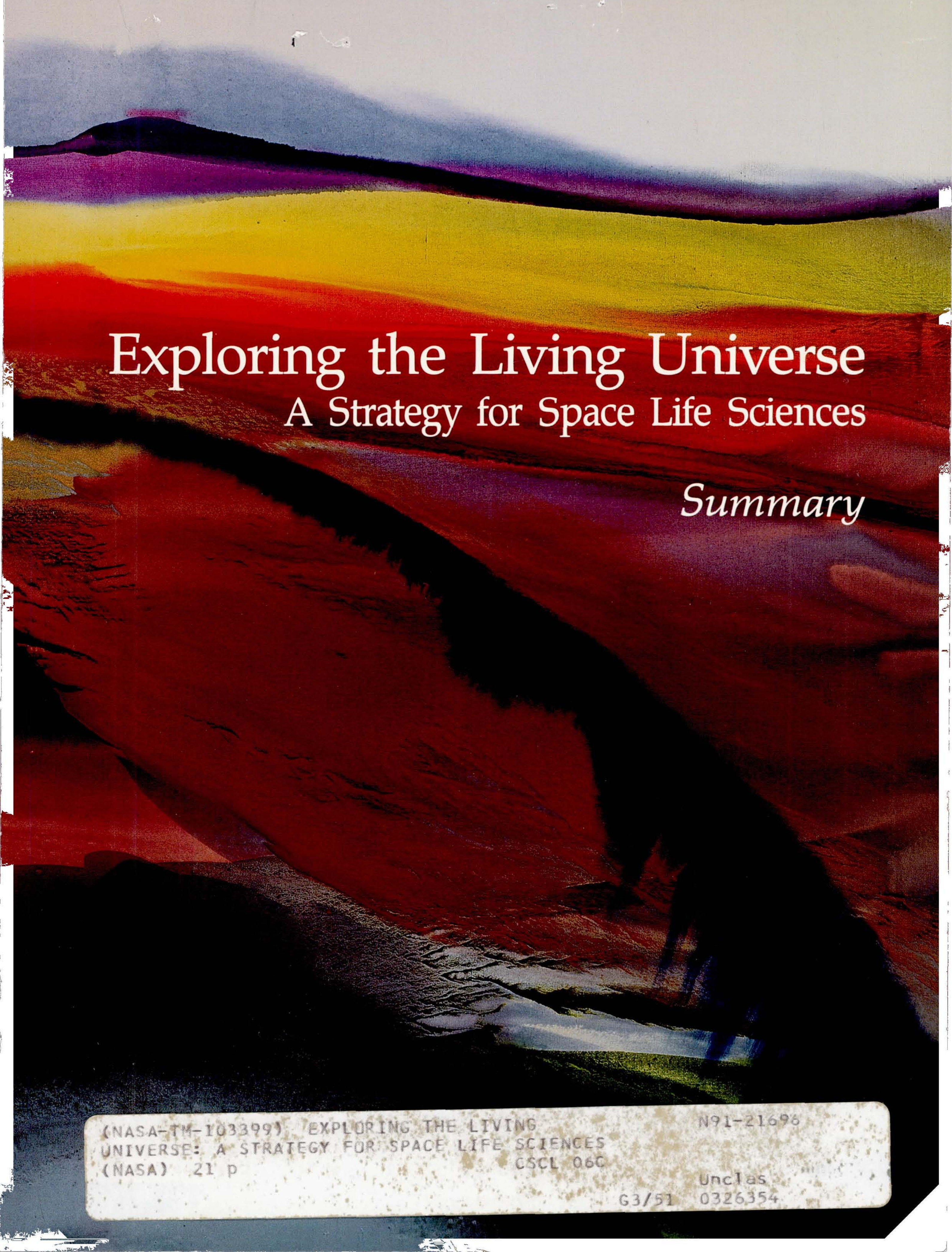

Exploring the Living Universe
A Strategy for Space Life Sciences

Summary

In his paintings, American artist Paul Jenkins has long explored abstract images having an affinity to those to be found in the universe. He sees parallels between the space in a canvas and space beyond this Earth. Both can be entered freely by the mind, and neither is open to real conquest. Jenkins believes that the exploration of the universe, like the expression of art, can "help us become more of what we are."

The paintings on the cover and divider page are reproduced with the permission of the artist.

