Life into Space

Space Life Sciences Experiments
NASA Ames Research Center
1965-1990

Edited by Kenneth Souza, Robert Hogan, Rodney Ballard

Life into Space PDF Edition

About the PDF Edition

Life into Space, 1965-1990, published in 1995, and *Life into Space, 1991-1998,* published in 2000, present an overview of space life sciences missions, payloads, and experiments developed and/or managed by the NASA Ames Research Center and Kennedy Space Center. In order to extend access to this information, the original print publications have been adapted for electronic distribution. These PDF versions allow for printing any or all of the books as they appeared in the published hard copy form.

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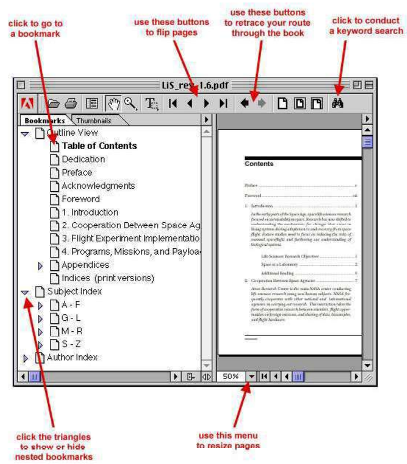

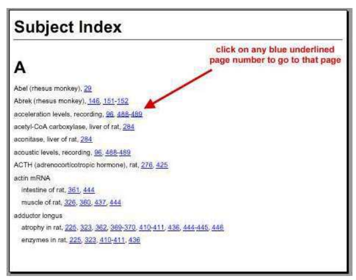

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Life Into Space 1965-1990

Pages A-B	book cover and "About the PDF Version" page
Pages i-viii	contents, dedication, preface, acknowledgments, and foreword
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Life Into Space 1991-1998

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Pages 1-666	main section of the book

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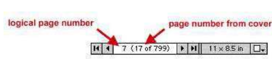

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This version has been reorganized to take full advantage of hypertext navigation.

For More Information

Life Sciences Division
NASA Ames Research Center
Moffett Field, CA

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DEDICATION

Life into Space is dedicated to Rodney Ballard, the former Assistant Chief of the Space Life Sciences Payloads Office at Ames Research Center and coeditor of this book, who died in August 1993. This book would not have been started without his conviction that these space life sciences accomplishments should be made readily available to the current and upcoming generation of scientists and engineers. He believed strongly in the benefits of international scientific cooperation, and was very pleased to have had a key role in some of the processes described herein. The interviews with several participants in these endeavors, included in this book, were done primarily at his urging. He thought it important for the reader to have a glimpse of some of the people and extraordinary challenges associated with conduct of this research. All those who were fortunate enough to know him will greatly miss the international vision, steadfastness, goodwill and unabashed optimism he brought to his endeavors on behalf of the Space Life Sciences Payloads Office.

A quote from a recent essay captures much of Ballard's legacy to his colleagues at home and abroad:

> In a chaotic world, friendship is the most elegant, the most lasting way to be useful. We are, each of us, a living testament to our friends' compassion and tolerance, humor and wisdom, patience and grit. Friendship, not technology, is the only thing capable of showing us the enormity of the world.

(Steven Dietz, notes from the director for the play "Jody's Maps," January 1994.)

PREFACE

Ames Research Center (ARC), along with other NASA centers, supports life sciences research in space using various living systems. Among the centers, it is the only one with the comprehensive facilities and expertise required to develop complex animal experiments. ARC began developing space life sciences experiments in the early 1960s and continues to actively support NASA's life sciences research program.

This book is the first compilation of the results of ARC's space life sciences research in a single volume. It profiles the background, objectives, and methods for this research. There have been major changes within NASA and ARC during the past 25 years, and in the way this research is managed and conducted. There has been an evolution from mission to mission toward internationalization at all levels. The core of the book describes individual missions from Gemini 3 in 1965 to STS-41 in 1990. The year 1990 was chosen as the cutoff date because the results of missions completed after this point had not yet been fully analyzed. The book provides top-level overviews of mission objectives, payload and experiment development, operations before, during, and after flight, and brief descriptions of mission results.

One-page summaries of over 200 completed experiments and the associated hardware items are provided in two major appendices. Publications for each experiment are listed in another appendix. This information should be useful to three major groups: first, NASA and contractor personnel who are responsible for experiment and payload development; second, current and prospective space life sciences investigators in universities, NASA centers, industry, and the international space life sciences community; third, members of the life sciences community that provide counsel on the content, structure and future direction of NASA's life sciences program. We asked NASA investigators to review their experiment results and associated publications so that our descriptions are as accurate as possible. We also invited input from other selected reviewers.

This book describes accomplishments by many scientists, engineers and managers at ARC, the large university science community that supports NASA life sciences research objectives, our many international colleagues, and our aerospace industry hardware development and support contractors. We are grateful for their contributions. We appreciate all the people who produced the facilities, equipment, experiments, and scientific results described in this book and are proud to have been part of this effort.

Kenneth Souza, Chief
Robert Hogan, Deputy Chief
Rodney Ballard, Assistant Chief (deceased)
Space Life Sciences Payloads Office
Ames Research Center, 1995

ACKNOWLEDGMENTS

The editors are indebted to a large group of people for their contributions to this volume. William Berry, Oleg Gazenko, Eugene Ilyin, Harold Klein, Claude Milhaud, Nello Pace, Joseph Saunders, Lyuba Serova, Joseph Sharp, Richard Simmonds, and David Winter gave insightful accounts of their involvement in space life sciences research. Several NASA staff reviewed the volume and provided valuable criticisms and suggestions, especially Paul Callahan, Bonnie Dalton, James Connolly, Michael Skidmore, Emily Holton, Charles Winget, and John Dyer. Eugene Benton and Charles Fuller also provided many helpful corrections and comments. Without the help of John Tremor, Robert Mah, Paul Dolkas, and Gary Thorley, it would have been difficult for us to collect information on several older missions. We are grateful to the more than fifty reviewers who corrected and commented on the information in this book. The staff of Spaceline (Ron Dutcher and Kathy Scott) deserve acknowledgment for their generous and substantial assistance in providing and verifying citations for this book. Also, the assistance of the Ames Research Center Life Sciences Library staff was instrumental in obtaining hard-to-find material. Bertie Cox and Lorraine Tanner (both formerly of ARC Publications Branch) gave critical support for concept development of the book and Bethann Dennis of Scientific and Commercial Systems Corporation provided invaluable editorial support.

We would especially like to thank the staff of Mains Associates: Richard Mains for his comprehensive book concept and overall management of this project; Ruvanee Pietersz for research, writing, and translation of French material; Gretchen Gold for book production, illustrations, graphics, layout, and overall coordination; Wesley Rakeman for database development and management, and production assistance; Barbara Chan for book design, editing, illustrations, and publication project consultation; Alan Wood for database design; Karen Walker for content review and database production; Galina Tverskaya for translation of Russian material, review of material on the U.S.S.R./Russian space program, and conduct of Russian interviews; Melissa Padgett for several text illustrations; Richard Herron for most of the hardware illustrations; David Beckerman and Greg Leonard for production assistance; and Trisha Lamb Feuerstein for the index.

FOREWORD

Since the writing of this book began more than three years ago, extraordinary changes have taken place in Eastern Europe. The dramatic collapse of Communism in the former U.S.S.R. and the parting of the Iron Curtain that divided Eastern and Western Europe for over 40 years have transformed our view of the future. Many of the consequences of these changes are still uncertain. It is clear, however, that the references to the U.S.S.R. in this book are outdated. Since the book was written from the perspective of 1990, we have let this terminology and the description of the former U.S.S.R. space agency stand.

