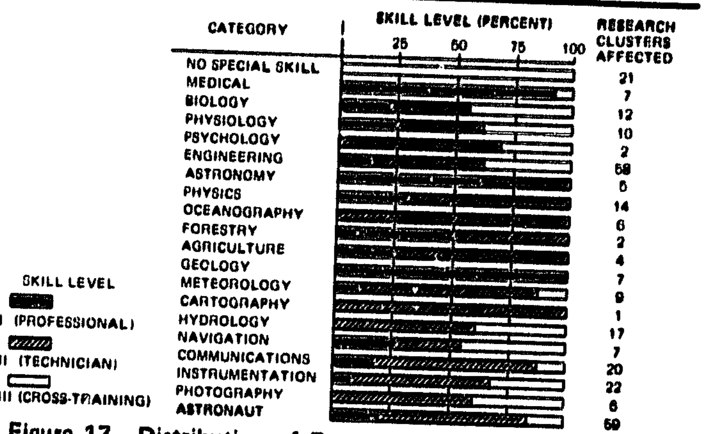


Figure 17. Distribution of Experience Levels

Biomedicine

Most of the biomedical experiments require extensive crew participation since crewmen will be utilized both as experiment monitors and experiment subjects. Experiments involving the effects of radiation and toxicology involve instrumented animals.

The skill-level II investigator plays an indispensable role in the experiment program. The experiment setup, including subject preparation, usually requires the participation of an individual experienced and knowledgable in physiology. The conduct of the experiment, particularly when a preliminary evaluation of data validity is involved or when blood sampling is part of the experiment regimen, requires the same experience level. Cross-trained skill-level III crewmen may be utilized for the simple experiment preparations and post-run cleanup. The experiment subjects, although primarily crewmen, in most cases must be thoroughly trained in the experimental techniques during the establishment of preflight baselines. The skill-level I investigator is required in only a few research clusters and then only for a minimum of tasks.

Before flight, instrumented animals will be prepared for automated data production and will require only minimum monitoring and general maintenance from a crewman.

The exposure of mice and rats to radiation and toxic contaminants, and the treatment of experimental lesions will require at least a skill-level II crewman with significant experience in these specific activities. The analytical chemical laboratory will be manned by an individual of similar experience.

Man-Systems Integration

In general, these experiments are addressed to the evaluation of man's behavior as an individual, in a group setting, and at the interface with hardware. As such, they require heavy participation by the crew as experiment subjects. The crew is also involved in setting up conditions for individual experiment runs and in the operation, monitoring, and maintenance of experiment measurement equipment. In many of the man-systems integration experiments, the manned activities observed are regularly scheduled mission tasks and will therefore not impose additional time requirements on crew members serving as experiment subjects.

Life Support and Protective Systems

The nature of the specific experiment determines the level of crew involvement. Basic heat and mass transport experiments are shorter in duration (minutes to hours), but they require setup, startup, data taking, and continuous observation by at least one crew member. Evaluations of complete life-support systems and subsystems extend over long durations (weeks to months) and require close monitoring only during startup; once in operation, however, they depend heavily on automatic data recording, testing, and controls. The crew must follow a daily schedule of monitoring and must perform weekly equipment maintenance. Onboard data evaluation, both from direct observation during runs or from recorded tape, will also be required for immediate assessment of results.

Engineering Experiments

All of these experiments are concerned primarily with the evaluation of hardware and do not require the crew to serve as experiment subjects except for data management experiments, where man serves as an experiment subject while interfacing with the subsystem hardware. Engineering at skill-level II predominates for these experiments, with a minor requirement for navigation and communications skills. For several of the engineering experiments, support is required from the astronaut crew in controlling and maintaining the vehicle in attitude, velocity, and torque disturbances. For the most part, data collection is automated, with the crew providing a monitoring function to assure that instruments are operating properly. An important crew function for most of these experiments is periodic reconfiguration of experiment equipment setups.

Operations Experiments

The objective of these experiments is to evaluate mission operations as a complex of hardware, procedures, and crew skills. The crew will serve as experiment subjects in most of these experiments. However, the crew time required for these investigations will not be an additional burden since these are such operations as the setting up and monitoring of the measurement equipment and the recording, collation, assembly, storage, and transmittal of data that will be performed onboard in any event.

Space Biology

This research program has been divided into the following four specimen-oriented research clusters: vertebrates, invertebrates, plants, and protists and tissues, each with a preliminary phase, intermediate phase, and advanced phase. The preliminary phase of all clusters is directed toward the initial investigation of general phenomena and will involve extensive automation of observations requiring minimal crew participation. The nonautomated tasks associated with this phase, such as the preservation of specimens, the identification of developmental abnormalities, and the separation of individuals according to sex are neither time consuming nor complex and may be accomplished by a cross-trained (level III) crewman.

The intermediate phase is characterized by experimentation in the phenomena for which alterations due to the space environment are indicated. Such experiments will necessitate real-time observations in an onboard laboratory rather than postflight analysis on returned specimens. The laboratory analyses are expected to involve standard procedures and instruments modified for spacecraft use. They will, however, make increased demands on the experimenter's time, and will require the experience of at least a level II investigator. The assignment of this individual to space biology research on a nearly full-time basis should be anticipated with the part-time assistance of two cross-trained crewmen.

The advanced phase of the research program will involve a detailed examination of the mechanisms responsible for the observed changes. Although the changes to be examined are unknown at present, it can be predicted that the investigation will require sophisticated techniques and a flexibility of investigative approach and direction. The onboard presence of a principal investigator, or at least a research biologist (level I) assigned full-time to the laboratory, is required to meet the criteria of this advanced phase. The full-time assistance of cross-trained crewmen also should be anticipated.

Space Astronomy

These experiments generally involve long data-taking periods, which are highly automated and consequently require minimal crew activity. The crew will be required to unpackage and activate the experiments initially, periodically calibrate and check out the hardware, and perform servicing and maintenance functions. The predominant skill levels required will be levels I and II, considering the sophistication of the astronomical instruments.

Space Physics

Some of these experiments are performed within the space vehicle, and some are performed with free-flying vehicles released from the space laboratory. For the latter, crew involvement includes assembly, deployment, and retrieval of experiment equipment through the scientific airlock. For all experiments, the crew will set up and check out the experiment, and perform maintenance as required. During the automatic data-taking phase, the crew will monitor the operation periodically and change film magazines, filters, and lenses as required. When unexpected events occur, the crewman will be required to operate equipment manually for short periods of time. Film will be processed onboard, and a quick-look analysis will be performed to check data quality. Consumables must be resupplied, and maintenance and calibration performed as required. The majority of onboard crew support will require skill-level II.

Communications and Navigation

Crew involvement is heaviest at the initiation of these experiments for installation, calibration, and initial setup of the experiment. For some of these experiments, crew EVA will be required at the outset in performing such tasks as erecting, assembling, and visually inspecting antennas, components, feeds, and test equipment. During automated data collection, crew participation will include monitoring of experiment operation and the collection of data, monitoring and control of the remote maneuvering satellite, and adjustment of experiment equipment as required. An extremely important function to be performed by the crew is periodic reconfiguration of experiment equipment either as a scheduled event or in response to conditions that the experimenter observes during the conduct of experiments. The experimental activities in this area will require approximately an equal mix of skill-levels I, II, and III.

Earth Observations

The crew is required to set up these experiments initially and to reconfigure the equipment periodically. During experiment operation, the crew will be required to start the photographic sequences and to locate and photograph targets of opportunity. The crew is also required to change film, service and maintain the equipment, and process the film. An approximately equal mix of skill-levels I and II will be required.

The methodology employed in the analysis of crew requirements for this study is typical of approaches to problems of this kind and is quite adequate as a methodology. The detailed results of the analysis, however, should be viewed with caution and should be considered more as approximations than as hard data. They do, however, serve a useful purpose by providing a basis for order-of-magnitude comparisons of the crew requirements for different types of experiments.

REQUIREMENTS RELATED TO DATA ACQUISITION AND MANAGEMENT

The principal product of research activities in space is data. The data are generated by specially designed sensor systems to provide information crucial to the solutions sought and to describe the conditions under which the scientific data were obtained. Data systems onboard a space research facility impose operational requirements upon the mission and requirements on the space research facility in such terms as weight, space, and power supply.

Each research cluster was analyzed to determine the characteristic output of each sensor and the required ancillary information, such as: (1) operating methods and techniques to define controls and displays required for a research operation and to specify real-time data flow processing required for quality control and visibility; (2) experiment sequencing to specify data-generation duty cycles and modes of instrument function (warmup, calibration, and data acquisition) and to identify and solve data traffic control and queuing problems; and (3) user requirements to identify real-time data handling problems, principal-investigator interfaces, information enhancement potentials, and allowable data manipulation and processing. Measurement requirements range from the simple task of obtaining candid photographs of the crew to the sophisticated manipulating of elaborate and delicate astronomical telescopes. The requirements imposed on the data management system by the operational methods and techniques involved in controlling the various experiments affect operations planning, conceptual mission planning, crew skill mix, as well as overall management of onboard operations.

The data requirements portion of each research cluster description identifies the critical planning information for data handling. The physical format of the data is an important category of such information; if photographic film or magnetic tape is required, for example, the impact of onboard processing and storage can be significant. The specification for the precision required of the data determines how much onboard processing is necessary before the user receives the data. Some data must be used immediately; and some will require storage, handling, and retrieval. The data management system may be called upon to handle any or all of the following: photographic film, magnetic tape, electrical signals, physical samples, and biological specimens. Many research activities may require two data-collection modes, quick-look and long-duration. In addition to the basic information to be collected in support of research, data of a secondary nature will also be required for calibrating, referencing, and verifying the conditions under which the scientific data were collected.

To define required operating modes, scheduling of data, collecting and handling, and other such parameters, the information from research cluster descriptions that appeared to place the heaviest demands on a data management system was extracted and prepared in a summary matrix form. A chart then was prepared, detailing data management functions according to commonality for the various research clusters. Table 7 summarizes the data handling and support requirements for those research areas that appear to place the heaviest data demands on future systems.

CONFIGURATION ANALYSIS

The research clusters, in addition to providing a base for mission planning, were surveyed for any data relevant to spacecraft configuration planning. An instrumentation matrix was assembled for each discipline. Unique research activities requiring remote modules or subsatellites were also included in the data developed to aid the mission planner. Layouts were made for representative space research facility configurations. For each of these layouts, instruments basic to the most common measurements of the discipline can be accommodated, with options for adding other instrumentation for additional aspects of the research. As an example, Figure 18 shows a conceptual layout for a communications and navigation laboratory work center.

APPLICATION OF REQUIREMENTS TO MISSION PLANNING

Mission planning in this study consisted in selecting, within imposed constraints, a set of research activities that are responsive to major objectives and are complementary with respect to their demands on space facility resources, so that the research objectives may be achieved with the most judicious expenditure of resources.

Mission planning depends basically on two things: clearly defined objectives, and accurate information on the requirements imposed in satisfying those objectives. The critical issues derived from the overview analysis of the six disciplines present the objectives in the form that they must be addressed by the mission; that is, in terms of specific research information to be gained. Analysis of the research clusters developed sets of requirements. However, in-depth consideration of the various requirements and analysis of available spacecraft systems will be necessary before mission planning can proceed.

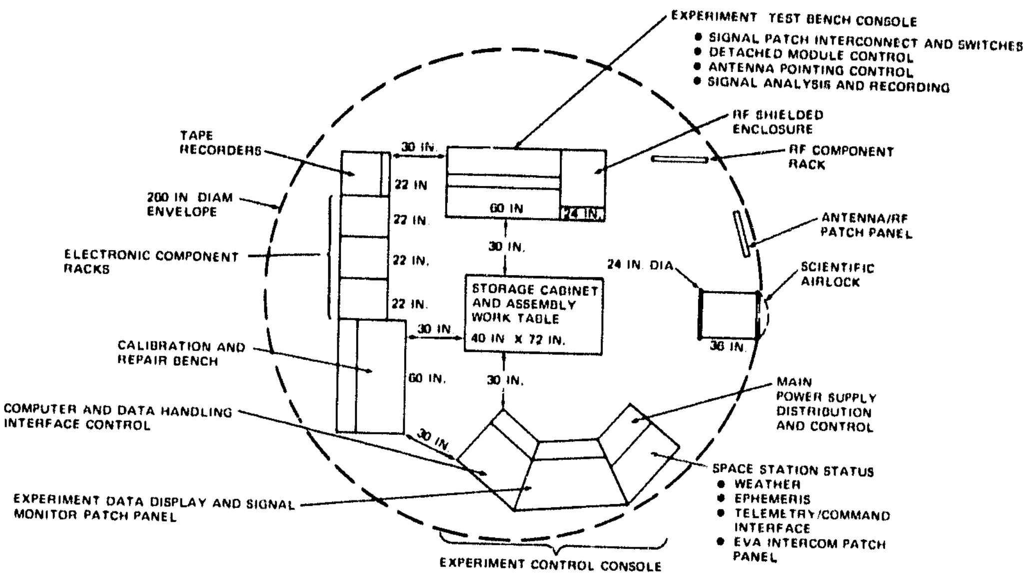


Figure 18. Conceptual Layout for Communications and Navigation Laboratory Work Center

Table 7
PRINCIPAL DATA HANDLING AND SUPPORT REQUIREMENTS FOR RESEARCH CLUSTERS

Research Cluster Group		Location			Original Data Form									Data Conditioning			Data Buffering				Data Processing					Storage			Display				Control					Services Support						Crew Time			
No.	Title	Integrated	Attached	Free Flying	Hardcopy, Notes	Specimens, Samples	Voice	Film/Plates	Magnetic Tape	Digital	Analog	Video	Remarks	Film Processing (See Note)	Analog Electronic	Digital Electronic	Within Experiment	Within DMS	Digital	Analog	Preprocessing	Redundancy Removal	Evaluation	Computation	Trafficking	Analog	Digital	Physical	Alphanumeric	Image	Analog	Special Purpose	Preprogrammed	Adaptive/Manual	Nonadaptive/Manual	Remote	Sequencing	Pointing/Stabilization	Environmental Control	Resupply	Onboard Checkout	Rendezvous and Dock	Concurrent Ground	Specialist	Highly-Trained Nonspecialist	Nonspecialist	
1-BM	Biomedical	o			o	o	■	o	■	■	o	o	(1)		o	o	o	■	■	o	o	o	o	o	o	o	o	o	■	o	o	o		o	■				o	o	o			■	■		Manned Spaceflight Capability
1-BR	Behavioral Research	o			o			■	o	o	o	■	(2)		o	o		o	o		o	o	o	o	o	o	o	o	o	o		o		o	■				o		o			■	■		
1-MM	Man-Machine Research	o			o		o	o	o	o	o	o			o	o	o	o	o		o	o	o	o	o	o	o	o		o			o		o				o						o		
1-LS	Life Support and Protective Systems	o			o		o		o	o	o				o	o	o	o	o		o	o	o		o	o	o	o	o					o	o				o	o	o				o		
1-EE	Engineering Experiments	o		o	o		o	o		o	o			o	o	o	o	o	o		o	o			o		o		o					o	o			o			o				o		
1-OE	Operations Experiments	o		■ EVA	o	o	o	■		o	o	■	(2)	■	o	o		o	o		o	o	(3)		o		o	o				(4)		o	■	o			o				o		o		
2-IN	Invertebrate Biology	o		o	o	o	o		o	o					o	o		o	o		o	o			o		o	o						o					o	o				■			Space Biology
2-P/T	Protist and Tissue Culture Biology	o			o	o	o			o															o			o	o					o					o	o				■			
2-VB	Vertebrate Biology	o			o	o	o	o		o	o				o	o	o		o		o	o			o		o	o							o				o	o			o	■	o		
2-PL	Plant Biology	o			o	o	o	o		o	o				o	o	o		o		o				o		o	o	o						o				o	o				o			
3-O	Optical Astronomy			o			o	■		■	o	o			o	o	o	o	o	o	o	o			o		o	o	o	o		o	o		o	■		■		o		o		■			Space Astronomy
3-XR	X-Ray Astronomy			o			o	o	o	■		o				o	o	o	o	o	o	o			o	o	o	o	o	o					o	■		o		o		o			o		
3-LF	Low-Frequency Radio Astronomy			o			o			■						o	o	o	o		o	o			o		o		o						o	■		o				o			o		
4-P/C	Physics and Chemistry Laboratory	o			o		o	o		o	o	o			o	o	o		o		o				o		o	o	o	o						o			o	o				o			Space Physics
4-PP	Plasma Physics Laboratory			o			o	o	o	o	o	o			o	o	o	o	o		o	o			o	o	o	o	o	o					o	o		o				o		o			
4-CR	Cosmic-Ray Laboratory	o	o		o		o	o		o	o				o	o	o	o	o		o	o			o		o	o	o					o	o	o		o	o	o				o	o		
5-N	Noise	o					o	o	o	o	o				o		o	o	o	o					o			o			o	o	o		o			o		o	o				o		Communications and Navigation
5-P	Propagation	o					o		o	o	o				o	o	o	o	o		o		o	o	o	o	o		o		o	o	o		o								o		o		
5-TF	Communication-Navigation Facility	o					o			o	o	o			o	o	o		o	o	o				o				o	o		o			o			o	o	o				o			
5-CS	Communications Systems	o					o			o	o				o	o	o		o		o				o		o		o						o			o					o		o		
5-NS	Navigation Systems	o					o		o	o	o	o			o	o	o				o				o	o			o						o			o							o		
6-A/F	Agriculture and Forestry		o				o	■		■				■		o	o	o	o	o	o				o		o	o	o	o		o		o	o	o		o		o	o		o		o		Earth Observations
6-G/C	Geography and Cartography		o				o	■	o	■				■		o	o		o		o	o			o		o	o						o	o	o		o	o	o			o		o		
6-EP	Earth Physics		o				o	■		■				■		o	o		o		o	o			o		o	o	o				o	o	o	o		o	o	o	o		o		o		
6-G	Geology		o		o		o	o	o	o		o		o		o	o	o	o		o	o			o		o	o	o	o				o	o	o		o	o	o					o		
6-H	Hydrology		o				o	o	o	o		o		o		o	o	o	o		o	o			o		o	o	o	o				o	o	o		o	o	o			o		o		
6-M	Meteorology		o				o	o	o	o	o			o	o	o	o	o	o		o	o			o	o	o	o	o					o	o	o		o	o	o					o		
6-O	Oceanography		o				o	o	o	o	o			o	o		o	o	o	o	o	o			o	o	o	o	o	o				o	o	o		o	o						o		

Key: o Nominal Requirement
■ Significant Requirement

LEGEND:
(1) Commercial Quality TV
(2) Video or Film
(3) Visual Evaluation
(4) Visual Analysis

Note: Onboard Film Processing is not a Firm Requirement, Implementation will require a Development Effort.

The mission planning factors displayed in Figure 19 identify the many technical and operational considerations that collectively influence the development of definitive mission concepts. The various factors relevant to defining missions are not only numerous but are extremely complex in their influence on one another. After the disciplines have been analyzed and the critical issues identified and grouped into research clusters according to commonality of instrumentation and measurements, compatible sets of research activities can be established by using the data from the research clusters to develop statistical measures of the requirements placed upon the mission and upon the space research facility.

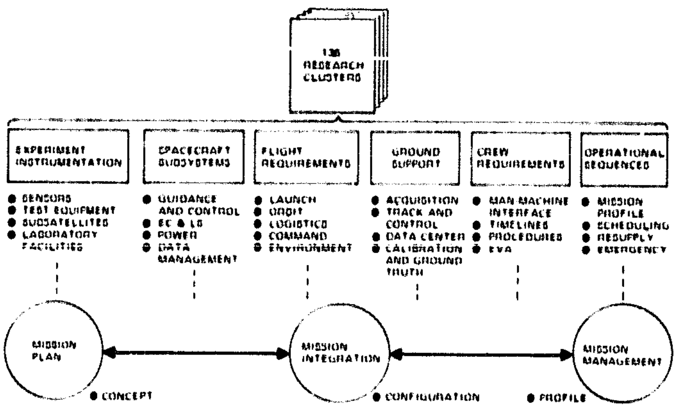


Figure 19. Mission Planning Considerations

Several important mission-selection parameters are identified in the sample mission planning worksheet, Figure 20. These parameters are grouped in such categories as orbit, spacecraft pointing and demand, environment, crew, and special requirements. Data developed from analysis of the research cluster descriptions are entered in these worksheets. Each entry provides a check against a given mission profile to identify any particularly severe requirements that might conflict with the mission profile. The special-requirement items pinpoint areas where further detailed analysis is required, and individual worksheets may be used to display the detail required in any significant research area for the development of mission strategies.

Example of Mission Sensitivity Analysis

In the mission planning process, the planner is often constrained by the availability of equipment, as reflected by its development status; or by such factors as weight, volume, and power required by equipment; or by crew availability. In the case of equipment availability, he must consider the relative value of the allocation of resources to the development of one piece of equipment in comparison with another. Regarding the other factors, his decision will be based on the incremental gain in research objectives as a function of incremental commitments of weight, volume, power, or crew time.

RESEARCH CLUSTER \ MISSION PLANNING PARAMETER	ORBIT: ALTITUDE: LOW (H<300 NMI)	ORBIT: ALTITUDE: MED (300<H<1,000 NMI)	ORBIT: ALTITUDE: HIGH (H>1,000 NMI)	ORBIT: INCLINATION: LOW (i<30°)	ORBIT: INCLINATION: MED (30°<i<55°)	ORBIT: INCLINATION: HIGH (i>55°)	ORBIT: SPECIAL ORBIT REQUIREMENTS	SPACECRAFT POINTING: ORIENTATION: TOWARD EARTH	SPACECRAFT POINTING: ORIENTATION: TOWARD SPACE	SPACECRAFT POINTING: ACCURACY: HIGH (<10 ARC SEC)	SPACECRAFT POINTING: ACCURACY: MED (10 ARC SEC-30 ARC MIN)	SPACECRAFT POINTING: ACCURACY: LOW (>30 ARC MIN)	SPACECRAFT DEMAND: VOL: HIGH (>100 FT³)	SPACECRAFT DEMAND: PWR (AV): HIGH (>3,500 W)	SPACECRAFT DEMAND: WT: HIGH (>1,000 LB)	ENVIRONMENT REQUIREMENTS: FREE FLYING SATELLITE REQUIRED	ENVIRONMENT REQUIREMENTS: ACCELERATION SENSITIVE	ENVIRONMENT REQUIREMENTS: CRYOGENICS REQUIRED	ENVIRONMENT REQUIREMENTS: ACCELERATION (ARTIFICIAL GRAVITY) REQUIRED	ENVIRONMENT REQUIREMENTS: ATMOSPHERE CONTROL	ENVIRONMENT REQUIREMENTS: HIGH TEMPERATURE	CREW REQUIREMENTS: EVA REQUIRED	CREW REQUIREMENTS: HIGH INVOLVEMENT (>40 HR/WK)	CREW REQUIREMENTS: CREW AS SUBJECT	SPECIAL REQUIREMENTS: STRUCTURE	SPECIAL REQUIREMENTS: SHIELDING	SPECIAL REQUIREMENTS: HUMAN CENTRIFUGE	SPECIAL REQUIREMENTS: ANIMALS	SPECIAL REQUIREMENTS: REAL TIME DATA	SPECIAL REQUIREMENTS: PHOTO DEVELOPMENT	SPECIAL REQUIREMENTS: EFFLUENT SENSITIVE	SPECIAL REQUIREMENTS: ELECTROMAGNETIC INTERFERENCE SENSITIVE	SPECIAL REQUIREMENTS: THERMAL CONTROL	SPECIAL REQUIREMENTS: COOLING REQUIRED		
IBM-4																							●	●										●		
IBM 5																												●	●					●		
IBM-6																							●	●										●		
IBM 7																								●					●	●						
IBM-8																								●										●		
IBM 10																								●										●		
IBM 12																												●	●				●	●		
IBM 13																								●										●		
IBM 14																							●	●										●		
IBM 16																	●						●	●			●							●		

Figure 20. Mission Planning Worksheet

To illustrate the type of problem that can be addressed using the data base developed during the study, an example can be cited from one of the topical problems of the day: the subject of environmental pollution.

In the Earth Observations discipline, 29 critical issues (representing five of the seven subdiscipline areas examined) were identified with the subject of pollution (Figure 21). The information and measurement requirements of these critical issues were examined, and they were included in six research clusters on the basis of commonality of their requirements (Table 8). For each research cluster, the instrumentation requirements, mission requirements, data requirements, and supporting technology development requirements were identified. This information provides the data base from which the traceability of mission and spacecraft requirements and supporting technology developments to NASA's goals and objectives may be demonstrated, and from which sensitivity analyses may be made. Table 9 summarizes the 15 instruments identified with pollution research.

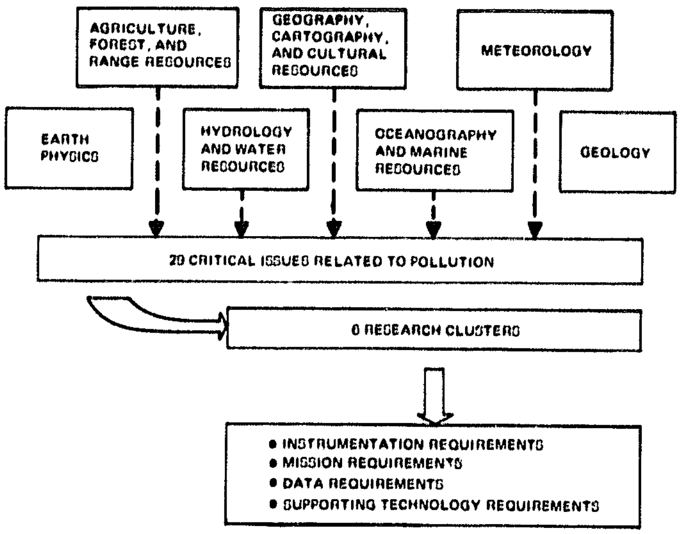
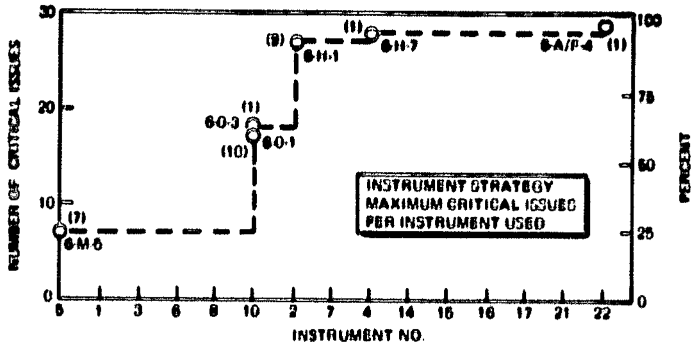


Figure 21. Pollution Research

Using pollution research as an example, selection strategies could be developed for relating specific instruments to critical issues. If it were desired to maximize the number of critical issues that could be addressed by the fewest number of instruments (Figure 22), the planner might first consider selecting instrument No. 5 (an absorption spectrometer) for his inventory. With this instrument, seven specific



6-M-5	DETECTION AND MONITORING OF ATMOSPHERIC POLLUTANTS
6-O-3	OCEAN POPULATION DYNAMICS AND FISHERIES RESOURCES
6-O-1	OCEAN POLLUTION IDENTIFICATION, MEASUREMENTS AND EFFECTS
6-H-1	DETERMINATION OF POLLUTION IN WATER RESOURCES
6-H-7	SURVEY OF HYDROLOGIC FEATURES OF MAJOR RIVER BASINS
6-A/F-4	CROP VIGOR AND YIELD PREDICTION

Figure 22. Instrument Selection Strategy

critical issues could be investigated. Before a further expansion of the scientific program could be undertaken, however, five additional instruments (Nos. 1, 3, 6, 8, and 10) would have to be added. This step would increase to 17 the number of critical issues that could be investigated. Before all 29 critical issues related to pollution could be addressed, a total of 15 instruments would be required

Although instrument-selection strategy may be useful in suggesting a point of diminishing scientific returns as a function of specific instrument development efforts, it is also helpful to be able to establish numerical indices of information return in a general research area per pound or per cubic foot of payload. For this purpose, the research clusters provide a broad set of requirements covering many critical issues that are related in terms of common information needs or measurement requirements although not necessarily restricted solely to pollution. Table 10 summarizes pertinent data derived for the six research clusters that address one or more of the critical issues dealing with pollution. The weights and volumes cited in this table include basic instrumentation plus support equipment, such as consoles and test units. This information is typical of that needed to develop facility requirements.

It should be noted that the column labeled Pollution Critical Issues in Table 10 reflects only the specific issues that relate to the problem of pollution. In every case, the total number of critical issues related

Table 8
29 CRITICAL ISSUES IN ENVIRONMENTAL POLLUTION

	Primary Research Cluster
AGRICULTURE AND FORESTRY	
What are the sources of pollution?	6-M-5
What are the distribution mechanisms of pollution?	6-M-5
Where is pollution or overuse endangering the recreational use of water or forest areas?	6-A/F-4
Where is pollution emission in excess of standards?	6-H-1
GEOGRAPHY AND CARTOGRAPHY	
How can pollution from industrial expansion be controlled, i.e., atmospheric/hydrologic?	6-O-1
How is pollution related to the Earth's topography and climate?	6-H-1
How can pollution and waste from large population centers be effectively controlled?	6-O-1
How is pollution affecting the coastal ecological environment?	6-O-1
HYDROLOGY	
What are the effects of streamflow and wastes upon coastal waters?	6-H-7
What is the extent of saline instrusion in estuaries?	6-H-1
What is the dispersion of visible pollutants in coastal waters, estuaries, large lakes, and reservoirs?	6-H-1
How can the occurrence and extent of algal blooms be determined?	6-H-1
How can oil slicks on the surface of water be identified?	6-H-1
How can the transportation and deposition of sediment be determined?	6-H-1
What pollutants are evident in the atmosphere and in what percentage? What is their rate of change?	6-M-5
What general aspects of man's progress induce pollution and changes in topography and river systems?	6-H-1
How are pollutants derived from population increase and the cultural and social advancement of man affecting the water ecologic system?	6-H-1
OCEANOGRAPHY	
How are the physical properties of the oceans affected by ocean pollution?	6-O-1
How does ocean pollution affect electromagnetic emission from the sea surface?	6-O-1
How does ocean pollution affect the chemical reactions and salinity in the oceans?	6-O-1
How do tidal flushing patterns affect salinity and pollution characteristics?	6-O-1
How is the productivity of the oceans related to ocean pollution?	6-O-1
How are marine population dynamics affected chemically by ocean pollution?	6-O-3
How can the transport of pollution in the ocean be effectively controlled?	6-O-1
How are marine population dynamics affected by the transport of ocean pollution?	6-O-1
METEOROLOGY	
How are all ecologic systems affected by atmospheric pollution?	6-M-5
What effect is exerted on the air ecologic system by the pollution of water and soil?	6-M-5
What are the effects of air pollution upon the climate of urban areas?	6-M-5
What chemical constituents are present in the atmosphere?	6-M-5

Table 9
INSTRUMENT LIST FOR POLLUTION-RELATED EXAMPLE

No.*	Name	Weight (lb)	Volume (ft^3)	Peak Power (Watts)	Main Characteristics
1	Metric Camera	300	21	785	4 lens; 41 by 61-deg FOV; 0.4-0.9 μ; 12-in. F.L.
2	Multispectral Camera	275	8	1,120	70mm (6 ea); 0.[illegible] 0.9 μ;41- by 41-deg FOV
3	10-Band Multispectral Scanner	300	19	190	0.4-12.5 μ; 11-deg FOV; cryo cooling; 26.4 MB/S
4	Radar Imager	620	112	2,500	8-10 GHz; 4 data channels; 50-150 MB/S on film
5	Absorption Spectrometer	30	1	18	280-500 μ; 30-deg FOV; 1.2 MB/S; 6 data channels
6	Multichannel Ocean Color Sensor	13	0.25	6	0.4-0.7 μ; 34-deg FOV; 12-kHz analog; 2 data channels
7	Radar Altimeter/ Scatterometer	75	1.5	130	86 Hz; 60-deg FOV; 3.2 kB/S; 21 data channels
8	Microwave Scanner Scatterometer	200	9.5	25	10 and 19.5 GHz; 50-deg FOV; 1-4 kB/S; 12 data channels
10	Data Collection System	10.5	0.5	7.5	450 MHz; 100-deg FOV; PCM data receiver; 10 channels
14	Interferometer Spectrometer (IR)	35	1.5	24	5-50 μ; 2-deg FOV; N_2 purge; 13-sec duty cycle; 16 channels
15	Multispectral Tracking Telescope	850	38	540	0.35-0.85 μ; 24-in. optics; 1.4-deg FOV; ±45-deg gimbal
16	Selective Chopper Radiometer	34	0.6	5	14.5-15 μ; 3 by 2 channels; 10-deg FOV Earth and space
17	IR Filter Wedge Spectrometer	30	1.25	7	1.5-6 and 8-16 μ; 1- by 3-deg FOV; N_2 cooling; digital
21	Visible Wavelength Polarimeter	25	1.27	50	0.38-0.58 μ; 3-deg FOV ±60-deg gimbal; 16 data channels
22	UV Imager/Spectrometer	150	3.5	45	0.35-0.4 μ; 15- or 1-deg FOV; 2 analog channels

*Instruments 9, 11, 12, 13, 18, 19, and 20 were not critical for pollution measurements.

NOTES: FOV = Field of view
B/S = Bits per second

to the designated research cluster is much larger. In the case of 6-A/F-4, for example, which is a research area dealing with problems of crop vigor and yield prediction, 121 critical issues are addressed in all, although only one of them deals specifically with pollution. Thus, while the capabilities reflected by the space facility requirements defined by each research cluster are required in order to address the specific issues on pollution associated with it, the facility defined in this way is capable of supporting research in other problem areas as well.

Figure 23 presents a cumulative plot of the weight and volume commitment, as research clusters are added to accommodate a major program in pollution research. As might be expected, the weight and volume growth curves show a considerable correlation with each other.

Table 10
SENSITIVITY ANALYSIS WORKSHEET – POLLUTION

Research Cluster	Pollution Critical Issues	Weight* (lb)	Weight /Crit. Issue	Rank	Volume* (ft³)	Volume /Crit. Issue	Rank	Power* (W)	Power /Crit. Issue	Rank	No. of Instruments
6-A/F-4	1	4,000	4,000	6	290	290	6	4,600	4,600	6	9
6-H-1	9	3,170	352	3	120	13	3	1,300	144	3	5
6-H-7	1	3,900	3,900	5	200	200	5	3,800	3,800	5	5
6-M-5	7	970	139	1	21	3	1	500	71	2	1
6-O-1	10	2,255	226	2	80	8	2	700	7	1	6
6-O-3	1	2,185	2,185	4	81	81	4	700	700	4	5

*Includes basic instrumentation plus support equipment.

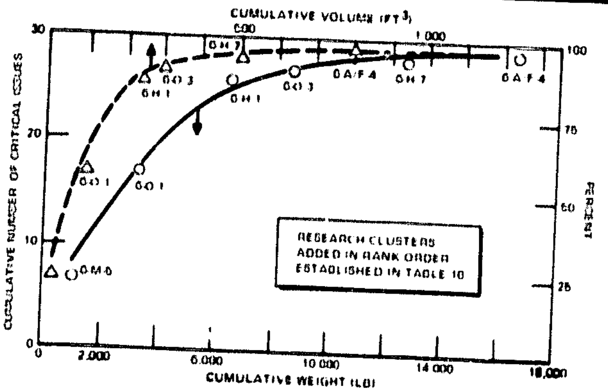


Figure 23. Sensitivity of Weight and Volume to Number of Research Clusters

The large penalties per information unit associated with 6-A/F-4 and 6-H-7 (see also Table 10) suggest the need for a closer examination of the criticality of the research required. In the case of 6-A/F-4, the critical issue addressed (see Table 8) deals with the determination of areas where pollution or overuse is endangering the recreational use of water or forest areas. In the case of 6-H-7, the critical issue addressed deals with the effects of streamflow and wastes on coastal waters. At this point, judgments would be required from the scientific community regarding the true importance of these problems.