Cover: *Phenomena Waves Without Wind,* 1977

Exploring the Living Universe

A Strategy for Space Life Sciences

A Report of the NASA Life Sciences Strategic Planning Study Committee

June 1988
Washington, DC

NASA
National
Aeronautics and
Space
Administration

NASA Life Sciences Strategic Planning Study Committee

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Dedication

James H. Bredt, Ph.D.
Executive Secretary of the
Life Sciences Strategic Planning
Study Committee, 1986-1988

The NASA Life Sciences Strategic Planning Study Committee dedicates this publication to the memory of our friend and colleague James Bredt, who died on April 25, 1988. As Executive Secretary of the Committee, Jim made significant contributions to its deliberations. Even in the last stage of a debilitating disease, he continued to participate in Committee activities. His courage, commitment, and professionalism will be long remembered.

CASE WESTERN RESERVE UNIVERSITY · CLEVELAND, OHIO 44106

May 27, 1988

Mr. Daniel J. Fink
Chairman, NASA Advisory Council
National Aeronautics and Space
Administration (NASA)
600 Independence Avenue, SW
Washington, DC 20546

Dear Dan:

On behalf of the NASA Advisory Council's Life Sciences Strategic Planning Study Committee, I am pleased to forward herewith our final report. The Committee began its work in September 1986. It was charged with reviewing the status of Life Sciences within NASA, examining its goals, and suggesting ways and means of attaining these goals.

The Committee's findings and recommendations are presented in abbreviated form in the summary. More detailed information, which provides support for the Committee's conclusions, is contained in a series of papers that comprise the body of the report. Background on the Committee and its members is presented in the appendix.

The Committee is firmly convinced and cannot emphasize enough that a stronger Life Sciences program is an imperative if the U.S. space policy is to construct a permanently manned Space Station and achieve its stated goal of expanding the human presence beyond Earth orbit into the solar system. The same considerations apply in regard to the other major goal of Life Sciences: to study biological processes and life in the universe. Developing a stronger program will require increasing the involvement of first-rate investigators at both universities and research institutions as well as at the present NASA research centers, such as Ames and Johnson. Some of our recommendations deal specifically with these issues. It is evident that much depends upon varied flight opportunities. From the point of view of learning what is necessary so that man can exist safely for extended periods in space, however, the availability of the Space Station becomes crucial. Not only is the Space Station critical, but the facilities need to be adequate as to size and equipment to achieve their purpose. The complexity of the issues and the multidisciplinary nature of the Life Sciences enterprise require that life scientists be intimately involved in most aspects of NASA's overall planning and design activities, whether they concern setting budget priorities, developing the Space Station, designing space suits, or programming unmanned probes to Mars.

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The Committee recognizes that its recommendations, if implemented, could increase more than twofold the expenditures on life sciences activities. However, if indeed one of our priorities is to place man in outer space under conditions that are safe and yet permit an adequate quality of life and work, we see no alternative to a considerable expansion of the program directed to this end. In our opinion, the recent experience of a Soviet cosmonaut who spent over 300 days in space only highlights the need for well controlled and designed experiments to elucidate further the physiological and psychological effects of prolonged existence in space and to devise and test means to counteract them.

Although there is a tendency to emphasize manned space flight, we would regard the Mission to Planet Earth or the Biospherics Program also to be of paramount importance in view of the extraordinary manmade threat that promises to seriously and perhaps permanently imperil the ecological balance on Earth. It is through such programs as Biospherics that we can define the problem and approach solutions.

The Exobiology Program and parts of the program of Gravitational Biology are directed at problems of great intrinsic scientific interest.

We would further wish to emphasize that, like much of the research conducted by NASA, life sciences research will contribute to scientific knowledge irrespective of its applicability to the specific needs of the space program.

Finally, I should like to comment upon the importance the Committee placed upon international cooperation. Because of the many other topics addressed in the report, this one may not command the reader's attention to the degree it deserves. The Committee feels that much mutual benefit can be derived from expanding true international cooperation despite the difficulties this may entail. Increased interaction with the U.S.S.R. could be particularly valuable in view of their more extensive experience with man in space for prolonged periods.

It has been gratifying to observe that, as we have been in the process of developing our report, certain changes have occurred in the Life Sciences program that have anticipated some of our recommendations. Thus, the program is stronger today than it was 18 months ago.

The Committee is appreciative of the opportunity to conduct this study. We wish to acknowledge the assistance and cooperation of the scientific community at large, those Federal agencies involved, and, especially, the NASA Headquarters and field centers, which gave so generously of their time and information. Furthermore, I personally wish to thank the Committee members and the Staff Associates for their extraordinary efforts in making this report possible.