It will be obvious, if perhaps surprising to some readers, that a majority of the space flight experiments described in this book were conducted on U.S.S.R. Cosmos biosatellites. The Cosmos Program was especially important for obtaining regular access to space for Ames Research Center during the 1980s after the Challenger disaster. Following the August 1991 collapse of the U.S.S.R., the tenth, and last, Cosmos mission in this series was launched in December 1992 with several U.S. experiments onboard. The Russians (formerly the Soviets) worked hard against great odds to conduct this mission as planned. The Russians are developing a commercial, improved biosatellite for future use by the international space life sciences community. Significant interest in this plan has been expressed by many space agencies, including NASA.

The major part of this book was produced directly from the Space Life Sciences Payloads Office (SLSPO) Flight Experiments Database (FED), which has been under development for about four years. It includes descriptions of both developing and completed experiments along with hardware and publications information. This book could not have been produced without the FED and is a good example of what computers and software tools can accomplish. The FED has now become a part of the SLSPO Data Archiving Project, a key element of the new NASA Headquarters Life Sciences Data Archiving program. This program will provide information similar to that in this book via an online database for direct user access through the National Space Science Data Center (NSSDC), Greenbelt, Maryland.

This book intentionally has no concluding chapter, since it describes the results of ongoing research supported by the SLSPO at Ames Research Center. Although the future can never be projected with much accuracy, it promises to be as varied as the past in terms of the types of space flight missions undertaken. In addition to new biosatellites, new options on the Russian Mir space station, longer-duration Space Shuttles, and the International Space Station are being planned. Constrained funding has increased the trend toward international cooperation among space agencies. This trend was already accelerating due to the many advantages of coordinated research. Worldwide, the private and public sectors are collaborating more often to support space life sciences research and development. This book should be a useful resource for those prepared to participate in these opportunities.

1 Introduction

Life sciences research has been conducted in space for several decades. Initial U.S. efforts with biological payloads can be traced to 1946, when a collection of fungal spores was launched from Alamogordo, New Mexico, in a pioneering balloon flight. In the early years of the space age, the aim of life sciences research was to assess the ability of living organisms to survive space flight. Once it became apparent that animals and humans could withstand exposure to microgravity, cosmic radiation, and the rigors of launch and re-entry, the focus of inquiry shifted to the biological changes that occur during and after space flight.

A considerable body of knowledge has been gathered in this field. From both the mission and science standpoints, future generations of researchers can benefit from the achievements and lessons of the past only if the results are documented. This book is a record of the space life sciences research supported by the NASA Ames Research Center (ARC) Flight Experiments Program from 1965 to 1990. Life scientists and space industry personnel will find the book a valuable resource for guiding future research efforts. Laymen and students will also benefit from reading about the history of space life sciences research.

For the purposes of this book, life sciences research is defined as the study of biological and biomedical processes using live specimens as experimental subjects. All experiments conducted by or through the ARC, using microorganisms, cell cultures, plants, and animals are discussed here. A few radiation studies that used no biological materials are included because they accompanied the live specimens and are relevant to life sciences research. The significant research conducted by ARC in the areas of exobiology, life support, and other fields related to space life sciences is not considered. Studies undertaken by other NASA centers and experiments using human subjects are also outside the scope of this book.

This first chapter of the book discusses the objectives of life sciences research and the use of space as a laboratory. Although the book is written from a U.S. perspective, the increasingly international nature of space life sciences research is fully acknowledged. Chapter 2 addresses the interaction between NASA and foreign space agencies in implementing the ARC Flight Experiments Program.

Chapter 3 briefly describes the challenging process of developing an experiment for space flight. The program and mission descriptions in Chapter 4 comprise the major portion of the book. Commentaries by pioneers in space life sciences have been added when possible. Descriptions of ARC flight experiments are included in Appendix 1. Appendix 2 lists selected publications relating to these flight experiments. Appendix 3 contains descriptions of all the major hardware items flown on ARC-developed missions.

Life Sciences Research Objectives

Early space flight research was conducted simply to evaluate the viability of living systems in the microgravity environment. Later, researchers began to examine the changes that occur in such systems in response to microgravity. Today, research is increasingly focused on attempts to understand the mechanisms for changes observed, and to develop methods to counter those changes.

Space life sciences research has two general objectives. The first is to study the effects of exposure to microgravity on biological systems to reduce the risks of manned space flight. The second is to use the microgravity environment to broaden scientific knowledge about the influence of gravity on living systems.

In mentioning these objectives, the importance of ground-based studies in simulated microgravity must not be forgotten. Many of these, such as bed rest, water immersion, and suspension studies were developed because it was difficult and costly to conduct research in space. Ground-based studies continue to provide information that is extremely valuable in helping to design and interpret experiments carried out in space.

Space as a Laboratory

The Space Environment

Where does space begin? It does not begin abruptly at an arbitrary point above the surface of the Earth (Fig 1-1). Broadly speaking, space can be said to begin just beyond the biosphere, which is the part of the universe in which life can be sustained without artificial support. The biosphere includes the land and sea masses of the Earth (lithosphere and hydrosphere) and the mass of air (atmosphere) above them. The atmosphere consists of a mixture of gases held in place around the Earth by gravitational forces. The density and pressure of the air declines as the distance from the Earth's surface increases. At an altitude of 12.20 km, no human can survive without an artificial atmosphere comprised entirely of oxygen. At an altitude of 18.29 km, a space suit or a pressure cabin becomes absolutely necessary for survival. "Physiological space" can be said to begin at this point. However, a finite atmospheric pressure of 54 mm Hg still exists. It is only at an altitude of 80.5 km that pressure

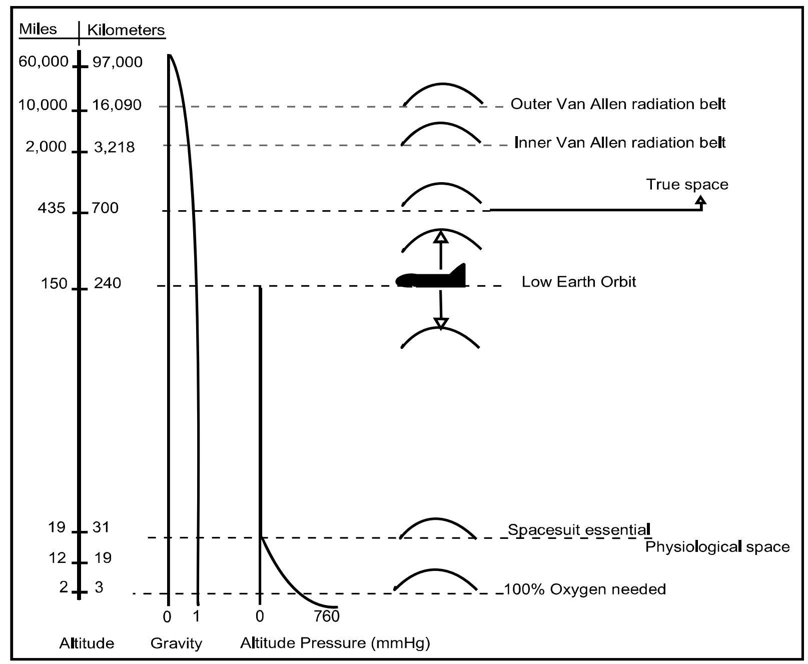

Figure 1-1: The transition from Earth's atmosphere to space (Harding 1989).

approaches zero, and not until an altitude of 700.35 km does a vacuum exist. This point can be considered to be the beginning of "true space." Even at this distance, the Earth still exerts a considerable gravitational attraction. It is theorized that no spacecraft launched from the Earth would be entirely free of the gravitational pull of the Earth until it was several million miles away. By then the gravitational effects of other celestial bodies would begin to have an effect. However, because an Earth-orbiting spacecraft is in "continuous free-fall," balanced by equal and opposite forces toward (gravitational) and away from (centripetal) the Earth, it is exposed to a very small force of gravity. The effective force of gravity may in fact be reduced to up to one millionth of its value on Earth (thus the term "microgravity").