Although the basic facility requirements were defined by working from broad objectives to increasingly specific needs, the traceability afforded by the analysis makes it feasible to assess which issues (and thus which objectives) could be addressed when specific facility capabilities are available. Conversely, the major objectives that cannot be addressed when specific facilities are unavailable can also be identified.

Implementation Options

Among the candidate systems presently proposed for future research missions are extensions of the current Skylab program, a space shuttle, and larger permanent space stations. Experiment modules, either attached to one of these facilities or free-flying, can be used in various combinations. The suitability of each system for research activities in the six disciplines can be examined.

Shuttles would characteristically be manned by a small crew, would have missions of short duration (5 to 7 days), and be limited in power, volume, and data management resources. The short duration and small crew (in particular) tend to define the kinds of research that could be performed aboard a space shuttle. Both of these aspects, however, make the shuttle an ideal facility for qualification testing and checkout of equipment and techniques. The responsiveness and reliability of sensors must be demonstrated for example, before they are sent on automated data-gathering missions involving the viewing of the Earth's surface or of planets and stars. Such checkouts can be performed in the few days' duration of a shuttle mission, so that the time demands on the scientist required only for instrument checkout would be minimized. A shuttle can also be useful for the testing of techniques such as the melting of metals in zero gravity that involve hazardous conditions and might necessitate a rapid return to Earth.

In some of the disciplines, particularly in Communications and Navigation, the system becomes increasingly automated as the system-test phase of development is approached. System equipment at this juncture is amenable to final checking in a shuttle, and some of it may even be placed in a free-flying module by a supply shuttle. Noise surveys of Earth's radiated RF energy are a good example of the type of research for which a survey package, once activated, can continue in an automated data-collection mode. Radiometric receivers using broad-beam antennas and linked to a tape recorder can be accommodated by an automated module. In many cases, man is needed only to change a tape or film cartridge or a similar piece of equipment. In general, research activities that are best suited to shuttles can be modularized and are less complex than those requiring free-flying modules hosted by a space station.

It is apparent that long-duration research missions are better suited to a space station or space base than to a shuttle. Such missions are required most frequently in disciplines that depend on man-oriented research activities, such as Manned Spaceflight Capability, Space Biology, and Space Physics. Research that would be suited to a space-station-type facility would encompass activities such as sophisticated life science studies including induced mutation, space toxicology, and small-animal behavior; and Space Physics studies such as fluid physics, and processing and manufacturing of specialized materials, including high-purity pharmaceuticals. Attached research modules are extensions of the host research facility that are brought into space independently and are docked and functionally integrated with the research facility. They are configured to provide either additional working space or special research conditions. They are suited to Earth survey and to solar astronomy instrumentation, including x-ray telescopes. Free-flying modules are decoupled and isolated from host-research-facility accelerations or contaminations and may operate in orbits remote from that of the host facility. They are particuarly suited to certain classes of stellar astronomy. The research activities in Earth Observations and in Communications and Navigation, which are more amenable to automation, are well suited to either a space station or a shuttle, although the longer-term requirements favor the permanent research facility. In the case of Space Astronomy, the detached module, whether hosted by a space station or by a shuttle, is the best choice, primarily because of the disturbing accelerations created by man's presence on the spacecraft.

A space station operated in conjunction with a free-flying module could support a greater percentage of individual research requirements than any of the other concepts. Although the space shuttle and shuttle-plus-module concepts are limited in the amount of electrical power and the hours of manned participation they can provide, they could nevertheless perform a considerable amount of useful research, particularly in Earth Observations, Communications and Navigation, and Space Astronomy.

The mission parameters for Skylab, a shuttle, or a space station would, in an actual planning exercise, be checked against the entries in a mission planning worksheet as illustrated in Figure 20, and the research clusters compatible with these parameters would be identified. Thus, any research activity described in this report can be screened to determine which currently planned space program would suit it best.

Space activities to date have been primarily of an exploratory nature, and the results have been gratifying. We are now in a position to move positively into an even more productive phase and to begin to reap large-scale benefits from the space program. The Earth Orbital Experiment Program and Requirements Study has delineated the substance of a comprehensive research program to match this opportunity in six scientific and technological disciplines. This study has translated society's goals for the next few years in these selected areas into specific research activities to be performed by man in Earth orbit.

The two disciplines in which space research will probably have the most immediate impact on the largest number of people are Communications and Navigation, and Earth Observations. In Communications and Navigation, research in such areas as noise interference, propagation effects, and tropospheric scatter losses will open up the electromagnetic spectrum for broader use in commercial and educational braodcasting, information networking, data collection, and navigation and traffic control. It will also contribute to the effective management of these activities through more realistic frequency allocations and their more effective usage and control. The study revealed that in communications research especially, a manned space research facility would offer a unique advantage by permitting the periodic reconfiguration of the laboratory instrumentation, enabling it to be readily redirected from one research activity to another. Man's presence thus gives a flexibility and adaptability difficult if not impossible to achieve with automated spacecraft, and results in more efficient, more comprehensive, and more meaningful research.

Earth Observations can have perhaps the most profound influence on the future of mankind. The perspective from space has already given new direction in attacking man's problems on Earth, and we are already enjoying some of the immediate benefits of space research. Because space coverage of weather is global, prediction techniques have improved and serve agriculture and transportation with more accurate and more timely information. As our sensing capabilities and knowledge increase, crop infestations and disease will be recognized from space, and through timely intervention, they can be better controlled. Sources and locations of pollution are identifiable from space, as are new sources of fresh water, geothermal energy, mineral resources, and marine resources. Thus, research from space contributes directly to the solution of two particularly pressing problems: pollution, and the feeding and support of rapidly multiplying populations.

In Biology, it can be anticipated that all branches of terrestrial biological research can be fruitfully extended into space, and this research can be accomplished most expeditiously and most efficiently by using a biology laboratory approach instead of a discrete-experiment approach. A phased program that poses general questions first and undertakes mechanistic investigations later, thereby coinciding with the growth in sophistication of orbital research facilities, will yield maximum information at minimum cost and will result in the most efficient utilization of scientist-astronaut time. More of the critical issues of concern to biologists can be addressed through research on vertebrates than through research on plants, protists, or invertebrates (which rank in that order), but all four life forms must be included to study and assess the universality of the effects of the space environment and to develop understanding of the importance of the role of gravity in the basic life processes. It was found that man's direct participation in biological research activities increases tenfold the number of critical issues that can be addressed in orbital facilities.

In Space Astronomy, the role of man in orbit is intermittent, although he is involved in x-ray, optical, and low-frequency radio observations. His functions will principally lie in the deployment, calibration, resupply, and maintenance of large, complex telescopes. The periodic maintenance of these instruments greatly increases their scientific productivity, which is a vital concern for these sophisticated devices.

In Space Physics, new insights into fluid dynamics and mixing phenomena will evolve through the use of a physics and chemistry laboratory, and the development of new materials and processes will be explored. The space facility itself will serve as a base for learning more of the space environment and for developing research facilities for understanding such phenomena as plasma physics and cosmic rays Man will be required in the implementation and operation of the plasma physics and the physics and chemistry laboratories, and to set up experiments in a cosmic-ray research facility.

The sixth specific area of space research examined during this study was Manned Spaceflight Capability. This research subject includes the study of man himself, from the biomedical and behavioral standpoint, to determine his potential capabilities as well as his operational limitations in the space environment. It includes the identification of the engineering and operations research needed in space to provide man with the facilities required to support a broad-based research program. The critical issues identified in this area need to be resolved before the ultimate potential of manned orbital research facilities can be realized.

Attendant upon the research activities of the space program for the next decade is the development of the technology base required to support the planned research. The relationship between research and supporting technology development is such that advances in one frequently propel the other ahead as well. Some research activities outlined in this report will not be feasible until certain technology developments have occurred; but developments in technology have in the past, and will in the future, lead to the generation of new research, even, perhaps, to whole new fields of investigation. For example (looking into the past), the modifications that Leeuwenhoek made to the microscope of his day made microbiology possible. In a contemporary vein, now that viewing of the sky over the entire electromagnetic spectrum has become feasible, research in x-ray and low-frequency-radio astronomy has received new impetus. Instruments developed for ground monitoring of the vital signs of men in space are already being used by medical personnel to diagnose conditions of patients on Earth. Numerous specific examples of technology developments required to support manned orbital research were identified in the study. It was found that technology requirements impact early in relation to known programs, they depend on results from these programs, and the efforts that they generate can be expected to continue well into the span of the research program itself. Early emphasis on supporting technology development is therefore required to enable man to meet the challenges that face him.

As noted above, one of the most important results of the study was the improved insight it provided into the value of a manned research facility in space and of the utility of laboratories devoted to specific research areas, each providing a broad capability in its own area through the ability to rearrange or reconfigure a basic complement of research instruments. The presence of man in connection with this reconfiguring, and in many cases, in the role of a manipulator and monitor of the research, is essential to the productive utilization of these laboratories.

Insight of this kind is developed only with experience. Without doubt the experience of man in space will result in insight toward the solution of many problems that relate to conditions on Earth. It is not unreasonable to expect that continued research by man in space may give the key, not only to continuing man's stay on Earth but to continuing it in health, in comfort, and in peace.

APPENDIX

Research Cluster Summaries

APPENDIX CONTENTS

**Numbers 1-BM-1, -2, -3, -9, -11 and 1-BR-5 were assigned to clusters that were later combined with others or eliminated.*

RESEARCH CLUSTER 1-BM-4–EFFECTS OF WEIGHTLESSNESS ON CIRCULATORY FUNCTION

ABSTRACT

OBJECTIVES. Detect and measure changes in circulatory function due to weightlessness, establish time histories, investigate physiological and biochemical mechanisms.

BACKGROUND. Data reference from ECG and blood pressure measurements on all Mercury, Gemini, and Apollo flights, ground-based water-immersion and bed-rest studies, and planned experiments on Skylab A.

RESEARCH DESCRIPTION. Initial determination and quantification of changes. Blood volume measured by dilution of injected tagged blood cells and plasma. Orthostatic tolerance studied with lower body negative pressure (LBNP) device; associated measurements include heart rate, blood pressure, leg plethysmogram, and cardiac output. Circulatory compensation evaluated following ergometer exercise by heart rate, blood pressure, and cardiac output measurements. Urine volume and analysis involved in defining the nature of the changes. Later measurements to determine mechanisms of changes include pulse wave form and velocity, venous pressure and compliance, arteriolar reactivity, circulation time, and heart size. Ergometer and LBNP conditioning programs investigated as countermeasures.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Onboard isotopes for blood volume measurements require shielding. Oscilloscope, stripchart, and tape recorders. Other items: electrode lead systems and preamplifiers, blood pressure assembly, leg plethysmograph, cardiotachometer.

CREW. Crew as subjects, six desirable, three mandatory; plus experienced medical or physiological technician. Physician required for a few measurements.

DATA. Notes, tapes, and fluid samples returned to Earth.

OPERATIONS. Minimum crew cycles 90 days. Measurement frequency high early in cycle, reduced later. No spacecraft rotation during measurement program commenced on zero-g crewman. Space simulation of gravity should occur only during last two weeks of crew cycle.

RESEARCH SEQUENCING. Early detection and quantification of changes, later investigation of nature and mechanisms.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Noninvasive central venous pressure measurement technique.

RESEARCH COMMONALITIES. Receives information from 2-VB-1, -2; common measurements with 1-BR-3.

RESEARCH CLUSTER 1-BM-5–RADIATION, TOXICOLOGY, AND MEDICAL PROBLEMS

ABSTRACT

OBJECTIVES. Determine changes in susceptibility to and recovery from illness or injury and in tolerance to radiation and toxicology caused by altered state in weightlessness.

BACKGROUND. Terrestrial radiation and toxicological limits well established. Physiological changes observed in previous space missions could alter tolerance.

RESEARCH DESCRIPTION. Small laboratory animals. On first group, produce preflight injuries and lesions that could occur to astronauts in space. At intervals, animals frozen, returned for study. Orbit second group intact; after three weeks, expose to predetermined radiation doses. Recommended radiation doses: 25, 50, 100, 200, and 400 rem. Third group similarly treated but with predetermined concentrations of toxic contaminants. Toxic contaminants include pulmonary irritants, central nervous system depressants, and producers of kidney damage.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Animal housing, 35 to 40 cu ft, not including automatic food and water dispensing and automatic waste management. X-ray radiation source, tubes, approximately 200 lb, 500 to 1,000 w. Toxicological exposure chamber, associated with contaminant concentration analyzer. Frozen animals stored in -70°C freezer.

CREW. Extensive participation. Animal care, observation, and treatment. Blood sampling and analysis. Tasks probably within capabilities of cross-trained crewmen.

DATA. Notes, tapes, and frozen specimens returned to Earth.

OPERATIONS. Transfer of animals to exposure chambers, exposure, and subsequent observation, analysis, and sacrifice, as well as treatment and observation of experimental lesions very time consuming. Experiments should not be scheduled during period of extensive crew activity.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Animal toxicological chamber, radiation source, animal research facility.

RESEARCH COMMONALITIES. Receives information from 2-P/T-2.

RESEARCH CLUSTER 1-BM-6—EFFECTS OF WEIGHTLESSNESS ON STRESS RESPONSE

ABSTRACT

OBJECTIVES. Determine changes in physiological responses and tolerance limits to potential environmental stresses in order to better define physiological design criteria for spacecraft.

BACKGROUND. Ground-based limits for O_2 and CO_2 concentrations, temperature extremes, and work capacity reasonably well defined. Physiological changes observed in previous spaceflights could potentially change tolerances in space.

RESEARCH DESCRIPTION. Physiological responses to various environmental stresses measured and tolerance changes determined. Exercise performed on bicycle ergometer, and heart rate, blood pressure, oxygen consumption, body temperature, and oxygen debt measured. Hypoxia and hypercapnia (high CO_2) produced by predetermined breathing mixtures; time of useful consciousness; ventilatory response used as criteria of tolerance; associated respiratory and circulatory measurements made concomitantly. Tolerance to high temperatures measured at rest and during ergometer exercise with subject in special thermal enclosure. Body core temperature and heart rate used as dual criteria of tolerance.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Bicycle ergometer (60 lb, 20 cu ft in use, 10 w) and metabolic analyzer (40 lb, 3 cu ft, 30 w) as well as electrophysiological measuring equipment. About 150 to 175 lb of gas mixtures required for hypoxia and hypercapnia responses. The thermal enclosure requires development and may be either an individual enclosure or a chamber: accurate control of temperature and humidity essential.

CREW. Six crewmen serve as experimental subjects. Participation of medical or physiological technician required.

DATA. Notes and magnetic tapes returned to Earth.

OPERATIONS. Test intervals predetermined to avoid stress adaptation. Status of physiological changes monitored and spacecraft rotation avoided during total test period.

RESEARCH SEQUENCING. Time histories of physiological changes established prior to stress testing and used as a basis for test scheduling.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Thermal enclosure.

RESEARCH COMMONALITIES. Receives information from 2-VB-1, -2. Common measurements with 1-MM-2, -5, and 1-BR-3.

RESEARCH CLUSTER 1-BM-7—EFFECTS OF WEIGHTLESSNESS ON THE NERVOUS SYSTEM

ABSTRACT

OBJECTIVES. Determine time course and mechanisms of changes produced in nervous system function by weightlessness.

BACKGROUND. Nausea and disorientation reported from early Soviet spaceflights and by some Apollo crewmen. Continuation of planned Skylab A experiments M-131, Human Vestibular Function, and M-133, Sleep Monitoring.

RESEARCH DESCRIPTION. Investigate three aspects of neurological function: (1) vestibular function in orientation and motion sickness, (2) electroencephalographic (EEG) patterns associated with sleep and alertness, (3) spinal reflexes as tested during a neurological examination. Vestibular function studied with rotating litter chair designed for the Skylab A program; both semicircular canal and otolith activities tested. Similar measurements made later in association with the onboard manned centrifuge. Computerized pattern recognition applied to the EEG's of sleeping and working crewmen and compared with performance evaluation. Cranial, superficial spinal, and deep tendon reflexes evaluated with advanced techniques such as attached accelerometers and electromyography where possible.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Rotating litter chair, 210 lb, 30 cu ft (in use), 200 w (400-w peaks). Equipment associated with EEG studies common to other experiments. Equipment associated with reflex testing has negligible weight, power, and volume requirements.

CREW. Six crewmen serve as subjects. If reflexes are subjectively evaluated, an experienced observer is required; other measurements may be made by cross-trained crewmen.

DATA. Notes, tapes, and stripchart records returned to Earth. No requirement for telemetry.

OPERATIONS. Litter chair and EEG measurements made frequently early in crew cycle, less frequently thereafter. Reflex tests evenly spaced throughout cycle.

RESEARCH SEQUENCING. Vestibular and EEG studies to be performed on Skylab A; should be repeated at earliest opportunity.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Sensitive quantitative evaluation of reflex functions.

RESEARCH COMMONALITIES. Closely associated with 1-MM-4.

RESEARCH CLUSTER 1-BM-8—EFFECTS OF WEIGHTLESSNESS ON GASTROINTESTINAL FUNCTION

ABSTRACT

OBJECTIVES. Determine changes in digestion, absorption, and gastrointestinal movements produced by prolonged weightlessness.

BACKGROUND. Detailed information on gastrointestinal function in space is necessary to ensure meeting crew nutritional requirements. No evidence of changes in previous flights; reports of nausea and weight loss thought to be vestibular and metabolic in origin.

RESEARCH DESCRIPTION. Specifically designed test meals eaten by crewmen. Feces analyzed for composition; blood and urine analyzed for changes in normal concentrations of dietary constituents. Feces weighed, dried, and returned for ground-based analysis. Additional specific test substances administered to measure particular aspects of dietary function. Measurements of motility and pH made with ingested endoradiosonde. Signals transmitted to external receiver. If changes are noted, then subsequent tests, addressing implicated functions, verify and detail the initial findings.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Fecal wet packaging, drying, and storage packaging by waste management system. Urine and blood storage requires -70°C freezer (-20°C acceptable for urine). Onboard fluid analysis requires biomed analytical laboratory (see 1-BM-10). Specimen mass measuring device to weigh feces.

CREW. Six crewmen serve as subjects. Skilled medical or physiological technician required for endoradiosonde measurements and fluid analysis.

DATA. Notes, tapes, and fecal samples returned to Earth.

OPERATIONS. Test meals carried onboard, specifically designated for individual crewmen. Fecal processing and weighing performed by all subjects. Dried feces packaged, sealed, and stored unrefrigerated.

RESEARCH SEQUENCING. If changes observed in gastrointestinal function, subsequent research required to specify involved function.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Further development of endoradiosonde techniques.

RESEARCH COMMONALITIES. Contributes information to 2-VB-1, -2, and 1-LS-6, -9.

RESEARCH CLUSTER 1-BM-10–BODY FLUID ANALYSIS

ABSTRACT

OBJECTIVES. Measure biochemical composition of blood, urine, sweat, saliva, vomitus, and feces as necessary to satisfy the analytical requirements of the other research clusters.

BACKGROUND. Calcium, creatine and creatinine of the Biosatellite III primate automatically measured by the urine collection and storage system. Urine of Gemini astronauts returned for analysis. Some modification required to adapt ground-based analytical techniques to spacecraft use.

RESEARCH DESCRIPTION. Spectrophotometry for analysis of nonionic inorganic compounds and nonprotein nitrogenous compounds; specific ion electrodes or flame photometry for inorganic ions; blood gas analyzer and pH electrodes for analysis of blood gases and fluid pH; microscopy and photomicrography for examination of included solids, formed elements, and particulate matter; radiation detection for measurement of radioactive tracers; mass spectrometry for heavy or light isotope tracers; and electrophoresis and paper chromatography for specialized measurements. All analyses supported by basic laboratory preparatory equipment.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Clinical chemistry analytical laboratory a major facility of biomedical program. Weight, power, and volume requirements of individual items not excessive but integration into a workable laboratory with extensive automation a major undertaking.

CREW. Laboratory should be manned by a well-trained, experienced technician whose primary training is in clinical chemistry.

DATA. Notes and taped data returned to Earth. Some fluid samples returned for specific measurements. Little requirement for telemetry.

OPERATIONS. Samples allowed to accumulate until required number obtained. Storage of samples in freezers, -70°C for blood and -20°C for urine.

RESEARCH SEQUENCING. Determined by requirements of other experiments.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Inflight body fluid analysis and fluid handling techniques.

RESEARCH COMMONALITIES. Research in space biology will require many of the measurements specified by biomedicine. The two sets of requirements should be evaluated to determine extent of facility combination.

RESEARCH CLUSTER 1-BM-12–STUDIES ON INSTRUMENTED ANIMALS

ABSTRACT

OBJECTIVES. Determine mechanisms of changes observed in earlier experiments when invasive techniques and those too traumatic for use on humans are required.

BACKGROUND. Valuable information derived from instrumented primate of Biosatellite III. Additional research necessary to verify findings and investigate problems uncovered.

RESEARCH DESCRIPTION. Use of instrumented animals most applicable in areas of cardiovascular and neurophysiological research. Relationship of cardiac output to regional blood flow, cardiovascular reflex activity, cardiac work capacity, changes in electrical activity of higher brain centers, and electrical activity of vestibular apparatus would contribute significantly to understanding of mechanisms. Primates used for most experiments, dogs for selected cardiovascular studies, and cats for selected nervous system studies. Data either telemetered or transmitted by hardwire to onboard receivers. Ancillary measurements of heart rate, blood pressure, and blood analysis performed with primary measurements to define physiological state of subjects.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Experimental animals enclosed in self-contained modules, automated for food and water dispensing and waste management. Each module, 300 to 500 lb, 30 cu ft, 50 w (20 w during dark phase of day-night cycle). Modules relatively autonomous with number onboard limited by spacecraft capacity. Output of modules fed to amplifiers, displayed on oscilloscopes, and recorded on magnetic tape for later analysis.

CREW. Crew involvement minimal and low-skilled. Primarily requires actuation of data collection equipment.

DATA. Notes, tapes, and few fluid samples returned to Earth.

OPERATIONS. Most subjects returned alive for additional studies; preparation necessary by crewmen. If food dispensing and waste management not automated, then performed by crewmen.

RESEARCH SEQUENCING. Scheduled later in space research program to investigate mechanisms of earlier observed changes.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Specific implanted sensors, animal experiment modules.

RESEARCH COMMONALITIES. Closely associated with 2-VB-1, -2.

RESEARCH CLUSTER 1-BM-13–EFFECTS OF WEIGHTLESSNESS ON PULMONARY FUNCTION

ABSTRACT

OBJECTIVES. Detect and measure changes in pulmonary function and investigate associated physiological processes that will lead to a greater understanding of involved mechanisms.

BACKGROUND. Preflight and postflight tests on astronauts, and ground-based experiments involving prolonged bed rest and water immersion reveal no significant changes in respiratory variables. Inflight tests necessary to verify.

RESEARCH DESCRIPTION. Measurements of lung volumes and breathing mechanics, which include the volumes, flows, and pressures associated with various pulmonary activities, made early in the research program; equipment simple, and measurements require minimal crew time and skill. Measurements designed to reveal changes in the lung membrane, such as diffusion capacity and alveolar-arterial P_{O_2} and P_{CO_2} differences require more complex analytical procedures and the sampling of arterial blood. A physician is required for this aspect of the research. Later measurements will also include residual volume, respiratory dead space, lung compliance, and pulmonary resistance.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Display and recording equipment common to that required by other research clusters. Accurate respiratory flowmeter equipped with flow integrator and pressure gage will meet requirements of most lung volume and breathing mechanics measurements. Compliance and resistance measurements require esophageal balloon or substitute for transpulmonary pressures. Later testing resources must include an He-CO gas source and analyzer, and a blood gas (O_2 and CO_2) analyzer.

CREW. Early measurements by cross-trained crewmen. Subsequently require experienced lab technician and physician skills for arterial blood sampling.

DATA. Notes, stripchart, and magnetic tape records returned to Earth.

OPERATIONS. Three crewmen subjects required for most procedures. Most measurements spaced evenly throughout a 90-day crew cycle.

RESEARCH SEQUENCING. Adaptive, depending upon spacecraft facilities. More complex and demanding measurements performed later.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Measurement of transpulmonary pressure.

RESEARCH COMMONALITIES. Valuable information derived from 1-BM-6.

RESEARCH CLUSTER 1-BM-14—EFFECTS OF WEIGHTLESSNESS ON METABOLISM

ABSTRACT

OBJECTIVES. Investigate energy metabolism and intermediary processes to determine whether changes produced during long weightlessness.

BACKGROUND. Preflight and postflight measurements on Mercury and Gemini astronauts, as well as ground-based studies simulating weightlessness, reveal decreases in muscle size and strength, bone calcification, and work efficiency. Changes in basic metabolic processes are implicated in these observations. Metabolic phenomena are scheduled for investigation during the Skylab A program.

RESEARCH DESCRIPTION. Establish time history of reduced exercise tolerance, bone density, and muscle size and strength as well as relationship to respiratory and cardiovascular changes, calcium balance, and nitrogen balance during earlier phases of research program. Investigate protein and lipid utilization during carbohydrate deprivation, glucose tolerance, lean-body mass, and adipose-tissue mass later. Liver function tests performed as necessary to define the nature of any observed changes in protein metabolism.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Bicycle ergometer, 60 lb, 20 cu ft, and 10 w in use; metabolic analyzer, 40 lb, 3 cu ft, 30 w; x-ray bone densitometer, 100 lb, 2 cu ft, 1,000 w (during very brief use). Weighing, drying, and stowage of feces for nitrogen balance measurements places specific demands on waste management system. Requires specimen mass measurement device. Chemical analysis facility required for many measurements as well as body mass and volume for lean-body mass determination.

CREW. Six crewmen serve as subjects. Many measurements require the participation of an experienced and skilled technician.

DATA. Notes, stripchart, magnetic tape records, and biological samples returned to Earth for additional analysis.

OPERATIONS. Many later procedures require specific dietary regimens for the crew. Significant demands placed on waste management systems.

RESEARCH SEQUENCING. Investigation of known changes first priority.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Body volume measurement.

RESEARCH COMMONALITIES. Closely associated with 2-VB-2 and -3.

RESEARCH CLUSTER 1-BM-15—CENTRIFUGE STUDIES

ABSTRACT

OBJECTIVES. Determine changes in cardiovascular, respiratory, and vestibular responses to acceleration and rotation. Determine usefulness of centrifuge as conditioning device.

BACKGROUND. Value of an onboard manned centrifuge and feasibility of design demonstrated by several ground-based studies. The biomedical difficulties resulting from spacecraft rotation also investigated in terrestrial laboratories.

RESEARCH DESCRIPTION. Cardiovascular and vestibular effects of centrifugation and rotation, tolerance to reentry acceleration profiles, and investigation of centrifuge conditioning regimen. Acceleration tolerance tested weekly; tolerance indicated by the greyout threshold to a peripheral light. During slow rotation, examine sensitivity to angular acceleration, susceptibility to motion sickness, and occurrence and persistence of nystagmus and ocular illusions. Reentry profiles simulated both in magnitude and direction. Various conditioning programs investigated; absence of evidence of deconditioning in ancillary tests will be criterion of program effectiveness.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Onboard centrifuge facility approximately 1,700 lb at launch. Structural chamber height of 9 ft, diameter of 20 ft, incorporates a 42-in-diameter passageway through the hub. Five kw for spin-up and 500 w during operation.

CREW. Seven crewmen serve as subjects, four for conditioning program, three for other tests. Physiological and engineering technicians required.

DATA. Notes, stripchart records, and magnetic tapes returned to Earth.

OPERATIONS. Centrifuge operations scheduled during periods of low power loads. Collateral tests required on the centrifuge subjects.

RESEARCH SEQUENCING. Must await the development of a suitable orbiting facility.

SUPPORTING TECHNOLOGY DEVELOPMENTS. None.

RESEARCH COMMONALITIES. May be used as biocentrifuge in 2-VB-2, 2-IN-2, 2-PL-2, and 2-P/T-2. Studies closely associated with 1-BR-1.

RESEARCH CLUSTER 1-BR-1—SENSORY, PSYCHOMOTOR, AND COGNITIVE BEHAVIOR

ABSTRACT

OBJECTIVES. Determine effects of extended spaceflight on man's basic capability to sense, comprehend, and react to his environment.

BACKGROUND. Reliable long-term data on sensory, psychomotor, and cognitive behavior in space is limited. Because this type of behavior responds slowly to stress, there are inadequate data on relationships between physiological and behavioral changes, and spaceflights to date have been relatively short.

RESEARCH DESCRIPTION. Individual self-administered testing periods scheduled to sample as large a population of available crewmen as possible. Sufficient number of measurements made to determine if changes take place, course of change over time, and nature of individual differences. Physiological measurements correlated with observed changes. Experiments initially addressed to determination of change and later to testing of remedial programs and equipment to alleviate such changes.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Dedicated area of the space facility isolated from distractions, noise, and extraneous light. Measurement equipment 250 lb, 10 cu ft, 50 to 100 w.

CREW. Crew serves as experimental subjects, requiring approximately 40 hours per crewman per 90-day mission cycle. No special crew training.

DATA. Voice, TV, test scores, and environmental data on three digital and three analog (1 to 5 kHz) channels, telemetered to Earth.

OPERATIONS. Measurement techniques for vision, audition, orientation, psychomotor, and cognitive functions similar to those employed on Earth. No data analysis operations required in flight.

RESEARCH SEQUENCING. Initiated early, to permit follow-up research on complex behavior.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Development of task-oriented hearing, psychomotor, and cognitive capability tests.

RESEARCH COMMONALITIES. No special considerations.

RESEARCH CLUSTER 1-BR-2–GROUP DYNAMICS AND PERSONAL/SOCIAL ADJUSTMENT

ABSTRACT

OBJECTIVES. Determine effects of extended spaceflight on group dynamics and personal/social adjustment.

BACKGROUND. Anecdotal literature, small group research, confinement studies, and research with isolated groups indicate extended spaceflight may result in altered group structure, degraded group effectiveness, interpersonal conflict, and personality changes. Little is known on group dynamics in space.

RESEARCH DESCRIPTION. Long-range continuing research effort. Collect data on group productivity by measuring crew task performance and group structure. Process by observing crew interaction and personal and social adjustment by standard personality tests. Controlled observations during normal work and off-duty activities; crews of different sizes, different compositions, under different mission conditions. Using TV, microphones, questionnaires, and personality tests, gather data on task times and errors, verbal and physical interaction, mood, and personality variables. Augment by clinical interviews and physiological data collected in biomedical research. Group behavior of concern observed every ten days.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Four TV cameras, five microphones, video tape recorder, auxiliary lighting. 160 lb, 8 cu ft, 520 w (2% duty cycle).

CREW. Operation, maintenance, and adjustment of video equipment; crew time less than three hours per crewman each 30 days.

DATA. Two analog channels (voice, 10 kHz; video, 2.9 MHz), one digital channel for test scores (40 bits). Data processed onboard, telemetered for analysis.

OPERATIONS. Onboard monitoring of data quality; adjust and relocate measuring equipment. Experiment operations controlled from ground to maximum extent to assure nonobtrusiveness. Storage space for magnetic tape.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Automated video, audio data gathering and analysis instruments and techniques; assessment of verbal behavior.

RESEARCH COMMONALITIES. Biomedical research on physiological stress indices (1-BM-6).

RESEARCH CLUSTER 1-BR-3–COMPLEX TASK BEHAVIOR

ABSTRACT

OBJECTIVES. Investigate human capabilities in performance of complex operator, maintenance, and scientific investigator tasks in space.

BACKGROUND. For time durations and space conditions experienced on both USA and Soviet spaceflights, considerable knowledge regarding complex task behavior has been gained. It can be tentatively concluded that, with the exception of EVA tasks, almost any task that man can perform on the ground can be performed in space provided proper and adequate restraints are used.

RESEARCH DESCRIPTION. Repeated, precise measurement of spaceflight tasks under operational conditions to determine performance under extended spaceflight conditions, performance changes over time, and performance differences among crewmen of different backgrounds and training. Task performance will be evaluated by using TV cameras, timers, biomedical instrumentation, and crew logs and will include both IVA and EVA tasks. Parameters to be measured are task time and error, physiological indices, and subjective responses from crew regarding hardware adequacy and difficulties encountered.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Measurement equipment, which includes TV cameras, video recorder, and lights, approximately 150 lb, 20 cu ft, 50 w during operation.

CREW. Involvement minimal since crew will be performing normal mission activities while being observed as experimental subjects.

DATA. Data include magnetic tape, electrical, and photographic film either telemetered to Earth or returned for ground analysis.

OPERATIONS. Impact on operations minimal since required special activities include only turning measurement equipment on and off.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Preflight psychomotor baseline measurements are required on tasks to be observed during space operations.

RESEARCH COMMONALITIES. This research cluster plus 1-BR-4, 1-MM-1, -2, 1-EE-1, -2, and 1-OE-1 through -5 all require observations of crewmen performing complex mission tasks. Data required for several of these research clusters can be obtained from observation of one task.

RESEARCH CLUSTER 1-BR-4–SKILL RETENTION

ABSTRACT

OBJECTIVES. Investigate acquisition and retention of critical skills needed in extended spaceflight; identify those skills which degrade in space and the time course of their degradation; and discover ways of preventing such degradation. Evaluate procedures and equipment for maintaining critical skills in space.

BACKGROUND. For extended spaceflight there is a gap in knowledge regarding maintenance of proficiency for extended durations, characteristics of any degradation which may occur, frequency with which retraining should occur, and the form which such retraining should take.

RESEARCH DESCRIPTION. Observe in-orbit crew performance to determine skill degradation of two types: that which occurs because of long-term disuse, and that which occurs gradually in frequently used skills. Later research will investigate techniques, equipment, and procedures for preventing skill degradation. Measure task time and error using onboard timers and video tape techniques.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Simulation facilities required for those skills which cannot be observed in operational mission tasks. Provision for human centrifuge 1,720 lb, 2,000 cu ft, 5,300-w peak power.

CREW. Experimental subjects, but in most cases also performing normal mission activities. Centrifuge technician required.

DATA. One video channel (1.3 MHz) to relay TV image to ground, plus one low-rate digital channel shared with other data.

OPERATIONS. Centrifuge operations require a control console manned by a test administrator to operate and monitor centrifuge and monitor physiological condition of experimental subjects.

RESEARCH SEQUENCING. Adaptive crew mix for tasks performed frequently and those performed infrequently. Tasks selected and scheduled to take maximum advantage of time available for detection of skill degradation.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Ground studies to delineate the operational problems and hypotheses to be tested.

RESEARCH COMMONALITIES. Common observations with 1-BR-3.

RESEARCH CLUSTER 1-BR-6–PERFORMANCE MEASUREMENT

ABSTRACT

OBJECTIVES. Evaluate activities, techniques, and equipment for monitoring, measuring, and assessing human performance in space. Includes crew task performance, psychological states, crew interaction and group processes, and personality variables.