Respectfully,

Frederick C. Robbins

Frederick C. Robbins, M.D.
University Professor Emeritus,
Dean Emeritus, School of Medicine

National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

June 3, 1988

Honorable James C. Fletcher
Administrator
National Aeronautics and Space Administration
Washington, DC 20546

Dear Jim:

I am pleased to forward with this letter the report of the NASA Advisory Council's Life Science Strategic Planning Study Committee. The report, "Exploring the Living Universe: A Strategy for Space Life Sciences," is the product of an intensive study by a group of renowned experts in various life science and other disciplines. It addresses and provides recommendations on goals, objectives, and priorities for the overall life science program; for the sub-programs of human space flight, gravitational biology, and planetary biological research; for flight programs; and for program administration. When presented to the full Council at its meeting on May 25, 1988, it was enthusiastically endorsed and approved for transmittal to you.

One principal recommendation of the report is for NASA to expand its program of ground- and space-based research contributing to resolving questions about physiological deconditioning, radiation exposure, potential psychological difficulties, and life support requirements that may limit stay times for personnel on the Space Station and complicate missions of more extended duration. Other key recommendations call for strengthening programs of biological systems research in: controlled ecological life support systems for humans in space, Earth systems central to understanding the effects on the Earth's environment of both natural and human activities, and exobiology. The Council has long supported strengthening space life science programs and our concerns voiced in prior reports to NASA were in large measure responsible for commissioning this study.

This report joins those of the Solar System Exploration Committee and the Earth Systems Science Committee as keystones for planning the respective programs for some years to come. Fred Robbins and his committee members, associates, and staff have earned NASA's and the Council's commendations and thanks for a job well done.

Sincerely,

Dan

Daniel J. Fink, Chairman
NASA Advisory Council

Enclosure

Summary

Lunar Moth, 1958
© Paul Jenkins

Summary

Visionaries have long speculated over a future in which humans understand the scientific truth about their origins, control their environment on Earth, and live successfully outside of that environment. Their speculations, however, have frequently overlooked some fundamental facts: that the universe is complex and mostly inhospitable and that life as we know it evolved in the protective shelter of an atmosphere and a constant gravitational force.

The knowledge obtained by space life sciences will play a pivotal role as humankind reaches out to explore the solar system. To conduct the types of space missions contemplated by the National Aeronautics and Space Administration (NASA), information is needed concerning the existence of life beyond the Earth, the potential interactions between planets and living organisms, and the possibilities for humans to inhabit space safely and productively.

Our experience in space thus far has given us a glimpse of the potential problems and rewards facing humans on future missions, particularly those of long duration. Within the United States space program, NASA life sciences are responsible for acquiring knowledge that will contribute to the human exploration of space. Programs in the involved disciplines are an integral part of NASA's current and future missions, from near Earth orbit, to human missions to the Moon and Mars. To realize their objectives, they require the development and operation of diverse ground and flight facilities and close coordination with numerous scientific and governmental organizations in the United States and abroad.

Study Committee Charge

Given the need for a vigorous and forward-looking program in the space life sciences, Dr. James Fletcher, the NASA Administrator, charged the NASA Advisory Council (NAC) with developing a strategic plan that will prepare the Agency for the approaching era of space exploration. To accomplish this task, the NAC organized the Life Sciences Strategic Planning Study Committee (LSSPSC) under the leadership of Frederick C. Robbins, M.D.

The LSSPSC pursued its work within a context shaped by the reports of recent task groups: *Leadership and America's Future in Space* (NASA, 1987), *A Strategy for Space Biology and Medical Science for the 1980s and 1990s* (National Academy of Sciences, 1987), and, among others, *Pioneering the Space Frontier* (National Commission on Space, 1986). Many of the issues discussed in these publications were relevant to the objectives of the LSSPSC, which cited the volumes on several occasions. The Committee, however, considered these matters independently and made efforts to avoid duplication of activity. The findings and recommendations in the LSSPSC report are consistent with those given in the other task group publications, particularly in *A Strategy for Space Biology and Medical Science for the 1980s and 1990s,* and with the National Space Policy, issued by President Ronald Reagan in February 1988. **To reassert U.S. leadership in space research and exploration, it is vital that life sciences be an integral part of the Nation's space program.**

The NASA Space Life Sciences Program

Gravitational Biology

- Understanding the role of gravity in the development and evolution of life

Biomedical Research

- Characterizing and removing the primary physiological and psychological obstacles to extended human space flight

Environmental Factors

- Defining the space environment and habitat in which humans must function safely and productively, including air and water quality and the biological effects of radiation fields

Operational Medicine

- Developing medical and life support systems to enable human expansion beyond the Earth and into the solar system

Biospherics Research

- Developing methods to measure and predict changes on Earth on a global scale and the biological consequences of these changes