Life forms have adapted to the force of gravity on Earth through millions of years of evolution. Gravity continuously acts upon living systems from microorganisms to humans. It is likely that the near absence of this force would evoke both acute and chronic changes in most biological systems. Investigation of these changes is the central theme of life sciences research in space.

The responses to microgravity thus far observed in animals and humans fall into three main categories. First, functional neurophysiological changes are known to occur as a result of the modified sensory input during space flight. Second, hormonal, humoral, and autonomic adjustments take place in response to a headward fluid shift. A third change occurs in the cardiovascular system and in bone and muscle tissue because of the absence of gravitational loading and the reduced necessity for physical activity in microgravity.

Space flight also exposes crew and passengers of spacecraft to radiation levels that are greater than either the background exposure at the Earth's surface or the occupational exposure for radiation and health workers. The source may be charged particles, neutrons, or ionizing photons. The risks of manned space flight can be assessed only after an accurate dosimetric picture of the space environment is available. Fluence, charge, velocity, specific energy, and time course of dose deposition must all be considered when predicting biological responses to radiation. Ground-based studies alone cannot provide this information. Ground-based studies rely on single sources of unidirectionally applied, monoenergetic radiation species. Some of these radiation sources do not exist or are insignificant in space. Shielding is usually not used in ground-based studies; it is always present in space. Furthermore, the potentially synergistic effects of microgravity and radiation cannot be determined from ground-based studies.

If humans are to live in space for long periods in the not too distant future, the physiological consequences of space flight must be thoroughly evaluated. Countermeasures must be developed to combat the detrimental effects of space flight to ensure health and productivity in this alien environment. In addition, hardware must be developed that is capable of providing adequate housing and life support.

The conditions of space flight, microgravity, and radiation (exclusive of the acceleration, noise and vibration levels encountered at launch and re-entry) cannot be reliably duplicated in ground-based simulations. Therefore, life sciences research ultimately must be performed and hardware design and operations must be verified in space.

We can increase our understanding of some fundamental biological processes by studying them in space as well as on the Earth. For instance, studying calcium metabolism and bone mineral depletion in space may provide insights into the clinical problems of bone decalcification and osteoporosis. The study of cardiovascular responses to body fluid changes associated with weightlessness may be useful in understanding the causes of hypertension and congestive heart failure. Likewise, the muscle deconditioning that frequently accompanies prolonged bed rest may be better understood by investigating similar changes in muscle structure and function that occur in response to microgravity.

The conduct of life sciences research in space is subject to numerous constraints. The high cost involved is a primary consideration. The cooperative spirit that has emerged between countries, in place of the intense competition of the early space age, has to some extent alleviated this problem. Joint space ventures between countries are advantageous because technology, resources, and scientific results can be shared.

Cost constraints also affect the choice of implementing research programs versus research projects. In an uncharted environment such as space, fruitful research can only be performed after initial exploratory studies are conducted. In other words, answers can only be sought after the correct questions are determined. Science objectives can, therefore, be better achieved through research programs encompassing several missions, although funding is often easier to obtain for research projects carried out on single missions.

One of the most difficult problems that researchers face is the fact that experiment technology frequently becomes outdated during the long period required for developing a mission. Preserving the flexibility to incorporate new technology is often difficult, especially if the mission is complex. Flight hardware designers have to finalize their plans several years before the planned launch date to ensure that there will be adequate time to fabricate and test the equipment.

Constraints influence not only the planning phase of a mission, but also the flight phase. Science requirements for various experiments must often be modified to meet mission requirements. Unmanned missions using nonhuman subjects require the development of fully automated life-support systems. Research on manned missions needs to rely less on automated hardware, although crew operations with animal subjects are usually very limited because of time constraints. At the same time, the complex issue of biologically isolating the animal subjects from crew members must be addressed.

Research Subjects

Although the ultimate objective of biomedical research in space is to ensure the crew's safety and well-being in the space environment, research using human subjects has serious limitations. Experiment procedures required for gathering important physiological data often cannot be implemented in humans for practical or ethical reasons. Research variables like temperature, diet, light cycle, activity, and stress cannot be easily controlled for humans. Continuous physiological monitoring using implanted sensors is not feasible. Crew members cannot usually be dedicated to specific in-flight experimental goals because of operational considerations. Data collected from crew members may be compromised by countermeasures taken to combat microgravity effects such as space sickness. Furthermore, crew members are rarely available for the extensive preflight and postflight analyses that constitute an important part of space flight studies.

For these reasons, nonhuman organisms often need to be used as research subjects in the space life sciences. These organisms can frequently be selected from a homogeneous population. Experiments using such subjects are not constrained by operational considerations. They can be allowed to adapt to the space environment without application of countermeasures. Environmental variables can be strictly controlled in-flight as well as during preflight and postflight ground-based studies. Measurements can be made using invasive techniques, tissue samples can be obtained, and drug testing can be carried out.

Various species of nonhuman subjects have been used in space life sciences research (see Table 4-2, p. 30). The use of vertebrate subjects, particularly mammals, is important because it is often possible to extrapolate experimental results to humans. Rats and primates are suitable experimental models for many studies. The adaptive responses of these animals have been studied in a number of biosatellite and Space Shuttle flights.

Non-mammalian vertebrates studied in space have included amphibians and fish. Among invertebrates, insects have been useful in experiments investigating the effects of microgravity and cosmic radiation.

Several experiments have been conducted on plants in space, including studies on germination and growth. Gravity plays a very important role in plant growth on Earth, enabling shoots to grow upward and roots to grow downward. Experiments conducted in space indicate that microgravity influences plant physiology, development, and metabolism. Research on the adaptation of plants to microgravity is obviously important if humans are to attempt to exist in space for long periods of time.

Lower organisms such as bacteria and fungi, as well as cell cultures, have also been studied in space. These simple life forms have enabled us to better understand biological processes that cannot be readily investigated in the presence of terrestrial gravity.

Additional Reading

Anderson, M., J.A. Rummel, and S. Deutsach. *BIOSPEX: Biological Space Experiments, A Compendium of Life Sciences Experiments Carried on U.S. Spacecraft.* NASA TM-58217, June 1979.

Asashima, M. and G.M. Malacinski, eds. *Fundamentals of Space Biology.* Japan Scientific Societies Press and Springer-Verlag, 1990.

Ballard, R.W., E. Morey-Holton, W.P. Gilbreath, T. Halstead and M.L. Richardson. *The Reusable Re-Entry Satellite: A New Capability for NASA.* 40th Congress of the International Astronautical Federation, October 7–13, 1989, Malaga, Spain, IAF-89-D15, 1989.

Cipriano, L.F. *A Capsule Summary: The Life Science Experience in Space 1948-1975.* Unpublished report. March 1979.

Harding, R.M. *Survival in Space: Medical Problems of Manned Spaceflights,* Routledge, 1989.

Heinrich, M.R. and K.A. Souza. *Final Reports of the U.S. Rat Experiments Flown on the Soviet Satellite Cosmos 1129, Final Report.* NASA TM-81289, 1981.