BACKGROUND. Advanced direct, indirect, and subjective methods of assessing performance and behavior have been developed, but verification in space of adequacy of those techniques is needed.

RESEARCH DESCRIPTION. Initiate various advanced measurement techniques (e.g., time-lapse video, voice-record analysis, physiological indices, instrumented hardware) to be used in human research in space. Close coordination required with each of the human research experiment principal investigators. A carefully prepared plan of in-orbit data segregation and accumulation will be worked out before each flight. Analysis of the data and evaluation of the techniques will be done on the ground. To achieve maximum value, data-taking for some other experiments may have to be modified to permit simultaneous use of several promising measurement techniques.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. No special considerations.

CREW. Restricted to onboard activity required to accumulate and segregate data related to effectiveness of performance measurement techniques.

DATA. Data will be that ordinarily collected for other experiments, but must be segregated for assessment of performance measurement techniques.

OPERATIONS. No special considerations.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. No additional requirements are imposed beyond the requirements for measurement technology development identified in other research clusters.

RESEARCH COMMONALITIES. Measurement techniques to be evaluated will be used in 1-BR-2, -3, and -4; 1-MM-1 through -5; 1-EE-1 and -2, and 1-OE-1 through -5.

RESEARCH CLUSTER 1-MM-1–CONTROLS AND DISPLAYS

ABSTRACT

OBJECTIVES. Accumulate in-space human engineering data on the interface between man and controls and displays, under conditions of extended duration, weightlessness, and artificial gravity, to verify applicability of ground-based human engineering design principles to space.

BACKGROUND. Much ground-based human engineering is required on advanced display and control concepts. An extensive evaluation program in space is needed to verify or revise human engineering design criteria as they apply to spaceflight.

RESEARCH DESCRIPTION. Verification of ground-based design criteria accomplished through observation and crew evaluation during operational use of controls and displays. Controlled human engineering experiments also conducted at an experimental work station. Task times, reaction times, and errors collected along with subjective comments of flight crew. Data will generally be automatically recorded, processed through the computer, and telemetered to Earth for analysis.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Onboard computer console required for programmed presentation of problems to experimental subjects. The experimental work station will weigh 750 lb, occupy a volume of 336 cu ft, and require 350-w average power, 550-w peak power.

CREW. At least three crewmen will serve as experimental subjects during each crew cycle, for a total of 120 30-min experiment sessions.

DATA. Time and error data will be automatically recorded on magnetic tape, time indexed, and telemetered to Earth for analysis.

OPERATIONS. Periodic reconfiguration of experimental control/display station. Onboard capability for extensive retrofit of the work station and logistics resupply of replacement controls and displays.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Computer hardware and software development.

RESEARCH COMMONALITIES. The objectives of this research cluster and 1-BR-3 are complementary and may be achieved by evaluation of the same crew tasks.

RESEARCH CLUSTER 1-MM-2–LOCOMOTION AND RESTRAINT

ABSTRACT

OBJECTIVES. Obtain quantified in-space data on crew locomotion and restraint techniques and equipment needed for design requirements, procedures, and equipment evaluation.

BACKGROUND. Valuable experience in restraint and locomotion devices has been gained in spaceflight to date, and additional data will come from Skylab A experiment M-509. To fulfill the multiple need of prolonged flight under zero-g and partial-g conditions, additional space research is needed.

RESEARCH DESCRIPTION. Pretest on the ground and evaluate in space carefully designed experimental tasks, using specific locomotion and restraint techniques and equipment. Using impact and acceleration sensors, biomedical instrumentation, timers, and TV cameras, collect data on energy expenditure, impact forces, accelerations generated, crew time, and difficulties encountered in using the techniques and devices. Subjective evaluations by crewmen will be an important part of the data collected.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Equipment specifically designed for this research cluster will weigh approximately 100 lb and occupy approximately 64 cu ft. Electrical power will average 40 w.

CREW. Experimental subjects and evaluators of techniques and equipment.

DATA. Data generated will consist of written copy, magnetic tape, video tape, and voice recordings transmitted to Earth for analysis.

OPERATIONS. Research includes both IVA and EVA tasks, spacecraft operations may be curtailed or modified during some experiments.

RESEARCH SEQUENCING. Experiments should occur every 10 days over a 3-year period; take advantage of periods of zero-g and artificial-g; and provide for experiments with advanced equipment and techniques.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Portable metabolic analyzer, on-body accelerometers, and ground simulation of research tasks.

RESEARCH COMMONALITIES. None.

RESEARCH CLUSTER 1-MM-3—HABITABILITY

ABSTRACT

OBJECTIVES. Obtain space verification of ground-developed design criteria for space-vehicle architecture, environment, mobility, food and water management, personal hygiene, housekeeping, and off-duty facilities.

BACKGROUND. Current knowledge based on ground simulations and short-duration manned spaceflights. Actual spaceflight stresses on habitability design require verification under real conditions of extended spaceflight.

RESEARCH DESCRIPTION. Measurements made while crewmen perform normal activities to determine effects of habitability features on physical health and work efficiency. Subjective crew evaluations of habitability features elicited. Advanced concepts for providing reconfigurable interiors evaluated for their need, adequacy, and crew reaction. Physical health data collected with biomedical instrumentation. Most other data will be derived by time-lapse video and crewman responses to habitability questionnaires.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Measurement and recording equipment plus equipment for reconfiguring interiors 125 lb, 7.0 cu ft, 90 w average power.

CREW. Each crewman will respond to a habitability questionnaire every 10 days, requiring 180 min per crewman per 90-day cycle.

DATA. Written copy, magnetic tape, and electrical data requiring one low-rate (500 bit/sec) digital and one analog (1.3 to 3.0 MHz) channel, telemetered to ground for analysis. Biomedical data from related experiments require segregation for use in this research.

OPERATIONS. No interference with daily routine operations. Measurement equipment shared with other experiments. Logistics resupply must accommodate nine 2,400-ft rolls of magnetic tape each 90 days.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Ground simulation to perfect techniques and procedures.

RESEARCH COMMONALITIES. Identical data on crew health are required in several biomedical research clusters.

RESEARCH CLUSTER 1-MM-4—WORK-REST-SLEEP CYCLES

ABSTRACT

OBJECTIVES. Determine effects of extended spaceflight on circadian rhythms, sleep behavior, reaction to emergencies when awakened from sleep, and optimum scheduling of work, rest, and sleep periods.

BACKGROUND. Ground-based research on circadian rhythms and work-rest cycles, along with experience accumulated in manned spaceflight provides a starting point for this research.

RESEARCH DESCRIPTION. Continuing long-range effort using different types of vehicles, crews of different sizes and composition, and under different mission conditions. Record, on a non-interference basis, data on circadian rhythms, length and depth of sleep, work efficiency under different work-rest schedules, and crew responses to emergencies when awakened from sleep. Collect data on circadian changes in biomedical and behavioral indicators such as cardiovascular activity, body temperature, metabolic rate, blood chemistry, fatigue, level of attention and concentration, and work efficiency. Sleep data will include EEG recording and subjective responses of crewmen.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Measurement equipment, shared with other behavioral and biomedical experiments, 60 lb, 2.5 cu ft, 100 w average.

CREW. Crew serve as experimental subjects while performing normal activities. No special skill requirements.

DATA. Biomedical data, TV tape, and crew voice logs, processed and collated onboard for transmission to ground for detailed analysis.

OPERATIONS. Flexible operational schedule to vary work-rest-sleep cycles. Safety monitoring necessary during crew response to emergency testing.

RESEARCH SEQUENCING. Adaptive scheduling must consider multiple use of measurement equipment by different experiments. Sleep measurements will be scheduled preflight, early, midway, and late in each crew cycle.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Analytic ground research to identify emergency tasks.

RESEARCH COMMONALITIES. Equipment and data shared with 1-BR-3.

RESEARCH CLUSTER 1-MM-5—PERFORMANCE AIDS

ABSTRACT

OBJECTIVES. Acquire in-space data on man-machine interface, human capabilities, and design criteria for tools, remote manipulators, optical aids, and job aids.

BACKGROUND. Considerable ground research has been done on space tools, remote manipulators, and computer-generated job aids by various governmental and industrial researchers, but optical aids for enhancing man's visual capabilities in space have received little attention.

RESEARCH DESCRIPTION. Research activities divided into four subgroups: tools, remote manipulators, optical aids, and job aids. Individual experiments over several years of spaceflight, changing as advanced aids become available. Observations generally made as crewmen use performance aids in normal mission tasks, but simulated tasks used where necessary. Data collected on task times and errors, accuracy, energy expenditure, forces, torques, and difficulties encountered, by using instrumented task boards, timers, TV cameras, and crew logs as measurement devices.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Task boards, remote manipulators, other performance aids, and measurement equipment approximately 300 lb, 200 cu ft, 350 w.

CREW. Approximately 1,000 hr over five-year period.

DATA. Data will consist of magnetic tape, TV film, and voice; one analog channel for video and 21 to 25 digital channels for measurements from instrumented hardware.

OPERATIONS. For some optical aids experiments, spacecraft must be over ground truth sites.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Universal, flexible task boards which can be reconfigured in space and used for a variety of experiments; tool selection program for powered and unpowered tools; space-qualified bilateral master/slave remote manipulator; optical aids for Earth visual surveys.

RESEARCH COMMONALITIES. Common data requirements with 1-BR-3.

RESEARCH CLUSTER 1-LS-1—PHASE CHANGE AND THERMAL PROCESSES

ABSTRACT

OBJECTIVES. Gain basic knowledge of phase separation and boiling heat transfer in weightlessness, to improve the design of advanced life support systems.

BACKGROUND. Life support systems designs for extended space operations rely upon converting crew waste to useful commodities. Candidate approaches convert liquid to gas by boiling heat transfer. Subcritical cryogenic-atmosphere storage requires liquid-to-gas phase change in heat exchanger by boiling heat transfer. Solid amine CO_2 control concept consists of absorption beds regenerated by steam generated by boiling heat transfer. Currently, 1 g extrapolation is insufficient to design efficient zero-g hardware confidently.

RESEARCH DESCRIPTION. Study incipient and nucleate boiling by heating typical surfaces (plates, spheres, cylinders) in a liquid tank. Vary orientations, heat flux, pressure, and low-g forces. Dynamics of bubble size, growth rate, and velocity observed with high-speed TV and cameras through tank ports.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Electrical power (peak 1,500 w (10%), average 200 w). Cylindrical plexiglas tank, cameras (TV and film), various typical surfaces, recording and display equipment.

CREW. Engineering skill required to set up test surfaces, monitor instrumentation, and operate controls. Understanding of boiling phenomenon and research cluster objectives required.

DATA. Film or video magnetic tape. Voice annotations of observations. Onboard processing and viewing of filmed observations desirable.

OPERATIONS. Controlled low-g forces for short periods. Transient random accelerations above 10^{-6}g not permitted during data run.

RESEARCH SEQUENCING. Control reference in 1 g for comparison with space data.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Fluid physics apparatus, zero-g condenser, boiling and condensing steam.

RESEARCH COMMONALITIES. Data applicable to research clusters 1-LS-3, -4, and -7. Common objectives with 4-P/C-3.

RESEARCH CLUSTER 1-LS-2—MATERIAL TRANSPORT PROCESSES

ABSTRACT

OBJECTIVES. Obtain empirical data concerning condensing heat transfer and fluid dynamics in zero gravity.

BACKGROUND. Design of advanced life support systems for long-duration spaceflight to a large extent involves material transport processes. Steam-desorbed resin, a candidate for CO_2 removal, relies on hot steam to desorb the beds. To design a zero-g condenser-separator, empirical data is needed to supplement theory. Current theory derived for the 1-g environment may require revision for zero- or partial-g applications.

RESEARCH DESCRIPTION. Pass condensable fluid, heated to the gas vapor stage, through glass condensing tubes. Instrumentation will include TV monitoring and high-speed film recording of the condensing process. Evaluate local and mean condensing heat-transfer coefficients, pressure drops. Variables to be monitored include temperatures, pressures, flow rates, and power. Repeat for various levels of vehicle acceleration. Record flow instability and vapor/liquid flow distribution.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Electrical power 1,500 w. Fluid tank and condenser cameras (TV and film), sensing instrumentation, and metering equipment.

CREW. Engineer skills, to set up and adjust boiler and condenser equipment, monitor test runs, and analyze results.

DATA. Film and video magnetic tape. Voice annotation of observations. Onboard processing and viewing of film data.

OPERATIONS. Produce various low-g forces for short periods. Random accelerations not permitted during data run. Return to steady-state condition required between each programmed set of variables.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Fluid physics equipment development and test routines. Negative pressure device.

RESEARCH COMMONALITIES. Data applicable to 1-LS-3, -4, -7, and -10. Common objectives with 4-P/C-2.

RESEARCH CLUSTER 1-LS-3—ATMOSPHERE SUPPLY PROCESSES

ABSTRACT

OBJECTIVES. Determine the most effective methods for spacecraft atmosphere storage and processing in an integrated spacecraft life support system.

BACKGROUND. To reduce the supply and resupply weight of expendables, it is necessary to close the loop by recovering as much oxygen as possible from CO_2 and water. Various methods (Sabatier, Bosch, and components of the molten carbonate and solid electrolyte systems) have been developed and tested on Earth. Final selection must be made in the operational weightless environment.

RESEARCH DESCRIPTION. Perform comparative functional tests on three or more life support units, each containing a complete atmosphere supply process. Stored CO_2 and H_2 are fed to the units at controlled mixture ratios while products of reaction are collected and analyzed. Measurements will also include requirements for electric power, heating and cooling, and maintenance. Test EC and LS devices operate through one crew cycle each.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Requires gas supply of CO_2 and H_2. Electrical power 1,000 w. Units for test (Sabatier, Bosch, molten carbonate), plus storage tanks, heat exchangers, purging apparatus, gages and controls, and recording and display equipment.

CREW. Engineer with knowledge of life support system operation and familiarity with the test equipment, to configure equipment, adjust controls, and monitor results.

DATA. Automated units with continuous crew monitoring. On-call readout of data output.

OPERATIONS. Safety system for control in event of test failure.

RESEARCH SEQUENCING. Prelaunch qualification test of units in ground simulator.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Research in related materials, catalysts, zero-g condensation, boiling, and zero-g two-phase liquid-vapor separation.

RESEARCH COMMONALITIES. Data applicable to 1-LS-5, -7, and -12.

RESEARCH CLUSTER 1-LS-4—WATER MANAGEMENT

ABSTRACT

OBJECTIVES. Test and evaluate, in the space environment, various techniques and hardware associated with the storage, preservation, and reclamation of water for manned spacecraft.

BACKGROUND. Several techniques have been tested on Earth but require flight test. Pasteurization is a promising system for preservation. Reclamation processes involve membrane filtration and phase change processes, among others. Air evaporation for zero-g operation has been tested on the ground, as has a vapor pyrolysis system. A vacuum distillation vapor filtration technique has been demonstrated, but design and testing are required for zero-g operation.

RESEARCH DESCRIPTION. Functional capabilities of various pilot units using different approaches will be tested in space. Units will be fed with biowastes and wash water diverted from the baseline system, and the recovered H_2O and gases will be collected and analyzed. Measurements include water and gas chemical content analysis, microbial tests, and crew reaction. Test unit operation and data acquisition will be automated.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Equipment weight is 400 lb, volume 20 cu ft, electrical power 700 w, with instrumented sensors on line.

CREW. Engineer familiar with water recovery unit operation and maintenance, to activate recovery and water system unit tests, monitor sensors and gages, and perform minor adjustments and maintenance.

DATA. Automated data output of parameters on magnetic tape. Voice annotation.

OPERATIONS. No special considerations. After setup and activation, monitoring and maintenance at 10% of astronaut time. At least five days of operation per test cycle.

RESEARCH SEQUENCING. No special considerations, other than convenient diverting of spacecraft operational water system. Preflight simulation testing of units desired in integrated life support system.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Study of mass handling, phase change, gas/liquid/solid separation in zero-g, and microbial detection and suppression.

RESEARCH COMMONALITIES. Data applicable to 1-LS-9 and -12.

RESEARCH CLUSTER 1-LS-5—WATER ELECTROLYSIS

ABSTRACT

OBJECTIVES. Test and evaluate various systems to obtain design data for the electrolysis of water as a source of oxygen, in the weightless environment.

BACKGROUND. Recovery of oxygen from CO_2 and water will reduce consumable storage requirements. Current process approaches to electrolysis of water (asbestos matrix KOH vapor feed, sulfuric acid/water vapor cell, absorbent KOH matrix, solid polymer electrolysis cell) require testing and evaluating subsystems and components in weightlessness.

RESEARCH DESCRIPTION. Evaluate functioning of three or more advanced water electrolysis test units. Units are essentially automated closed systems. Data to be gathered include water use rate, heat rejection rate, gas composition, gas contamination, temperature, and pressure. Performance measurements include requirements for electric power, heating and cooling, and maintenance. Oxygen generated will be returned to spacecraft system, and the H_2 used for life support processing requirements.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Estimated weight of units under test, 450 lb. Occupy 48 cu ft. Electrical power 700 w, thermal output 300 w. Oxygen and hydrogen gases returned to spacecraft system. Gas contamination mass spectrograph, gas chromatograph, and ozone meter.

CREW. Engineer familiar with test unit operation and maintenance, to monitor data results and perform analyses.

DATA. Automated, approximately 60 data channels, for magnetic tape. Voice annotations and visual displays.

OPERATIONS. No special considerations. Collected H_2 stored and added to baseline waste collection system. Stable voltage and current during tests.

RESEARCH SEQUENCING. No special considerations. Gas analysis run periodically.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Requires research in two-phase flow separation and condensation in zero-g, and improved electrode and separator life. Water electrolysis test unit.

RESEARCH COMMONALITIES. Data applicable to 1-LS-3, -9, and -12.

RESEARCH CLUSTER 1-LS-6—FOOD MANAGEMENT AND PROCESSES

ABSTRACT

OBJECTIVES. Evaluate various methods of food storage, processing, and regeneration in the weightless environment.

BACKGROUND. Only short duration spaceflight test data on a few storage techniques are available. Data required on long term crew response and subsystem impact. Regeneration methods to be developed include edible fat synthesis. Work on *Hydrogenomonas eutropha*, hydrogen fixing bacteria, halted because of poisoning of test rats. Another food regeneration process should replace research in this cluster if this process development is not continuous.

RESEARCH DESCRIPTION. Test food storage methods including freeze dried, frozen, and irradiated. Obtain data on palatability, energy storage, and water storage requirements. Test food regeneration processes including chemical synthesis via the glycerol process, photosynthesis from living plant cells, and biochemical reactions by such hydrogen fixing bacteria as *Hydrogenomonas eutropha*. Data to be collected include requirements for power, thermal energy, efficiencies, and chemical and microbial water potability analysis.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. For food regeneration, test unit estimated 1,700 lb, 100 cu ft, 6,000 w. Food storage depends on crew requirements, estimated at 2,500 lb, 100 cu ft, and 1,000 w. *Hydrogenomonas* mixing chamber, H_2O distillation unit, electrolysis unit, incinerator, and analysis equipment.

CREW. Engineer familiar with test unit operation and maintenance. Evaluate test data.

DATA. Automated data on magnetic tape. End product samples saved for analysis.

OPERATIONS. Complex process precludes interruption during test cycle. Initial tests must await accumulation of biowaste. Some system processes gravity sensitive.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Integration of *Hydrogenomonas eutropha* system components. Evaluate *Hydrogenomonas eutropha* process in simulation prior to flight.

RESEARCH COMMONALITIES. Data applicable to 1-LS-9 and -12.

RESEARCH CLUSTER 1-LS-7–ATMOSPHERE PURIFICATION METHODS

ABSTRACT

OBJECTIVES. Test and evaluate the operation and effectiveness in the weightless environment of various methods of atmosphere purification for manned spacecraft.

BACKGROUND. Removal of CO_2 from spacecraft atmosphere is prime activity. Systems are considered which remove and concentrate CO_2 for processing by oxygen recovery systems. Methods currently under development include electrodialysis, solid amines, molecular sieves, liquid absorption, and carbonation cells. Solid amine and molecular sieve have been tested in manned simulators. Electrochemical carbonation cell is promising and in early stages of development.

RESEARCH DESCRIPTION. Test several CO_2 concentrator systems, using cabin air introduced into test units, and collect and analyze resulting effluents. Data gathered include liquid and gas flows, chemical analysis of liquids and gases, temperatures, electric power, and heating and cooling requirements. Performance of each candidate system evaluated for a variety of test conditions.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Advanced CO_2 units under test, 300 lb, 20 cu ft, 400 w. Vacuum pump, electric power regulation system, cabin-air blower, and associated metering equipment for CRT display and recording.

CREW. Engineer with thorough knowledge of units under test. Assess, adjust, and repair system, including data evaluation.

DATA. Automated data collection on magnetic tape. Sample data displayed at console on CRT.

OPERATIONS. Possible impact on operation of baseline system, which will not operate at maximum capacity during tests due to bypassed cabin air. Test cycle over 90-day period for each system.

RESEARCH SEQUENCING. Continuous data review for first 24 hr, then one sample per hour.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Investigations required in areas of zero-g boiling and condensing, zero-g liquid-vapor separation, and zero-g mass transport. Automated instrumentation for sample analysis.

RESEARCH COMMONALITIES. Data applicable to 1-LS-3 and -12.

RESEARCH CLUSTER 1-LS-8–MONITORING AND CONTROL

ABSTRACT

OBJECTIVES. Establish requirements and technology for automated monitoring and control of life support systems in manned spacecraft.

BACKGROUND. Experience with integrated life support systems in manned simulator programs has shown that excessive crew time is required for the manual monitoring, control, and adjustment of life support system operation. Recent studies by the NASA have examined diagnostic computer programs for acquiring subsystem data, comparing with selected values for out-of-tolerance, activating controllers, fault isolation, and display.

RESEARCH DESCRIPTION. Onboard evaluation of automated data management system console. Contains the monitoring, controls, displays, storage, and telemetering functions at varying levels of automation. The initial system will control the life support system at a primitive level with significant crew manual involvement. Acquisition and comparison functions gradually merged with the reduction and command functions to bring crew participation to a minimum. Crew will observe at console all sensed data from life support subsystems and adjust operating parameters.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Life support data management systems 1,500 lb, 25 cu ft, 2,000 w. Includes data console display and recording with computer interface.

CREW. Engineering background and familiarity with the life support system operations, to monitor data output, operate controls, and observe system capabilities at successive complexity levels.

DATA. Recorded and displayed sensed data from life support system fed to data management system. Crew will monitor output, note and evaluate performance, and respond to equipment control requirements.

OPERATIONS. Mission duration. Introduce automated control and monitoring functions progressively.

RESEARCH SEQUENCING. Crew participation will gradually decrease as automated control capability is demonstrated.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Data management methods, automated water potability measurements, and display/control/computer capabilities.

RESEARCH COMMONALITIES. Life support subsystems in 1-LS-( ) series.

RESEARCH CLUSTER 1-LS-9–WASTE MANAGEMENT

ABSTRACT

OBJECTIVES. Test and evaluate, in the weightless environment, various methods for biowaste collection, handling, and disposal in manned spacecraft.

BACKGROUND. Spaceflights to date have employed the bag-and-stow method of waste management. Advanced methods to be tested include vacuum drying, vapor compression, and incineration. The wet oxidation method shows promise but is still in feasibility demonstration phase.

RESEARCH DESCRIPTION. Activate various test systems in place of the spacecraft baseline system. Operation monitored and adjusted by crew. Data collected on system operation include mass flows, thermal flows, and power requirements for durations up to full crew cycle. Samples of effluents analyzed for water potability, bacteria, radiation level, and chemical constituents. Crew use of waste collection facility recorded by camera. Waste treatment and water recovery systems essentially automatic.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Test systems power and thermal loads will replace baseline system requirements. Test system 900 lb, 100 cu ft, 500 w. Commode and urinal, phase separators, pyrolysis and incineration chambers, condensers, compressors, and associated hardware for control, recording, and display.

CREW. Engineering background and familiarity with operation of systems under test, schedule replacement of screens and filters, and perform routine maintenance and repair.

DATA. Automated data on magnetic tape. Solid byproducts samples to be returned.

OPERATIONS. Radiation shielding and monitoring of radioisotope (RITE) test system. Up to 90-day test period for each system being evaluated.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Zero-g phase separation; waste management systems concepts.

RESEARCH COMMONALITIES. Data applicable to 1-LS-4 and -12.

RESEARCH CLUSTER 1-LS-10—HEAT-TRANSPORT EQUIPMENT

ABSTRACT

OBJECTIVES. Test and evaluate various components and circuits for the transport of thermal energy in a spacecraft environment. Achieve optimum design with respect to weight, volume, power, and reliability.

BACKGROUND. Providing a long-term habitable area involves thermal control by transporting source heat to thermal sinks, air circuits for crew comfort, waste heat circuits, and coolant loops. Processes involved include thermal conduction, forced convection, radiation, condensing, and evaporation or boiling processes in two-phase flow. Current approaches suffer a weight penalty. Two-phase condensation flow in zero-g would permit the design of lighter-weight radiators and heat-transfer circuits.

RESEARCH DESCRIPTION. Obtain performance data on heat-transport equipment, single loops, and integrated loops. Basic hardware and components will be interconnected into loops of increasing complexity. Test active and passive thermal control techniques. Parameters to be measured include temperatures, fluid flow, pressures, moisture content, heat-transfer rates, and power.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Heat-transport test unit weight 700 lb, volume 40 cu ft, electrical power 1,000 w. Includes insulation, radiative surfaces, condensers, etc., instruments for metering, recording, and display.

CREW. Engineer skilled in test unit operation and maintenance, to start, switch over, and shut down test, monitor operations, and assess test data.

DATA. Automated data recorded on magnetic tape and visual displays, with optional manual override.

OPERATIONS. Tests may be interrupted and restarted. Fourteen-day continuous monitoring.

RESEARCH SEQUENCING. Components inserted into heat-transport loop to replace baseline system.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Multiphase flow phenomena in steady and transient conditions and zero-g condenser.

RESEARCH COMMONALITIES. Data applicable to 1-LS-8 and -12.

RESEARCH CLUSTER 1-LS-11—CREW EQUIPMENT AND PROTECTIVE SYSTEMS

ABSTRACT

OBJECTIVES. Evaluate in the weightless environment the requirements for and techniques of the detection and control of conditions which are hazardous to the crew, such as fire, temperature extremes, biological and atmospheric contaminants, fluid spills, radiation, and hazards caused by space vacuum and meteoroids.

BACKGROUND. Fire detection systems such as infrared and ultraviolet sensors, smoke alarms, and condensation nuclei counter are being developed for space. Fire suppression techniques such as CO_2, halocarbons, inert flooding, and atmosphere dump are being investigated. Similarly, various techniques for detection and repair of leaks, and radiation detectors are being investigated. A variety of spacesuit designs exists and new ones are being investigated. Final evaluation of these efforts requires testing in space.

RESEARCH DESCRIPTION. Conduct research activities in a hazard-controlled area of the space laboratory. Fire detection and suppression tested in bell jars. Tracer fluid spill detection and control conducted on large volumetric scale. Spacesuits evaluated under test and operational conditions.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Separate and self-contained isolated test area required, 10 x 10 x 10 ft. Maximum power 500 w. Leak detectors, fire extinguisher, spacesuits, etc., to simulate hazards under controlled conditions. Includes recording cameras (TV and film) and recorders with displays.

CREW. Engineers familiar with research activities and data evaluation, to control tests closely and assess safety hazards.

DATA. Video and film. Includes tested spacesuits, etc. (Information gained from tests will be immediately useful.) Voice annotations on magnetic tape.

OPERATIONS. Isolated and controlled. Spacesuit testing to include EVA. Noninterference with spacecraft baseline systems.

RESEARCH SEQUENCING. No special considerations other than emergency procedures for crew protection.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Contaminant-proof environment control and life support system; improved EVA suits.

RESEARCH COMMONALITIES. Data applicable to 1-LS-7, -8, and -12. Some equipment commonality with 4-P/C-1 and -4.

RESEARCH CLUSTER 1-LS-12—MAINTENANCE AND REPAIR

ABSTRACT

OBJECTIVES. Determine under operating conditions in the space environment the requirements for and optimum methods of maintenance, repair, and retrofit of life support systems.

BACKGROUND. Maintenance and repair techniques of systems and components have been examined in manned simulators. Final designs and maintenance and repair methods will depend upon constraints imposed on crew tasks by weightlessness and on the development of task aids techniques for spillage control. Final evaluation of techniques must be performed by man in the weightless environment.

RESEARCH DESCRIPTION. Perform routine system maintenance and task boards to observe times and degree of difficulty in disassembly, repair, and reassembly of electrical, mechanical, and fluid transmission elements of typical failed system. Annotate unscheduled maintenance requirements in detail. Television and film monitoring of maintenance operations. Examples of testing to include valve signatures via pump performance, and temperature sensor responses.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Workshop area containing maintenance task board, electric power sources, fluid locks, diagnostic equipment, zero-g hold-down equipment, and recording and display devices.

CREW. Engineers skilled in diagnosis of failures, maintenance and repair techniques, and data gathering.

DATA. All modes of recording and display. Data obtained from tests immediately applicable. Voice annotations on magnetic tape.

OPERATIONS. No special considerations, other than following maintainability procedures on advanced system components.

RESEARCH SEQUENCING. No special considerations. Task board and site operational maintenance subjected to time and motion analysis.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Aids to man's performance in maintenance and repair (see research cluster 1-MM-5).

RESEARCH COMMONALITIES. Data applicable to all research clusters in 1-LS-( ) series and for 1-BR-3, 1-MM-5, and 1-OE-2.

RESEARCH CLUSTER 1-EE-1–DATA MANAGEMENT

ABSTRACT

OBJECTIVES. Evaluate data management hardware and crew procedures in space for in-orbit processing, storage, retrieval, and display of experimental data to identify human engineering design criteria, improved procedures, and selection and training requirements.

BACKGROUND. Optimum use of man's capabilities in space and the huge amounts of data to be collected demand greater crew participation in data handling, which dictates development and test of advanced equipment, techniques, and procedures.

RESEARCH DESCRIPTION. Data management procedures developed in ground simulation will be verified in space by having crewmen perform data processing, evaluation, editing, storage, and retrieval using advanced hardware and procedures with selected experimental data generated by other experiments. Adequacy of equipment and procedures will be measured by examination of the resultant products, by automated computer scoring techniques, and by analysis of crew comments. Considerable ground-based development and experimentation will precede the inflight research.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Onboard film processing, photo enlargement, and microfilming facilities are required.

CREW. Full crew participation. Evaluation will involve three to four manhours per week throughout the four-year research program.

DATA. Photographic film, magnetic tape, crew logs (tape recorded), and computer printouts returned to Earth for detailed analysis.

OPERATIONS. No special considerations.

RESEARCH SEQUENCING. Research activities must be sequenced to coordinate with availability of data from other research clusters.

SUPPORTING TECHNOLOGY DEVELOPMENTS. None.

RESEARCH COMMONALITIES. Correlation required with other research disciplines such as Earth Observations whose data will be handled, and with 1-OE-5, which is concerned with data management operations.

RESEARCH CLUSTER 1-EE-2–STRUCTURES

ABSTRACT

OBJECTIVES. Obtain in-orbit design data on the dynamic characteristics of advanced structural concepts, including deployable, expandable, extendable, and rotating structures of the type used in solar cell arrays, large antennas, extendable booms, and expandable tunnels, airlocks, and shelters.

BACKGROUND. In-space design data are needed on mechanisms for deploying structures, large-diameter dynamic space seals, lubricant stability, thermal control, stowage and packaging, and rigidization requirements for advanced structures.

RESEARCH DESCRIPTION. Monitor the operating parameters for (1) mechanisms required for deployment of large structures, (2) prototype expandable airlocks, tunnels, or experiment bays, and (3) extendable booms for positioning various sensors. Parameters include temperature, pressure, voltages, currents, speeds of rotating machinery, dimensions of deployed and retracted structures, and crew performance in interfacing with structures. Measurement methods use visual observations, TV cameras, and manual sampling of lubricant.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Spacecraft must accommodate experimental structures in stowed condition and provide for deployment of each structure, which may involve penetrations of the vehicle shell. Viewing ports are required. Typical experiment electrical power 550 w average, 1,000 w peak.

CREW. Crewmen will act as experimental subjects and as observers.

DATA. Visual observations annotated on magnetic tape, TV vidicon, and film transmitted to Earth for ground analysis.

OPERATIONS. Logistics resupply requirements include shipment of advanced structures to orbit and return of obsolete structures. EVA activity is required for some expandable structures to be tested.

RESEARCH SEQUENCING. No special considerations, except as dictated by operational test procedures.

SUPPORTING TECHNOLOGY DEVELOPMENTS. None.

RESEARCH COMMONALITIES. Research data on crew capabilities can be used to partially fulfill requirements of 1-BR-3. Structures research can be combined with some aspects of 1-OE-3, and with 5-TF-1.

RESEARCH CLUSTER 1-EE-3–STABILIZATION AND CONTROL

ABSTRACT

OBJECTIVES. Acquire in-space engineering design and crew performance data on advanced stabilization and control systems.

BACKGROUND. Skylab A experiments and operations will contribute valuable information in this area, particularly with regard to crew motion disturbances and performance of control moment gyros. Additional in-space effort beyond Skylab A is required.

RESEARCH DESCRIPTION. Activities involve drift measurement of gyroscopic attitude controls, disturbance torque measurements, and biowaste electric propulsion. Gyro drift measurements using gyros in detached modules with data transmitted to manned spacecraft. Acceleration disturbances from various sources measured by accelerometers mounted in spacecraft. Data fed to computer for analysis. Biowaste electric propulsion system, using gases from life support methane Sabatier system, tested to evaluate thruster materials, waste collection, conditioning, and feeding and operating parameters. Measurement and recording of operating parameter data automated. Data on crew performance obtained from crew comments.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Facility must provide for remote module deployment, retrieval, docking, access to module while docked, and remote monitoring of experiment. Biowaste propulsion experiment 200 lb, 50 cu ft, 325 w.

CREW. High-level engineering skills required for intermediate assessment of data quality and necessary modifications as experiments progress.

DATA. Attitude, acceleration, system status, and voice data produced, displayed onboard, and transmitted to Earth for detailed analysis. Gas samples analyzed onboard for propellant composition.

OPERATIONS. Remote module operations accommodate drift measurement experiments on noninterference basis. Station-keeping operations augmented by biowaste electric propulsion experiment during its operation.

RESEARCH SEQUENCING. Disturbance torque measurement experiments sequenced to coincide with routine disturbances, such as docking.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Development and ground test of flight-rated biowaste resistojet.

RESEARCH COMMONALITIES. None.

RESEARCH CLUSTER 1-EE-4–NAVIGATION AND GUIDANCE

ABSTRACT

OBJECTIVES. Evaluate hardware concepts and the man-machine interface for advanced navigation and guidance systems. Qualify navigation and guidance equipment for long-duration manned spaceflight and determine man's potential contribution to its effectiveness.

BACKGROUND. Basic theory is well established and some experimental designs have been built. Inflight evaluation of hardware and the man-machine interface is needed.