Physicochemical and Bioregenerative Life Support Systems

- Assembling the knowledge base needed to design, construct, and operate life support systems and extravehicular suits in space that are independent of major resupply

Exobiology

- Exploring the origin, evolution, and distribution of life in the universe

Flight Programs

- Conducting experiments in space, including the development of facilities and hardware for space flight, mission planning integration, and flight plan implementation

Overarching Recommendations and Strategies

In its deliberations, the Committee recognized that the resolution of certain key factors was pivotal to the foundation of vigorous life sciences programs. It stresses the importance of these factors by incorporating them in a set of overarching recommendations. The Committee recommends that the Agency should:

- **Maintain and expand the Nation's life sciences research facilities located at NASA's field centers, universities, and industrial centers by:**
  - **Establishing a mechanism for attracting promising young scientists to work on NASA projects and developing additional training programs at major universities and NASA installations**
  - **Establishing a program of NASA-supported professorships in space life sciences at selected universities**
  - **Encouraging industries to develop capabilities in space life sciences through technology research and development.**
- **Assure timely and sustained access to space flight, thereby facilitating the conduct of critical life sciences experiments. This should be accomplished through:**
  - **Accumulating state-of-the-art instrumentation**
  - **Flying an augmented series of Spacelab missions**
  - **Using a series of autonomous bioplatforms to study radiation and variable-gravity effects**
  - **Dedicating suitable facilities on the Phase 1 Space Station for life sciences research**
  - **Conducting a major augmentation of life sciences capabilities during the early Post-Phase 1 Space Station.**
- **Synergize the presently independent research activities of national and international organizations through the development of cooperative programs in the life sciences at NASA and university laboratories.**
- **Complete and consolidate the unique national data base consisting of basic life sciences information and the results of biomedical studies of astronauts conducted on a longitudinal basis. This data base should be expanded to incorporate information obtained by other spacefaring nations and be available to all participating partners.**

To achieve these recommendations, NASA should initiate work immediately, in the 1989 fiscal year, on the following set of strategic milestones:

1989-1991

- **Strengthen the planning process of the Life Sciences Division by assuring its timely integration into the Agency's overall strategic planning process.**

- **Augment life sciences research programs to establish the base of scientific knowledge required by planners and engineers to conduct missions relevant to Agency goals.**
- **Provide adequate funding to develop new state-of-the-art flight hardware for upcoming manned and unmanned life sciences missions in space.**
- **Initiate advanced technology development in the areas of minimally invasive biomedical instrumentation, biological remote sensing, exobiological flight instrumentation, and microwave signal processing.**
- **Increase the frequency of life sciences data acquisition on the Space Shuttle and international missions.**
- **Conduct a study to determine the requirements for extravehicular activity (EVA) for the next 20 years, to delineate innovative options, and to identify needed technologies.**

1989-1994

- **Operate reusable biosatellites to obtain environmental, radiation, and artificial variable-gravity data on plants and animals.**
- **Achieve ground-based validation of major physiological and psychological countermeasures for long-duration missions.**
- **Conduct ground-based research on bioregenerative life support systems to achieve 90-percent closure.**
- **Initiate the Microwave Observing Project of the Search for Extraterrestrial Intelligence (SETI) Program.**

1989-2004

- **Establish a combined national and international life sciences research facility on the Space Station. This facility must support basic research on plants, animals, and humans necessary to develop an understanding of the fundamental biological processes affected by gravitational forces.**
- **Develop an advanced biomedical research facility in space to investigate and verify technologies and medical support necessary to enable the planning and implementation of human exploration of the solar system.**
- **Develop and test in space a fully operational bioregenerative life support system(s) for future use in solar system exploration.**
- **Conduct cooperative missions with other national and international organizations to study the behavior of the biosphere and the origin, evolution, and distribution of life on Earth and in space.**

The strategic milestones emphasize the importance of international cooperation in space life sciences research and missions. The LSSPSC believes that considerable mutual benefit can be derived from expanding such efforts. Increased interaction with the U.S.S.R. could be particularly valuable because of their more extensive experience with humans in space for prolonged periods.

The LSSPSC also discussed the need to quantify resources, including the funding, personnel, and facilities required for implementation of the strategic milestones. It determined that this activity was critical but could not be satisfactorily accomplished in the time available to the Committee. The LSSPSC accordingly recommends that this effort be initiated immediately after publication of the report through techniques and resources readily available to NASA and that the results be communicated as available to the NASA Advisory Council.