Mains, R.C. and E.W. Gomersall. *U.S. Monkey and Rat Experiments Flown on the Soviet Satellite Cosmos 1514.* NASA TM-88223, 1986.

Miquel, J. and K.A. Souza. Gravity Effects on Reproduction, Development and Aging. *Advances in Space Biology and Medicine,* vol. 1, pp. 71–97, 1991.

Needell, A.A., ed. *The First 25 Years in Space; Proceedings of the Symposium, Washington, D.C., October 14, 1982.* Smithsonian Institution Press, Washington D.C., 1983.

Saunders, J.F., ed. *The Experiments of Biosatellite II.* NASA SP-204, 1971.

Schatte, C., R. Grindeland, P. Callahan, W. Berry, G. Funk, and W. Lencki. *Animal Studies on Spacelab 3.* Proceedings of the 2nd International Conference on Space Physiology, Toulouse, France, November 20–22, 1985, ESA SP-237, 1986.

Sibonga, J.D., et al., eds. *Cells in Space.* Proceedings of the Cells in Space-II Conference, San Juan Batista, Calif., Oct. 31–Nov. 4, 1988, NASA CP-10034.

Webb, P., ed. *Bioastronautics Data Book.* NASA SP-3006, 1964.

Wunder, C.C. *Life into Space: An Introduction to Space Biology.* F.A. Davis Company, 1966.

2 COOPERATION BETWEEN SPACE AGENCIES

This chapter describes the cooperative activities that ARC has undertaken in conducting research in space life sciences. Interactions between NASA and space agencies of other countries are reviewed in the context of this research.

In the 1960s and 1970s, the struggle for national superiority was one of the main forces driving the development of space activities. In contrast, international cooperation is now an important factor in many countries' space agendas. In 1958, the United Nations General Assembly created an ad hoc Committee on the Peaceful Uses of Outer Space (COPUOS). The committee now includes more than 50 member nations. The Scientific and Technical Subcommittee of COPUOS promotes scientific cooperation in outer space and provides technical assistance to developing nations in space-related matters.

Cooperation in space research benefits the international community in many ways. It allows scientific ideas, technical expertise, and facilities to be exchanged, and enables costs to be shared. Life scientists from around the world can collaborate effectively to solve problems of mutual interest. In addition to these advantages, there are political benefits to establishing cooperative enterprises.

National Aeronautics and Space Administration

NASA was created in 1958 to provide a formal structure for American civilian space activities dedicated to the peaceful uses and exploration of space. NASA now has several centers located around the country. Activities connected with space life sciences research are conducted primarily at four of these sites (Fig. 2-1). The Life Sciences Division at NASA Headquarters is responsible for overall program guidance and direction, and for integrating the activities of the various NASA centers. ARC in Moffett Field, California, Johnson Space Center (JSC) in Houston, Texas, and Kennedy Space Center (KSC) in Cape Canaveral, Florida, are responsible for implementing the life sciences research program. Activities at these centers include development of program and mission objectives, experiment selection, flight support, and data analysis.

JSC is concerned mainly with space biomedical research on human subjects. Life sciences research using nonhuman experimental subjects is conducted mostly at ARC. KSC carries out some life sciences flight experiments using plant subjects. Marshall Space Flight Center, together with KSC and JSC, also plays an important role in ARC flight experiments by supporting many preflight and postflight activities.

Ames Research Center

Although ARC was founded in 1939 as part of the National Advisory Committee for Aeronautics (NACA), NASA's predecessor, space life sciences research did not become part of the ARC agenda until 1960. Early life sciences research at ARC was concerned mainly with questions raised by preparations for the Apollo missions to the moon. Interest was centered on the effects of radiation, isolation, and changes in gravitational loading, and on crew life support requirements during space flight. Studies were also conducted on gastrointestinal function, tissue breakdown, and possible changes in the processes of reproduction, development and aging in the space environment.

By late 1963, life sciences research was being conducted by four groups at ARC. The Environmental Biology Division focused on physiology, pathology, and radiobiology; the Biotechnology Division on human performance and man-machine interactions; and the Exobiology Division on biosynthesis and cell biology. The fourth research group was the Biosatellite Project Office, which was in charge of developing a series of unmanned biosatellite missions.

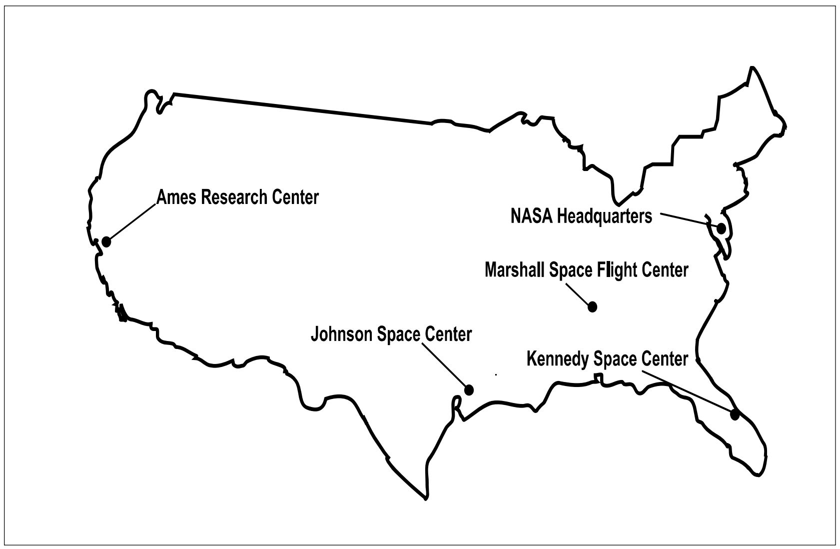

Figure 2-1: NASA facilities involved in life sciences research.

More resources became available for life sciences research beginning in 1963. During that year, a Bioscience Laboratory was built with an attached vivarium for housing animals. It was needed to accommodate the several hundred macaque monkeys that were expected to be maintained at ARC by 1965. These animals were to be used as space flight candidates for the Biosatellite Project. The facility supervisor was a veterinarian and a member of the National Animal Care Panel, established to ensure the humane treatment of experimental animals. The Laboratory had state-of-the-art surgery facilities, a recovery room, isolation wards, stainless steel animal cages, and steam sterilizing equipment.

A 20 g animal/human centrifuge became operational at ARC in 1964. It could simulate the stresses of spacecraft launch and reentry. In 1965 a four-story Life Sciences building was completed for use in a wide range of research activities. Three long-duration animal centrifuges were available for hypergravitational studies by 1968.

Three biosatellite missions were developed by the Biosatellite Projects Office in the 1960s. The first mission, Biosatellite I, was launched in 1966. Because of a hardware malfunction, it was never recovered. Biosatellite II, launched in 1967, was a replicate of Biosatellite I. It carried several biological specimens into orbit and was successfully retrieved. Biosatellite III was launched in 1969, carrying onboard a single monkey. The monkey's untimely death, shortly after the biosatellite landed, focused a good deal of negative public attention on the Biosatellite research program. The controversy generated by this mishap, and the absence of plans or funds for a follow-on project resulted in the dissolution of the Biosatellite Projects Office in the early 1970s. It was replaced in 1977 by the Life Sciences Flight Projects Office (LSFPO).