RESEARCH DESCRIPTION. Investigate onboard laser ranging, interplanetary or translunar navigation by spectroscopic binary satellite, landmark tracker orbital navigation, and conduct navigation/subsystem candidate evaluation. These activities evaluate effectiveness of various types of navigation equipment and combinations of equipment to acquire, lock on, and track targets; to determine vehicle position and velocities; and to integrate various measurements for determination of orbital parameters. Experimental results compared with data derived from ground tracking and other established techniques. Measurement parameters recorded automatically for ground analysis.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Variety of advanced navigation equipment includes laser ranging devices, landmark trackers, and (if operational hardware cannot be used) transmitters and receivers. Capability for switching experimental devices into operational navigation system required.

CREW. Navigation skills required. Crew participation heavy at beginning of each experiment, but later limited to monitoring system operation, periodic adjustments, and data management.

DATA. Data displayed onboard for preliminary screening and evaluation and transmitted to ground for detailed analysis.

OPERATIONS. All experiments sensitive to space-vehicle disturbances and require correlation with space-vehicle inertial attitude.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. State-of-the-art advancements needed in onboard laser ranging systems and landmark tracking systems.

RESEARCH COMMONALITIES. Strongly correlated with navigation experiments in 5-NS-3 and may use some of same hardware.

RESEARCH CLUSTER 1-EE-5–COMMUNICATIONS

ABSTRACT

OBJECTIVES. Determine man-machine relationships and design concepts of high data rate, long-range optical communications in space.

BACKGROUND. The higher frequencies of laser beams permit more channels on a single carrier and higher rates of modulation for the carrier. Also, smaller size antennas with larger apertures can be used.

RESEARCH DESCRIPTION. Communication link required between manned spacecraft and deep-space vehicle (DSV). A prearranged transmission code established so that errors in reception correlated with events in operational situation. Equipment on deep-space vehicle consists of CO_2 laser transmitter, Pockels cell modulator, gimbaled refracting telescope for antenna, power supplies, message storage, precise timing synchronizer, and telescope pointing controls. The manned spacecraft has telescope, pointing controls, receiver, message storage and analysis, power supplies, and precise-timing synchronizer. Test messages transmitted on command from DSV to manned spacecraft evaluated for errors due to operational disturbances.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Optical and electronic equipment on manned spacecraft weigh 600 lb and occupy 42 cu ft. Average power of 50 w remains relatively constant during course of experiment.

CREW. Crew participation limited to laser beam acquisition for lock-on, then periodic monitoring by one crewman.

DATA. Three digital data channels required for communications test data, DSV status, and receiver status. Magnetic tape is primary recording mode.

OPERATIONS. In initial portion of experiment, interfering spacecraft operations may have to be curtailed to permit accurate alignment of DSV and spacecraft.

RESEARCH SEQUENCING. Since this cluster requires a deep-space vehicle and development of advanced optical communications hardware, research cannot be initiated until after 1980.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Integrated optical communications transmission and receiving system must be developed.

RESEARCH COMMONALITIES. Initial Earth-orbiting tests under 5-CS-2.

RESEARCH CLUSTER 1-OE-1–LOGISTICS AND RESUPPLY

ABSTRACT

OBJECTIVES. Evaluate logistics and resupply operational procedures and mechanical aids; evaluate and develop tools, aids, and procedures for handling emergency and rescue operations.

BACKGROUND. Mercury, Gemini, and Apollo provide valuable background information for this research cluster in rendezvous and docking, equipment transfer between vehicles, and spacecraft emergencies. Actual in-space experience with large-cargo transfer has not been obtained.

RESEARCH DESCRIPTION. Evaluate logistics, resupply, and rescue concepts developed in ground simulation. They include (1) equipment and operational procedures for transferring, handling, and storing packaged cargo, fluids, and large equipment items; (2) rendezvous and docking; and (3) emergency and rescue operations. Data collected on transfer time, ease of handling, energy expenditure, required skill levels, equipment damage or loss, and crew reaction time and mobility. Measurement methods include time and motion techniques, motion picture or TV coverage, and crew member subjective reports.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. The spacecraft environmental control and life support system must support crewman experimenter/observer in EVA mode for portions of this research. Electrical power requirements are 400 w average and peak.

CREW. Selected crewmen will require special training as experiment observers and photographers. Thorough training and indoctrination in safety procedures and practice of emergency rescue experiments in ground simulation required.

DATA. Consist of motion picture or TV film, crew [illegible] and mission data, all transmitted to Earth for analysis. No onboard data [illegible]

OPERATIONS. Simulated rescue operations of EVA crewman should be coordinated to take place in conjunction with normal EVA activities.

RESEARCH SEQUENCING. Adaptive. Observations will be taken of logistics and resupply operations as they occur.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Studies of assembly techniques.

RESEARCH COMMONALITIES. Research results for rendezvous and docking cargo transfer should be correlated with related operations in 1-OE-4.

RESEARCH CLUSTER 1-OE-2–MAINTENANCE, REPAIR, AND RETROFIT

ABSTRACT

OBJECTIVES. In-space evaluation of equipment, procedures, and manned skills required to perform (1) both IVA and EVA maintenance and repair functions, and (2) retrofit or reconfiguration in which entire spacecraft may undergo complete refurbishment.

BACKGROUND. Experience in manned spaceflight and in aircraft inflight maintenance programs has demonstrated feasibility of space maintenance. Maintenance and retrofit activities will be performed in Skylab A and follow-on flights, and a program of carefully controlled observations and measurements of these activities is necessary to develop, evaluate, and refine maintenance techniques for long-duration spaceflight.

RESEARCH DESCRIPTION. Two year research program includes observations and measurement of maintenance, repair, and retrofit operations, both IVA and EVA, performed as normal part of in-orbit space vehicle operations. Data on task times and errors, difficulties encountered, energy expenditures, and effectiveness of maintenance equipment will be obtained by direct observation, TV cameras, and crew verbal reports.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Spacecraft must support EVA activity approximately once per week. TV, video recorders, and tape recorders will have multiple usage with other research.

CREW. Engineer and technician skills required. Crewmen serve as experimental subjects and as observer/photographers.

DATA. Broadband video data can be telemetered to ground or returned via logistics vehicle for detailed analysis. Observations require about four hours of TV and two hours verbal annotation per month on magnetic tape.

OPERATIONS. To ensure adequate coverage and crew safety, some critical maintenance activities which may not occur naturally will require simulation and special scheduling.

RESEARCH SEQUENCING. No special considerations. Adaptive to maintenance incidents as they occur.

SUPPORTING TECHNOLOGY DEVELOPMENTS. None.

RESEARCH COMMONALITIES. Data obtained here will be useful in 1-BR-3, 1-MM-5, and 1-OE-3, -4.

RESEARCH CLUSTER 1-OE-3–ASSEMBLY AND DEPLOYMENT

ABSTRACT

OBJECTIVES. Evaluate and develop man's ability in EVA assembly and erection of large space structures.

BACKGROUND. Apollo lunar EVA and other zero g simulations (such as water immersion tests) have demonstrated feasibility of man performing useful work in space. Additional information will be obtained from Skylab A use of restraints and tools.

RESEARCH DESCRIPTION. First phase involves observation of assembly and deployment of unfurlable antennas and expandable structures such as crew tunnels, EVA maintenance enclosures, and airlocks. In second phase, observations will be made of operating parameters in deployed mode. The measurement program will evaluate deployment and performance characteristics of structures and physiological capabilities of man to perform necessary operations. Photographic and TV coverage and crew verbal reports will be means of measuring man's performance. Measurement parameters include time required, man's endurance level (heart beat and oxygen consumption), deflections of structure caused by temperature gradients, and dynamic stability characteristics.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Space required to stow, unstow, and deploy various structures of interest. An unfurlable antenna may weigh 500 lb and occupy 1,250 cu ft stowed, while other devices may have less impact. Measurement equipment is provided by other research clusters.

CREW. Crew will require extensive training and ground practice.

DATA. Four 100-Hz analog channels for biomedical data; one 3 MHz analog video channel; and one 2-kHz analog voice channel, indexed for time and crew member identity, and all transmitted to ground for analysis.

OPERATIONS. Vehicle operations may be curtailed during EVA.

RESEARCH SEQUENCING. Assembly and deployment phase should be sequenced early to provide maximum period for observation of deployed operating parameters.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Carefully conducted and controlled ground experiments required to define baseline for space comparison and refine assembly techniques and monitoring requirements.

RESEARCH COMMONALITIES. Closely related to 1-EE-2 and to 5-TF-1.

RESEARCH CLUSTER 1-OE-4–MODULE OPERATIONS

ABSTRACT

OBJECTIVES. Evaluate operational procedures, equipment, and man-machine interfaces involved in in-orbit operation of experiment modules flown in conjunction with manned orbital spacecraft.

BACKGROUND. Unmanned satellite programs and special module studies indicate feasibility and desirability of operating free-flying or attached experiment modules from orbital manned space facility. Problems which require in-space resolution include rendezvous and docking, module-to-space-facility communication, deployment, and retrieval, and maintenance.

RESEARCH DESCRIPTION. Activities concerned with module station-keeping, monitoring and communicating with modules, controlling module equipment, deployment and retrieval, and module maintenance and reconfiguration. Data on crew task times and errors, energy expenditures, quality of data, and response of module systems will be collected during initial six months' operation of each free-flying module. Most data can be obtained automatically from operational instrumentation and this will be augmented with TV camera coverage and crew verbal reports.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Monitor and control console require timers and other instrumentation for readouts to data management system. Electrical power requirements: 50 w average, 310 w peak. Viewing ports required.

CREW. Heavy involvement during deployment, retrieval, rendezvous and docking, and while docked; minimal otherwise. EVA required.

DATA. Data management system must provide computer programs to control acquisition and collation of data, data storage, and periodic telemetering of data to ground stations. Two hours TV observation time and 15 minutes verbal comments per month.

OPERATIONS. Observations coordinated with normal mission module operations. During rendezvous and docking and while module docked, spacecraft stability must be maintained.

RESEARCH SEQUENCING. No special considerations. Adaptive to routine occurrences.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Studies of assembly techniques.

RESEARCH COMMONALITIES. Closely related to 1-OE-2.

RESEARCH CLUSTER 1-OE-5–VEHICLE SUPPORT OPERATIONS

ABSTRACT

OBJECTIVES. Evaluate equipment, procedures, and crew skills in in-orbit provision of following support services: medical, food management, data management, power management, vehicle control, and communications.

BACKGROUND. Few guidelines or design criteria available to mission planners for estimating facilities, equipment, and procedures for centrally supplied support services in space vehicle. Evaluation necessary to support operations in space and to derive new or updated design criteria and guidelines where necessary.

RESEARCH DESCRIPTION. For each support area, make observations and measurements for initial period of six months, using crew logs, responses to questionnaires, timelines of crew time expenditures, and TV film records of selected operations. Parameters measured include time required to provide service, frequency with which service is required, time delays, availability of equipment when needed, and adequacy of equipment and procedures. Research to extend over three-year period, incorporating new criteria as they develop.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Electrical power for timing and recording measurement equipment: 50 w average; 300 w peak.

CREW. Activities of crew estimated at 32 man-hours per month responding to questionnaires, setting up cameras and lights, monitoring measurement operations, making crew log entries, and monitoring accumulation and segregation of data.

DATA. TV film records, audio tapes, and questionnaire responses, accumulated onboard and transmitted to ground for detailed analysis.

OPERATIONS. Routine operations to be observed are normal, onboard support activities, developed and thoroughly ground-tested in Earth-based simulation facilities.

RESEARCH SEQUENCING. When major changes are made in any support service operation, another six-month period of observations will be initiated.

SUPPORTING TECHNOLOGY DEVELOPMENTS. None.

RESEARCH COMMONALITIES. Data produced can be usefully correlated with 1-BM-5, 1-MM-3, 1-LS-6, and 1-EE-1.

SPACE BIOLOGY

RESEARCH CLUSTER 2-VB-1–PRELIMINARY BIOLOGY INVESTIGATIONS USING VERTEBRATES

ABSTRACT

OBJECTIVES. Increase understanding of biological processes by observing changes in fertilization, fetal development, growth, physiological function, and life span in vertebrates exposed to space environment.

BACKGROUND. Early information derived from suborbital and short orbital flights. Valuable data derived from primate experiment on Biosatellite III. Vertebrate module design being pursued at various laboratories.

RESEARCH DESCRIPTION. Rats, mice, instrumented primates in experimental modules with automated life support, waste management, and data collection. Primates instrumented before flight with implanted sensors; signals amplified and transmitted to onboard receivers, displayed and recorded on magnetic tape. Crew monitors animals, counts population and pregnancies, separates specimens for special analysis. Rats weighed for growth; embryos weighed and preserved for later analysis; some animals returned to Earth. Biocentrifuge maintains 1-g in control groups.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Experiment modules self-contained, depend on facility for data management and power. Modules 400 to 900 lb, 30 to 110 cu ft, 50 to 80 w. Onboard receiving and display equipment additionally required. Biocentrifuge, if onboard, 15- to 20-ft diameter, 3,500 lb, continuous average 450 w; may also be located in separate flight module. Centrifuge not essential for early experiments.

CREW. Task time and skill level minimal. Most data collection automated.

DATA. Notes, tapes, film, living and preserved specimens returned to Earth.

OPERATIONS. Acceleration level below 10^{-4}g 90% of time. Mission duration at least 180 days for most experiments.

RESEARCH SEQUENCING. Initial identification of changes; subsequent investigation of mechanisms of changes. Centrifuge control may be introduced in later experiments.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Zero-g animal cages, animal biocentrifuge, -180°C tissue freezer, surgical procedures.

RESEARCH COMMONALITIES. Contributes to understanding of changes observed in 1-BM-4, -5, -7, and -14, and 1-MM-4.

RESEARCH CLUSTER 2-VB-2–INTERMEDIATE BIOLOGY INVESTIGATIONS USING VERTEBRATES

ABSTRACT

OBJECTIVES. Improve definition of role of gravity in vertebrate behavior, physiology, reproduction, response to stimuli, and host-parasite relationships by measuring changes in these functions in space.

BACKGROUND. Biosatellite III results indicate that primate body-fluid balance is profoundly upset by weightless environment. Primate and small-animal experiments and modules being designed at various NASA and university facilities.

RESEARCH DESCRIPTION. Typical experiments include measurement of nerve action potentials, strength of muscle contraction, whole animal calorimetry, bone strength, antibody titer, spermatogenesis, psychomotor activities, and transport processes. Some experiments involve automated modules; most performed on subjects removed from cages in animal facility. Experimental techniques require animal manipulation and surgery, histological preparations, and laboratory analyses, including scintillation counting, mass spectrometry, spectrophotometry, gas chromatography, and amino-acid analysis. Biological specialists at least at technician skill level.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Onboard laboratories for animal surgery and testing, tissue preparation, and biochemical analysis. Animal holding facility for primates, rats, mice, cats, and dogs. Environmental control must isolate animals' atmosphere from crew's. Management of animal waste.

CREW. Skilled technician, full time. Cross-trained crewmen, part time.

DATA. Notes, tapes, film, stripchart recordings, and living and preserved specimens returned to Earth. Some taped data telemetered to ground.

OPERATIONS. Acceleration level of 10^{-4}g maintained 95% of time. Crew interaction with animal facilities rigorously controlled. Continuous 180 days required for some experiments.

RESEARCH SEQUENCING. Preliminary observations precede and govern intermediate research. Detailed examination of mechanisms will follow.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Zero-g animal cages, surgical procedures, tissue processor, -180°C tissue freezer, liquid handling, equipment analysis and integration.

RESEARCH COMMONALITIES. Contributes information to 1-BM-4, -5, -7, and -14, and 1-MM-4.

RESEARCH CLUSTER 2-VB-3—ADVANCED BIOLOGY INVESTIGATIONS USING VERTEBRATES

ABSTRACT

OBJECTIVES. Improve understanding of role of gravity and Earth-lunar periodicities in basic biological processes such as enzyme activity, energy production and transfer, membrane phenomena, and transport mechanisms by investigating mechanisms associated with earlier observed changes in vertebrates in space.

BACKGROUND. Changes in wide variety of biological forms noted in Biosatellite experiments and in terrestrial simulations of weightlessness. No study of mechanisms performed during study of change.

RESEARCH DESCRIPTION. No detailed experiments can be specified until changes are determined in earlier phases. Investigations will include studies at subcellular level. Radioactive and heavy or light isotopes will be used as tracer atoms. Tagged substrates will be reacted with isolated enzyme systems and enzyme activity determined by isotope disappearance from substrate or appearance in reaction products. Full range of sophisticated laboratory techniques will be utilized requiring advanced instrumentation and highly skilled investigators.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Facilities for 2-VB 1 and -2 utilized, in addition, facilities to provide capability for preparation of tissue grafts, partition chromatography, electrodialysis, electrophoresis and scintillation counting (liquid and well). Most resources shared by all areas of space biology research.

CREW. Research team: one or more principal investigators, two experienced technologists, all time.

DATA. Notes, tape, stripchart records, film, and some biological samples returned to Earth. Minimal data telemetering.

OPERATIONS. Acceleration levels of 10^{-4} g a continued requirement. Rigorous control of animal facility and laboratory environment. Most experiment durations at least 180 days.

RESEARCH SEQUENCING. Experiments governed by previous finding.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Zero-g homogenizer, dialysis equipment, fluid electrolyte analyzer, small-particle mass measurement, and equipment analysis and integration.

RESEARCH COMMONALITIES. Information to 1-BM-5, -10, and -14.

RESEARCH CLUSTER 2-IN-1—PRELIMINARY BIOLOGY INVESTIGATIONS USING INVERTEBRATES

ABSTRACT

OBJECTIVES. Increase understanding of aging, orientation, coordination, tidal and diurnal rhythms, genetics, and metabolism by observing changes in these processes in invertebrates exposed to space environment.

BACKGROUND. Influence of space environment on invertebrates established in Biosatellite II experiments. No weightlessness simulating device effective for invertebrate ground-based experiments.

RESEARCH DESCRIPTION. *Drosophila* behavior, life-cycle phenomena, and circadian rhythm; housefly aging; fiddler crab color change related to tidal rhythms; beetle embryogenesis and development; and spider web building activities. Most experiments in self-contained experimental modules with photographic and metabolic measurement capabilities. Crew tasks minimal: visual check of experiment progress, counting, sorting, and preservation of specimens, observation of abnormalities, and preparation of living specimens for Earth return. Onboard biocentrifuge desired for 1-g control subjects.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Experimental modules, approximately 40 lb, 2 cu ft, and 10 to 50 w each, provide pressure (Earth ambient), temperature (25°C), relative humidity (75%), 12-hour light-dark cycles, and photographic coverage. Biocentrifuge, 20-ft diameter, 3,500 lb, continuous average 450 watts; not essential for earlier experiments.

CREW. Most data collection automated. Additional tasks by cross trained crewmen.

DATA. Notes, tapes, film, specimens returned to Earth.

OPERATIONS. Acceleration level below 10^{-4}g 95% of time. Required mission duration minimum of 90 days. Experiment progress independent of crew cycles.

RESEARCH SEQUENCING. Preliminary experiments; subsequent research to investigate nature of observed changes.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Development of biocentrifuge, and development of advanced -180°C tissue freezer.

RESEARCH COMMONALITIES. Contributes to understanding of changes observed in 1-BM-5 and 1-MM-4.

RESEARCH CLUSTER 2-IN-2—INTERMEDIATE BIOLOGY INVESTIGATIONS USING INVERTEBRATES

ABSTRACT

OBJECTIVES. Increase understanding of biological processes by more complete examination of changes observed during experiments in preliminary phase.

BACKGROUND. Influence of space environment on invertebrates established in Biosatellite II experiments. Effects of weightlessness alone and zero-g enhancement of radiation effects were observed. No terrestrial weightlessness-simulating devices effective on invertebrates.

RESEARCH DESCRIPTION. Onboard comparisons between invertebrates in zero-g and artificial-g (biocentrifuge) controls. Dissection, tissue preparation, and microscopic examination of tissue samples. Initial experiments of metabolic pathways using radioactive tags on whole specimens or simple homogenates. Some experiments involve automated experimental modules, but most will involve invertebrate colonies in animal holding facilities. Increased facilities include tissue processing and biochemical analytical laboratories. Full-time biological research specialist required.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Holding facility for colonies of invertebrates. Onboard biocentrifuge, l-g at maximum radius of 10 to 12 ft, continuous 450 w. Tissue preparation laboratory: automatic tissue processor, vacuum infiltration oven, microtome, and compound microscope with built-in camera. Spectrophotometer, mass spectrometer, gas chromatograph, tissue homogenizer, and radiation detection equipment also required.

CREW. Skilled technician, full time. Part-time assistance of crewmen.

DATA. Notes, tapes, film, and specimens returned to Earth. Minimal telemetering of stored data at infrequent intervals.

OPERATIONS. Acceleration levels of 10^{-4}g required 95% of time. Environmental control of invertebrate holding facility separate from crew's.

RESEARCH SEQUENCING. Preliminary observations precede and govern intermediate research. Detailed investigation of mechanisms follow.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Animal biocentrifuge, tissue processor, zero-g homogenizer, and equipment analysis and integration.

RESEARCH COMMONALITIES. Contributes to understanding of changes observed in 1-BM-5 and 1-MM-4.

RESEARCH CLUSTER 2-IN-3—ADVANCED BIOLOGY INVESTIGATIONS USING INVERTEBRATES

ABSTRACT

OBJECTIVES. Improve understanding of role of gravity and Earth-lunar periodicities in basic biological processes such as enzyme activity, energy production and transfer, membrane phenomena, and transport mechanisms by investigating mechanisms associated with earlier observed changes in invertebrates in space.

BACKGROUND. Changes in wide variety of biological forms noted in Biosatellite experiments and in terrestrial simulations of weightlessness. No study of mechanisms performed during study of change.

RESEARCH DESCRIPTION. No detailed experiments can be specified until changes are determined in earlier phases. Investigations will include studies at subcellular level. Radioactive and heavy or light isotopes will be used as tracer atoms. Tagged substrates will be reacted with isolated enzyme systems and enzyme activity determined by isotope disappearance from substrate or appearance in reaction products. Full range of sophisticated laboratory techniques will be utilized requiring advanced instrumentation and highly skilled investigators.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Facilities for 2-IN-1 and -2 utilized; in addition, facilities to provide capability for preparation of tissues, partition chromatography, electrodialysis, electrophoresis and scintillation counting (liquid and well). Most resources are shared by all areas of space biology research.

CREW. Research team: one or more principal investigators, two experienced technologists, full time.

DATA. Notes, tape, stripchart records, film, and some biological samples returned to Earth. Minimal data telemetering.

OPERATIONS. Acceleration levels of 10^{-4}g a continued requirement. Rigorous control of animal facility and laboratory environment. Most experiment durations at least 180 days.

RESEARCH SEQUENCING. Experiments governed by previous findings.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Zero-g homogenizer, dialysis equipment, fluid electrolyte analyzer, small-particle mass measurement, and equipment analysis and integration.

RESEARCH COMMONALITIES. Information to 1-BM-5, -10, and -14.

RESEARCH CLUSTER 2-P/T-1—PRELIMINARY BIOLOGY INVESTIGATIONS USING UNICELLULAR SPECIMENS

ABSTRACT

OBJECTIVES. Observe abnormalities in microorganisms and tissue cultures caused by weightlessness.

BACKGROUND. Biosatellite II used protists and tissues including bread mold, frog eggs, amoebae, and bacteria. Skylab A will include experiment S-015 on the effect of zero-g on human cells.

RESEARCH DESCRIPTION. Preliminary investigations include microscopic examination of fertilized frog eggs to determine cellular growth structure and organization; visual measurements and photography of colony size, colonial morphology and conidial density in bread mold; determination of growth rates and frequency of mutation, transformation, and conjugation in bacterial cultures by optical density measurements, selective media and culture preparation and plating, and DNA extraction. Crewmen used for tasks not requiring excessive amounts of onboard time or preparatory training, such as media preparation, culture transfer, organism identification, photography and visual observations.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Experiments contained in automated modules. Additional items such as sterilizer, incubator, microscope, optical densitometer and media preparation equipment required. Special atmosphere requirements will be supplied and maintained by individual modules.

CREW. No special skills required. Tasks can be taught in short time. Individual experiments require average of 1 to 1.5 crew-hours per day.

DATA. Notes, film, and specimens returned to Earth.

OPERATIONS. Individual experiments during any continuous 30-day period; colonies and cultures maintenance from start of mission. Temperature of incubator carefully monitored. Acceleration level below 10^{-4} g 90% of time.

RESEARCH SEQUENCING. Initial identification of changes; subsequent investigation of mechanisms of changes.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Zero-g autoclave and incubator.

RESEARCH COMMONALITIES. Contributes information to 1-BM-5 and 1-LS-7.

RESEARCH CLUSTER 2-P/T-2—INTERMEDIATE BIOLOGY INVESTIGATIONS USING UNICELLULAR SPECIMENS

ABSTRACT

OBJECTIVES. Improve definition of spaceflight factors in microbiological host-parasite relationships and in basic cellular processes by more complete examination of changes observed in preliminary research on protists and tissue cultures in space.

BACKGROUND. Bread mold, frog egg, amoeba, and bacteria experiments on Biosatellite II. Human cell experiment on Skylab A.

RESEARCH DESCRIPTION. Studies on aerosol stability, effects of particle size on stability, dissemination rate, degree of penetration into respiratory tract, microbial viability in aerosols, and degree of infection from aerosol-borne bacteria. Air-particle sampling under various conditions, viable plate count by the Andersen method, and animal exposure, sacrifice, and examination for infections and particles in respiratory tract. Colony counting and identification of cultures from crew samples to determine alterations in normal flora, investigations of immune reactions of crew and vaccinated animals.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Sterilizer, media and plate preparation equipment, incubator, colony counter, microscope, and optical densitometer in common with 2-P/T-1. Aerosolizer and particle sampler; animal colonies; small-animal surgery, autopsy, and tissue preparation facilities; and blood chemistry laboratory in common with other areas of space biology research.

CREW. Microbiological technicians, full time. Scientist-astronaut qualified in study of infectious diseases, part time.

DATA. Notes, tape, specimens, and samples returned to Earth. Minimal data telemetry.

OPERATIONS. Acceleration level of 10^{-4}g desirable 90% of time. Most experiments require 30 days, should be repeated over 1 year.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Autoclave, incubator, tissue processor, bunsen burner substitute, automated microbial identification, and equipment analysis and integration.

RESEARCH COMMONALITIES. Information to 1-BM-5 and 1-LS-7.

RESEARCH CLUSTER 2-P/T-3—ADVANCED BIOLOGY INVESTIGATIONS USING UNICELLULAR SPECIMENS

ABSTRACT

OBJECTIVES. Improve understanding of role of gravity and Earth lunar periodicities in basic biological processes such as enzyme activity, energy production and transfer, membrane phenomena, and transport mechanisms by investigating the mechanisms associated with earlier observed changes in protists and tissue cultures.

BACKGROUND. Changes in wide variety of biological forms noted in Biosatellite experiments and in terrestrial simulations of weightlessness. No study of mechanisms performed during study of change.

RESEARCH DESCRIPTION. No detailed experiments can be specified until changes are determined in earlier phases. Investigations will include studies at subcellular level. Radioactive and heavy or light isotopes will be used as tracer atoms. Tagged substrates will be reacted with isolated enzyme systems and enzyme activity determined by isotope disappearance from substrate or appearance in reaction products. Full range of sophisticated laboratory techniques will be utilized requiring advanced instrumentation and highly skilled investigators.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES Facilities for 2-P/T-1 and -2 utilized, in addition, facilities to provide capability for preparation of tissue cultures, partition chromatography, electrodialysis, electrophoresis and scintillation counting (liquid and well). Most resources are shared by all areas of space biology research.

CREW. Research team one or more principal investigators, two experienced technologists, full time.

DATA. Notes, tape, stripchart records, film, and some biological samples returned to Earth. Minimal data telemetering.

OPERATIONS. Acceleration levels of 10^{-4}g a continued requirement. Rigorous control of animal facility and laboratory environment. Most experiment durations at least 180 days.

RESEARCH SEQUENCING. Experiments governed by previous findings.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Zero-g homogenizer, dialysis equipment, fluid electrolyte analyzer, small-particle mass measurement, and equipment analysis and integration.

RESEARCH COMMONALITIES. Information to 1-BM-5, -10, and -14.

RESEARCH CLUSTER 2-PL-1—PRELIMINARY BIOLOGY INVESTIGATIONS USING PLANTS

ABSTRACT

OBJECTIVES. Increase understanding of biological phenomena by investigation of physiological, gross morphological, and histochemical changes in plants due to the absence of gravity and cyclical cues.

BACKGROUND. Morphological and physiological changes observed in wheat seedlings and young leafy pepper plants in the Biosatellite II flights. Similar responses noted during weightlessness simulation on clinostats.

RESEARCH DESCRIPTION. Plant colonies, including *arabidopsis*, cucumber, and potato, observed periodically and preserved for subsequent ground based analysis. Tropistic responses and rhythmic movements photographed; respiration monitored by automated equipment. More sophisticated metabolic, genetic, and developmental studies performed on ground on returned freeze-preserved tissues. Crew activities restricted to maintaining colonies, harvesting, reseeding, preservation, and preparation of plants and tissues for return.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Colonies in experimental modules which depend on facility only for data management and power. Photography, respiration monitoring, and control of module environment are intrinsic to modules. Modules typically 80 lb, 2 to 9 cu ft, average of 20 to 40 w. Biocentrifuge 1 g control specimens desirable but not essential.

CREW. Minimal time of cross trained crewman required.

DATA. Notes, tape, film, and preserved and intact specimens returned to Earth.

OPERATIONS. Acceleration levels below 10^{-4}g essential 95% of time. Maintenance of plant colonies; visual checks of module functions, harvesting, replanting of seeds, preservation, preparation of plants and tissues for return. Mission duration at least 90 days.

RESEARCH SEQUENCING. Initial observation of changes; subsequent examination of altered parameters and study of mechanisms.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Amino-acid analyzer, -180°C tissue freezer.

RESEARCH COMMONALITIES. None.

RESEARCH CLUSTER 2-PL-2—INTERMEDIATE BIOLOGY INVESTIGATIONS USING PLANTS

ABSTRACT

OBJECTIVES. Increase understanding of biological phenomena by more complete investigation of physiological and structural changes in plants observed in preliminary phase of plant research in space.

BACKGROUND. Morphological and physiological changes observed in wheat seedlings and young leafy pepper plants in Biosatellite II. Similar responses noted during weightlessness simulation on clinostats.

RESEARCH DESCRIPTION. Investigations of respiration and photosynthetic activity, metabolic pathways, histochemical abnormalities, and lipid and protein catabolism selected to define more clearly nature of earlier observed changes. Plant tissue preparation and microscopic examination, chemical analyses of homogenized tissue by chromatography, spectrophotometry, mass spectrometry, amino acid analyses, and radioisotopic techniques. Increased participation of cross-trained crew members. Full-time experienced biological research technician required.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Some automated modules, plant colonies in controlled atmosphere facility. Refrigerated centrifuge, homogenizer, dialysis equipment, tissue processor, microtome and microscope for tissue preparation. Spectrophotometer, mass spectrometer, gas chromatograph, radiation detectors, and potentiometric measuring devices for analysis laboratory.

CREW. Full-time participation of experienced and skilled biology research technician. Part time assistance of trained crewmen.

DATA. Notes, tapes, film stripchart recordings, and plant specimens and tissue samples returned to Earth. Minimal data telemetering.

OPERATIONS. Acceleration levels of 10^{-4}g 95% of time. One-g controls on biocentrifuge. Controlled access to plant facility and laboratories.

RESEARCH SEQUENCING. Preliminary observations precede and govern intermediate research. Detailed investigation of mechanisms will follow.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Animal biocentrifuge, tissue processor, zero-g homogenizer, and equipment analysis and integration.

RESEARCH COMMONALITIES. None

RESEARCH CLUSTER 2-PL-3—ADVANCED BIOLOGY INVESTIGATIONS USING PLANTS

ABSTRACT

OBJECTIVES. Improve understanding of role of gravity and Earth-lunar periodicities in basic biological processes such as enzyme activity, energy production and transfer, membrane phenomena, and transport mechanisms by investigating mechanisms associated with earlier observed changes in plants in space.

BACKGROUND. Changes in wide variety of biological forms noted in Biosatellite experiments and in terrestrial simulations of weightlessness. No study of mechanisms performed during study of change.

RESEARCH DESCRIPTION. No detailed experiments can be specified until changes are determined in earlier phases. Investigations will include studies at subcellular level. Radioactive and heavy or light isotopes will be used as tracer atoms. Tagged substrates will be reacted with isolated enzyme systems and enzyme activity determined by isotope disappearance from substrate or appearance in reaction products. Full range of sophisticated laboratory techniques will be utilized requiring advanced instrumentation and highly skilled investigators.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Facilities for 2-PL-1 and -2 utilized; in addition, facilities to provide capability for preparation of tissues, partition chromatography, electrodialysis, electrophoresis and scintillation counting (liquid and well). Most resources shared by all areas of space biology research.

CREW. Research team: one or more principal investigators, two experienced technologists, full time.

DATA. Notes, tape, stripchart records, film, and some biological samples returned to Earth. Minimal data telemetering.

OPERATIONS. Acceleration levels of 10^{-4}g a continued requirement. Rigorous control of animal facility and laboratory environment. Most experiment durations at least 180 days.

RESEARCH SEQUENCING. Experiments governed by previous findings.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Zero-g homogenizer, dialysis equipment, fluid electrolyte analyzer, small-particle mass measurement, and equipment analysis and integration.

RESEARCH COMMONALITIES. Information to 1-BM-5, -10, and -14.

SPACE ASTRONOMY

RESEARCH CLUSTER 3-OW—OPTICAL STRUCTURE AND SPECTRA OF FAINT OR SMALL SOURCES

ABSTRACT

OBJECTIVES. Improve discrimination among cosmological models; determine properties of galaxy nuclei and quasars; stellar populations and emission mechanisms in galaxies. Elucidate structure of globules and small dark nebulae, comet nuclei, the outer planets, and large planetary satellites.

BACKGROUND. Ground-based observations fail to discriminate between major classes of cosmological models. Optical structure of quasars and most galaxy nuclei are poorly resolved and UV data are lacking. Study of structure of globules, fine structure of comet nuclei, and outer planet and large satellite structure and surfaces also generally limited by resolution.

RESEARCH DESCRIPTION. High angular resolution visible, UV, near-infrared imagery and photometry of galaxies, quasars, globules, comet nuclei, outer planets, large satellites. High-resolution UV spectroscopy of quasars, visible and near-infrared spectroscopy of faint galaxies. Uses 3-m diffraction-limited telescope with precision guidance.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Free-flying module for telescope. Optimum orbit geosynchronous.

CREW. Mechanical, electronic, and optical technicians. EVA assembly and periodic servicing.

DATA. Electronic and photographic (film and probably plates).

OPERATIONS. Man-aided assembly and deployment in free orbit. Activation and target acquisitions on remote command from ground. Data-taking automatic. Periodic supply (film) and servicing by men.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. High-resolution optics, precision target acquisition; film handling and protection in space; ground-to-high-orbit transportation; image tubes.

RESEARCH COMMONALITIES. Related research (extension of accurate galaxy distances, search for new satellites of outer planets) in 3-OS. 3-OB, and 3-OP use same telescope.

RESEARCH CLUSTER 3-OB—HIGH-RESOLUTION PLANETARY OPTICAL IMAGERY

ABSTRACT

OBJECTIVES. Elucidate long-period dynamic phenomena of Mars surface and atmosphere. Map Mercury to 30- to 100-km resolution for improved topographic study; seek evidence of atmosphere on Mercury.