Implementation of the strategic plan requires the careful scheduling of activities relevant to the two major program thrusts:

- The assurance of the health, safety, and productivity of humans in space
- The acquisition of fundamental scientific knowledge concerning space life sciences.

These emphases are equally important, the first being an Agency goal and the second being a part of the strategic plan developed by the NASA Office of Space Science and Applications (OSSA). Efforts associated with assuring the health, safety, and productivity of humans in space should be paced so as to provide the Agency with information vital in planning and conducting extended manned missions. While much can be done using ground research and short-duration flights, the key lies in the availability of appropriate life sciences facilities on the Space Station. Scheduling pertinent to the basic scientific programs should be consistent with the OSSA overall long-range strategic plan.

Committee Deliberations

The LSSPSC organized into 13 Study Groups to evaluate NASA life sciences activities. The Study Groups surveyed scientific literature, interviewed NASA researchers and administrators, and deliberated with international authorities from Europe, Japan, and the Soviet Union. The groups summarized the results of their research in papers that provided the basis for the Committee's findings and recommendations.

Based on the Study Group evaluations and research papers, the Committee developed approximately 30 detailed recommendations in addition to the four overarching recommendations. The full report contains the research papers that support these recommendations. This summary presents the detailed recommendations of the 13 Study Groups in five categories: Human Space Flight, Gravitational Biology, Planetary Biosciences, Flight Programs, and Program Administration.

Specific Recommendations and Findings

Human Space Flight

Four challenges potentially limit the duration of human space flight: physiological deconditioning, the biological effects of exposure to ionizing radiation, possible psychological difficulties on the part of the space crew, and environmental requirements, including the need of life support on lengthy space journeys. The disciplines of Biomedical Research and Operational Medicine focus on the health and safety of human space crews.

Biomedical Research concentrates on physiological deconditioning, which becomes a greater concern the longer the space mission. Ground and space research have identified unresolved scientific issues relevant to the following areas: cardiovascular physiology, specifically, a more complete characterization of cardiovascular deconditioning; neurophysiology and behavioral physiology, particularly space adaptation syndrome (space motion sickness); bone, endocrine, and muscle physiology.

Soviet Space Accomplishments

The recent return of Soviet cosmonaut Yuri Romanenko to Earth after 326 days in space has excited great interest, as evidenced by reports in the world press. His return suggests that humans can exist for considerable periods in space and successfully readapt to conditions on Earth.

Caution must be exercised, however, in drawing optimistic conclusions from a single case, particularly when the subject was unusually experienced in space missions and had been selected according to particular physiological and psychological attributes.

Furthermore, the assertion that regular exercise played a role in preserving his well-being has yet to be proved. It should be noted, in addition, that his exercise program consumed 4 hours each day.

Thus, while Romanenko's experience is encouraging, it only makes more imperative that we pursue as soon as possible the necessary studies in space to define better the physiological changes over time so that countermeasures can be rationally devised.

Radiation poses significant challenges for long-duration missions, such as the 1 to 3 years required for a round trip to Mars. While considerable information is available about radiation beyond the protection of Earth's magnetic field, substantive questions remain concerning the biological effects of exposure to galactic cosmic radiation and solar particle events and the shielding required to protect astronauts, as well as exposure-measuring instrumentation. Although critical unresolved issues remain, NASA does not have a focused program of radiation effects studies.

The success of extended missions will depend substantially on the psychological interactions among the space crew and between the space and ground crews. Information is not available on morale and productivity among small, isolated groups living in microgravity for lengthy periods. The most pressing issues for extended human missions, which will offer only limited possibilities for emergency rescue and return to Earth, involve crew/environment interactions, interpersonal interactions, human/machine interface, crew selection, command and control structure, and crew motivation.

Environmental factors and life support requirements directly relate to both the physiological and psychological well-being of the space crew. The primary concerns in this area include identifying requirements for a regenerative food, air, and water system, developing an environmental monitoring system capable of detecting all possible sources and types of contamination, determining the most workable systems to support EVA operations, and analyzing habitability requirements for extended missions.

The development of a bioregenerating life support system is especially challenging. NASA's Controlled Ecological Life Support Systems (CELSS) Program focuses on combining biological and physicochemical processes to provide food, air, and water by recycling materials inside the spacecraft. Ground-based research indicates that such a system is feasible. The behavior of plants in space, however, is not well understood.

Operational Medicine considers the health care of astronauts, particularly during long-duration missions. The most important operational issues include the development of requirements for the Health Maintenance Facility (HMF), definition of medical requirements for a Crew Emergency Return Vehicle (CERV), development of a data base for astronaut health records, and establishment of training programs for inflight medical specialists.