NASA began working on a concept for the Space Transportation System (STS) in 1969. In 1973, the Europeans agreed to build the Spacelab, an important element of the STS. In the mid-1970s, ARC conducted two initial simulation studies in conjunction with Marshall Space Flight Center and JSC. The objective of the studies (termed Spacelab Concept Verification Tests) was to verify the compatibility of life sciences flight experiments with the evolving design of the STS/Spacelab. A range of experiment subjects, including rats and rhesus monkeys, was used in the tests. Eventually, a life sciences payload was developed, which included human experiments from JSC. A seven- day flight simulation, termed the Shuttle Mission Development Test (SMD III), was then carried out at JSC to test this payload. By the conclusion of SMD III in mid-1977, the LSFPO had acquired its core staff and contractor support, and by the early 1980s had evolved into the current ARC Space Life Sciences Payloads Office (SLSPO).

In recent years, more resources have become available at ARC for life sciences research. A Vestibular Research Facility, developed in 1986, can deliver precisely controlled rotational and linear accelerations to animal subjects as large as young-adult macaques. The original Bioscience Laboratory has been expanded into an Animal Care Facility certified by the American Association for Accreditation of Laboratory Animal Care. An associated Biomedical Research Facility constructed in 1988 integrates animal housing and laboratories.

At the present time, life sciences activities at ARC are conducted within the Space Research Directorate. The Directorate comprises eight divisions and a staff of several hundred research scientists and engineers. Besides flight studies, the Directorate oversees ground-based research and new technology development.

Interagency Cooperation

NASA collaborates with other federal agencies and many universities in implementing its life sciences research program. Investigators from numerous academic and research institutions participate in the program. NASA is also pursuing opportunities with the National Institutes of Health (NIH) for joint biomedical and behavioral research. For example, a NASA-NIH workshop was held in 1989 to assess the similarities between the aging process and physiological deconditioning that occurs in space, and to discuss joint research in these areas. In 1992, the two agencies signed a memorandum of understanding that will enable them to carry out joint studies on such diverse subjects as neurological disorders, arthritis, and cancer. The Environmental Protection Agency is working with NASA to study the effects of global warming on aquatic systems NASA, the National Oceanic and Atmospheric Administration, and Farleigh Dickinson University's National Undersea Research Center are studying crews living in the Aquarius undersea habitat, as an analog to NASA's planned space station. NASA and the National Science Foundation are conducting joint basic scientific and technical research in the Antarctic. The studies are expected to be applicable to developing a lunar base or a journey to Mars. There are also a number of joint projects in the life sciences between NASA and the Department of Defense.

Through the years, NASA has established a vigorous program of international cooperation to take full advantage of the limited access to space. This program is important in achieving NASA's objectives in the space life sciences. Cooperative activities can be initiated by a foreign agency asking to participate in a NASA program or by NASA suggesting international cooperation in a program. There are four types of agreements between NASA and foreign countries. Executive or intergovernmental agreements signed by officials of each government and processed by the U.S. State Department are established for high-cost programs like Spacelab. Other programs involve agency-level memoranda of understanding signed by the NASA administrator and his foreign counterpart, with State Department concurrence. Letters of agreement signed by the NASA International Affairs Division and its foreign counterpart can also be used for a wide range of programs. Some informal projects may be carried out with simple verbal agreements.

NASA is currently conducting joint research with several foreign space agencies, including the European Space Agency (ESA) and those of the U.S.S.R./Russia, France, Germany, Canada, and Japan. These activities are briefly described below.

U.S.S.R./Russia

Before its breakup in December 1991, the U.S.S.R. operated what was probably the most active space program in the world. However, its agenda was frequently shrouded in secrecy, probably due to a lack of separation between military and civilian space activities. Since the formation of the Russian Space Agency in 1992, a number of changes have been made in space policy. Space activities have become less prolific because of budgetary restrictions, but at the same time, they have become more visible because of the need for cooperation with other countries.

Before 1991, the Soviet Academy of Sciences played a lead role in U.S.S.R. civil space activity. The Intercosmos Council for International Cooperation in the Study and Utilization of Space was created by the Academy to develop cooperation with the Socialist satellite countries, and later Western Europe and the U.S. The Council was responsible for the initial international agreements in space life sciences research. It coordinated the activities of the Institute of Biomedical Problems in Moscow, which manages the Cosmos biosatellite program.

The Institute of Space Research (IKI), a division of the Academy, was also highly involved in international cooperative efforts. The planetary studies laboratory at the Vernadsky Institute of Geochemistry frequently collaborated with the IKI. The Glavkosmos agency was created to develop the commercial aspect of Soviet space activity.

The restructuring of the former U.S.S.R. space program in 1992 has led to a separation of military and civilian activities, with the Defense Ministry being responsible for the former and the Russian Space Agency for the latter. Ten of the former states of the Soviet Union may also jointly fund the civilian program.

There have been three areas of cooperation in the space life sciences between the U.S. and U.S.S.R. The first was exchanging data from flight experiments relating to the human response to space flight. Soviet data on the effects of long-term space flight on bone loss and cardiovascular deconditioning have been very useful to American researchers, especially because there were no manned U.S. flights during the period from the 1975 Apollo-Soyuz Test Project to the first Shuttle mission in 1981. Second, joint ground-based simulations of space flight conditions, such as long-term bed rest studies, have been conducted. The third area of cooperation was in basic biological and biomedical research. A joint U.S.-Soviet three-volume publication on Space Biology and Medicine was produced in 1975. A second edition is currently in preparation. Life sciences investigations were performed jointly on the Apollo-Soyuz mission. The U.S. also participated in the Cosmos series of biosatellite missions, to gather important data and to exchange information on problems of space biology.

An agreement for cooperation in space at the interagency level was first generated in 1962, between NASA and the Soviet Academy of Sciences. In 1971, a Science and Applications Agreement was signed between the U.S. and U.S.S.R., paving the way for joint studies in Space Biology and Medicine. This agreement was reinstated in 1987. In 1974, the Soviets offered to fly U.S. experiments on their Cosmos biosatellite for the first time. Since then, the U.S. has taken part in eight Cosmos biosatellite missions. Seven of these missions are described later in this volume.

Initial U.S. experiments on Cosmos consisted of "carry-on" packages, which were for the most part functionally independent, requiring no electrical power from the spacecraft. On later missions, U.S. experiments were carried out on rhesus monkeys and rats housed in Soviet animal habitats. On these flights, U.S. battery-powered instruments were integrated with Soviet spacecraft data systems to record biomedical data.

In 1992, a new agreement was signed between the U.S. and Russia to facilitate scientific and technological cooperation. A commercial contract was also drawn up between NASA and the Russian firm NPO Energiya. Through this contract, NASA will be able to use Russian technology in future U.S. missions, including the International Space Station.

The overall success of the U.S.-U.S.S.R./Russian collaboration in the space life sciences is due to several factors. Focused science objectives were important. The selection of complementary study areas provided a stronger incentive for cooperation. Instrumentation used in the U.S.-U.S.S.R. missions was carefully reviewed to avoid violating technology transfer regulations. A relatively flexible institutional organization on both sides allowed plans to be implemented in spite of a frequently difficult political environment. And finally, mutual confidence, knowledge, and goals have developed between working groups with continuity of members over a long period of cooperation.

NASA plans to continue cooperative activities with the Russian Space Agency. A cosmonaut will fly on the U.S. Space Shuttle in the near future and a U.S. astronaut will spend some time on the Russian Mir Space Station. Substantial Russian participation is also expected on future U.S. missions, including docking the Space Shuttle with the Mir.

The European Space Agency

The ESA was formed in 1975 by 11 Western European nations. Member countries now number 13: Belgium, United Kingdom, Denmark, France, Ireland, Italy, The Netherlands, Spain, Sweden, Switzerland, Germany, Austria, and Norway. Canada has a technical agreement of cooperation with the agency. Headquartered in Paris, ESA has major facilities in The Netherlands, Germany, and Italy. Its principal objective is to achieve cooperation between member countries in developing space research and technology for peaceful purposes. Members contribute to ESA's general budget and mandatory scientific programs according to their gross national products. Each state also contributes voluntarily to optional ESA programs. A large percentage of ESA's budget is spent on financing contracts to European companies for building launchers, satellites, and other space flight hardware.