BACKGROUND. Planet flyby observations achieve extremely high disk resolution but are limited in time. The one planned Mercury flyby will map only modest fraction of planet. Ground-based observation unlimited in time, but limited to poor angular resolution. Balloon observations gain little for Mercury and too limited for Mars study. Research cluster permits longer-time coverage than planet flybys and better angular resolution than ground-based telescopes.

RESEARCH DESCRIPTION. High-resolution multicolor imagery (UV to near-infrared) of Mars and Mercury over periods of years. Follow-on spectroscopy and precision photometry. Extension to Jupiter and Saturn. Uses 1- and 3-m diffraction-limited telescopes, precision guidance.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Free-flying modules for telescopes. Possible 1-m telescope controls in space station. 3-m telescope, optimum orbit geosynchronous.

CREW. Mechanical, electronic, and optical technicians. EVA assembly and periodic servicing.

DATA. Electronic and photographic (film).

OPERATIONS. Man-aided assembly and/or deployment of telescopes in free orbits. Target acquisitions by remote control, possibly (1-m telescope) involving operator in space station. Data-taking automatic. Periodic resupply (film) and servicing by men.

RESEARCH SEQUENCING. (a) 1-m Mercury mapping; (b) 1-m Mars observations; (c) 3-m Mercury mapping; (d) 3-m Mars observations. Some overlaps due to sun angle, planet distances from Earth.

SUPPORTING TECHNOLOGY DEVELOPMENTS. High-resolution optics; precision target acquisition; film handling, protection in space; image tubes.

RESEARCH COMMONALITIES. 3-OS and 3-OP use 1-m telescope, 3-OW uses 3-m telescope.

RESEARCH CLUSTER 3-OS—FAINT-THRESHOLD, HIGH-RESOLUTION OPTICAL SURVEYS

ABSTRACT

OBJECTIVES. Improve determination of globular cluster populations, ages, compositions; extend accurate galaxy distance determinations to tens of megaparsecs; identify and determine properties of optical counterparts of x-ray sources and pulsars; improve census of small solar system bodies.

BACKGROUND. Globular cluster properties based mostly on giant star members; data on main sequence members needed. Galaxy distances accurate only to distances up to 4 to 10 megaparsecs, which is cosmologically insignificant. Data for more optical counterparts of x-ray sources and pulsars essential to elucidate nature of latter. Small solar system bodies are of system evolution interest.

RESEARCH DESCRIPTION. Imagery and photometry of main sequence stars in globular clusters, luminous objects in galaxies (Cepheids, HII regions, etc.), fields of x-ray sources, pulsars, planets, and selected others. Visual threshold 24 to 26 mag., comparable UV limits. Angular resolution 0.1 to 0.2 arc-sec. Follow-on spectroscopy, especially in UV. Uses 1- and 3-m telescopes with precision guidance.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Free-flying modules for telescopes, pointing controls, TV monitor, and supplies (e.g., film) possibly in space station.

CREW. Mechanical, electronic, and optical technicians. EVA assembly and periodic servicing.

DATA. Electronic and photographic (probably film only).

OPERATIONS. Man-aided assembly and/or deployment of telescopes in free orbits. Target acquisition by remote control, possibly involving operator in space station. Data-taking automatic. Periodic resupply (film) and servicing by men.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. High-resolution optics, precision target acquisition, film handling and protection in space, image tubes.

RESEARCH COMMONALITIES. Common research programs with 3-XR. 3-OB, and 3-OP use same telescopes.

RESEARCH CLUSTER 3-OP—HIGH-PRECISION STELLAR PHOTOMETRY

ABSTRACT

OBJECTIVES. Seek flare or spot activity in stars (especially solar types), evidence of planetary companions (dwarf stars). Obtain improved binary orbit inclinations, member and system properties. Better understand variable star mechanisms and evolution of massive stars in brief stages.

BACKGROUND. Dwarf flare stars exist, but flare, spot, etc., activity in solar-type stars is unproven. Such activity may be a key age indicator. Extremely shallow eclipses in binary stars, or eclipses by planetary companions, are unobservable from ground, due to limited photometric precision. Small-amplitude stellar variability study is in infancy, as is study of secular variability.

RESEARCH DESCRIPTION. Extreme precision visible and UV photoelectric photometry of type G, K, M dwarf stars, selected O stars, super giants, Cepheids, and other variables. Aim for 10^{-4}- to 10^{-5}-mag. precision. Seek irregular (flares), near-periodic (spots), and periodic (eclipses) fluctuations. Compare 10-year data for secular changes. Uses 1-m or larger diffraction-limited telescope with precision guidance and low-noise photometer.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Free-flying modules for telescopes. Possible (1-m telescope) pointing control in space station.

CREW. Mechanical, electronic, and optical technicians. EVA assembly and periodic servicing.

DATA. Electronic, transmittable to ground.

OPERATIONS. Man-aided assembly and/or deployment of the telescopes in free orbits. Target acquisition by remote control, possibly involving operator in space station. Data-taking automatic. Servicing by men.

RESEARCH SEQUENCING. Uncertain until optimum search patterns devised. Patrol-type observations would be impractically lengthy.

SUPPORTING TECHNOLOGY DEVELOPMENTS. High-resolution optics; precision target acquisition; low-noise photometers (critical); signal filtering; optimum search techniques.

RESEARCH COMMONALITIES. 3-OS and 3-OB use the 1-m telescope.

RESEARCH CLUSTER 3-SO—SOLAR PHOTOSPHERE AND CHROMOSPHERE OPTICAL STUDIES

ABSTRACT

OBJECTIVES. Improved determination of gross physical properties of quiet photosphere and chromosphere, e.g., temperature, pressure, composition distributions. Elucidate properties of details such as granulation, spots, prominences, etc.; magnetic fields, temporal relations of active phenomena.

BACKGROUND. Visible and UV wavelength observations indicate increasing complexity of photosphere and chromosphere structures with better spatial and spectral resolution. Study of temporal development of active phenomena contributes increasingly to understanding solar atmosphere energetics. Needed are substantial angular resolution improvement in UV, better combined angular and spectral resolution in visible, together with long-period monitoring.

RESEARCH DESCRIPTION. Broadband, time-lapse imagery of solar disk with 0.1- to 0.5-arc-sec resolution. Monochromatic imagery (spectroheliography) with a 0.5- to 1.0-arc-sec resolution. Spectroscopy with $\leqslant$0.01 Å and 1- to 3-arc-sec resolution. Wavelengths 1,000 Å to 1μ. Uses 60-in. f/75 telescope with precision guidance and numerous specialized secondary instruments.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Free-flying module for telescope. Sun-synchronous orbit necessary.

CREW. Mechanical, electronic, optical technicians. EVA assembly and periodic servicing.

DATA. Electronic and photographic (film only).

OPERATIONS. Man-aided assembly and/or deployment in free orbit. Target acquisitions by remote control, probably from ground. Data-taking automatic. Periodic resupply (film) and servicing by men.

RESEARCH SEQUENCING. Some observations coordinated with ground-based, satellite or other observations; e.g., in monitoring active events in several wavelength ranges.

SUPPORTING TECHNOLOGY DEVELOPMENTS. High-resolution optics, especially including thermal control; precision target acquisition; film handling and protection in space; image tubes.

RESEARCH COMMONALITIES. Solar cosmic ray (4-CR-1, -2, -4, -5) and gamma ray (4-CR-3) measurements.

RESEARCH CLUSTER 3-XR—IDENTIFICATION AND STUDY OF DISCRETE X-RAY SOURCES

ABSTRACT

OBJECTIVES. Identify and determine size, structure, spatial distribution, radiation mechanisms of discrete x-ray sources. With improved precision, determine angular distribution of diffuse x-ray background.

BACKGROUND. Sources identified with supernovae ejecta or remnants, peculiar bluish stars, radio galaxies. Others possible are Wolf-Rayet stars, novae, planetary nebulae. Accurate positions, images, and spectral energy distributions needed. X-ray background appears uniform, but improved photometry may reveal variations due to multiple components.

RESEARCH DESCRIPTION. (A) Conduct sky, selected area surveys for new discrete sources; locate known sources more precisely; determine angular size upper limits; obtain improved spectral energy distributions; monitor sources for variability. Use 200-sq ft proportional counter array, 1- to 20-kev range, continuous sky-scanning mode, 0.1- to 30-arc-min angular resolution. (B) Image known sources to 1-arc-sec resolution; spectroscopy and precision photometry. Use 750-sq in. grazing-incidence telescope.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Free-flying modules for telescope and proportional counter array. X-ray telescope pointing controls, TV monitor possibly required in space station.

CREW. Electromechanical, optical technicians (> 5 years experience), EVA assembly and periodic servicing.

DATA. Program (A): electronic data, sorted on magnetic tape, directly transmittable to ground. Program (B): photographic (film), electronic data.

OPERATIONS. Assembly x-ray telescope, proportional counter array, deploy both in free orbits. Counter array automatic. Telescope with man-aided target acquisition by remote control, TV monitor; other phases automated.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. High-resolution optics; precision target acquisition system; film protection, handling, use in space.

RESEARCH COMMONALITIES. Some sources may be detectable at gamma-ray energies (4-CR-3); simultaneous measures valuable. Optical observation of sources important to elucidate physical nature (3-OS).

RESEARCH CLUSTER 3-LF—LOCATION, STRUCTURE, AND PROPERTIES OF LOW-FREQUENCY RADIO SOURCES

ABSTRACT

OBJECTIVES. Identify and determine physical properties and emission and absorption mechanisms of discrete LF sources, LF background components, and intervening media.

BACKGROUND. No resolved discrete sources yet detected outside solar system. Radio galaxies, quasars, galactic HII regions, supernovae remnants, and the Galaxy's nucleus are prime candidates. LF background has been mapped to only 45- to 60-degree resolution in 0.4- to 10-MHz range with fair spectral resolution and radiometric precision.

RESEARCH DESCRIPTION. Scan sky sequentially at approximately 1[illegible] fixed frequencies in 0.1- to 10-MHz range, using 5-km log rhombic antenna with beamwidth 6 to 16 degrees for background mapping, joined to short dipole array forming an interferometer with 2-degree resolution for discrimination of discrete sources. Should detect about 100 discrete sources and greatly improve angular and spectral resolution of background.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Launch antenna package to geosynchronous orbit or higher. Infrequent returns for servicing.

CREW. Technicians. EVA servicing of antenna propulsion system and possibly electronics.

DATA. Electronic, transmitted to ground.

OPERATIONS. Antenna system deployment, activation, operation (continuous sky scan) and data-taking are automatic, with data transmitted to ground.

RESEARCH SEQUENCING. No special considerations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Study of automatic versus man-aided antenna deployment and servicing.

RESEARCH COMMONALITIES. No special considerations.

SPACE PHYSICS

RESEARCH CLUSTER 4-P/C-1—EFFECT OF THE SPACE ENVIRONMENT ON CHEMICAL REACTIONS

ABSTRACT

OBJECTIVES. Establish effects of near-zero gravity and absence of walls on chemical reactions, including combustion phenomena, with variances in materials and mixing processes.

BACKGROUND. Some data on flammability in zero-g generated from short-duration drop-tower and aircraft tests. Skylab A flammability experiment (M-749) will provide initial information for expanding scope of this research.

RESEARCH DESCRIPTION. React a variety of liquids and solids in various environments. Measure reaction/combustion products, reaction rates, flame-front profiles, temperatures, pressures and acceleration levels. Progress from simple to complex, as follows: (1) burn several solids at various O_2 partial pressures; (2) burn liquid hydrocarbons as above; (3) impinge hypergolic fuels and oxidizers at various mixtures, (4) burn various metals in different atmospheres. Accelerometers, pressure transducers, cameras, spectrometers, and pyrometers will be used to measure the various parameters.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Viewported combustion pressure vessel for tests; power, 750 w. Mass spectrometer, gas chromatograph, various gages and measuring devices.

CREW. Instrumentation specialist, to set controls, position test samples, and record visual observations.

DATA. Pressures, temperatures, and reaction-product species recorded on strip charts; flame-front profile on time-sequenced photographic film; residue test specimens returned for later analysis.

OPERATIONS. Film resupply. Combustion chamber effluents controlled to prevent interference with other research. Some personnel safety hazard.

RESEARCH SEQUENCING. Burn must be allowed to proceed uninterrupted. Activity sequence described at left.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Contaminant-proof environmental control and life support system in case of accidental escape of gases; self-balancing, rapid-response optical pyrometer.

RESEARCH COMMONALITIES. Apparatus common with other 4-P/C-( ) research clusters; some commonality with 1-LS-11.

RESEARCH CLUSTER 4-P/C-2—SHAPE AND STABILITY OF LIQUID-VAPOR INTERFACES

ABSTRACT

OBJECTIVES. Obtain data on nature and degree of instabilities at liquid-vapor interfaces for both cryogenic and noncryogenic liquids under various low-g conditions.

BACKGROUND. Linear analysis of liquid surface motion during filling and draining of tanks in low-g has been performed. Simple models of axisymmetric reorientation flow partially confirmed by drop-tower tests, but nonlinear effects (geyser decay, bubble entrainment) not observable due to short observation time. Long-term low-g data required to provide basic design information for future life support and propulsion systems.

RESEARCH DESCRIPTION. Viewported tanks with removable baffles and pressurization nozzles used to study static liquid-vapor interface shape, reorientation flow following tank accelerations, liquid sloshing response, interface dynamics during venting, pressurization, filling and draining; also surface shape and stability of rotating liquid drops. Wide range of vibration and g levels. Liquid dynamic behavior photographed. Vibration signature, g-level, tank configuration also of interest.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. 400-w power, two or more 600-kg test tanks, variable frame-rate movie camera, mass flowmeter, optical pyrometer, rotational speed indicator, and associated recording equipment.

CREW. Physicist (technician level), to prepare tank, operate valves, and monitor events.

DATA. Magnetic tape and movie film. Data run approximately 4 hr per test cycle.

OPERATIONS. Tank venting must be coordinated with other research activities; film resupply necessary. Constant acceleration not to exceed ± 0.1 cm sec^{-2} during test data run.

RESEARCH SEQUENCING. Initial tests use transparent tank with simulated cryogenics. Later tests use superinsulated tanks with viewports and hard cryogenic liquids.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Low-g accelerometer and isolation mounts; g-level control; onboard film processing.

RESEARCH COMMONALITIES. Some apparatus common with other 4-P/C-( ) research clusters. Common objectives with 1-LS-1.

RESEARCH CLUSTER 4-P/C-3—BOILING AND CONVECTIVE HEAT TRANSFER IN ZERO-GRAVITY

ABSTRACT

OBJECTIVES. Determine effect of gravity level on incipient and nucleate boiling and convective heat transfer.

BACKGROUND. Free and forced convection adequately described by theory and confirmed by 1-g testing, but no known data available regarding low-g behavior. No comprehensive boiling theory includes effects of gravity. In limited drop-tower and low-g aircraft tests, observation time too short for spacecraft heat-transfer design or for comprehensive boiling theory. No tests performed deal with important phenomenon of boiling and convection along a boundary in low-g.

RESEARCH DESCRIPTION. Tests in a 1-m-diameter by 2-m insulated tank containing LH_2 and heater surfaces of various types and orientations. Primary data are filmed histories of bubble formation, growth, and detachment from heaters as a function of heat flux, temperature differential, and local gravity vector. Of particular interst are point of incipient boiling, nucleate boiling, peak heat flux, and film boiling behavior.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. High peak power (3,000 w) but low average (30 w); 800 kg; 1-m-diameter x 2-m tank; TV and motion picture cameras; sensitive instruments to measure pressure, acceleration, and temperature.

CREW. Physicist (technician level) to activate heaters, observe liquid motions, and record data.

DATA. Photographic film augmented by audio records and computer printouts; raw data required by Principal Investigator on Earth for visual evaluation.

OPERATIONS. Research facility g-level must be maintained closely during experiments.

RESEARCH SEQUENCING. Progress from noncryogenic to cryogenic liquids and from 10^{-2} to 10^{-6}g (if possible). Test period cannot be interrupted once begun due to loss of correlation.

SUPPORTING TECHNOLOGY DEVELOPMENTS. G-level control; low-g accelerometers and isolation mounts; film/video-tape trade study.

RESEARCH COMMONALITIES. Much apparatus common with other 4-P/C-( ) research clusters. Common objectives with 1-LS-1.

RESEARCH CLUSTER 4-P/C-4—EFFECT OF ZERO-GRAVITY ON THE CONTROL OF MATERIAL DENSITY

ABSTRACT

OBJECTIVES. Utilize surface-tension effects, which dominate in zero-g, to produce materials having controlled-density characteristics (foams and composites).

BACKGROUND. Some foamed metals and glasses, some controlled-density coatings, and reasonably uniform composites produced on Earth. Composites usually reinforced by filaments, although greatest strength obtained by single-crystal whiskers. Production of single-crystal-whisker composites hampered by difficulty in uniform whisker distribution in a 1-g field. Improved understanding of mixing and solidification is necessary.

RESEARCH DESCRIPTION. Both uniform and controlled-density materials attempted. For foams, uniform density sought by extrusion of the melt through a gas sparger or by ultrasonic agitation; variable density foam made with centrifuge. For composites, uniform whisker distribution sought by heating and mixing in liquid state; centrifuge used to create variable density composites. Pressures, temperatures, and acceleration levels measured.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. High power required for high-pressure induction furnace: (5-kw average, 20-kw peak). Gas chromatograph, mass spectrometer, materials analysis microscope, tensile tester, timer, cameras (TV or film), and measuring devices for pressure, temperature, and acceleration.

CREW. Physicist (technician level), to load furnace, adjust test instrumentation and controls, and monitor test results.

DATA. Experiment foamed product itself is raw data. Some low-bandwidth parameter recording also necessary for control references. Voice annotation of observations and film.

OPERATIONS. Requires stable near-zero-g environment (10^{-4}g).

RESEARCH SEQUENCING. Would benefit from results of research cluster 4-P/C-2; predecessor to 4-P/C-6.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Contaminant-proof environmental control and life support system (in case of accidental release of molten material); low-g accelerometer and isolation mounts.

RESEARCH COMMONALITIES. Predecessor to 4-P/C-6; some equipment common to other 4-P/C-( ) clusters and to 1-LS-11.

RESEARCH CLUSTER 4-P/C-5—EFFECT OF ELECTRIC AND MAGNETIC FIELDS ON MATERIALS

ABSTRACT

OBJECTIVES. Establish effects of near-zero-g environment on behavior of materials in presence of electric or magnetic fields.

BACKGROUND. Electric and magnetic fields have been used to prevent liquid/vapor agglomeration in LOX transfer. Nonlinear electric fields increased heat-transfer coefficient of dielectric fluids and increased heat flux in both the nucleate and film-boiling regimes. Limited drop-tower and low-g aircraft tests partially confirm predicted behavior, but time of observation too short for complete confirmation in equilibrium situation.

RESEARCH DESCRIPTION. Sequential heat-transfer tests utilizing nonlinear electric or magnetic fields. Fluid introduced into cylindrical tank containing central heater with either concentric screen to provide nonuniform electric field or electromagnet to provide nonuniform magnetic field. Thermal gradient imposed across liquid, and heat flux at nucleate and film-boiling points and at liquid-vapor interface measured as function of field intensity.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Test chamber, (maximum power, 2 kw; average power 200 w), timer, camera (TV or film), flux meter, various test gages for power, temperature, and pressure control.

CREW. Physicist (professional level) and electronics technician, to prepare test chamber, control test variables, and monitor data results.

DATA. Motion pictures and magnetic tape; raw data required. Evaluated with Earth-based control measurements in 1 g.

OPERATIONS. Maintain $\leq 10^{-3}$g during tests; some high-voltage hazard to personnel.

RESEARCH SEQUENCING. Compare magnetic and field strength deformation effects with control experiments at zero field strength. Variable scheduling based on availability of crew time; up to 1,000 measurements may be made.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Low-g accelerometer and isolation mounts.

RESEARCH COMMONALITIES. Some equipment requirements common to other 4-P/C-( ) clusters.

RESEARCH CLUSTER 4-P/C-6—USE OF ZERO-GRAVITY TO PRODUCE SUPERIOR MATERIALS

ABSTRACT

OBJECTIVES. Utilize near-zero-g environment to produce superior glasses, single crystals, and whiskers (microscopic single crystals).

BACKGROUND. Theoretical aspects of crystal growth well known. However, measured properties of location density of Earth-grown crystals is much higher than would be expected. Gravity-induced effects or forces (i.e., thermal convection in the liquid phase, density-gradient difference during solution growth, weight, stress, etc.) contribute to imperfections.

RESEARCH DESCRIPTION. Produce large single crystals by float-zone, or solution growth techniques. Whiskers grown either by vapor transport, thermal dissociation, or surface reaction and preferential nucleation on a substrate, depending on material to be crystallized. Glasses produced by initial resistance-heating of the oxides until conductivity of material is sufficient for containerless induction-heating. Determine extent of crystal and glass impurities, and properties of specimens.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Furnace chamber, (peak power, 15 kw; average power, 4 kw; 10^{-8} torr vacuum), metallographic kit, x-ray, tensile tester, microscope, timer, camera (TV or film), instrumentation controls and recorders, gas chromatograph, and mass spectrometer. Airlock with extendable platform mechanism.

CREW. Physicist, (technicial level), to load chamber, establish experimentation controls, recover specimens and evaluate results.

DATA. Photographic film; raw samples required. Stripchart recording of control data and specimen analysis.

OPERATIONS. Maintain $\leq 10^{-3}$g during experiments. Automatic safety interlocks and molten material shielding required.

RESEARCH SEQUENCING. Depends upon some results obtained from research cluster 4-P/C-4.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Production of hard vacuums; low-g accelerometers and isolation mounts.

RESEARCH COMMONALITIES. Much apparatus common to other 4-P/C-( ) clusters.

RESEARCH CLUSTER 4-P/C-7—IMPROVEMENT OF MATERIALS BY LEVITATION MELTING

ABSTRACT

OBJECTIVES. Investigate levitation melting of conductive materials at near-zero-g levels, in both inert atmospheres and vacuum. Some samples vacuum-cast.

BACKGROUND. High-density, low-surface-tension metals cannot be levitation-melted. Large power requirements (10 to 50 kw) are necessary to levitate magnetically even a small (10-gram) specimen at 1-g conditions. Assuming that these restrictions are eased in near-zero-gravity, larger samples with lower electrical conductivity can be levitation-melted at lower power levels, and because of density differences, compound semiconductors can be melted without segregation.

RESEARCH DESCRIPTION. (1) Levitation melting in inert atmosphere and resolidifying samples at various cooling rates. (2) Levitation melting in vacuum, holding for specified times in molten state, and resolidifying at various cooling rates. (3) Levitation melting in vacuum and holding for various times in molten state. Molten samples then subjected to acceleration forces and cast into molds.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Induction furnace chamber (power: 2 kw average; 5 kw peak), camera (TV or film), optical pyrometer, gas chromatograph, mass spectrometer, and associated measurement and recording apparatus.

CREW. Physicist (technician level) and electronics technician, to prepare specimens, establish process controls, and monitor test results.

DATA. Photographs and stripchart process data; raw samples returned to Earth.

OPERATIONS. Controlled low-g and hard-vacuum operation; molten materials shielding and safety interlocks required (temperatures to 3,000°C). Specimen position held to ±0.1 mm from two reference positons, during 1-hour processing time.

RESEARCH SEQUENCING. Critical time-temperature relationship maintained during process.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Specimen positioning device; sensitive g-level control.

RESEARCH COMMONALITIES. Apparatus common to other 4-P/C-( ) clusters.

RESEARCH CLUSTER 4-P/C-8—EFFECT OF ZERO-GRAVITY ON PRODUCTION OF FILMS AND FOILS

ABSTRACT

OBJECTIVES. Produce single-layered and multilayered thin films in zero-g. Observe surface-tension effects on sputter and vapor-deposition processes.

BACKGROUND. Sublimination, sputtering behavior, and nucleation kinetics of thin-film production techniques are well known, but are limited with respect to material, thickness, dimensional tolerance, and size. Experiments are required on use of surface tension forces in a low-g environment to produce various types of thin films and foils, to confirm analytic predictions, and to provide materials for evaluation.

RESEARCH DESCRIPTION. Deposit thin films by sputter and vapor deposition techniques at various rates and thicknesses on various substrates, with an imposed thermal gradient across the substrate surface. Produce foils by extruding molten material through a die slit, touching the extruded material with a cooled knife-edge substrate, then rapidly withdrawing the edge. Vary withdrawal rate of the knife edge to produce foils of different thicknesses. Determine material properties and process variations.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Induction furnace (average power, 5 kw; peak power, 20 kw). Timer, film thickness monitor, x-ray, profilometer, gas chromatograph, mass spectrometer, camera (TV or film), and associated gages and controls.

CREW. Physicist (technician level) and electronics technician, to set up and prepare furnace, adjust process controls, draw samples, and analyze experimental results.

DATA. Physical samples plus tapes or printout of experimental parameters; some photographs.

OPERATIONS. Safety hazard, since experimenter is in close proximity to molten material; maintain low-g environment with an acceleration change of less than ±0.1 cm sec^{-2}.

RESEARCH SEQUENCING. Produce control-material specimens on Earth; compare with same materials produced in orbit.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Molten-film drawing mechanism. Low-g controls.

RESEARCH COMMONALITIES. Some apparatus common to other 4-P/C-( ) clusters.

RESEARCH CLUSTER 4-P/C-9—EFFECTS OF ZERO-GRAVITY ON LIQUID RELEASES AND LIQUID DROPS

ABSTRACT

OBJECTIVES. Advance the state of knowledge in basic behavior of fluids under zero-g conditions in support of future fluid-system design and development.

BACKGROUND. Behavior of droplets in zero-g has been observed in free-falling tubes containing mercury. More knowledge is required about the interaction of droplets and shapes, and the oscillations occurring in larger droplets. Kelvin-Helmholtz instability in simple geometries is understood, but influence of gravity on this phenomenon is not well understood.

RESEARCH DESCRIPTION. Measure size-distribution of liquid droplets, spray velocity, shape of droplets, spatial distribution, drop oscillation frequency, and damping constant. Air or another gas flows over liquid films of various thicknesses; gas stream is then passed through aerosol counter to determine droplet size distribution. Water-saturated air is passed over a condensing surface, and motion of the condensate and liquid droplet size distributions are observed. Drop-oscillation frequencies, shapes, and attenuation rates are determined by high-speed photography.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Liquid test chamber (average power, 175 w), laser holographic or TV camera, with associated controls and gages.

CREW. Physicist and electronics technician, to prepare gas-droplet mixture, observe and control measurements, and communicate with ground-based investigators on test results.

DATA. Film or video tape; raw data required. Voice annotation of test observations on magnetic tape.

OPERATIONS. Low-g level (10^{-3}g) required during tests, electrostatically or magnetically adjusted for random g-forces. Controlled gas flow-rate affects aerosol size, shape, and distribution.

RESEARCH SEQUENCING. Reference data collected in 1-g environment prior to flight.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Film/video tape trade study; laser holography for three-dimensional observation of rotating liquid drop.

RESEARCH COMMONALITIES. Application to cloud-physics research, 6-M-4; some apparatus common to other 4-P/C-( ) research clusters.

RESEARCH CLUSTER 4-P/C-10—CAPILLARY FLOW IN ZERO-GRAVITY

ABSTRACT

OBJECTIVES. Obtain information basic to understanding of capillary flow in zero-g, as found in wicks, packed beds, and straight and converging channels.

BACKGROUND. Capillary flow of liquids in screen wicks, packed beds, and various capillary channels in low-g are of interest because of the difficulty of simulation under normal gravity. Knowledge of these phenomena will contribute not only to basic scientific knowledge of capillary flow but also to design confidence required for future-generation space process equipment that makes use of this phenomenon.

RESEARCH DESCRIPTION. Observe flow of various liquids in wicks, packed beds, and straight and converging capillary channels in suitable test enclosures. Study wicking rates as well as flow under various pressure differences. Take data on volume change of bladdered liquid samples at one end of a test specimen; and visually observe motion of liquid-vapor interface, and temperature change at a prepositioned heated test element as liquid-vapor interface arrives at the location.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Test chamber tank system (average power, 250 w). Variable frame-rate camera, power meter, and associated controls, gages, and recording equipment.

CREW. Physicist (technician level) and electronics technician, to insert test specimens, adjust and operate controls, and monitor test results.

DATA. TV video and control parameters on magnetic tape; raw data desirable for comparison with ground control data.

OPERATIONS. Requires controlled and repeatable g-levels in four ranges (10^{-2} to 10^{-6} g) for 10-minute test periods.

RESEARCH SEQUENCING. Recommended that all tests at a particular g-level be done in sequence (360 minutes per sequence, four sequences). Requires reference data in 1-g prior to flight.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Low-g accelerometer and isolation mounts, g-level control system.

RESEARCH COMMONALITIES. Some apparatus common to other 4-P/C-( ) research clusters. Applies to advanced life support and protective systems.

RESEARCH CLUSTER 4-P/C-11—BEHAVIOR OF SUPERFLUIDS IN THE WEIGHTLESS STATE

ABSTRACT

OBJECTIVES. Gather low-g experimental data about the behavior of superfluids in space. Investigate influence on the fountain and creeping-film effects.

BACKGROUND. For the fountain effect, excellent agreement has been obtained between existing theories and 1-g experiments, using liquid helium. No comprehensive theory adequately predicts the results of 1-g experiments involving the creeping-film effect. Data not yet available concerning these effects in reduced-gravity environments.

RESEARCH DESCRIPTION. Use low-temperature liquid-helium dewar with one or more viewing ports to visually observe behavior effects in low-g environments. A concentric capillary tube with a wider section below it will be used to observe the response of the fountain of liquid helium upon the application of heat. The liquid transfer rate of helium to or from the inside of a partially submerged open-ended cup will be used to observe the creeping-film effect.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Cryogenic dewar test vessel (power requirements, 20 w); supply of liquid helium, timer, camera (TV or movie), and associated controls and gages.

CREW. Physicist (technician level), to prepare cryogenic tank, insert test object, observe and control measurement conditions, and record test results.

DATA. TV or movie film; raw data, test control data, test run of images transmitted to ground.

OPERATIONS. Must maintain three different g-levels: 10^{-2}, 10^{-4}, and 10^{-6}g, during experiments.

RESEARCH SEQUENCING. Perform experiment after liquid helium reaches equilibrium; compare with 1-g control data on ground. Time marker placed on TV-camera recordings.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Low-g accelerometers and isolation mounts; g-level control system.

RESEARCH COMMONALITIES. Same instrumentation as used for 4-P/C-3 and -10.

RESEARCH CLUSTER 4-PP-1 – SPACECRAFT-ENVIRONMENT PLASMA INTERACTION

ABSTRACT

OBJECTIVES. Determine properties and extent of disturbance caused by passage of a large body through the ambient space plasma environment.

BACKGROUND. Theoretical wake physics predictions limited to altitudes of 150 to 1,000 km. Plasma instabilities, collective effects, and complex spacecraft interactions have been ignored. Wake interaction dynamics extremely difficult to simulate in laboratory. Very limited measurements on previous spaceflights.

RESEARCH DESCRIPTION. Examine near-region of the wake from the space vehicle itself, using surface- and boom-mounted probes. Far-wake requires either tethered instrumentation or maneuverable subsatellites. Measure wake phenomena: (1) particle densities and temperatures with Langmuir probes, using retarding potential techniques, (2) ion analysis and neutral gas composition, (3) the local geomagnetic vector, and (4) fluctuating electric field measurements. Repeat measurements, since night/day and other variations will occur. Confirm the nature of these changes.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Generally modest subsystem support (200 w, 500 kg, and 1 m^3), Langmuir probes (20 m) on extendable booms, RF ion mass spectrometer, three-axis flux gate magnetometer, subsatellite probe, computer, and recording equipment.

CREW. Physicist (professional level) and electronics technician, to prepare probes, track and position subsatellites, and monitor tests.

DATA. Low data rates (< 3 kHz) but onboard computer analysis of raw data required until experiment becomes routine.

OPERATIONS. Coordinate subsatellite operations and boom deployment. Attitude sensing ≈ 1.0 degrees. Fixed circular equatorial orbit.

RESEARCH SEQUENCING. Runs continuously after release of probes or subsatellites.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Subsatellite design and operation; dc electric field instrument; coordinated theoretical and experimental plasma program, ground and space.

RESEARCH COMMONALITIES. Minor overlap with objectives of 5-P-1 and -3.

RESEARCH CLUSTER 4-PP-2–ENERGETIC PARTICLE DYNAMICS IN THE MAGNETOSPHERE

ABSTRACT

OBJECTIVES. Identify origin and dynamic processes of trapped energetic particles. Map magnetosphere electric and magnetic fields.

BACKGROUND. Main magnetosphere energetic-particle constituents are electrons and protons. Alpha particles detected, but limited observations of variations in abundance and spatial distribution. Electron energies range from below 1 kev to several Mev, whereas proton energies range up to several hundred Mev.

RESEARCH DESCRIPTION. Measure (1) release of alkali metal clouds, (2) injection of high-energy electrons, and (3) propagation of high-power VLF waves. For the first, a subsatellite equipped with diagnostic instrumentation releases a barium cloud several kilometers from research facility. For the second, generate artificial aurora by means of a 10-kev, 1-amp electron beam with diagnostics aboard the research facility, on the ground and in subsatellites. Lastly, propagate VLF waves from the research facility into high L-shells (L > 4) to stimulate VLF emission from the particles. Instrumentation aboard research facility and on subsatellites.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Subsatellites equipped with barium release canisters and/or diagnostic instrumentation. Ten-kw peak power for both VLF and electron beams. Magnetometers, photometer, camera, vidicon, Langmuir probe, electron energy detector, etc., with associated recorders and displays.

CREW. Physicist (professional level), aided by astronaut, to prepare, release, and control subsatellites, and to monitor results.

DATA. Onboard evaluation of data. Telemetry and TV channels from subsatellites. Tape recorder and film.

OPERATIONS. Barium release. Equatorial synchronous orbit; hazard from canisters. VLF waves: 55 degrees, 120-nmi orbit, 375-m antenna.

RESEARCH SEQUENCING. Continuous subsatellite data collected for 2 hours. (Subsatellite may be retrieved after experiment.) Record values 45 minutes before canister release.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Subsatellite design and operation. Film/video tape trade study.

RESEARCH COMMONALITIES. Similar to 4-PP-4.

RESEARCH CLUSTER 4-PP-3–THERMAL PLASMA IN THE IONOSPHERE AND MAGNETOSPHERE

ABSTRACT

OBJECTIVES. Understand processes for formation, control, and distribution of thermal plasma in ionosphere and magnetosphere.

BACKGROUND. Plasma behavior in ionosphere governed by latitude, geomagnetic field, and closed geometry. Processes in ionosphere complex, but characteristics obtained from changes caused by local-environment perturbations. Magnetospheric plasma exhibits different density and velocity profile since system is open at higher latitudes.

RESEARCH DESCRIPTION. Examine behavior by (1) alkali metal cloud tracer described in research cluster 4-PP-2; (2) VLF-wave propagation (cluster 4-PP-2, except only "tracer" experiment), to relate electron density to "whistler" ducting; (3) RF-plasma resonance, similar to ISIS topside sounder. Plasma resonances stimulated by propagating short RF pulses at various frequencies and with different orientations relative to magnetic field lines. Resonance structure found by observing resonant behavior with receiver. Instrumented subsatellite used to perform canister injection for cloud tracer, and measure orthogonal magnetic force field.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Crossed-dipole antenna, dipole arms 73 and 19 m. High-powered (> 10-kw) VLF through HF transmitter and receiver, magnetometers, subsatellites, controls, and displays.