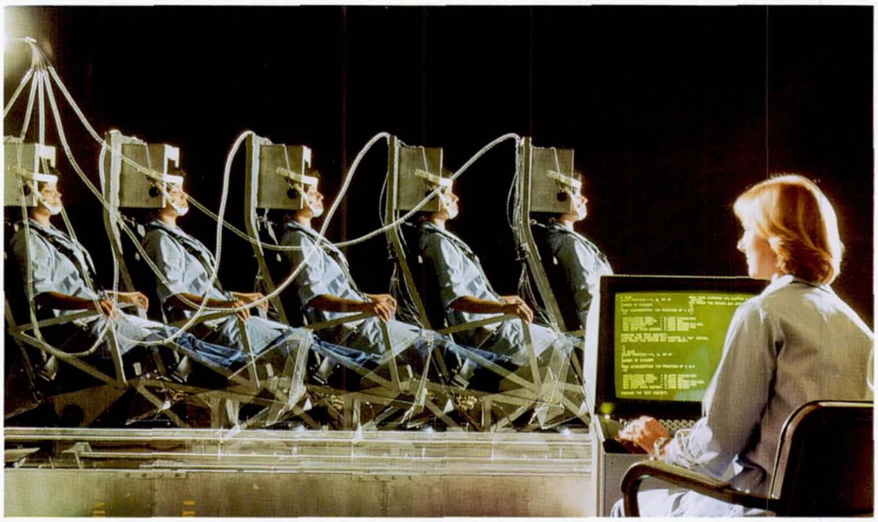
Recommendations: In addressing the ground- and space-based research needed to resolve the outstanding issues pertinent to human space missions of extended duration, NASA should:

- Immediately expand its program of ground-based research to resolve the outstanding questions about physiological deconditioning, radiation exposure, potential psychological difficulties, and life support requirements that may limit stay times for personnel on the Space Station and more extended missions.
- Plan an orderly, phased introduction of advanced life support and EVA technology into future manned space systems.
- Design and build a suite of variable-gravity facilities for life sciences research.
- In allocating payload and support resources for the Space Station, give first priority to life sciences research that will make human missions of extended duration possible.
- Take a number of steps, including the following, to ensure crew health and safety on the Space Station and missions of longer duration: include a physician among the crew, develop a Crew Emergency Return Vehicle to allow transport of crew members to Earth in urgent situations, and develop the capabilities of the Health Maintenance Facility for use on a possible human mission to Mars.

Gravitational Biology

Gravitational Biology studies the scope and operating mechanisms of one of the strongest factors influencing life on Earth: gravity. It addresses fundamental questions concerning how living organisms perceive gravity, how gravity is involved in determining developmental and physiological status, and how gravity has affected evolutionary history.

While these questions are motivated primarily by scientific interest, such research can help determine if life can function effectively for extended periods in weightlessness or reduced gravity, as on the Moon or Mars, or if artificial gravity is required. Space-based research, which requires variable-force centrifuge facilities, provides unparalleled opportunities to expose organisms to fractional gravity levels ranging from zero to 1 g, and thereby to investigate the effects of gravity on these organisms.



Ground-based vestibular sled experiments at NASA's Johnson Space Center test human response to rectilinear acceleration (NASA Photo LBJ S81-39883).

Recommendations: In understanding the role of gravity in the reproductive, developmental, and metabolic activities of all forms of life, NASA should:

- Increase the number, duration, and regularity of life sciences experiments flown in space.
- Provide adequate inflight research capabilities, including a suite of variable-force centrifuge facilities, on-orbit analytical equipment, and plant and animal vivaria capable of supporting successive generations subjected to varying, controlled gravity levels.
- Coordinate Gravitational Biology research with that conducted by interrelated science programs, such as CELSS and Space Biomedicine.
- Operate its intramural and extramural research programs in a manner that attracts and supports excellent new researchers, especially young scientists, into the relatively new field of Gravitational Biology, as well as into other areas of space life sciences.

Planetary Biosciences Research

The Biospherics Research Program studies the biological processes that have shaped the chemical history of Earth. Human activities, such as fossil fuel combustion, have markedly increased the concentrations of many atmospheric constituents, including greenhouse gases. A descriptive theory of the biosphere is required to understand the causes and consequences of these changes and to permit change measurement and prediction. Space capabilities are essential to this effort because they provide a global perspective.

The funding and logistical support needed to achieve biospherics goals transcends the resources of any single organization. Increased cooperation is, therefore, required among NASA organizations, Government agencies, and spacefaring nations.