NASA has participated in numerous collaborative ventures with ESA. A formal Joint Working Group in the life sciences was established in 1986. The Spacelab was built under the auspices of ESA for the U.S. STS. Personnel have been exchanged between the two agencies. The ESA-built Biorack hardware was jointly used by NASA and ESA on the NASA-sponsored International Microgravity Laboratory missions in 1992 and 1994. ESA is also expected to be a major contributor to the International Space Station program, and will be responsible for Columbus, a module that is to be attached to Space Station. Germany and Italy have proposed using Spacelab-derived hardware to form Columbus.

France

As the primary space power in Western Europe, France, together with Germany, is the driving force behind the ESA. Before 1992, the Soviet Union collaborated in more space activities with France than with any other country. France was the third nation, after the U.S. and the U.S.S.R., to achieve national launcher capability, and now has significant capabilities in space manufacturing, Earth observations and telecommunications satellites.

The French Centre des Recherches de Medicine Aéronautique (CERMA) has existed, under different names, since the 1920s. Its activities are concerned primarily with aeronautical medicine; it investigates problems of physiology and medicine posed by the airplanes of the French Air Force. Until 1964, CERMA's space-related research was carried out directly with military teams. In 1964, the French government created the Centre National d'Etudes Spatiales (CNES) to study scientific and technical problems of a nonmilitary nature. From then on, CERMA experiments

Claude Milhaud

Claude Milhaud was trained as a veterinarian and is a graduate in physiology, biochemistry and psychophysiology. He is now a General in the French Air Force.

He entered the arena of space life sciences research in 1967, when he became involved in a project at CERMA. A year later, he began to study the pharma*cology and toxicology of substances that could kee*p human beings awake for several days. He studied monkeys, looking at how specific drugs affected their behavior and physiology. In 1974, NASA came to Europe to present the Shuttle Program and to solicit research proposals. During the same time, ESA proposed the construction of Spacelab. "We saw the value of the rhesus monkey model," says Milhaud, "so we suggested studying a system for maintaining monkeys in space." Monkeys seemed to be good human surrogates for space physiology experiments. He recalls the failure in 1969 of the American Biosatellite III mission. "We at CERMA found it surprising. But this disappointment made us more aware that the first priority of a space flight experiment was to bring healthy animal subjects back to Earth."

In 1975, CNES became interested in the CERMA project, and asked the French aerospace firm MATRA to preliminarily evaluate the experiments. This very rudimentary study was presented to the Congress of Aerospace Medicine in Tel Aviv in 1975. At the Congress, a session dedicated to space physiology was presided over by Professor Nello Pace, a primate physiologist from Berkeley, California. (See page 61.) Pace's interest was kindled by the presentation because of his own experiments with macaques. He invited the CERMA team to the U.S. to visit his laboratory and ARC, and to build contacts for a possible future collaboration between the U.S. and France. "My colleagues and I made our first trip to the U.S. in September 1976," Milhaud remembers. "That was the point at which the cooperation began."

From 1976 to 1980, Milhaud's team began developing a system that could be used for pharmacology experiments and for studies on the Space Shuttle. They used this system to conduct research with 12 restrained monkeys maintained in controlled environments. "We always kept in mind dimensions and shapes compatible with the Spacelab," Milhaud says. "We had regular contact with people from Ames and NASA Headquarters. They used to stop in Paris during frequent trips to the U.S.S.R. as participants of the Cosmos Biosatellite Program." A CERMA delegation also participated regularly in joint meetings with NASA. The idea for the French-U.S. Rhesus Research Facility project crystallized slowly through these meetings. Initially, the contacts between the two countries were mostly personal ones, but in later years relations have become more formal, and resulted in a NASA-CNES cooperative program focused on space research utilizing rhesus monkeys.

were controlled, progressively more rigorously, by CNES. Today, CERMA is a contractor to CNES like many university laboratories. CNES is responsible for all the space activities in France, and particularly for those concerning physiology and medicine.

CNES is the largest national space agency in Europe. It provides a framework not only for the French national space program but also for the French commitment to ESA. Although headquartered in Paris, CNES has its principal engineering and technology facility in Toulouse, and several other operating centers are located nationwide, including Evry and Guyanais. It also maintains two balloon-launching sites at Aire-sur-l'Adour and Gap Tallard. CNES is accountable to the French government's Ministry for Research and Industry. In recent years, the agency has established several companies and economic interest groups to commercialize space activities.

It is through CNES that bilateral space programs developed between France and other countries are managed. NASA has collaborated with France in space science and technology for several years. A Joint Working Group in life sciences was established in 1985. The two agencies conducted joint investigations on the International Microgravity Laboratory missions. A NASA-CNES program to fly 2 rhesus monkeys within a jointly-developed Rhesus Research Facility on a 16-day Space Shuttle mission was under development. It was halted in 1994 due to the absence of a manifested mission.

Germany

Until recently, the Deutsche Forschungs-und Versuchsanstalt für Luft und Raumfahrt (DFVLR), the aeronautics research establishment of West Germany, was the primary national agency involved in space activities. In 1989, the Deutsche Agentur für Raumfahrt-Angelegenheite (DARA), became the central management organization for German space activities. A state secretaries' committee on space chaired by the federal minister for research and technology is responsible for defining goals and commissions for DARA. The agency has the legal status of a private company with limited liability, and is owned and financed by the federal government. A cabinet committee on space chaired by the Chancellor provides programmatic and budgetary guidelines for space policy.

DARA represents Germany at the international level and is responsible for multilateral and bilateral agreements. It emphasizes manned and microgravity programs. Germany has been involved in the Columbus program and has had extensive manufacturing and manned flight experience with the European-built Spacelab. It was, in fact, the largest contributor to the Spacelab. The Spacelab D1 mission flown in November 1985 included a number of German-sponsored life sciences experiments. Spacelab D1 represented the first time that a foreign government leased an entire shuttle mission from NASA. German scientists flew scientific experiments on the 1991 Spacelab Life Sciences-1 mission, IML-1, and again on the Spacelab Life Sciences-2 mission in 1993. Another German payload was flown on the Spacelab D2 mission in 1993. Coupling of studies carried out on Spacelab D2 and the Spacelab Life Sciences-1 and -2 missions benefited both countries.

Japan

Several national organizations are involved in Japanese space ventures. The Space Activities Commission was created in 1968 to coordinate and administrate space activities. The Science and Technology Agency provides the secretariat to the Commission, and is responsible for planning policy, developing international cooperation and promoting use of space. The Science and Technology Agency also controls the National Space Development Agency (NASDA), which was founded in 1969. NASDA is responsible for practical applications in space. Besides developing satellites and launchers, and launching, tracking and controlling satellites, NASDA promotes scientific experimentation in space. The National Space Laboratory is also linked to the Science and Technology Agency, and undertakes fundamental research in the space sciences. The University of Tokyo's role in space sciences has now been taken over by the Japanese Institute of Space and Astronautical Science. This institute carries out research and development activities on scientific satellites and launchers. In addition, several Japanese companies are constructing operational telecommunications satellites.

NASA established a Joint Life Sciences Working Group with Japan in 1985. Japan is in the process of building a national manned space program, using its experience in U.S. and international missions. Japanese scientists are involved in the International Microgravity Laboratory series of missions sponsored by NASA. The 1992 Spacelab-J mission was also a joint U.S.-Japan venture. Another important Japanese contribution to the international space effort is the Japanese Experiment Module, a pressurized microgravity facility that will be attached to the planned the International Space Station.