CREW. Physicist (technician level) and astronaut, to eject subsatellite, control operations, and observe results.

DATA. 35-mm film; video tape or direct telemetry transmission to ground. Three channels (50-kHz, 100-kHz; 3-MHz bandwidth).

OPERATIONS. Subsatellites for alkali metal cloud releases and remote observations, controlled from manned facility. VLF requires EVA for antenna deployment. Hazard associated with alkali metal canister pyrotechnics.

RESEARCH SEQUENCING. Alkali metal cloud tracer experiments, 2-hour uninterrupted observation. Requires subsatellite positioning and station-keeping. Ground-based research program coordinated with orbital activities.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Subsatellite design and operation.

RESEARCH COMMONALITIES. Equipment from 4-PP-2. Objectives complementary to 5-P-1 and -3.

RESEARCH CLUSTER 4-PP-4—AURORAL PROCESSES

ABSTRACT

OBJECTIVES. Produce small, artificial auroral spots at various latitudes by three processes: alkali metal injection, electron beam interaction, and VLF wave interaction.

BACKGROUND. Study and analysis of aurora dates back to Aristotle. Auroral displays result from the ionization of atmospheric constituents by the energetic electrons and protons of the solar wind. However, the fundamental processes within the aurora are still not understood.

RESEARCH DESCRIPTION. Triggering of aurora by alkali chemical means involves techniques described in research cluster 4-PP-2, except that chemicals proposed here include SF_6 and are released in much larger quantities. Techniques involved in auroral production by energetic electrons are same as those of cluster 4-PP-2. The third technique, auroral production by VLF wave interaction, is a second-order effect of research cluster 4-PP-2, since electrons that may be precipitated by VLF interaction could be related to natural auroral phenomena.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. High peak-power requirements (10 kw), deployable 375-m crossed-dipole antenna, instrumented subsatellites, electron beam accelerator, VLF transmitter/receiver, electron detector, plasma wave detector, etc., with associated recording equipment.

CREW. Physicist (professional level), aided by electro-mechanical technician and astronaut, to launch and control subsatellites, observe, and evaluate tests.

DATA. Onboard evaluation of raw data. TV video and photographic film. Telemetry and control data on magnetic tape.

OPERATIONS. Inclinations from 0 (for chemical releases) to 90 degrees (for VLF wave propagation). Chemical injection at ≈500 km.

RESEARCH SEQUENCING. Eject and position instrumented subsatellites. Test for periods of a few hours. Coordinate with ground measuring activities.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Design subsatellites; long-term coordination with other plasma research activities; film/videotape trade study; study of contamination by physics experiments.

RESEARCH COMMONALITIES. Similar to 4-PP-2.

RESEARCH CLUSTER 4-CR-1—CHARGE AND ENERGY SPECTRA OF COSMIC-RAY NUCLEAR COMPONENTS

ABSTRACT

OBJECTIVES. Determine charge and energy composition of nuclei that make up greatest part of high-energy cosmic-ray flux. Utilize available primary energies for interaction experiments.

BACKGROUND. Experimenters have measured flux and energy spectrum of protons in 20-MeV to 10-GeV range, and of helium nuclei from 15 MeV to 30 GeV per nucleon. Over roughly same energy range, data available on flux of Be, B, C, N, O, Ne, Mg, Si, and the group $16 \leqslant Z \leqslant 30$ (Z = atomic number). Above 10 GeV per nucleon, data are sparse on energy spectra of individual species.

RESEARCH DESCRIPTION. Three types of instruments are used to determine charge and energy of high-energy particles: (1) proportional or scintillation Cerenkov counters to measure Z^2 F(v), (2) magnetic spectrometers to measure momentum per Z, (3) total energy counters. For relativistic particles, any two of these measurements are sufficient to determine charge and energy, provided the ratio of mass to charge is known. To measure isotopic abundance, all three measurements are required. Requires a large magnet and total-energy spectrometer.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Superconducting magnet, cryogenic system, proportional Cerenkov counter, magnetic spectrometer, total-energy counters, etc., and supporting recording and metering equipment; 12,000 kg total.

CREW. Physicist (professional level), assisted by two electrical engineers, to calibrate and maintain equipment, monitor data inputs, and analyze results.

DATA. Raw data required for onboard analysis; photographic film and magnetic tape.

OPERATIONS. Maintain precise geometrical and electronic configuration during data run. Magnetic moment (10^6 amp/m^2) severely perturbs spacecraft stabilization. Avoid natural trapped-radiation belts.

RESEARCH SEQUENCING. Flexible scheduling and experiment reconfiguration mandatory since existence of many particles is not certain.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Large cryogenic systems in space; superconducting magnet design; film development.

RESEARCH COMMONALITIES. Complements other research clusters in 4-CR-( ) series.

RESEARCH CLUSTER 4-CR-2—ENERGY SPECTRUM OF THE HIGH-ENERGY PRIMARY ELECTRONS AND POSITRONS

ABSTRACT

OBJECTIVES. Determine properties of the electron-positron component of primary cosmic radiation. Test validity of theories of origin of cosmic radiation and diffuse x-ray background.

BACKGROUND. Primary electrons thought to be generated by two different processes: (1) by acceleration of low-energy electrons, and (2) as secondaries from the nucleonic-component collisions of the cosmic radiation. Approximately equal electrons and positrons result from nuclear reactions. If all cosmic-ray electrons were secondaries from the nuclear component, equal numbers of positrons and electrons would be expected. Measurements indicate about ten times as many electrons as positrons, at least between 0.5 and 10 GeV.

RESEARCH DESCRIPTION. Obtain data on flux and spectra over wide energy range. Experimental arrangement depends on large superconducting magnet. Uses multiwire spark chambers to define path of particle through magnetic field, a total-energy counter in which energy of electromagnetic shower is measured, and a set of counters to trigger the system.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Superconducting magnet, cryogenic cooling, spark chambers, total-energy counter, positron detector threshold electronics, and supporting recording and metering equipment at display console; about 1,000 kg total.

CREW. Physicist (professional level), assisted by two electrical engineers, to establish configuration geometry, perform calibrations, and monitor operations.

DATA. Raw data required for onboard analysis; tape and photographic film.

OPERATIONS. Incident direction of particle defined from instantaneous spacecraft orientation.

RESEARCH SEQUENCING. Flexible scheduling and experiment reconfiguration mandatory. Run continuously (once initiated) until sufficient statistics are accumulated.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Large cryogenic systems in space; superconducting magnet; film processing in zero-g.

RESEARCH COMMONALITIES. Complements other research clusters in 4-CR-( ) series.

RESEARCH CLUSTER 4-CR-3—ENERGY SPECTRUM AND SPATIAL DISTRIBUTION OF PRIMARY GAMMA RAYS

ABSTRACT

OBJECTIVES. Increase understanding of energy spectrum, source mechanisms, and spatial distribution of incident primary gamma rays from a manned orbital cosmic-ray laboratory.

BACKGROUND. Space study of the incident flux of primary gamma rays can lead to the solution of some of the most fundamental problems of astrophysics, such as the presence of antimatter in the universe, the properties of galactic and intergalactic matter and magnetic fields, and the general question of the origin and nature of discrete cosmic-ray sources. Weak sources of gamma rays are detected only above the atmosphere.

RESEARCH DESCRIPTION. Detect and count particles. For neutral particles to be detected, they must first interact to produce charged particles. High-energy gamma rays are detected through their production of electron-positron pairs in a converter. Determine the direction and energy of incident photons by analyzing the trajectory and energy of the pair produced. Multiplate spark chambers, a superconducting magnet, and scintillator arrays are required.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Superconducting magnet plus other heavy, bulky apparatus, such as scintillator arrays, multiplate spark chambers, and associated recording, computer, and display equipment.

CREW. Physicist (professional level), assisted by two electrical engineers, to establish configuration geometry, perform equipment calibration monitor operations, and analyze test data.

DATA. Raw data required for onboard analysis; photographic film and magnetic tape.

OPERATIONS. Pointing accuracies up to 0.1 degree. Space scanning direction for both scan and fixed pointing modes.

RESEARCH SEQUENCING. Flexible scheduling and experiment reconfiguration mandatory.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Large cryogenic systems, superconducting magnet, photographic film processing.

RESEARCH COMMONALITIES. Results impact upon 4-CR-5.

RESEARCH CLUSTER 4-CR-4—LONG-LIVED HEAVY ISOTOPES IN COSMIC RAYS

ABSTRACT

OBJECTIVES. Detect and identify the very very heavy (VVH) isotopes that are present in the primary cosmic radiation. Measure isotopic abundance and rigidity spectra of transuranic nuclei.

BACKGROUND. These particles have very short interaction lengths. Attempts to detect them with balloons have indicated only that such particles are indeed present in the incoming radiation, and in greater abundance than predicted by universal abundance compilations. Longer observation experiments to detect VVH primaries would be possible from onboard a space platform.

RESEARCH DESCRIPTION. Identify particles using nuclear film emulsions, plastic sheets, or stacks of both. Deduce particle mass, using the usual triggering logic and spark chambers and a transition radiation detector for measuring velocity, and a TANC detector for measuring energy. Alternatively, use large-area ionization and Cerenkov counters in combination to measure particle mass. Measurements run continuously until sufficient statistics are accumulated to permit the abundancies of the nuclei to be determined.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Shielded, temperature-controlled storage required if emulsions are used. Detector arrays, 100-kg/m^2; alternative detection systems of triggering electronics, spark chambers, or Cerenkov and ionization counters for automated threshold computer control.

CREW. Physicist (professional level), assisted by electromechanical technician, to perform EVA, reco⁻⁻r exposed plates, and analyze data.

DATA. Raw data required for onboard analysis; photographic film and magnetic tape. Computer printout in automated system.

OPERATIONS. Low equatorial orbit highly desirable to reduce emulsion fogging from radiation.

RESEARCH SEQUENCING. Flexible scheduling and experiment reconfiguration mandatory.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Transition radiation detector. Film processing and plate etching in zero-g.

RESEARCH COMMONALITIES. Supplements other research clusters in 4-CR-( ) series.

RESEARCH CLUSTER 4-CR-5—ANTINUCLEI IN COSMIC RAYS

ABSTRACT

OBJECTIVES. Detect antinuclei in cosmic rays and thus provide insight into fundamental questions in cosmic-ray physics, cosmology, and astrophysics.

BACKGROUND. With discovery of the positron, physicists and philosophers alike predicted existence of other antiparticles. Symmetry between particles and antiparticles is now fundamental principle of physics. Several questions arise. Where is the antimatter? What keeps it from annihilating with matter? How can it be detected? Key to the answer to last of these questions centers on observing primary cosmic rays for existence of antinuclei.

RESEARCH DESCRIPTION. Superconducting magnet is primary instrument, since no other instrument has the ability to separate and determine the sign of the charge of a high-energy nucleus. In addition to the polarity determination of the particle trajectory, the sense of the particle must be found, using scintillation counters and spark chambers. Time-sequence data can also be obtained with the scintillation counters. Measure total energy, using t   il-absorption nuclear cascade (TANC) counter.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Superconducting magnet plus other heavy, bulky apparatus; 12,000 kg total mass. Total absorption nuclear cascade (TANC) counter, computer-controlled threshold electronics, scintillators, spark chambers, etc., with associated recorders and displays.

CREW. Physicist (professional level), assisted by two electrical engineers, to configure instrumentation, monitor operations, and analyze data.

DATA. Raw data required for onboard analysis; photographic film and magnetic tape.

OPERATIONS. Experiment runs continuously once initiated. Requires careful timing sequence and geometric control.

RESEARCH SEQUENCING. Flexible scheduling and experiment reconfiguration mandatory since existence of antinuclei particles is not certain.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Large cryogenic systems superconducting magent, film processing in zero-g.

RESEARCH COMMONALITIES. Reconfiguration of same equipment as for 4-CR-1.

RESEARCH CLUSTER 4-CR-6—QUARKS (STABLE FRACTIONALLY CHARGED PARTICLES) IN COSMIC RAYS

ABSTRACT

OBJECTIVES. Search for quarks and verify physical theory.

BACKGROUND. The quark model of Gell-Mann and Zweig has had great success theoretically. It correctly predicted existence of the Ω^- particle. Its usefulness as a guide to the classification of states of elementary particles has been firmly established. The existence of quarks led to the prediction of the scalar meson. Quarks reportedly observed in two experiments, but much controversy exists and claims are currently being disputed. Further supportive work to search for quarks is important to cosmic-ray physics.

RESEARCH DESCRIPTION. Search for and positively identify fractionally charged particles. Use detectors and electronic counters rather than a bubble chamber. Positive identification of fractionally charged particles may employ spark chambers triggered by scintillators, a superconducting magnet, and energy-loss and total-energy detectors. Measure mass, energy, and charge level of the particle.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Superconducting magnet plus other heavy, bulky apparatus, such as spark chambers, energy-loss detector, total-energy detector, onboard computer, etc. with various controls and instrumented displays.

CREW. Physicist (professional level), assisted and by two electrical engineers, to configure apparatus, perform calibrations, and complete analysis.

DATA. Raw data required for onboard analysis; tape and photographic film.

OPERATIONS. Detection threshold of event is computer-logic controlled and alarm activated.

RESEARCH SEQUENCING. Flexible scheduling and experiment reconfiguration mandatory since existence of many particles is not certain. Recheck calibration of equipment immediately following event discovery.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Large cryogenic systems; superconducting magnet; film processing.

RESEARCH COMMONALITIES. Research may be combined with 4-CR-1.

RESEARCH CLUSTER 4-CR-7—UNKNOWN PARTICLES IN COSMIC RAYS

ABSTRACT

OBJECTIVES. Analyze the incoming cosmic-ray beam before it interacts with the atmosphere, to search for rare particles that have not been detected on the Earth.

BACKGROUND. Spaceborne research may offer unrealized research opportunities. Possibly only negative experiments will be performed; i.e., new lower limits will be placed on cross-sections or abundancies. Experiments, for the most part, are simply the identification of unusual events in other experiments. An exception to this occurs, however, when a specific particle is being sought (for example, the magnetic monopole).

RESEARCH DESCRIPTION. Nonspecific experiments. Analyze data from other experiments to search for and screen new particles. Theoretical predictions may indicate that experimentation should be undertaken in a search for some particular particle. Exploit reconfiguration capabilities, if such a need arises. Cosmic-ray laboratory will be capable of providing the apparatus necessary.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Uses cosmic-ray physics apparatus already aboard the space facility; these are described for other 4-CR-( ) research clusters.

CREW. Physicist (professional level), assisted in general activities by two electrical engineers and a technician.

DATA. Raw data probably required for onboard analysis; some photographic film and magnetic tape expected.

OPERATIONS. Variable but depends on experimental opportunities that are not defined at outset of mission.

RESEARCH SEQUENCING. Flexible scheduling and experiment reconfiguration mandatory since existence of many particles is not certain.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Same requirements as for other 4-CR-( ) research clusters.

RESEARCH COMMONALITIES. Need for experimentation in this research cluster can arise from any other cluster in the 4-CR-( ) series.

RESEARCH CLUSTER 4-CR-8—CHARACTERISTICS OF ALBEDO PARTICLES ABOVE 100 MeV

ABSTRACT

OBJECTIVES. Measure the intensities and energy spectra of all components of the cosmic-ray albedo.

BACKGROUND. Cosmic-ray albedo is the flux of particles leaving the atmosphere as a result of bombardment by cosmic-ray primaries. Great majority are secondaries generated by interactions of primaries in the atmosphere. Because of strong collimation in the forward direction, only a small fraction of the high-energy particles will leave the top of the atmosphere. Measurements of flux and energy distribution of neutrons leaving the atmosphere are important because of influence on the population of the radiation belts.

RESEARCH DESCRIPTION. Determine the spectrum and intensity of albedo electrons and positrons above 100 MeV, and observe how these parameters change with geomagnetic coordinates and time. Distinguish between primary particles and albedo particles by analysis of scintillation pulses. Requires a superconducting magnet, spark chambers, scintillation counters, a total-absorption scintillation counter (TASC), and electronics for control and analysis.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Requires superconducting magnet plus other heavy, bulky apparatus, as described in Research Cluster 4-CR-2.

CREW. Physicist (professional level), assisted by two electrical engineers, to set up apparatus configuration, perform calibrations, and monitor data results.

DATA. Raw data required for onboard analysis; tape, photographic film.

OPERATIONS. Spacecraft instantaneous orientation important to analyze particle incident direction.

RESEARCH SEQUENCING. Capability for flexible scheduling and experiment reconfiguration mandatory. Any data run, once initiated, must proceed to completion uninterrupted.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Large cryogenic systems in space; superconducting magnet, film processing in zero-g.

RESEARCH COMMONALITIES. All other clusters in 4-CR-( ) series provide some data for this cluster.

RESEARCH CLUSTER 4-CR-9—NUCLEON-NUCLEON CROSS SECTIONS AT HIGH ENERGIES

ABSTRACT

OBJECTIVES. Measure the cross-sections of the p-p, p-n, and n-n interactions at high energies.

BACKGROUND. Many of the questions in interaction physics that cannot be answered with the energies currently available at high-energy accelerators would benefit greatly from a spacecraft facility. For example, several predictions of the Regge pole model require higher energies for adequate testing. Unnecessary to work with the highest possible energy. Predictions can be verified with energies only a few orders of magnitude greater than the levels now achievable with accelerators.

RESEARCH DESCRIPTION. Study fundamental nuclear reactions. To make effective use of the cosmic-ray laboratory in studying high-energy interactions, incident beam should be of higher energy than that obtainable in a ground-based laboratory. Study of the high-energy beam capabilities of both current and planned accelerators shows that the space cosmic-ray laboratory will be useful only for studying reactions above about 10^{12} eV, with possible later developments raising this value to 10^{14} eV.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Superconducting magnet plus other heavy, bulky apparatus. Incoming particle identification system, hydrogen target, magnetic spectrometer, total-energy detector, and support equipment.

CREW. Physicist (professional level), assisted by two electrical engineers, to establish equipment configuration, calibrate and operate system, and analyze data.

DATA. Raw data required for onboard analysis; tape and photographic film.

OPERATIONS. Cryogenics resupply for magnet and liquid hydrogen target. Safety hazard related to liquid hydrogen target. Computer-controlled logic and signal-threshold alarms.

RESEARCH SEQUENCING. Flexible scheduling and experiment reconfiguration mandatory since existence of many particles is not certain.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Large cryogenic systems for use with liquid-hydrogen target device, superconducting magnet, film processing in zero-g.

RESEARCH COMMONALITIES. Apparatus shared with other research in 4-CR-( ) series.

RESEARCH CLUSTER 4-CR-10—SPALLATION CROSS SECTIONS AT HIGH ENERGIES

ABSTRACT

OBJECTIVES. Study nuclear spallations involving high-energy nuclei on protons using the primary cosmic radiation as the incident beam.

BACKGROUND. The energy of a single proton beam, 5 X 10^{11} eV, at the National Accelerator Laboratory (NAL), represents the highest energy at which spallation reactions can currently be studied. Experiment should be performed with nuclei incident on protons. For the value $Z \geq 6$, energies available from accelerators are limited to less than 100 MeV per nucleon, and a space laboratory is a superior alternative.

RESEARCH DESCRIPTION. Measure reaction rates and reaction products of high-energy particles. Incoming particle passes through a transition detector and a multiwire proportional counter which determine the charge, energy, and location. Employs a chamber containing liquid or solid hydrogen, a superconducting magnet to separate low-energy particles from the primaries, and a second multiwire proportional counter to determine final energy.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Superconducting magnet plus other heavy, bulky apparatus, including transition detector, proportional counters, liquid/solid hydrogen target, and associated recording and display equipment.

CREW. Physicist (professional level), assisted by two electrical engineers, to configure apparatus, calibrate and operate equipment, and analyze test data.

DATA. Raw data required for onboard analysis; tape and photographic film.

OPERATIONS. Cryogenics for magnet and liquid-hydrogen target. Safety hazard associated with liquid-hydrogen target.

RESEARCH SEQUENCING. Flexible scheduling and experiment reconfiguration mandatory. Detector timing sequences, referenced to spacecraft coordinates, determine incident particle direction.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Large cryogenic systems in space, superconducting magnet, transition radiation detector, film processing in zero-g.

RESEARCH COMMONALITIES. Apparatus common to other research clusters in 4-CR-( ) series.

COMMUNICATIONS AND NAVIGATION

RESEARCH CLUSTER 5-N-1–TERRESTRIAL NOISE MEASUREMENTS

ABSTRACT

OBJECTIVES. Statistical contour mapping of the Earth's apparent RF noise temperature. Determine ambient radio signal environment, as seen from spacecraft, for VHF through EHF wavelengths.

BACKGROUND. Earth-to-space communications system design involves knowledge of the spectral density of man-made and natural RF energy at the spacecraft. Only a few localized noise measurements from mobile and airborne receivers have been made, with data widely separated in time, frequency, and location.

RESEARCH DESCRIPTION. Global detection of terrestrial RF noise emissions mapped for various meteorological conditions, yielding apparent ambient source temperatures as a function of location, frequency, angle of incidence, signal polarization, and receiver bandwidth. Uses 20 radiometric, low-noise receivers with bandwidths of about 100 MHz to cover the spectrum from 100 MHz to 100 GHz. External noise temperature seen by antenna would be related to geographic coordinates to plot noise-contour maps and to establish signal detection thresholds. Polar orbits desirable to achieve complete Earth coverage.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Radiometric broadband receivers and antennas for coverages from 100 MHz to 100 GHz. Calibration to internal reference and cosmic background radiation. Attitude control for antenna pointing.

CREW. Communications specialist, to set up equipment, monitor operations, and record data. Possible EVA for large erectable antennas.

DATA. Magnetic tape and X–Y plotter outputs of antenna directivity correlated to spacecraft altitude and geographic coordinates.

OPERATIONS. Continuous 3-hour data runs. Data covering 1 year desirable.

RESEARCH SEQUENCING. Initially, concentrate on areas covered by space communications systems. Full global coverage is a major research objective.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Develop computer software; refine design of cryogenic radiometric low-noise receivers.

RESEARCH COMMONALITIES. Predecessor to 5-N-2. EVA may be evaluated by 1-OE-2 and -3.

RESEARCH CLUSTER 5-N-2–NOISE SOURCE IDENTIFICATION

ABSTRACT

OBJECTIVES. Geographically locate and identify discrete sources of terrestrial electromagnetic energy emitters, primarily in 100-MHz to 100-GHz range. Collect and analyze RF noise emitter signatures to determine origin and character (natural or man-made) of these interfering, radiating sources.

BACKGROUND. Reliable Earth-space communications systems links must consider RF power levels and associated modulation structures of interfering noise or unwanted random signals. These data permit more effective use of RF spectrum.

RESEARCH DESCRIPTION. Locate terrestrial noise sources and subsequently identify and characterize emissions using swept-band receivers connected to narrow-beam broadband antennas, with appropriate signal processing and spectrum analysis equipment. RF source geographic coordinates obtained as function of spacecraft position and antenna pointing and acquisition geometry. Ground target resolution depends upon antenna aperture, spacecraft altitude, stability, and pointing accuracy. Polar orbits desirable to achieve complete Earth coverage.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Swept-band radiometric receivers, narrow-beam antennas, spectrum analysis and panoramic video display devices, recorders, etc., for RF signal coverage from 100 MHz to 100 GHz.

CREW. Communications specialist, to operate equipment and evaluate output data. May require EVA for large antenna deployments.

DATA. Magnetic tape; panoramic signal recorded on film; spacecraft altitude position, and antenna scanning data correlated to targets.

OPERATIONS. Perform calibration checks with cooperative ground transmitter sites, using spacecraft antenna pointing and control. Global mapping coverage desirable, although most primary targets at latitudes between plus and minus 60 degrees.

RESEARCH SEQUENCING. Initial noise surveys taken over selected target areas; subsequent data taken worldwide.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Develop computer software; refine sensitive receivers, precision antenna pointing, stabilization, and control subsystems.

RESEARCH COMMONALITIES. Target selection from 5-N-1 data.

RESEARCH CLUSTER 5-P-1—IONOSPHERIC PROPAGATION MEASUREMENTS

ABSTRACT

OBJECTIVES. Measure and characterize innospheric effects on radio wave propagation. Increase predictability of RF transmission errors due to the ionosphere.

BACKGROUND. Space communications passing through the ionosphere (≈60 km to 1,000 km) highly affected by electron density. Maximum electron distribution (D, E, and F layers) is a function of spatial and temporal variables, and influences frequency, phase, polarization, and attenuation, which produce errors in communications and navigation systems.

RESEARCH DESCRIPTION. Measure electron-density distribution, using ionosonde devices located in spacecraft and in subsatellites. Perform topside sounding and one-way transmissions to subsatellites, and record ionograms. Correlate spacecraft position to sounding data. Perform multiple modulation of carrier bandwidth and analyze relative amplitude and phase difference over extended periods to determine short-term, diurnal, and seasonal variations in electron density profile (f < 100 MHz).

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Swept-band digital ionosonde transponder automatically controlled by programmed frequency synthesizer. Remote subsatellite transponder.

CREW. Communications specialist, to establish system parameters, extend antennas, operate ionosondes, record and process data, and deploy and control subsatellites.

DATA. Record on film, strip charts, and magnetic tape. Process encoded ionograms for digital transmission to Earth data-analysis centers.

OPERATIONS. Spacecraft position and tracking data correlated to geographic coordinates of sample soundings. Deploy, track, and control operation of subsatellites.

RESEARCH SEQUENCING. Variable character of ionosphere requires extended research. Pulsed (30-sec) ionogram signals transmitted from spacecraft to cooperating subsatellite.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Advanced digital ionosonde onboard processing techniques.

RESEARCH COMMONALITIES. Complements 4-PP-3 and 5-P-3.

RESEARCH CLUSTER 5-P-2—TROPOSPHERIC PROPAGATION MEASUREMENTS

ABSTRACT

OBJECTIVES. Determine troposphere dielectric properties and transmissibility effects on RF propagation from 0.1 to 100 GHz. Measure tropospheric (<60,000 ft) water vapor and molecular oxygen as functions of transmitter frequency.

BACKGROUND. Fluctuations in dielectric constant and troposphere introduce variances in Earth-to-space links. Experimental verification of theoretical models needed, particularly in higher frequency bands, where the effects are more pronounced.

RESEARCH DESCRIPTION. Using precision multiband receivers, measure signal power from several calibrated ground-station transmitters to define variance of RF propagation through the troposphere. Statistically relate frequency to refractive index, meteorological conditions, spatial and seasonal variance, signal path lengths, and angles of arrival. Synchronous orbit preferred. Localized ground station refractive index soundings and meteorological conditions required during test sequences.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Multiband receiver, antennas, precision calibration reference sources, recording equipment.

CREW. Communications specialist, to calibrate and operate equipment, acquire ground stations, and monitor data recordings.

DATA. Record ground-station signals for later analysis. Several minutes of data, 48 times per day, on signal level, frequency, direction of arrival, polarization, and refractive index.

OPERATIONS. Synchronous orbit preferred to simplify antenna pointing and to stabilize range and Doppler effects on phase and angle measurements.

RESEARCH SEQUENCING. Frequent system calibration checks between samples. Local surface meteorological conditions required for statistical reference.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Continuation of ongoing propagation studies, particularly in millimeter wave and optical wave technology programs.

RESEARCH COMMONALITIES. Complements 5-P-1 and -4.

RESEARCH CLUSTER 5-P-3—PLASMA PROPAGATION MEASUREMENTS

ABSTRACT

OBJECTIVES. (A) Investigate feasibility of circumventing communications blackout by positioning a data-relay satellite behind ionized plasma sheath of a reentry vehicle. (B) Investigate conductivity, dc voltage breakdown, and degradation from RF multipacting in high-power transmitters in orbit.

BACKGROUND. Attenuation of RF signals due to thermally ionized atmosphere (plasma) during spacecraft reentry results in a temporary loss of communication. (Water injection has been used to reduce this effect.) This plasma sheath may be employed as a reflector of RF energy to a data-relay satellite positioned for continuous communications.

RESEARCH DESCRIPTION. (A) Tune tracking antennas and receivers in spacecraft to cooperating reentry vehicle probe. Monitor probe RF transmissions simultaneously by surface data terminals. (B) Monitor high-energy RF breakdown by detecting arcing or conduction between exposed electrodes and by measuring forward and reflected power, atmospheric pressure, and atmospheric composition.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. High-wattage RF transmitter and antenna for RF breakdown research. VHF and X-Band telemetry receivers and recorders, with tracking antennas for reentry plasma studies.

CREW. Communications specialist, to set up test equipment and coordinate scheduling and tracking of reentry probe trajectory.

DATA. Multiplexed digital and analog data recording on magnetic tape or strip recorder. Data telemetry to ground for analysis. Specimens from RF breakdown returned to Earth.

OPERATIONS. Optical tracking of reentry probe launch. Spacecraft external ambient conditions monitored for RF breakdown measurements. May require EVA for initial inspections of arcing damage.

RESEARCH SEQUENCING. Coordinated scheduling with participating ground launch facilities and tracking stations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. High-efficiency, high-power RF transmitters.

RESEARCH COMMONALITIES. Data on RF breakdown may supplement 4-PP-( ) series.

RESEARCH CLUSTER 5-P-4—MULTIPATH MEASUREMENTS

ABSTRACT

OBJECTIVES. Develop reliable statistical models of multipath phenomena affecting fading and other signal variances in links between aircraft and relay satellites.

BACKGROUND. Mathematical fading models (Two Ray, Ricean, Rayleigh) proposed, but limited flight data available to verify actual conditions. System performance specifications must account for multipath propagation signal degradation.

RESEARCH DESCRIPTION. Examine signals in several candidate air-traffic radio bands between VHF and X-Band. Uses various deployment geometries, airborne and space-system components, modulation schemes, and signal-processing techniques. Requires cooperating jet aircraft and ground control centers, and radio link tests over many different types of terrain. Measure path loss, fading characteristics, and relative signal strength from direct and reflected paths. Process data for postflight analysis and upgrading of prediction models for simulation studies. Full global coverage desirable for complete testing program.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Multiband space transponders and antennas with associated measurement and recording hardware.

CREW. Communications specialist, for system checkout, calibration, and component qualification, and ground and aircraft coordination.

DATA. Initial data analysis onboard space facility. Strip chart and magnetic tape recording with digital output and display.

OPERATIONS. Spacecraft orbit and aircraft flight paths coordinated with ground stations, to maintain relative range and angle geometry for transmission tests.

RESEARCH SEQUENCING. Test scheduling incorporates variable frequency settings and various degrees of Earth surface roughness.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Develop computer software for model simulation.

RESEARCH COMMONALITIES. Complements other propagation studies under 5-P-( ) series.

RESEARCH CLUSTER 5-TF-1—SPACE DEPLOYMENT AND CALIBRATION

ABSTRACT

OBJECTIVES. Define and prepare space facility to erect, align, and test space antennas for communications and navigation research.

BACKGROUND. Space communications research calls for a variety of antenna designs, pointing control capabilities, and erection techniques to accommodate the frequency ranges and apertures specified. Assembly procedures, tools, and perhaps remote manipulators are required for assembly, maintenance, and calibration of these antenna systems. EVA erection of large structures not yet attempted in manned space missions.

RESEARCH DESCRIPTION. Erect antennas, install feeds, boresight antennas, and measure gain of experiment hardware. Assembly and deployment may require EVA for performing visual checks, changing feeds, and conducting initial tests. Test gain and radiation pattern using local reference standards and external calibration signals from known emitters. Precision stabilization and control required for narrow-beam antenna calibration.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Variety of antennas, couplings, test components, and support apparatus, including cryogenics.

CREW. Communications or instrumentation specialist, for erection, deployment, installation, repair, and calibration of experiment hardware.

DATA. Strip chart, film, and magnetic tape recording for calibration data runs. TV monitoring of EVA and display consoles.

OPERATIONS. Coordination with ground calibration transmitters during some data runs. Precision attitude control and stabilization for close-tolerance antenna pointing.

RESEARCH SEQUENCING. Responsive to research mission requirements.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Dictated by demands of individual research cluster activities.

RESEARCH COMMONALITIES. Concurrent with 5-TF-2, to comprise total facility. Manned activites similar to 1-BR-3, and to 1-EE-( ) and 1-OE-( ) series.

RESEARCH CLUSTER 5-TF-2—DEMONSTRATION AND TEST

ABSTRACT

OBJECTIVES. Provide manned orbital facility for development, demonstration, testing, and qualification of candidate communications and navigation systems, components, and materials.

BACKGROUND. Conventional terrestrial laboratories provide basic means for research and for qualifying and demonstrating materials, devices, and techniques for communications and navigation systems. Extension of this capability into space will provide component, subsystem, and system-level testing to implement advanced techniques.

RESEARCH DESCRIPTION. Within basic manned orbital facility, assemble and configure instruments, components, etc., required for individual research requirements. Perform simulation of candidate systems or subsystems, subject to typical stresses to demonstrate validity of concepts in actual space environment. Develop or qualify procedures and techniques applicable to long life high reliability systems and assess performance of candidate apparatus. Reflects space research activities in 14 communications and navigation research clusters.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. General purpose communications facility with test consoles, equipment racks, recorders, displays, etc., capable of flexible and diversified space testing of materials, components, subsystems, and systems.

CREW. Communications and instrument specialists. Activities involve reconfiguration, modification, and repair of various electronic assemblies and test equipment required by research clusters.

DATA. Magnetic tapes, strip charts, film, written copy, visual displays, and computer printouts.

OPERATIONS. Responsive to research clusters, to include ground and aircraft coordination, and deployment of controlled subsatellites during testing.

RESEARCH SEQUENCING. Scheduling to be responsive to research clusters.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Dictated by demands of individual research cluster activities.

RESEARCH COMMONALITIES. Capabilities developed in conjunction with 5-TF-1.

RESEARCH CLUSTER 5-CS-1 – MILLIMETER-WAVE DEMONSTRATION

ABSTRACT

OBJECTIVES. Demonstrate and evaluate millimeter-wave system technology under space environment conditions. Test and space-qualify new components and techniques.

BACKGROUND. Future user requirements emphasize need for use of available EHF spectrum (millimeter-wave class). Propagation is attenuated or distorted by atmospheric effects and climatic conditions. Various modulation and encoding processing techniques require space qualification.

RESEARCH DESCRIPTION. Operate millimeter-wave transponders in test mode in cooperation with ground terminals. Measure path attenuation versus weather, signal phase coherence as function of bandwidth, and scattering effects with changing geometry between spacecraft and Earth terminals. Accurate timing and precision antenna pointing necessary for narrow-beam, wideband transmission tests at high data rates. Changing of components and antenna feeds may require EVA. Obtain background sky noise using radiometer for environmental reference.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Millimeter-wave experiment instrumentation, system calibration test set, antenna assemblies and tracking system, and space transponders with processing and recording equipment.

CREW. Communications specialist experienced in mm-wave technology.

DATA. Magnetic tape primary recording mode for telemetering to ground data centers. Signal display CRT and strip chart recorders for onboard calibration and test monitoring.

OPERATIONS. Precision pointing and control for lock-on with Earth terminals during data runs. Astronaut EVA may be required. Equipment reconfiguration required during test program.

RESEARCH SEQUENCING. Adaptive, controlled by local weather conditions and availability of cooperating ground sites and remote data relay satellites.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Data correlators and phase-measuring equipment.