Exobiology focuses on questions long pondered by humankind, such as, Are we alone in the universe? What led to the origin of life on Earth? Exobiologists believe that the early environments of Mars and Earth were similar and that samples from Mars could fill gaps in Earth's geological record. Any valid indication of life on Mars would support the hypothesis that life can originate wherever the physical and chemical environment is favorable. For these reasons, robotic probes followed by human missions to Mars will yield important scientific answers.

Recommendations: To understand the exobiology and biospherics issues relevant to the origin, evolution, and distribution of life in the universe, NASA should:

- Make the science requirements of biospherics and exobiology integral to plans for its Mission to Planet Earth and Exploration of the Solar System initiatives.
- Develop within those divisions having similar interests in planetary biology—the Life Sciences, Solar System Exploration, Earth Science and Applications, and Astrophysics Divisions — additional programs to promote maximum return from collaborative research.
- Include the Biospherics Research Program as a participant in the development and implementation of the Earth Observing System and other remote-sensing technologies.
- Initiate the Microwave Observing Project now, before radiofrequency interference makes it exceedingly difficult or impossible to conduct research from Earth.
- Pursue vigorous programs of ground-based research, remote observations, and instrument development for use on missions to assess evidence bearing on the possible origin of life on Mars and the nature of chemical evolution on other solar system bodies.
- Develop the technology of robotic round trip, sample selection and analysis, and sample return for exploration of the surface of Mars, asteroids, and comets. This effort should include precautions to avoid the spread of contamination within the solar system.
- Significantly enhance the ground- and space-based research capabilities and infrastructure (funding, personnel, and facilities) for planetary biology in order to maintain the Agency's leadership role in this area and to optimize the scientific return of future missions.

Flight Programs

Flight Programs includes the development of equipment, facilities, expertise, and flight opportunities needed to conduct life sciences research successfully in space. The hiatus in flight activity following the *Challenger* accident has been discouraging to life sciences researchers, many of whom have waited 10 years or more to fly their experiments. The current challenge is to assure that a sufficient number and variety of flight opportunities are available for life sciences research when the Shuttle resumes operations.

Astronaut Harrison Schmitt explores the huge lunar boulder during Apollo 17 *extravehicular activity at the Taurus-Littrow landing site (NASA Photo 75-HC-159).*

An additional challenge is to pursue a vigorous ground program that is closely integrated with and supportive of the flight program through significant ground preparations. These preparations include the design of equipment and the development of models that replicate space phenomena.

Recommendations: To facilitate the achievement of NASA and Life Sciences objectives, NASA should:

- Increase the flight opportunities for life sciences research by doing the following:
  - Dedicating a greater number of regularly scheduled Shuttle middeck lockers and commercially developed flight facilities
  - Increasing the flight rate of Spacelab and dedicating a larger percentage of Spacelab volume, time, and resources for life sciences experimentation
  - Dedicating clinical and biological research centers on the Phase 1 Space Station
  - Deploying an unmanned spacecraft that is reusable and can support a variety of flight experiments.
- Encourage students and non-NASA life scientists to participate in mission-related research but be careful not to encourage unrealistic expectations of flight opportunities.
- Develop a new generation of ground-based and of flight-certified instrumentation, including noninvasive monitoring techniques for biomedical applications, to support the research objectives of the Life Sciences program.