Canada

The Canadian Space Agency was formed in 1989, drawing together the space activities of the Ministry of State for Science and Technology, the Department of Communications, the Department of Energy, Mines and Resources, and the National Research Council. The agency manages the civil space program, which includes the development of space science and technology and the astronaut program. Canada's involvement in international space activities arises through its associate membership in the ESA and its long history of close collaboration with NASA.

Canada developed the Remote Manipulator System for the U.S. Space Shuttle, making it the largest national contributor to the STS outside the United States. Canadian experiments have been flown on several Shuttle missions and some have included Canadian scientists as crew members. Canada plans to provide a Mobile Servicing Station for the International Space Station, which will be critical for assembling, maintaining, and servicing the station. Canada is also expected to participate in materials sciences and life sciences research on the space station.

Additional Reading

Calvin, M. and O.G. Gazenko, eds. *Foundations of Space Biology and Medicine.* Scientific and Technical Information Office, NASA, Washington, D.C., 1975.

Florini, A. *Developing the Final Frontier: International Cooperation in the Peaceful Uses of Outer Space.* United Nations Association of the United States of America, 1985.

Hartman, E.P. *Adventures in Research: A History of Ames Research Center 1940-1965,* NASA Center History Series, NASA SP-4302, 1970.

NASA. *Guide to the Life Sciences Flight Experiments Program,* unpublished report, July 1984.

NASA. *Space Life Sciences Status Report.* Life Sciences Division, NP-120, February 1990.

NASA. *U.S.-Soviet Cooperation in Space, A Technical Memorandum.* Congress of the United States, Office of Technology Assessment, Washington, D.C., July 1985.

Rycroft, M., ed. *The Cambridge Encyclopedia of Space.* Cambridge University Press, 1990.

Wilson, A., ed. *Interavia Space Directory. 1991–1992.* Jane's Information Group, Alexandria, Va., 1991.

U.S. Congress. House Committee on Science, Space, and Technology. *International Space Policy for the 1990s and Beyond.* Washington, D.C., GPO, 1988.

3 FLIGHT EXPERIMENT IMPLEMENTATION

Conducting a life sciences experiment onboard a spacecraft can be a formidable task (Fig. 3-1). Designing experiments, assembling the necessary resources, building the appropriate hardware, conducting innumerable tests and coordinating experiments with missions are time-consuming, complex activities. The entire effort may take from 2 to 10 years, depending on the nature of the experiment and the mission (Fig. 3-2). The need for ground-based control studies to verify the scientific validity of inflight data further complicates the process.

The major activities involved in carrying out an experiment in space are described for two cases. The STS program represents a situation where experiments can be performed in manned spacecraft. In such cases the experiment design, types of animals, hardware used, and preflight and postflight operations must be compatible with crew safety requirements. The Cosmos Program is an example of a situation where experiments can be conducted in an unmanned vehicle. In this case, experiments are not constrained by crew

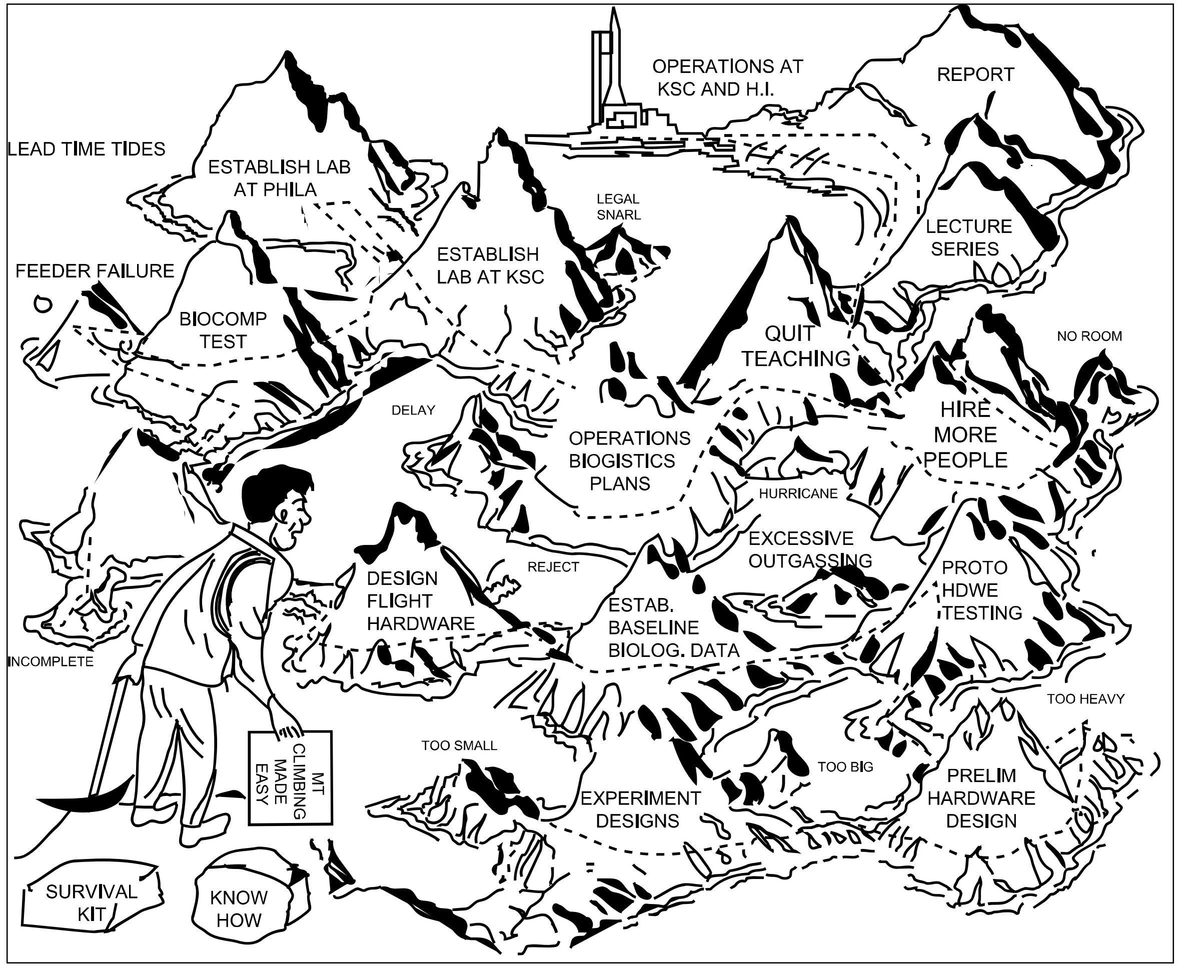

Figure 3-1: The space life science researcher's story from the U.S. Biosatellite era . Adapted from the American Institute of Biological Sciences, Experiment Survey Program, Biosciences, U.C. Berkeley,1968.

safety standards, but they must rely on automated hardware because inflight crew manipulations are not possible.

Experiments on the Space Transportation System

Preparation of a payload for flight on the STS occurs at three levels: experiment, payload, and mission (Fig. 3-3). Objectives, design, and hardware requirements must first be developed for individual experiments. All of the experiments must then be integrated into a single payload which satisfies the requirements of each experiment. Finally, this payload must be incorporated into a designated mission. This means that the payload must accommodate the constraints set on the mission by other payloads, by the design of the spacecraft, and by crew safety and operation requirements.