RESEARCH COMMONALITIES. Incorporates propagation measurements and system parameters from 5-N( ) and 5-P-( ) series.

RESEARCH CLUSTER 5-CS-2 – OPTICAL FREQUENCY DEMONSTRATION

ABSTRACT

OBJECTIVES. Extend application of laser communications technology into space for wideband space-to-ground and space-to-space links. Define and characterize optical communications equipment and techniques.

BACKGROUND. Optical communications offers potential for wide-bandwidth, narrow-beam transmissions. Many system variables, such as atmospheric attenuation and scattering, remain to be quantified before practical operations are possible.

RESEARCH DESCRIPTION. Investigate signal-to-noise characteristics of optical system designs. Determine propagation limitations and test alternative modulation techniques over wavelengths from 0.45 to 10.6 microns. Assess configurations, optical and electronic components, and precision acquisition and control mechanisms, with relation to reliability and ease of operation, during daylight and darkness. Analyze system variations as functions of wavelength, bandwidth, beam path length, size of collecting aperture, coherence variance, meteorological conditions, angle of arrival, and beam pointing errors. Participation by ground terminal and another orbiting spacecraft required.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Laser optics, electronics, acquisition and pointing control subsystems, and miscellaneous test equipment.

CREW. Communications specialist in laser technology, to program beacon for initial search and lock-on, to reconfigure system components, and to monitor status of operations.

DATA. Continuous during link tests. Tape recorder with computer printout and CRT display. Variable wideband transmissions to 1 GHz. Photographs of cloud cover taken during data runs.

OPERATIONS. Precision spacecraft attitude control during search mode. Autotrack after lock on. No effluent releases during test sequence.

RESEARCH SEQUENCING. Tests require proper geometry for line-of-sight transmissions between cooperative Earth terminals and orbiting spacecraft.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved optical acquisition and pointing systems, advancement in laser component technology.

RESEARCH COMMONALITIES. Complements 5-NS-2 and 1-EE-4.

RESEARCH CLUSTER 5-NS-1 – TERRESTRIAL NAVIGATION TECHNIQUES USING SATELLITES

ABSTRACT

OBJECTIVES. Evaluate proposed satellite radio navigation techniques through system performance testing. Verify individual contributions to system error experimentally.

BACKGROUND. Precise, near-real-time, position and velocity information considered essential to high-speed transportation systems. Space experimentation can provide engineering data for selection among numerous candidate satellite navigation systems.

RESEARCH DESCRIPTION. Select leading system candidates for verification testing of concepts. Determine comparative accuracies and error statistics for single- and multiple-satellite systems, using active or passive techniques. Demonstrate methods to reduce errors affecting each system, such as measurements of atmospheric effects at VHF through L-band, multipath [illegible]ding, timing stability [illegible]d synchronization, and system noise. [illegible] evaluate range, range [illegible] ence, Doppler shift, interferometry, pseudo noise, tone rangin[illegible] [illegible]nd angle, etc. Cooperating ground control sites and jet aircraft req[illegible]red to simulate actual systems.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Navigation transceivers (VHF through L-band), precision timing, range code generator, interferometers, and test equipment, including recorders.

CREW. Communications specialist, to set up equipment and coordinate testing with participating ground sites and aircraft.

DATA. Magnetic tape outputs computer-processed range and angle inputs to transform spacecraft ephemeris to user position and velocity.

OPERATIONS. Precision orbit determination critical to error determination. Position and altitude known to 0.1 nmi or less. Low spacecraft altitude initially, extending to synchronous orbit in final system configuration.

RESEARCH SEQUENCING. Based on ground-station and aircraft availability.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Computer software; improved satellite position determination.

RESEARCH COMMONALITIES. Information from 5-N( ) series and 5-P-( ) series, to complete RF range error analysis.

RESEARCH CLUSTER 5-NS-2—LASER RANGING AND ALTIMETRY

ABSTRACT

OBJECTIVES. Evaluate onboard laser techniques for tracking, rendezvous, and docking of space vehicles. Evaluate laser ranging devices in altimeter role. Determine optimum engineering parameters for various modes of operation.

BACKGROUND. Optical radar wavelengths allow high resolution and good accuracy in range, rate, and angle with relatively low power. In space, scattering and absorption atmospheric effects are not limiting over relatively short distances between maneuvering spacecraft. Target acquisition and tracking techniques required for cooperative and noncooperative spacecraft dockings.

RESEARCH DESCRIPTION. Compare performance of continuous wave doppler and pulse type laser devices. Select wavelength based on power, efficiency, reliability and ease of operation. Perform search, acquisition, ranging, and tracking tests to 300 miles, investigate transponding beacons and passive reflectors. Determine reflected energy detection thresholds, limiting receiver sensitivity (solar glare, specular reflection), and statistical false alarm rate as function of range and target cross sectional area.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Laser devices (i.e., modulators, filters, optics), pointing controls, and signal processing equipment.

CREW. Communications specialist in laser techniques, to assemble, calibrate, operate, modify, or reconfigure test devices, and to assess results.

DATA. Real time display of range, velocity, and angle, supplemented by computer printouts and magnetic tape recordings. Data continuous during test.

OPERATIONS. Precision autotrack with manual override. Docking maneuvers under pilot control. Effluent release prohibited except as part of test.

RESEARCH SEQUENCING. Schedule to availability of radar target vehicle; also test in conjunction with Research Cluster 1-EE-4.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Long range lasers to be developed for advanced phases of testing.

RESEARCH COMMONALITIES. Complementary to 5-CS-2 and 1-EE-4.

RESEARCH CLUSTER 5-NS-3—AUTONOMOUS NAVIGATION SYSTEMS FOR SPACE

ABSTRACT

OBJECTIVES. Evaluate performance in space of various prototype space navigation devices and system components.

BACKGROUND. Earth orbital, lunar, and planetary navigation systems employ inertial reference units, star and landmark trackers, sun and planet sensors, and radar and radio beacon techniques. Qualification of these devices and techniques requires analysis and space experimentation.

RESEARCH DESCRIPTION. Test candidate techniques and components: parametric analysis of accuracy, reliability, maintainability, response time, alignment and calibration complexity, and cost, with relationship to orbit determination and spacecraft position. Establish magnitude of spacecraft and environmental disturbances affecting system accuracies and sensitivities. Verify and refine computer error models predicting system performance. Coordinate testing with cooperative ground tracking sites and with spacecraft operational navigation and guidance subsystem.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Prototype optical, electronic, and mechanical navigation sensors and ancillary equipment. Computers, recorders, and display units.

CREW. Navigation instrumentation specialist skilled in setting up and evaluating prototype system configurations. May serve as test subject in Research Cluster 1-EE-4.

DATA. Analog-to-digital conversion for navigation computer operations. Magnetic tape and printer outputs with appropriate displays.

OPERATIONS. Some sensors effluent sensitive. Low acceleration levels ($<10^{-4}$ g) and precision stability and pointing controls required.

RESEARCH SEQUENCING. May require coordination with ground calibration sites or other space vehicles.

SUPPORTING TECHNOLOGY DEVELOPMENTS. High precision autonomous navigation sensors.

RESEARCH COMMONALITIES. Incorporates activities under 1-EE-4 and 5-NS-2.

RESEARCH CLUSTER 5-NS-4—AIR-TRAFFIC SURVEILLANCE SYSTEMS

ABSTRACT

OBJECTIVES. Develop new techniques leading to global air traffic surveillance employing Earth-orbiting satellites. Qualify reliable multiple accessing and encoding systems involving accurate location techniques and low power random accessing.

BACKGROUND. Spaceborne air surveillance systems offer the advantage of unlimited or selective global coverage in providing data to control dense air traffic, particularly over oceanic routes. Commercial air traffic flow limited at present by flight safety considerations for lateral separation between aircraft.

RESEARCH DESCRIPTION. Operate transponder equipped aircraft in system simulation with ground control station and orbiting facilities (may include deployed subsatellites). Determine location and separation accuracies, response time, sensitivity thresholds, and saturation levels of various modulation and multiple accessing schemes, as function of frequency (VHF through L Band), bandwidth, power output, coding, and traffic density for various equipment configurations. Monitoring and surveillance by participating air traffic control ground station.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Modular transponders at VHF, UHF, and L Band. Antennas, duplexers, receivers, frequency translators, transmitters, and recorders.

CREW. Communications specialists, to set up, adjust, and operate transceiver relay equipment and to coordinate testing.

DATA. Primary data mode is magnetic tape for system and component performance evaluation. Position data telemetered to ground ATC station. Target update every 1 to 2 minutes.

OPERATIONS. Coordinate flight plan with aircraft and ATC station. May deploy and control relay subsatellite from orbiting spacecraft.

RESEARCH SEQUENCING. Based on availability of system participants. Postflight data analysis at ground processing center.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Subsatellite design. Data processing software.

RESEARCH COMMONALITIES. Inputs from 5-P-( ) series and 5-NS-1.

RESEARCH CLUSTER 5-NS-5—COLLISION AVOIDANCE SYSTEM TECHNIQUES

ABSTRACT

OBJECTIVES. Demonstrate practical system employing space transmissions of time-reference signals for collision avoidance in general aviation (commercial, private, and military).

BACKGROUND. Synchronization of aircraft movements to a satellite providing wide areal coverage could alleviate threat of midair collisions. Requires compensation for diurnal and seasonal variations in radio propagation phenomena.

RESEARCH DESCRIPTION. Test common timing signal modulating four carriers in VHF through X-band frequencies. Comparative tests include signal quality, drift rate, synchronization error, and false-alarm rate for various path geometries. Satellite clock transmitter accurate to one part in 10^{11} or 10^{12}. Ground or airborne receivers record and demodulate satellite clock signals from different carriers to evaluate precision of timing synchronization. Spacecraft equipment essentially automatic. Low orbit for early testing, extending to synchronous altitude for final acceptance testing over broad area.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. RF transmitters in VHF through X-band, clock-reference cesium beam oscillator, frequency synthesizer, encoder, modulators, antennas, and associated equipment.

CREW. Communications specialist, to configure and monitor automated equipment and coordinate with ground traffic-control centers.

DATA. Minimum onboard spacecraft; equipment status monitoring. Principal data recording at ground sites or in test aircraft.

OPERATIONS. Continuous transmission over test areas. Receiver correlation reference and timing display in advanced system tests.

RESEARCH SEQUENCING. Timing depends on coordination with ground or airborne test locations, spacecraft orbit parameters, and environmental conditions.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Precision clock test transmitter. Modest-cost user receiver equipment.

RESEARCH COMMONALITIES. Propagation data useful to 5-P-( ) series.

RESEARCH CLUSTER 5-NS-6—SEARCH AND RESCUE SYSTEMS

ABSTRACT

OBJECTIVES. Provide design performance data on detection and localization by satellite of emergency location transmitters (ELT) for search and rescue operations.

BACKGROUND. Various search and rescue satellite concepts proposed. Problems include selection of proper frequency, determination of location methods, and selection of suitable modulation technique. Evaluation of candidate systems includes compliance with existing FAA standards for ELT position location.

RESEARCH DESCRIPTION. Simulate distress situations leading to development of simple, reliable, low-powered emergency beacon transmitters and search-and-rescue (SAR) satellite system. Space-qualify components to receive and relay Doppler signals to ground data center. Evaluate frequency and phase stability, noise characteristics, multipath and other fading in low signal-to-noise environment, and other system tests as functions of beacon output power, modulation and coding, and orbital parameters. Determine signal-detection range and location prediction capabilities of candidate systems under various meteorological and geographic conditions.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. RF beacon transponder and interferometric signal processing equipment operating at 121.5- and 243.0-MHz emergency frequencies.

CREW. Communications specialist, to set up and operate equipment and to process beacon signals.

DATA. Primary data mode magnetic tape recording. Stored data, spacecraft position, and timing telemetered to ground computation site. Simulated emergency beacon signals transmitted every 2 minutes to orbiting spacecraft.

OPERATIONS. Initial system testing requires ELT signal conditioning and signal processing onboard spacecraft. Final system operation at synchronous orbit.

RESEARCH SEQUENCING. Responsive to available ground SAR sites and coordination of data runs.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Design of ELT signal detector.

RESEARCH COMMONALITIES. Characterization of noise and propagation phenomena in VHF band useful to tests, reference 5-N-( ) and 5-P-( ) series.

C-2

EARTH OBSERVATIONS

RESEARCH CLUSTER 6-EP-1—PHOTOGRAPHIC COVERAGE OF THE EARTH

ABSTRACT

OBJECTIVES. Generate and update, for worldwide dissemination, geotectonic maps of the Earth's surface with precision of 500 meters or better.

BACKGROUND. Large geographic regions of the Earth have never been mapped synoptically to a scale of 1:1,000,000 or better. Limited experience from manned missions has demonstrated the value of low-to-medium-resolution space photography to the compilation of geotectonic and geomorphological maps. Such maps are required of high-latitude regions and in developing areas of the world. The synoptic coverage obtained from space can be a valuable tool for global mapping.

RESEARCH DESCRIPTION. Selectively photograph the Earth's surface over cloud-free areas, using film-filter combinations that are optimized to geographical location and atmospheric conditions. Initial trails will establish these optimal film-filter combinations. Maintain knowledge of spacecraft, ephemeris, altitude, and attitude, to locate subsatellite point to within 500 meters to achieve precise location of geological features.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric and multispectral cameras equipped with changeable lenses, filters, and film magazines. Precise camera alignment and space platform attitude must be measured to calibrate and register the imagery.

CREW. Engineering and hydrology skills. Training required in camera setup and operation, adjustments and calibration, minor maintenance functions, and ground coordination activities.

DATA. Raw data on photographic film, and magnetic tape records of ephemeris data; observation period: 1 year.

OPERATIONS. Spacecraft stable platforms required to orient sensors in local vertical mode. Polar orbits required for full global coverage. No effluent releases during measurements.

RESEARCH SEQUENCING. Not critical, except as affected by cloud coverage.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved photographic sensors, onboard film storage, ground data processing center.

RESEARCH COMMONALITIES. Complementary to 6-G/C-1.

RESEARCH CLUSTER 6-EP-2—IDENTIFICATION OF VOLCANIC ACTIVITY

ABSTRACT

OBJECTIVES. Gather volcanic data from remote satellite sensors to establish periodicity, correlate activity with local seismic data, and relate volcanism to the movement of crustal plates and seismicity on a global scale. Determine whether submarine volcanic eruptions that disturb surface waters can be detected.

BACKGROUND. Thermal infrared sensing techniques have been proven in detecting the Surtsey volcano in Iceland. Submarine volcanism is presently largely unobserved and presents potential severe hazards to life and property. In cases of catastrophic volcanic events, high resolution real-time imagery is desired on a daily basis over the affected area.

RESEARCH DESCRIPTION. Using thermal infrared imagery in the 10.2- to 12.6-micron range, survey and map known areas of volcanism, and monitor oceanic regions of possible new activity. Close coordination between ground and space monitoring of geological dynamics is essential. Geometric precision: 2 to 5 parts in 10^4; temperature resolution, $\pm 1^\circ$ Kelvin.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Principal instruments are metric camera, multispectral camera, radar imager, microwave radiometer, and multispectral scanner with cryogenic cooling of infrared heads.

CREW. Engineering and geology technicians, to set up sensors, load cameras, acquire desired ground track, and coordinate target selection and recording.

DATA. Primarily film (color, false-color infrared, and black and white) and tape. Also multiplexed data from electronic scanners, 81 channels and up to 2.4 Mbps/channel.

OPERATIONS. Global mapping requires high-inclination orbits. Target overflights at least once each quarter. Spacecraft ephemeris correlated to ground meteorological conditions during data run.

RESEARCH SEQUENCING. Early daylight recording requires 30-degree solar elevation angle to permit optimum infrared imagery and microwave radiometry in conjunction with photography. Cloud cover over target areas: $\leq$ 20 percent.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved instruments such as 10-band multispectral scanner, and signature analysis techniques.

RESEARCH COMMONALITIES. Data and instrumentation requirements similar to those of 6-G-4.

RESEARCH CLUSTER 6-A/F-1—CROP INVENTORY AND LAND USE

ABSTRACT

OBJECTIVES. Construct thematic and land-use maps from space-gathered data showing cultivated and natural forested areas, identifying major crop, forest, and range types. Obtain information on distribution of cultivated, forested, and ranged lands. Information needed to manage programs effectively to improve soils and forest stands and to protect watersheds. Make investigations to determine whether spacecraft can provide better data at less expense than other methods.

BACKGROUND. U.S. Department of Agriculture annually surveys 200-million acres, using aircraft. Repeat photography is required every 5 years. Apollo 9 photographs supported by aircraft flights demonstrated the value of space-acquired data.

RESEARCH DESCRIPTION. Make initial measurements, using multispectral sensors, over agricultural truth sites in cooperation with investigators on the ground. Use replication of previous ground and aircraft experiments to verify signatures and measurement techniques.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Multispectral-multisensor installation with ability to select and modify film-filter combinations, data channels, and instrumentation configuration. Cryogenically cooled sensors involved.

CREW. Engineering and forestry and agriculture skills, for sensor setup and operation, adjustment, maintenance, and calibration. Voice annotation to supplement sensor data.

DATA. Film and magnetic tape records of sensors returned for postflight analysis. Sensors operate 30 to 60 minutes per orbit during 8 to 10 orbits per week.

OPERATIONS. Sensor-target geometry and temporal relationships critical and sensitive to mission design. Preferred orbit inclination: 55 degrees

RESEARCH SEQUENCING. Late spring and early summer observations coordinated with ground truth site data.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved ground resolution of cameras and multispectral scanners. Advanced signature analysis techniques.

RESEARCH COMMONALITIES. Instrumentation similar to that of 6-A/F-3.

RESEARCH CLUSTER 6-A/F-2—SOIL TYPE MAPPING

ABSTRACT

OBJECTIVES. Determine, from space-gathered data, recognition criteria for soil types, moisture content, salt content, organic composition, friability, insect population, and microorganisms present in typical soil classes. This research leads to preparation of current maps of soil type and quality.

BACKGROUND. Soil Conservation Service of U.S. Department of Agriculture has continuing program of soil classification and mapping, using field observations and a limited amount of aerial photography. In a program of systematic and aggressive research, the full utilization of space-platform remote sensing and the timely application of these techniques will support solutions to major agricultural and forestry problems.

RESEARCH DESCRIPTION. Conduct multispectral imagery and photography in conjunction with *in situ* measurements over known agriculture research farms. Verify space measurement techniques by replication of previous ground- and aircraft-obtained signatures.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Multispectral-multisensor installation with ability to select and modify film-filter combinations, data channels, and instrumentation configuration. Cryogenically cooled sensors.

CREW. Engineering and forestry skills, for sensor setup and operation, adjustment, maintenance, and calibration.

DATA. Film and magnetic tape records of sensors to be returned for postflight analysis. Precisely coordinated ground truth data required during initial phases of the experiment program.

OPERATIONS. Sensor-target geometry and temporal relationships critical and sensitive to mission design. Preferred orbit inclination: 55 degrees.

RESEARCH SEQUENCING. Late spring and early summer observations coordinated with ground truth site data.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Development of cameras, scanners, and spectrometers with improved spatial and spectral resolution.

RESEARCH COMMONALITIES. Instrumentation similar to that of 6-A/F-5.

RESEARCH CLUSTER 6-A/F-3—CROP IDENTIFICATION

ABSTRACT

OBJECTIVES. Develop space-based measurement techniques that can provide data for agricultural community in formulation of maps and statistical tables on plant and tree species in principal agricultural areas.

BACKGROUND. The Agricultural Stabilization and Conservation Service (ASCS) and the Statistical Reporting Service (SRS) of the U.S. Department of Agriculture currently rely on aerial photographs to identify cultivated crops and major vegetation types on range lands. An agricultural census, published every 5 years by the SRS, contains information on crop species broken down by state and county. Plans directed toward advancing of automated methods of acquiring and analyzing data required for these reports.

RESEARCH DESCRIPTION. Conduct multispectral imagery and photography in conjunction with *in situ* measurements over known agriculture research farms. Use replication of previous ground- and aircraft-obtained signatures to verify space measurement techniques.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Multispectral-multisensor installation with ability to select and modify film-filter combinations, data channels, and instrumentation configuration. Cryogenically cooled sensors.

CREW. Skills required in sensor setup and operation, adjustment, maintenance, and calibration.

DATA. Film and magnetic tape records of sensors to be returned to ground. Weekly data replications of truck-farm crops during growing season.

OPERATIONS. Sensor-target geometry and temporal relationships critical and sensitive to mission design. Preferred orbit inclination: 55 degrees

RESEARCH SEQUENCING. Late spring and early summer observations coordinated with ground truth.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Development of cameras, scanners, and spectrometers with improved spatial and spectral resolution.

RESEARCH COMMONALITIES. Instrumentation similar to that of 6-A/F-1.

RESEARCH CLUSTER 6-A/F-4—CROP VIGOR AND YIELD PREDICTION

ABSTRACT

OBJECTIVES. Develop space sensing techniques for use in preparing statistical information on size, vigor, and expected yield of crops; and to indicate transient, long-duration stress conditions. Also, coordinate data gathered from space with historical data gathered from conventional sources, such as cropping practices, climate, soil type and fertility, and transportation routes.

BACKGROUND. Improved techniques using infrared films and false-color imagery used to appraise forest infestations. Researchers have used panchromatic, color, infrared, and color-infrared photography of controlled nursery plots to identify healthy grain and grain infected with black-stem rust and other diseases. Photographs at scales as large as 1:500 might be required for accurate estimates although useful scales range from 1:2,000 to 1:10,000.

RESEARCH DESCRIPTION. Restrict initial missions to coverage of controlled-environment, highly instrumented truth sites. As signature-detection techniques evolve, extend coverage to other agricultural areas.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Multispectral-multisensor installation with ability to select and modify film-filter combinations, data channels, and instrumentation configuration. Cryogenically cooled sensors.

CREW. Skills required in sensor setup and operation, adjustment, maintenance, and calibration.

DATA. Film and magnetic tape records of sensors to be returned to Earth for postflight analysis.

OPERATIONS. Sensor-target geometry and temporal relationships critical and sensitive to mission design. Preferred orbit inclination: 55 degrees.

RESEARCH SEQUENCING. Late spring and early summer observations coordinated with ground truth.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved ground resolution of cameras and multispectral scanners.

RESEARCH COMMONALITIES. Instrumentation similar to that of 6-A/F-3.

RESEARCH CLUSTER 6-A/F-5—WILDFIRE DETECTION AND MAPPING

ABSTRACT

OBJECTIVES. Develop space-based techniques for monitoring and detection of incipient and active wild fires in forest, range, and wild lands. Remotely determine flammability index or dryness of forest and range.

BACKGROUND. Current annual cost of forest fire detection is about $10-million, and value of timber annually lost is about $20-million. Annual cost of fire control is estimated at about $100-million. Lookout towers and low-altitude aircraft are restricted in their effectiveness by smoke and darkness. Reaction time, coupled with need for real-time data, suggests an important role for spacecraft monitoring techniques.

RESEARCH DESCRIPTION. Compare relative effectiveness of space satellite altitudes versus low altitudes for fire detection and speed of data processing. Concurrently, evaluate feasibility of extending present fire and lightning surveillance techniques to space. Perform remote detection of smoldering fires in controlled environment of truth sites. Interrogate *in situ* sensors, using collection system, to measure surface conditions.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Variety of multispectral scanning, camera, spectrometer, radiometer, and data-processing equipment with onboard photographic processing capability.

CREW. Engineering and forestry skills, to prepare sensors, operate tracking telescope, select targets of opportunity, and coordinate with ground stations.

DATA. Primarily film strip maps during search mode, converting to voice and vidicon transmissions after fire sighting.

OPERATIONS. Near-real-time raw data transmitted to ground control sites; includes spacecraft position, target location, and weather status. Sun angle greater than 30 degrees for visual monitoring.

RESEARCH SEQUENCING. Nonscheduled data runs of approximately 10 minutes over truth sites and detected ground targets.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved sensor designs and techniques for onboard film developing and processing.

RESEARCH COMMONALITIES. Similar sensor requirements for 6-A/F-2.

RESEARCH CLUSTER 6-G/C-1—PHOTOGRAPHIC AND MULTISENSOR MAPPING

ABSTRACT

OBJECTIVES. Provide accurate geometric description of entire Earth surface, using photogrammetric techniques from space. Determine optimum frequency of observations for both photographic and multisensor mapping to acquire cartographic data.

BACKGROUND. All manned space programs have included experiments relevant to geography and cartography. Apollo 9 experiment S-65 proved feasibility of using vertical space photographs as basis for standard 1:250,000 topographic maps. However, Earth has been only sparsely photographed from space under cloud-free conditions.

RESEARCH DESCRIPTION. Using three basic instruments (metric camera, multispectral camera, 10-band multispectral scanner) observe Earth under favorable conditions of cloud cover, sun angle, and season. Use selected test sites, such as area between Salton Sea (in southern California) and Pacific coastline, which contains many significant geographic and geologic features, to provide meaningful calibration and photointerpretation scaling for data obtained from space in other geographic regions.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, multispectral camera, 10-band multispectral scanner, and onboard photographic film processing capability and recorders.

CREW. Cartographic and engineering skills, to prepare, adjust, operate, and maintain equipment, and to record comments on visual observations.

DATA. Primary data mode is photographic film. Postflight analysis conducted at ground data centers. TV and visual scanning of prevailing meteorological conditions on magnetic tape.

OPERATIONS. Observation period approximately 1 year. Geometric precision requirements demand calibration and careful handling of camera and film. High inclinations for global mapping.

RESEARCH SEQUENCING. Variable, constrained by surface weather and cloud cover. Frequency of observation from once per day to once per year.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Onboard film development in zero-g. Advanced high-resolution cameras and multispectral scanners.

RESEARCH COMMONALITIES. Primary instruments named are used in majority of research clusters in Earth Observations.

RESEARCH CLUSTER 6-G-1–ROCK AND SOIL TYPE IDENTIFICATION

ABSTRACT

OBJECTIVES. Determine performance of space-based sensors in identifying rock and soil types. Establish signature-recognition criteria. Produce geological photomap of North and South American continents.

BACKGROUND. Limited experience in application of space-acquired data in comparison with ground and airborne observations. Statistical electronic processing may provide second generation of analytical data useful to the geological engineer, the photogrammetrist, or the economic geologist.

RESEARCH DESCRIPTION. Correlate space data acquired with six instruments (metric camera, multispectral camera, 10-band multispectral scanner, infrared radiometer, side-looking radar (SLR), and microwave radiometer) covering same geographic regions as data acquired on the ground. Compare imagery from vertical-looking metric camera and multispectral camera with that obtained from oblique-looking radar. Coordinate with ground truth measurements.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, multiband multispectral camera, IR imagery and spectrometry, microwave radiometry, side-looking radar imager.

CREW. Geologic and engineering skills, to perform equipment checkout; to use optical scan for selecting, pointing, and tracking to targets; and to adjust or modify flight plan.

DATA. Film and magnetic tape recording, with digital printouts of orbital parameters during data runs.

OPERATIONS. Repeatable ground tracks every 10 to 20 days. Overflights of ground truth sites required to establish spectral characteristics of rocks and soils. Orbit inclinations to 73 degrees.

RESEARCH SEQUENCING. Coordination of duplicate instrumentation aircraft overflights during ground truth calibrations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Advanced spectral analysis techniques. Improved sensors.

RESEARCH COMMONALITIES. Similar instrumentation in other Earth Observations research clusters.

RESEARCH CLUSTER 6-G-2–STORAGE AND CONDITIONING OF COMMODITIES IN EARTH'S CRUST

ABSTRACT

OBJECTIVES. Determine feasibility of obtaining remote-sensing data from space to identify subsurface and landfill storage sites and to solve problems of underground waste disposal and dangerous-commodity storage and conditioning.

BACKGROUND. Contamination from chemical, biological, or radioactive waste is an increasingly serious problem. Efforts are being made to contain waste materials, yet accidents are common and annually cause millions of dollars in damage. Some natural subsurface waste-storage sites have been identified in the U.S., but worldwide knowledge is largely lacking.

RESEARCH DESCRIPTION. Demonstrate feasibility of remote-sensing techniques. Use space-acquired stereophotography, supported by data obtained by side-looking radar to penetrate vegetation and cloud cover, to define regional topography. Identify types of overburden from analysis of multispectral photographic, thermal infrared, and microwave radiometric data. Overflights of known truth sites are of particular importance.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, multispectral camera, multispectral scanner, microwave scanner, side-looking radar, and IR spectrometer with appropriate recording devices and onboard film processing.

CREW. Geology and engineering skills, to set up and operate equipment, to make visual observations, to obtain calibration of ground-truth data, and to perform analysis.

DATA. Film and magnetic tape recordings, supplemented by video recorders.

OPERATIONS. Truth-site overflights coordinated with instrumented aircraft. Sun angle of up to 30 degrees for IR imagery and spectrometry, nominal 30 degrees for photography. Target location accuracy: 0.5 nmi.

RESEARCH SEQUENCING. Variable, based on cloud cover of 20 percent or less. Seasonal overflights between late spring and fall.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Onboard preparation of stereophotographs. Improved resolution capabilities of sensors.

RESEARCH COMMONALITIES. Similar to principal instrumentation in other Earth Observations research clusters.

RESEARCH CLUSTER 6-G-3–GEOLOGICAL DISASTER AVOIDANCE

ABSTRACT

OBJECTIVES. Develop space-based surveillance and warning techniques, capable of identifying symptoms of a destructive geological event and relaying these data to affected area, to minimize loss of life and destruction of property.

BACKGROUND. History records many long-term and short-term natural disasters. It is possible to (1) predict hazards with difficulty, (2) detect hazards with ease, and (3) in some cases disclose an impending danger, depending on the nature of the disaster. Orbiting spacecraft can add a new synoptic dimension to these three functions.

RESEARCH DESCRIPTION. Detect thermal anomalies and surface temperature patterns of volcanic activity. Obtain synoptic imagery of sand-dune movement, storm sources, tsunami occurrences, snow-melt patterns, geological fracture patterns, and other geophysical phenomena. Collect seismic sensing data from surface-based detectors placed along major fracture systems, and record high-resolution photoimaging of natural disasters for near-real-time damage assessment.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, multispectral camera, multispectral scanner (10.2 to 12.6 microns), microwave radar and radiometer, TV photoimager, and data-collection system with recorders.

CREW. Geology and engineering skills, to prepare equipment, monitor sensor and target display or computer output, and perform initial analysis of data.

DATA. Primarily photographic, including video imagery on film. Data collection on magnetic tape, with computer printout.

OPERATIONS. Spacecraft ephemeris correlated to data runs over target areas. Laser altitude ranging desired. Thirty-degree nominal sun angle for infrared imagery and microwave radiometry.

RESEARCH SEQUENCING. Adaptive, based on natural phenomena. Routine monitoring on monthly schedule. Catastrophic events in near-real-time for disaster alert and warning

SUPPORTING TECHNOLOGY DEVELOPMENTS. Higher-resolution data sensors. Onboard film processing.

RESEARCH COMMONALITIES. Principal instruments similar to other Earth Observations research clusters. Flood-warning data applicable to 6-H-2.

RESEARCH CLUSTER 6-G-4—UTILIZATION OF GEOTHERMAL ENERGY SOURCES

ABSTRACT

OBJECTIVES. Determine how remote space sensors might identify geothermal power sources and develop signature-recognition criteria for geothermal potential. Better understanding of heat flow and a global inventory are required as products of this research.

BACKGROUND. Impressive literature exists on geothermal power sites in New Zealand, Kamchatka, California, Italy, and Iceland. Investigators have suggested the role of remote sensors in defining extensions to original sources and in identifying new sites. As engineering progresses in economics of tapping geothermal sources, the quest for new sites will increase.

RESEARCH DESCRIPTION. Using thermal infrared and microwave radiometers, locate sources of geothermal anomalies. Precise scheduling of observations is of particular importance, because subsurface hydrothermal values may be different at night than during day. Synoptic day-to-night sensing before and after rainfall, before and after spring thaw, and before and after winter snowfall, to provide useful data on local heat flux.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, multispectral camera, multispectral scanner (thermal infrared), microwave radiometer, side-looking radar, and associated data recording and processing equipment.

CREW. Geology and engineering skills, for preparation of sensors, selection of target areas, monitoring of equipment operation, and comparisons of outputs.

DATA. Primary data mode is film (color, false-color infrared, and black and white), with magnetic tape and computer printouts.

OPERATIONS. Nominal 30-degree sun angle for infrared sensors. Global coverage requires high-inclination orbits. Selected geothermal truth sites require comparative geophysical data for correlation control.

RESEARCH SEQUENCING. Not critical. Seasonal observations, once per quarter per site, taken over 1-year period.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Onboard film processing in zero-g. Improved resolution of sensors.

RESEARCH COMMONALITIES. Similar instrumentation to other Earth Observations research clusters.

RESEARCH CLUSTER 6-G-5—MINERAL AND OIL DEPOSIT DISCOVERY

ABSTRACT

OBJECTIVES. Develop space sensing techniques to discriminate among major classes of mineral and oil deposits, including ores, saline building materials, and fossil fuels. Discrimination capabilities to include determination of site, grade of the deposit (where applicable), spatial configuration, and geological control.

BACKGROUND. Photographs by hand-held cameras from space, using conventional color films over geologically random points, have proven to be highly significant to oil and ore companies throughout the world. Literature in field of remote sensing highlights scaling advantages that can be gained from space in the search for economic mineral deposits.

RESEARCH DESCRIPTION. Initially, target cameras on areas covering known major metalliferrous and petroleum deposits of the world for stereoscopic topographic analysis. Use spectral and thermal data obtained from multispectral scanner, supported by topographic radar data, to identify potentially valuable deposits. Assess optimum scaling selection and response of remoted instruments, using ground-based control targets.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Multisensor, multispectral devices (microwave, visible, UV, and IR bands) for high-resolution spectral imaging and scanning, radiometry, and photography.

CREW. Geologist and engineering skills, to perform target selection, set up and operate remote sensors, and coordinate ground control surveys.

DATA. Film and magnetic tape. Onboard computer-controlled parameters with ground-aided computation backup. Voice annotation of target geologic features.

OPERATIONS. High-inclination orbit. Sun angle between 15 and 60 degrees for sensor evaluation. Laser ranging accuracy desired for stereo aerotriangulation of control targets.

RESEARCH SEQUENCING. Spacecraft truth-site overflights concurrent with instrumented aircraft. Repeated observation of targets each quarter.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Refinement of spectral signature techniques. Onboard photographic processing in zero-g.

RESEARCH COMMONALITIES. Similar instrumentation in 6-G-1.

RESEARCH CLUSTER 6-G-6—IDENTIFICATION OF LAND FORMS AND STRUCTURAL FORMS

ABSTRACT

OBJECTIVES. Develop capability to analyze land forms by remote sensing techniques, primarily space photography. Identify spectral signatures of various types of rocks, soils, and vegetation.

BACKGROUND. Numerous aircraft flights at Purdue University have produced spectral signatures of soil in the 0.4- to 1.1-micron range. Use of thermal infrared and microwave radiometry offers additional techniques for soil classification and determination of moisture content. Optical image processing permits quantitative analysis of terrestrial stratigraphic features.

RESEARCH DESCRIPTION. Observe and photograph various land forms in North and South American continents, using metric camera, multispectral camera, 10-band multispectral scanner, infrared radiometer, side-looking radar, and microwave radiometer. Establish optimum conditions for stereoscopic analysis of topography structure and geologic formations. Obtain and compare thermal and spectral radiance of rock and soil types with similar data (including controlled calibration sites) recorded from aircraft.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, multiband multispectral camera, infrared imagery and spectrometry, microwave radiometry, and side-looking radar imager.