Program Administration

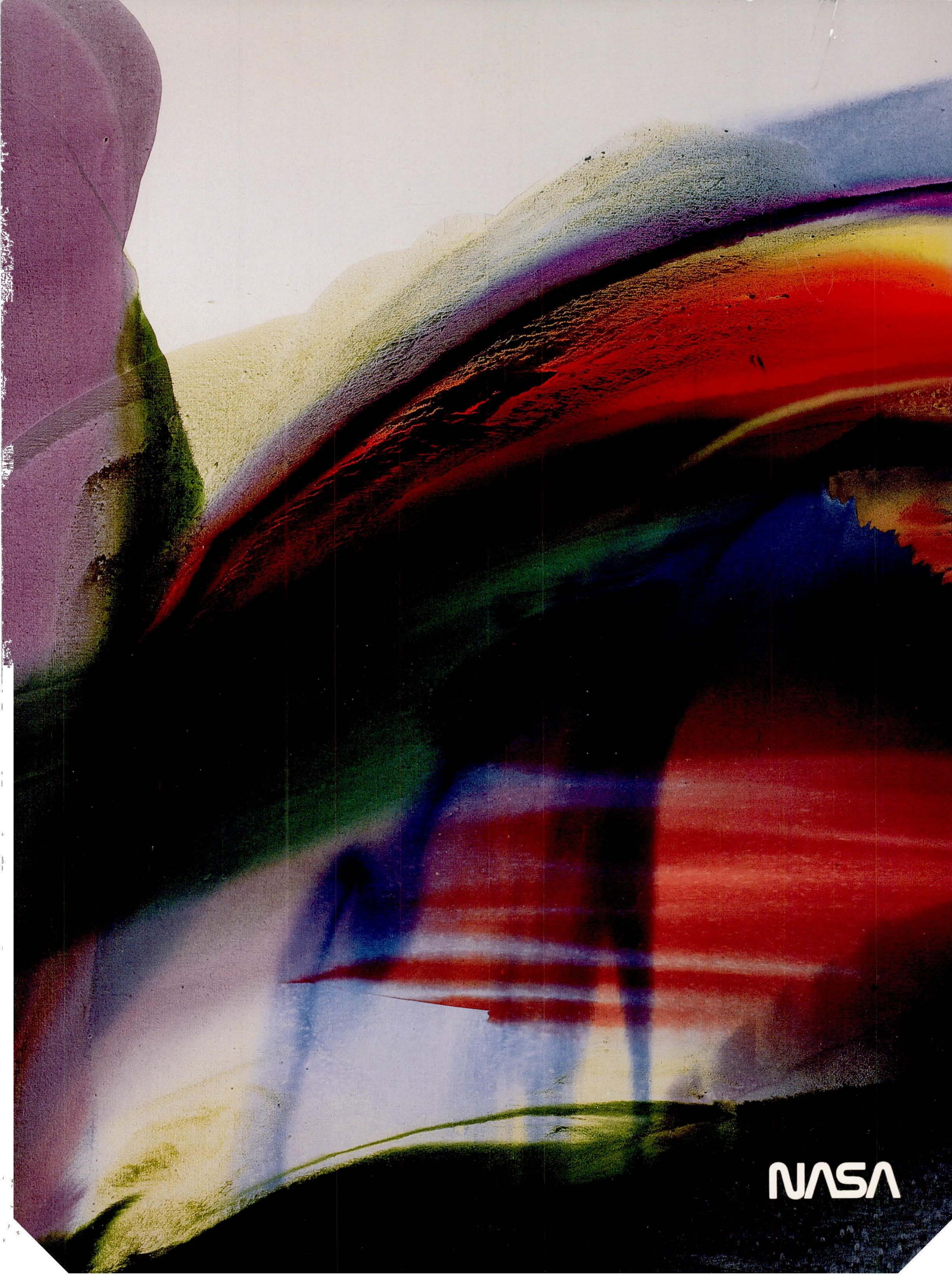
The administration of the Life Sciences program poses several difficult challenges. Because it encompasses basic science, applied science, operations, and engineering/technology activities, its management involves complex relationships that extend beyond disciplinary and organizational lines. Increased collaboration within NASA and stronger ties with universities are needed.

Although the Agency is committed to life sciences goals and objectives, the challenge of realizing these goals requires a major increase in Division resources. The provision of these needed resources at the proper time to permit required program growth is a critical issue. Increased budgets both in annual funding and for civil service personnel will enable the achievement of program objectives.

Recommendations: To strengthen the administration and organization of the life sciences, senior NASA management should:

- Support the continuation of Division efforts to establish a strong program by:
  - Strengthening the Division's role in Agency-wide planning
  - Facilitating access to flight opportunities
  - Indicating to the rest of the Agency that biomedical research relevant to the safe conduct of human space flight is essential to ongoing and future NASA initiatives.
- Include senior personnel from the Life Sciences Division as participants in all top-level planning of Agency flight programs.
- Increase substantially the resources for Life Sciences programs to assure implementation of the recommendations given in this report.
- Increase Agency efforts to expand the numbers of scientists at the Centers and Headquarters and institute new efforts to provide career development opportunities for existing staff.
- Support the Life Sciences Division in its efforts to establish formalized agreements and working groups with other agencies and organizations.
- Provide funds to expand and implement plans to establish Specialized Center of Research (SCOR) units within selected universities.
- Support the Life Sciences Division in generating and maintaining a data base through collaborative arrangements with NASA's Scientific and Technical Information Facility and the National Library of Medicine.

The U.S. civil space program has reached a significant threshold. This country is contemplating a future in space that will involve increasingly complex missions that may include human bases on the Moon and Mars, as well as intensified satellite observation of Earth. NASA has recognized the critical role of the life sciences in facilitating and participating in such missions and must now commit the resources required to implement the strategy given in this report.


NASA