CREW. Geologic and engineering skills, to check out equipment; to use optical scan for selecting, pointing and tracking to targets; and to adjust or modify flight plan.

DATA. Film and magnetic tape recording, with digital printouts of orbital parameters during data runs.

OPERATIONS. Observations to be made quarterly. Overflights of ground truth sites to establish spectral characteristics of rock and soil types. Orbit inclinations up to polar required.

RESEARCH SEQUENCING. Coordination of duplicate instrumentation aircraft overflights during ground truth calibrations.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Advanced spectral analysis techniques. Improved sensors.

RESEARCH COMMONALITIES. Similar instrumentation in other Earth Observations research clusters, principally 6-G-1.

RESEARCH CLUSTER 6-H-1—DETERMINATION OF POLLUTION IN WATER RESOURCES

ABSTRACT

OBJECTIVES. Determine feasibility of sensing from space, the pollution of water resources, extent of the pollution, and its effects on water resource utilization. Determine feasibility of transmitting pollution warnings within 8 hours after data acquisition.

BACKGROUND. Legislation by Congress and the establishment in 1970 of the Environmental Protection Agency mark a commitment to reverse the adverse pollution trends. Water pollution from wastes takes four forms: chemical, biological, thermal, and mechanical. Baseline space sensing data on the ecological thresholds of each type or combination of pollution forms is required.

RESEARCH DESCRIPTION. Photograph the sedimentation and water circulation patterns and visible pollutants in waters along U.S. coastlines, rivers, lakes, and streams in visible and infrared spectra. Obtain high-resolution spectrophotometric signatures and multispectral thermal scanner outputs of surface water evaporation rate to determine presence of surface pollutants. Collect data from surface-based platforms capable of defining local salinity, chemical, and radiological parameters in waters.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, multispectral camera, multispectral scanner (0.4 to 12.5 microns), multichannel ocean-color spectrophotometer, and data collection and recording equipment.

CREW. Hydrology and engineering skills, to prepare and operate sensors, select targets, and monitor status and data displays.

DATA. Film (black and white, color, false-color infrared) and magnetic tape. Computer printout of data collection inputs. Voice annotation of observed data.

OPERATIONS. Orbit inclinations to 60 degrees. Catastrophic pollution warning in near-real-time. Monthly duty cycle for routine observations. No effluents emitted from space facility during data run.

RESEARCH SEQUENCING. Periodic calibration with ground truth sites. Preemptive response to catastrophic events as they occur.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Onboard film development in zero-g. Pollution signature analysis techniques.

RESEARCH COMMONALITIES. Similar to other Earth Observations research clusters, mainly 6-H-( ) series.

RESEARCH CLUSTER 6-H-2—FLOOD WARNING AND DAMAGE ASSESSMENT

ABSTRACT

OBJECTIVES. Determine effectiveness of high-resolution multispectral imaging sensors in orbit in providing global surveillance information on the areal distribution of snow cover, precipitation, and flood-water extent. Establish synoptic imagery techniques for improved water system management and flood control. Develop real-time acquisition and communications of flood warning information.

BACKGROUND. Need for rapid synoptic collection of hydrological data for use in flood forecasting and warning is urgent. To date, satellites are limited to relatively low-resolution TV imagery to supplement data from numerous surface gages. Expanding sensing capability of satellites will offer benefits in both rapidity and value of data obtained.

RESEARCH DESCRIPTION. Conduct and evaluate high-resolution photography and near-real-time high-resolution TV of surface floodwater. Provide supplemental data and support for an all-weather capability, using imagery from side-looking radar and a microwave radiometer. Test spaceborne date-collection system of surface-based hydrologic sensors.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Radar imager, radiometer, metric camera, TV photoimaging, and data collection system, with appropriate scanning, recording, and display devices.

CREW. Hydrology and engineering skills, to check out equipment, monitor outputs, perform "quick-look" analysis, and coordinate ground processing of data.

DATA Primary data mode is film and magnetic tape. Also, TV scanning and digital transmission of synoptic data to ground.

OPERATIONS. Onboard film processing and transmission of video tapes. Nominal sun angle of 30 degrees for visible spectrum sensors. Orbit inclinations up to at least 55 degrees. Data transmitted to ground processing center in near-real-time.

RESEARCH SEQUENCING. Repeated overflights of target areas between March and June at weekly intervals; 1 to 3 days during floods.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Onboard film development and synoptic data processing techniques. Improved sensor resolution.

RESEARCH COMMONALITIES. Similar instrumentation in other Earth Observations research clusters, mainly 6-H-( ) series.

RESEARCH CLUSTER 6-H-3—SYNOPTIC INVENTORY OF MAJOR LAKES AND RESERVOIRS

ABSTRACT

OBJECTIVES. Obtain space data defining portion of world's water budget contained in major lakes, reservoirs, and rivers. Inventory geographical location and areal extent of fresh water resources on North and South American continents.

BACKGROUND. Only gross data exist on geographical location and areal extent of world's major lakes and reservoirs. In a cooperative international program under sponsorship of UNESCO, temporal and spatial data on fresh water resources, on a regional and worldwide scale, have been costly and time-consuming to obtain. Space applications offer a rapid and economic method for obtaining this inventory.

RESEARCH DESCRIPTION. Test feasibility of surveying and inventorying areal extent and shape of major lakes and reservoirs, employing black-and-white metric photography from space. Provide secondary data on topographical features and nature of surrounding vegetation from infrared and radar imagery and multispectral cameras. Obtain additional hydrologic data from ground-emplaced sensors, using a spaceborne data-collection system.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric cameras, multispectral cameras, infrared scanner, microwave radar imagery, and data collection system.

CREW. Hydrology and engineering skills, to prepare equipment, locate and select target sites, and review and assess data return.

DATA. Sensor outputs principally on film and magnetic tape. Computer printout of data collection and ephemeris information. Voice annotation of target features.

OPERATIONS. Inclinations up to 66 degrees for principal target coverage. Overflight observations obtained quarterly for each target. Data collection from surface hydrologic sensors.

RESEARCH SEQUENCING. Ground truth site calibration to obtain water-depth sensing. Seasonal survey requirements.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Photographic development capability in zero-g. Improved resolution in sensors.

RESEARCH COMMONALITIES. Similar instrumentation in other Earth Observations research clusters, mainly 6-H-( ) series.

RESEARCH CLUSTER 6-H-4–SYNOPTIC INVENTORY OF SNOW AND ICE

ABSTRACT

OBJECTIVES. Evaluate several different instruments and techniques for obtaining data from space on the areal extent of the Earth's snow cover and ice pack. Acquire albedo and surface temperature measurements of the same areas.

BACKGROUND. Physical understanding of the dynamic characteristics of Earth's hydrologic cycle requires knowledge of the contribution of snow and ice. This knowledge required for management of hydroelectric power production, irrigation systems, flood warning, and regional and municipal water supplies. Limited data obtained from Gemini and Apollo spacecraft and from ESSA satellites.

RESEARCH DESCRIPTION. Using high resolution black and white and color photography, obtain synoptic inventories of boundaries, texture, and albedo of snow and ice fields. Evaluate radar imagery and passive microwave radiometry for temperature differentiation of snow and ice and for determining their densities and depths. Obtain hydrologic parameters from surface sensors for correlation and comparison analysis.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, infrared scanner, microwave radar and passive radiometer, and data collection system with recording and display devices.

CREW. Hydrology and engineering skills, to prepare equipment, observe and select targets, and monitor operations and data display.

DATA. Film and magnetic tape recording. Voice annotations of visual sightings. Video scan and display of imaged data.

OPERATIONS. Polar orbit required. Photography limited for clear weather (cloud cover < 20 percent). Ground truth correlation of infrared and microwave temperatures. Overflights of surface sensors for collection of hydrologic data.

RESEARCH SEQUENCING. Quarterly observations except during spring thaw, then weekly. Frequent sensor calibration to truth site references.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Radiometric techniques for depth and density measurements and mathematical models. Onboard film processing and analysis. Improved sensor resolution.

RESEARCH COMMONALITIES. Similar instrumentation in other Earth Observations research clusters, mainly 6-H-( ) series.

RESEARCH CLUSTER 6-H-5–SOIL MOISTURE SURVEY IN SELECTED AREAS OF NORTH AMERICA

ABSTRACT

OBJECTIVES. Provide periodic surveys from space to map soil moisture of agricultural areas of the North American continent, the major river basins during flooding seasons, and sporadic and discontinuous permafrost in Canada and Alaska. Develop techniques to identify spectral, spatial, and temporal characteristics for global distribution of soil moisture.

BACKGROUND. Areal distribution and seasonal variation of soil moisture and temperature data are important to both agriculture and hydrology. Moisture content affects plant vigor, salt content, compaction, and stability. Frozen moisture in the arctic soil (permafrost) presents difficult construction engineering problems.

RESEARCH DESCRIPTION. Assess whether soil type and texture, areas of water infiltration, vegetation patterns, standing water, and permafrost conditions can be determined using high-resolution photography. Use thermal infrared imagery and microwave radiometry to obtain temperature distribution, and evaluate this technique for acquiring soil moisture signatures.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric cameras, infrared scanner, microwave radiometer, and data collection system with recording and display devices.

CREW. Hydrology and engineering skills, to prepare and operate equipment, record visual observations, and monitor data output.

DATA. Panchromatic and false color film and magnetic tape. Data from surface sensors on computer printer.

OPERATIONS. Near polar inclination desired for global mapping. Minimum solar angle 30 degrees and cloud cover below 20 percent for photography. Comparative truth-site calibration overflights.

RESEARCH SEQUENCING. Agricultural areas surveyed at 2-week intervals; spring thaw flooding surveyed within 1 week.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved sensor resolution. Onboard film processing. Synoptic soil signature analysis techniques.

RESEARCH COMMONALITIES. Complements other research in 6-H-( ) series.

RESEARCH CLUSTER 6-H-6–LOCATION OF UNDERGROUND WATER SOURCES IN SELECTED AREAS

ABSTRACT

OBJECTIVES. Evaluate sensing techniques and determine feasibility of identifying from space the distinguishing spectral, spatial, and temporal characteristics that relate to locating underground water resources.

BACKGROUND. By the use of thermal infrared radiometric techniques, underground sources of water can be detected by locating areas of ground-water discharge to surface water bodies. Several ground-water sources in Hawaii and California have been discovered by this method. Ground-water discharge can also be identified in arid regions by observing the character and density of vegetation.

RESEARCH DESCRIPTION. Using the thermal infrared band of the multispectral scanner, obtain images of temperature discontinuities identifying areas of ground-water discharge into rivers and large bodies of water. Provide supplemental data using photography and microwave radiometric measurements. Initial observations in southwestern United States and Mexico and along major river systems of North America.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric cameras, multispectral (infrared only) scanner, and photoreduction and interpretation equipment.

CREW. Hydrology and engineering skills, to operate equipment and perform interim assessment of thermal discontinuities for target identification.

DATA. Simultaneous panchromatic and false-color film. Tape recording of infrared scanner and voice annotation of target area descriptions.

OPERATIONS. Solar angle 30 degrees for photography. Night operation for infrared imagery. Truth site overflights for meteorological data.

RESEARCH SEQUENCING. Responsive to interim analysis and identification of potential targets. Successive overflights of target area not to exceed 2-week intervals. Late spring and fall observation periods.

SUPPORTING TECHNOLOGY DEVELOPMENTS. High resolution sensors. Onboard film processing.

RESEARCH COMMONALITIES. Supports other research clusters in 6-H-( ) series.

RESEARCH CLUSTER 6-H-7—SURVEY OF HYDROLOGIC FEATURES OF MAJOR RIVER BASINS

ABSTRACT

OBJECTIVES. Evaluate use of space platforms to obtain information on the topography and hydrologic features of major river basins and estuaries. Provide data for routing of canals and waterways.

BACKGROUND. Seasonal surveys of the major river basins of North and South America are sought to provide information on the development of water resources. Periodic surveys of the drainage characteristics are important in water system management, flood control, hydroelectric power generation, control of soil erosion, wildlife protection, and recreation. In semiarid regions where flash flooding occurs, the courses of rivers can change annually.

RESEARCH DESCRIPTION. Obtain topographic information in areas of high terrain relief, using wide-angle stereometric photography. Infer topography of areas of low relief from photographic interpretation. Use multispectral photography for bottom topography, plant life, and vegetation analysis. Use infrared imagery to observe thermal patterns of drainage conditions.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, multispectral camera, infrared scanner, and radar imager. Computer printouts and photointerpretation equipment. Data collection system and displays.

CREW. Hydrology and engineering skills, to set up and operate equipment, monitor and interpret data, and correlate ground sensor inputs.

DATA. Primary data mode is film (black-and-white, color, false-color infrared) used with filters. Magnetic tape for digital data.

OPERATIONS. Orbit inclinations up to 68 degrees. Minimum 30-degree solar angle for photography. Cloud cover of 20 percent or less.

RESEARCH SEQUENCING. Seasonal observations (3-month intervals). Surface sensor overflights for hydrologic parameters.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Large-capacity film processing in zero-g.

RESEARCH COMMONALITIES. Supports 6-H-2, -3, and -6.

RESEARCH CLUSTER 6-0-1—OCEAN POLLUTION IDENTIFICATION AND MEASUREMENT

ABSTRACT

OBJECTIVES. Develop effective space-based techniques for monitoring effects of pollution on physical, chemical, and biological processes of the ocean. Increase knowledge of the interaction between pollution and ocean ecological systems so that marine pollution can be controlled and reduced.

BACKGROUND. Ocean and fresh-water pollution affects health, esthetics, recreation, fishing, and agriculture. Ocean pollution results directly from effluent outfalls, land runoff, harbor and shipping activities, dumping, and offshore seeps and spills. Marine biological phenomena, such as red tides, are also sources of highly toxic materials.

RESEARCH DESCRIPTION. Test remote sensing techniques and acquire data, such as sea-surface temperature, reflectance, sea color, and shoreline currents (using tracer dyes), which are indicative of pollutants. Initially, evaluate ocean color imagery by using metric and multispectral cameras. Measure sea surface temperature using infrared scanner and microwave radiometer. Select targets from surface-instrumented truth sites.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, multispectral scanners, absorption spectrometer, ocean-color sensor, microwave radiometer, and data collection system with recording and display devices.

CREW. Oceanographic and hydrologic skills, to prepare and operate sensors, perform interim analysis, and coordinate with ground data stations.

DATA. Photographic film and magnetic tape recording. Voice annotation of ocean glitter, color, and apparent turbidity.

OPERATIONS. Orbit inclinations above 50 degrees to cover selected U.S. targets. Ground truth site overflights of Scripps Pier, La Jolla, California, and Galveston Bay, Texas, required for correlation of surface data. Coincident aircraft overflights during calibration.

RESEARCH SEQUENCING. Daily observations covering 1 year. Timelines not critical unless impending catastrophic pollution event is detected during tests.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved sensor resolution. Synoptic signature analysis techniques.

RESEARCH COMMONALITIES. Similar Research in 6-H-1.

RESEARCH CLUSTER 6-0-2—SOLAR ENERGY PARTITION AT THE SEA SURFACE

ABSTRACT

OBJECTIVES. Determine feasibility and develop space-based remote-sensing techniques to contribute to understanding the nature of partitioning incoming solar energy in the atmosphere and heating at the air-sea interface. Particular requirement for energy absorbed by sea-surface layer.

BACKGROUND. Oceanographers presently estimate energy partition by indirect methods, averaging measured values of the energy parameters. Diagnostic studies require data of the global-scale air-sea interactions and temperature change in the oceans. Real-time synoptic-data acquisition may lead to increased accuracy in long-term weather predictions.

RESEARCH DESCRIPTION. Measure apparent temperature and net heat flow at the ocean surface, using dual-channel microwave radiometer in 8-mm to 3-cm wavelength ranges onboard spacecraft during initial tests. Extensive laboratory investigations relative to optical properties of water in these wavelengths required, followed by aircraft trials as precursors to space activities.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Multispectral infrared and microwave radiometer, radar, ocean-solar sensor, metric camera, and data collection system, with recording and display equipment.

CREW. Hydrology and oceanography skills, to prepare equipment, monitor operations, and perform interim data-quality analysis.

DATA. Primary data mode is magnetic tape. Photographs of cloud-cover characteristics during data runs. Voice annotation of target area data. Primary analysis at ground processing center.

OPERATIONS. Orbit inclinations up to 90 degrees. Sun angle between 30 and 60 degrees. Adjustment of initial flight instruments to select wave length and polarization during the mission.

RESEARCH SEQUENCING. Daily observations over period of 1 year.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Microwave radiometer for measuring heat flow.

RESEARCH COMMONALITIES. Supports other oceanographic research in 6-O-( ) series.

RESEARCH CLUSTER 6-0-3–OCEAN POPULATION DYNAMICS AND FISHERY RESOURCES

ABSTRACT

OBJECTIVES. Develop techniques of remote sensing from space to improve understanding of the fish population distribution dynamics and fishery production of the oceans. Determine effects of pollution on fish population dynamics. Develop models relating physical, biological, and chemical parameters to overall productivity.

BACKGROUND. Predictions of overall fish production are derived from analytic models of ocean population (food chain) dynamics, which use estimates of primary organic production as inputs. These models are subject to site variations. Accurate measurements of sensible parameters, such as sea temperature, heat flux, etc., will reduce model uncertainties in the development of improved dynamics models.

RESEARCH DESCRIPTION. Correlate multispectral signatures of chlorophyll concentration, reflected solar radiation, suspended sediments, and pollutants with ground th data from cooperating oceanographic research ships. Map 18 parameters over large geographic regions of the oceans.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, multichannel infrared scanner radiometer, multispectral ocean color sensor, microwave radiometor, and recorders and display equipment.

CREW. Oceanography and hydrology skills, to prepare equipment, monitor operations, and coordinate ground truth calibrations

DATA. Film and magnetic tape (analog and digital). Voice annotation of visual observations.

OPERATIONS. Polar orbit inclination desired Sun angle between 30 and 60 degrees. One-year observation period. Limited onboard data analysis.

RESEARCH SEQUENCING. Daily observations Simultaneous overflight of ground truth sites with instrumented aircraft.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Onboard film processing, high-resolution sensors, computer signature analysis, and model simulation techniques

RESEARCH COMMONALITIES. Supplements other oceanographic research clusters in 6-O-( ) series.

RESEARCH CLUSTER 6-0-4–OCEAN CURRENTS AND TIDE FORECASTING

ABSTRACT

OBJECTIVES. Develop remote sensing techniques from space to improve the determination of sea-surface height variations and improve global forecasts of ocean-current structure, as an aid to transportation and other ocean-surface activities.

BACKGROUND. Knowledge of global ocean currents is importa it in forecasting oceanic and atmospheric parameters. Accurate measurements of ocean-surface slope, mean sea-surface height, surface winds, temperature, and salinity are needed in determining surface currents and subsurface current distribution. Synoptic data of mean sea-surface height is a prime candidate for acquisition from spacecraft.

RESEARCH DESCRIPTION. Estimate sea surface mean height by correlating precision radar-altimeter test data with precise orbital data. Reduce noise or signal fluctuations caused by wind, waves, and swell by using error analysis involving variations in the altimeter return signal by gating and averaging. Ground truth data includes sea-surface temperature, roughness, gravity field, ocean currents, and wind velocity.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Radar altimeter/scatterometer, radar imager, metric camera, and data collection system supported by computer, recorders, and display instruments

CREW. Hydrology and oceanography skills, to prepare and operate sensors, make visual observations, monitor surface data, and assess results

DATA. Magnetic tape Photographs of clouds and glitter patterns. Critical inputs from hydrographic surface sensors. Ground truth data include sea-surface temperature, surface roughness, gravity field, ocean currents, and wind velocity.

OPERATIONS. Polar orbit inclinations for global coverage Precision altitude determination (relative error of ±3 cm desired).

RESEARCH SEQUENCING. Daily observations over period of 1 year

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved instrument resolution and computer software of analytical models.

RESEARCH COMMONALITIES. Supplements other oceanographic research clusters in 6-O-( ) series.

RESEARCH CLUSTER 6-0-5–OCEAN PHYSICAL PROPERTIES

ABSTRACT

OBJECTIVES. Determine role of remote sensing from space in acquiring knowledge of physical and chemical properties of the oceans; in particular, the density structure and its variations, which are basic to many physical and chemical characteristics of the oceans

BACKGROUND. Density variations in the ocean are fundamental factors in determining relative heights of pressure surfaces and hence large-scale currents Density is determined by the temperature, pressure, and composition of sea water. Composition is represented by salinity. Temporal variations of density at a given point are due to salinity and temperature changes from turbulent mixing, advection, and heating or cooling. Several of these parameters can be observed remotely.

RESEARCH DESCRIPTION. Determine whether salinity variations can be remotely determined by polarimetric and radiometric techniques Buoys or ships provide truth data. Advanced activities involve multispectral and multisensor acquisition of data over controlled and extended areas.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Microwave scanner radiometer, radar imager, metric camera, and data collection system with recording and display instruments.

CREW. Hydrologist, to perform instrumentation-correlation measurements with ground truth sites, and to visually observe conditions

DATA. Magnetic tape and photographic film. Voice annotation of cloud cover and sea state. Data collection from surface sensors.

OPERATIONS. Orbit inclinations above 50 degrees. Comparative overflights by instrumented aircraft.

RESEARCH SEQUENCING. Coordinated sensing from buoys and aircraft to validate measurement techniques. Daily observations taken over 1-year period.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved computer model of oceanic physical and chemical properties.

RESEARCH COMMONALITIES. Supplements other research in 6-O-( ) series.

RESEARCH CLUSTER 6-O-6—OCEAN BOUNDARY PROCESSES

ABSTRACT

OBJECTIVES. Develop remote sensing techniques from space to measure solid boundary processes that change character and shape of coastlines and adjacent ocean bottom. Forecast nature and rates of erosion and accretion; effect of harbor and coastline construction; and relationship of high swells, tsunamis, and tidal waves to bottom topography and coastline shape.

BACKGROUND. The bottom depths and the coastline shape are continually changing. These changes must be monitored continually to assess the effects of man-made modifications to natural processes and thereby predict both natural and induced potential disasters in coastal provinces.

RESEARCH DESCRIPTION. Provide surface data on coastline shape, using metric camera and high-resolution radar imagery. Use multispectral photography for bottom topography in shallow water areas. Analyze relationship between wind velocity, long shore current, and beach erosion. Initial research will require extensive ground truth measurements.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, multispectral scanner, multispectral camera, radar altimeter/scatterometer, and data collection systems.

CREW. Hydrology and oceanography skills, to check out and operate instruments, perform photointerpretation of target data, and coordinate ground truth calibrations.

DATA. Magnetic tape and film. Photostereoscopic onboard data processing.

OPERATIONS. Polar orbits for global coverage. Concurrent aircraft overflights for ground truth comparisons.

RESEARCH SEQUENCING. Variable, based on occurrence of natural events (storms, earthquakes, tsunamis). Daily observations over 1-year period.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Computational models. Onboard film development.

RESEARCH COMMONALITIES. Similar instrumentation in 6-O-( ) research cluster series.

RESEARCH CLUSTER 6-O-7—OCEAN SURFACE ACTIVITY FORECASTING

ABSTRACT

OBJECTIVES. Develop space-based techniques to remotely determine sea-surface roughness or sea state. Information on current and future sea state is vital to ocean transportation and surface activities.

BACKGROUND. Theory relating sea surface roughness characteristics to the wind field is quite well developed. Most observations of sea state and wind velocity are taken from ships, buoys, and fixed platforms. One area that requires further study is the effect of wind on surface stress characteristics and the effect of the vertical temperature profile near the surface on wave characteristics.

RESEARCH DESCRIPTION. Measure sea state by various techniques and instrument combinations, such as radar or lidar altimeter scatterometry, active and passive radar, multichannel passive microwave radiometry, and optical imagery. Correlate data with selected ground truth measurements from ships or instrumented buoys for further evaluation of space techniques that appear desirable.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, radar altimeter-scatterometer, microwave scanner radiometer, and data collection system with recording and display devices.

CREW. Oceanography and hydrology skills, to prepare sensors, make visual observations, and correlate data with surface-data collection sensors.

DATA. Film and magnetic tape. Data evaluation of techniques performed at ground processing centers. Ground truth data from buoys and ships required for correlating space measurements.

OPERATIONS. Polar orbit inclination desired. Daily observations with repeatable track, over 1-year period.

RESEARCH SEQUENCING. Not critical, except for overflight of surface sensors during data collection and for data-management telemetry.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved mathematical models relating surface parameters to electromagnetic and emission phenomena, leading to high-resolution sensor designs.

RESEARCH COMMONALITIES. Supports other oceanographic research clusters in 6-O-( ) series.

RESEARCH CLUSTER 6-M-1—DETERMINATION OF ATMOSPHERIC BOUNDARY LAYER EXCHANGE PROCESSES

ABSTRACT

OBJECTIVES. Develop techniques for using space infrared radiometers and spectrometers in deriving three-dimensional temperature and moisture fields and character of the boundary and cloud layers in the atmosphere. Improve predictive models of atmospheric processes for global and regional weather forecasting.

BACKGROUND. Transfer of energy by heat and moisture across air-to-land and air-to-water interfaces determines the primary heat sources and sinks for atmospheric circulation. These exchange processes depend critically on the vertical gradient of temperature, moisture, and wind in the atmosphere. Remote atmospheric probing from satellites began more than a decade ago, with the launch of Explorer VII. The development of an operational capability has been the goal of the TIROS and Nimbus satellite programs.

RESEARCH DESCRIPTION. Measure reflected and emitted radiation in five infrared absorption bands, using several different radiometers and spectrometers. Ground and space sensing provides basis for comparing merits of instrumentation approaches and thereby of identifying the best candidates for operational use.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Multisensor and multiband infrared (H_2O and CO_2) radiometers and spectrometers, metric camera, and recording and display devices.

CREW. Meteorology and engineering skills, to prepare equipment, provide interim evaluation of results, and coordinate with ground stations.

DATA. Film and magnetic tape. Voice annotation of visual observations during data runs. Multiple data channel readouts on strip charts.

OPERATIONS. Orbit inclination up to 70 degrees. Targets of opportunity on global scale.

RESEARCH SEQUENCING. Adaptive, based on observation opportunities of atmospheric weather phenomena. Surface and airborne soundings in target areas required for data correlation.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved mathematical models of small and mesoscale processes and associated software programs.

RESEARCH COMMONALITIES. Supports other research clusters in 6-M-( ) series.

RESEARCH CLUSTER 6-M-2–UHF SFERICS DETECTION

ABSTRACT

OBJECTIVES. Develop space-based remote sensing techniques for observing ultra-high frequency (UHF) electromagnetic emissions from cumulus-type clouds in the atmosphere to provide global distribution data. These data are necessary to define distribution and intensity of thunderstorm activity in the atmosphere.

BACKGROUND. Information on spatial and temporal variations of thunderstorm activity has both basic-research and applied values. Among basic-research problems are those of determining general atmospheric circulation and distribution of contaminants, since it is believed that intense thunderstorms play a vital role in exchanges between the stratosphere and troposphere. Applications include location of electrical discharges as an aid in forest management, aircraft routing, radio communications, and tornado location.

RESEARCH DESCRIPTION. Measure UHF emissions in the 610 MHz region from appropriate thunderstorm targets, using the onboard sferics detector. Simultaneous aircraft, ground, and meteorological satellite observations obtained for postflight correlation and analysis.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Sferics detector, metric camera, and recording and display equipment.

CREW. Meteorology and engineering skills, to prepare and operate equipment, locate targets, and monitor operations.

DATA. Magnetic tape and film. Visual observations annotated, along with spacecraft position, altitude, and attitude, to index events and rate of occurrence.

OPERATIONS. Medium to high orbit inclinations. Calibration from cloud-free regions (i.e., Southwestern U.S.), 20- to 60-minute monitoring periods.

RESEARCH SEQUENCING. Adaptive, based on seasonal storm activity, since observations are transitory. Day and night operations, correlated with ground and airborne data. Postflight analysis.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Sensitive (- 3-db noise input) sferics detector and associated signal analysis software.

RESEARCH COMMONALITIES. Supports other meteorological research clusters in 6-M-( ) series, and in 5-P-2.

RESEARCH CLUSTER 6-M-3–ATMOSPHERE DENSITY MEASUREMENTS BY STELLAR OCCULTATION

ABSTRACT

OBJECTIVES. Determine the feasibility of remotely measuring the density of the Earth's atmosphere by the diffraction and scattering of electromagnetic waves, using stars as the source of radiation and sensors mounted on a space platform.

BACKGROUND. Weather prediction models depend on a knowledge of the initial flow and mass distribution of the atmosphere. Vertical temperature and pressure profiles can be derived by radiosonde data measuring of the atmospheric density. Measurements from space can also be inferred from stellar ray-path refraction by the atmosphere. This special technique has been studied analytically; the next step requires orbital testing.

RESEARCH DESCRIPTION. Telescopically acquire stars slightly above the horizon and on azimuths behind the space platform, and track accurately until occultation at the horizon occurs. Determine refraction angle as a function of time during occultation. From this ray-path data, deduce vertical atmospheric density profile at the tangent point in the lower stratosphere.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Star tracking telescopes with appropriate scanning optics.

CREW. Meteorology and engineering skills, to set up and operate optical tracker telescope during star acquisition and to calibrate electronics.

DATA. Occultation and spacecraft ephemeris data telemetered to ground data center. Visual observations annotated during data run.

OPERATIONS. Orbit inclination of 50 degrees desired. Altitude and attitude stability during data run, ± 1 arc-sec. Obtain five or six targets.

RESEARCH SEQUENCING. Simultaneous radiosonde data recorded along line of sight during occultation data run for correlation of density predictions.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Improved star-tracking telescope design. Atmospheric density mathematical model.

RESEARCH COMMONALITIES. Common to meteorological research clusters in 6-M-( ) series.

RESEARCH CLUSTER 6-M-4–CLOUD PHYSICS EXPERIMENT IN A ZERO-GRAVITY ENVIRONMENT

ABSTRACT

OBJECTIVES. Acquire data for advancing the understanding of microphysical atmospheric mechanisms and processes of cloud formation and precipitation to improve weather prediction capabilities and artificial weather modification and control.

BACKGROUND. Microphysics lies at the very foundation of cloud modeling. The ability to model cloud-growth dynamics is fundamental to mesoscale modeling of thunderstorms and squall-line complexes. Laboratory simulations seek to provide insights into the microphysics, and theoretical studies contain assumptions that require validation. Ground experiments are unable to simulate cloud processes realistically, because the gravity effect (convection) limits observation time.

RESEARCH DESCRIPTION. Observe water droplets and ice crystals suspended in onboard zero-g cloud chamber. Monitor droplets under controlled changes in pressure, temperature, dewpoint, aerosol population, electric field, ionization, and gaseous composition. Normal and microscopic observations by a trained investigator include growth, charge behavior, coalescence mechanism, evaporation, and condensation characteristics.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Highly instrumented cloud chamber with wide range of pressure, temperature, dewpoint, aerosol population, electric field, etc.

CREW. Meteorologist with cloud physics experience, to prepare chamber, introduce controlled test variables, and observe and record results.

DATA. Time-lapsed photomicroscopic records of behavior of the cloud chamber's contents. Magnetic tape and strip charts of environmental parameters.

OPERATIONS. Maximum acceleration tolerance of 10^{-4} to 10^{-5} g during experiments.

RESEARCH SEQUENCING. Adaptive, based on ground evaluation and analysis.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Zero-g cloud-physics laboratory.

RESEARCH COMMONALITIES. Similar instrumentation for 4-P/C-2, -5, -9, -10, and -11.

RESEARCH CLUSTER 6-M-5—DETECTION AND MONITORING OF ATMOSPHERIC POLLUTANTS

ABSTRACT

OBJECTIVES. Develop space techniques and instrumentation to detect, identify, and measure pollutant concentrations in the atmosphere. Specifically, acquire data on transport and diffusion properties of the atmosphere and on the effect of pollutants on absorption and scattering of solar radiation.

BACKGROUND. Influences of the weather and of diurnal and seasonal effects on large-scale patterns of pollution are not well known. For example, it is not clear whether temperature is increasing because of the "greenhouse effect" of CO_2 pollution or decreasing because of the addition of aerosol pollution that reflects solar energy away from the Earth.

RESEARCH DESCRIPTION. Using solar illumination, to scan (with two correlation spectrometers and a common mirror device) the amount of SO_2 and NO_2 over predesignated targets and test sites. As an independent determination, radiometrically measure atmosphere-scattered and surface-reflected radiation at several wavelengths in the UV and visible range. Correlate with ground and airborne sensors.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Scanning dual spectrometer, metric camera, UV radiometer, and associated recording and display equipment.

CREW. Meteorology and hydrology skills, to prepare and operate equipment, survey and select targets, and coordinate with aircraft and ground sites.

DATA. Magnetic tape, backed up by photographic documentation. Voice annotation on selected targets observed visually. Supporting data derived from ground measurements by point sampling and monitoring networks.

OPERATIONS. Orbit inclination of 50 degrees desired. Sun angle greater than 30 degrees. Mission adaptation to special situations desirable, such as frequent overflights during high pollutant concentrations.

RESEARCH SEQUENCING. Initial calibration over ground truth sites. Daylight hour recording only, during all seasons.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Pollution signature analysis techniques. Spectrometer design.

RESEARCH COMMONALITIES. Pollution research in 6-H-1 and 6-O-1.

RESEARCH CLUSTER 6-M-6—METEOROLOGICAL STUDIES OF SPECIAL GEOGRAPHICAL AREAS

ABSTRACT

OBJECTIVES. Provide intensive observational meteorological support for the study of special geographic areas. Test the hypothesis that a manned space laboratory can have a significant role in correlation of weather data obtained from space with ground-based sensors.

BACKGROUND. A remaining problem area in numerical weather prediction is in defining general circulation cycles in the equatorial regions of the world. Lacking synoptic observational data, a combination of observing systems has been recommended to the Global Atmospheric Research Project (GARP) for world data collection. An extensive test area is planned for tropical Atlantic Ocean to model a composite system.

RESEARCH DESCRIPTION. Use multisensor and multispectral radiometers and spectrometers to provide high-resolution measurements of atmospheric radiation originating at the land-to-ocean interface. Provide close coordination with ground activities by real-time visual observations of the GARP target area. Correlate with other data from cloud photography and sferics measurements.

CONSIDERATIONS FOR IMPLEMENTATION

SPACE FACILITY RESOURCES. Metric camera, UHF sferics detector, infrared radiometers and spectrometers, and appropriate recording and data collection and display equipment.

CREW. Hydrology and meteorology skills, to check out equipments, coordinate activities with surface stations, and monitor data results.

DATA. Magnetic tape, film, and strip chart display of sensor data. Data collection from ground stations, balloons, radiosondes, buoys, and aircraft in target area.

OPERATIONS. Synchronous equatorial orbit, otherwise up to 30-degree inclination at 100- to 300-nmi altitude.

RESEARCH SEQUENCING. Adaptive to targets of opportunity in GARP test area. Simultaneous sensor coverage by cooperating aircraft and surface truth sites.

SUPPORTING TECHNOLOGY DEVELOPMENTS. Tropical cloud system mathematical model. Improved sensor resolution.

RESEARCH COMMONALITIES. Instrumentation similar to that of 6-M-2 and 6-O-1, -2, and -3.