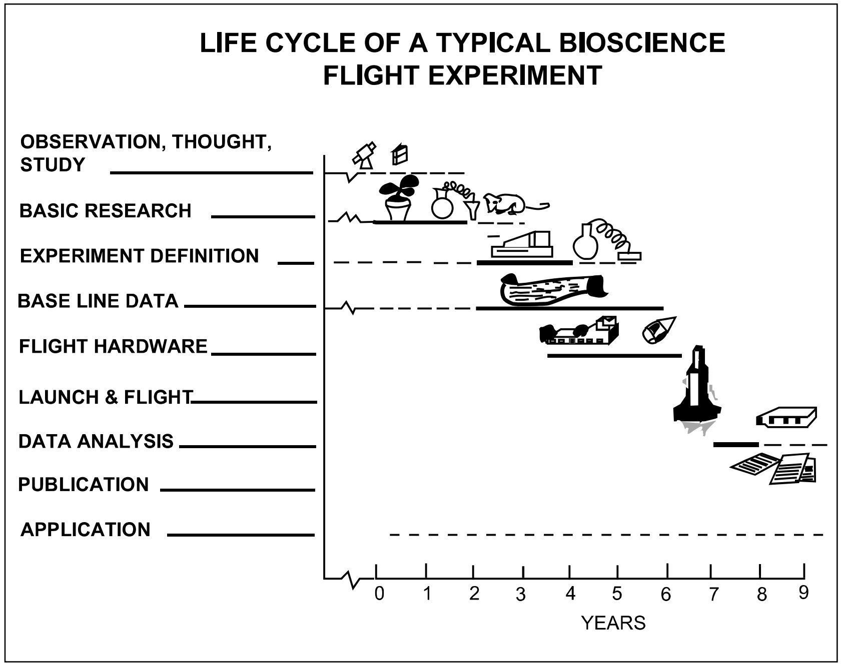

Figure 3-2: Life cycle of a typical life science flight experiment from the U.S. Biosatellite era. Adapted from American Institute of Biological Sciences, Experiment Survey Program, Biosciences, U.C. Berkeley, 1968.

NASA conducts at least three reviews at each preparatory level. These are the Preliminary Requirements Review (PRR), the Preliminary Design Review (PDR), and the Critical Design Review (CDR). Through these reviews NASA maximizes the potential for implementing a successful life sciences experiment in space. The three reviews within a level progressively refine the experiment, payload, or mission. The results of the reviews from one level are fed into the next level of development.

Experiment Development

Selection

NASA receives both solicited and unsolicited proposals for flight experiments from researchers in various life sciences disciplines. NASA, or an external agency selected by NASA, evaluates the scientific merit of each proposal through a peer review process. ARC, JSC, or KSC determines the feasibility of conducting each proposed experiment in space. They address engineering and experiment development costs, management requirements, and availability of NASA resources. NASA Headquarters then selects a subset of feasible experiments. This is the candidate pool from which experiments are finally chosen for definition.

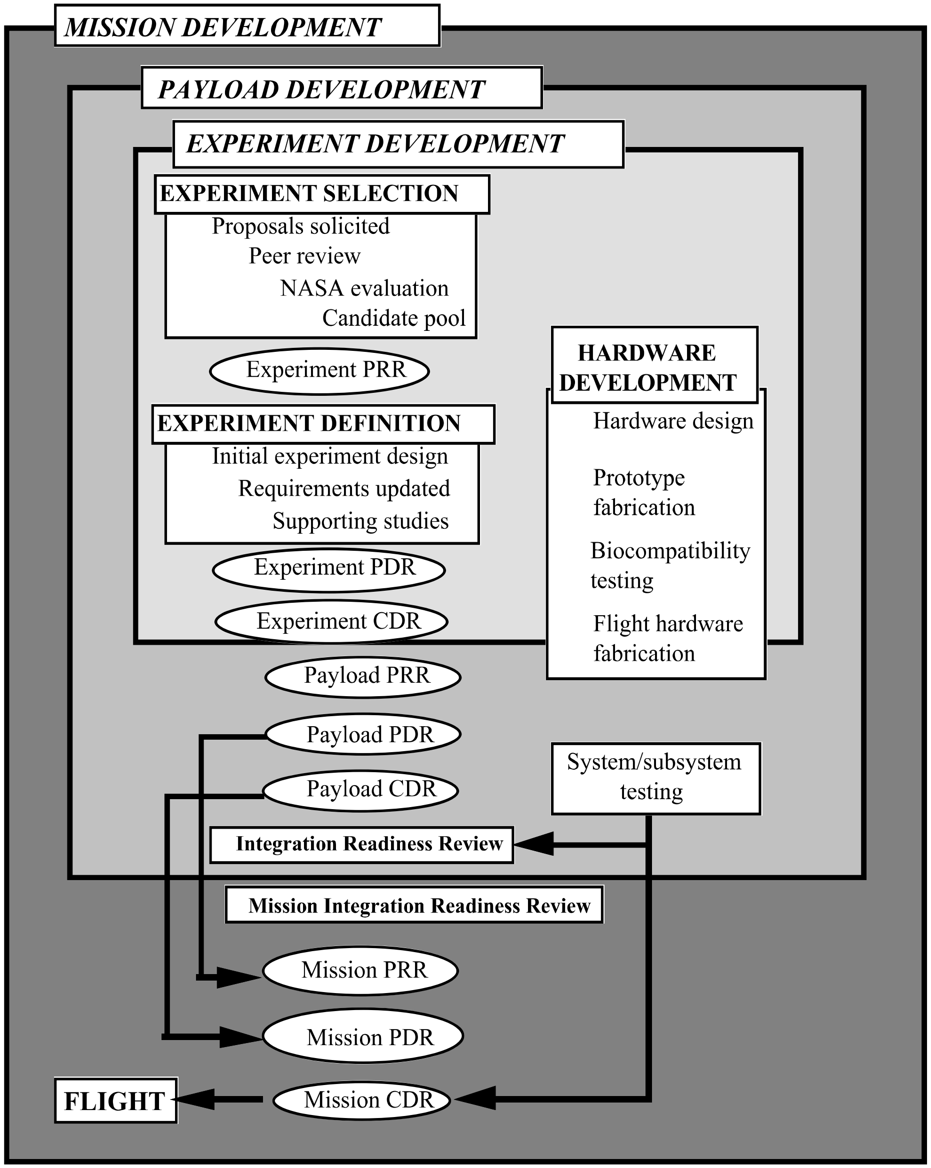

Figure 3-3: Preparation of a payload for a Space Shuttle mission.
- *PRR: initial design formulated.*
- *PDR: design reviewed and hardware requirements incorporated.*
- *CDR: design finalized and building of flight hardware approved.*

Three major factors are considered when assigning experiments to a particular mission. First, scientific yield from different research areas has to be maximized. Second, there must be minimal interference between experiments. Finally, maximum use must be made of common facilities, sensor systems and data processing equipment.

Definition

Detailed definition of experiment requirements begins after a contract or grant is negotiated between an investigator and NASA. Several issues must be addressed to fully define an experiment (Table 3-1).

The science objectives of the experiment must be clearly formulated and the feasibility of conducting the experiment in space carefully evaluated. The resources required for developing the experiment must be available. Ground-based operations necessary for conducting the flight experiment, and supporting studies to assess experiment feasibility, must also be defined.

Requirements are updated as the experiment undergoes continuous refinement. Supporting studies are conducted to provide baseline data for each experiment. Such studies are initiated early because they affect the experiment's overall design. If the initial design does not receive NASA concurrence, new approaches are considered.

Science Objectives
- Hypothesis
- Experiment Goal
- Research Subjects

Hardware/ Data Requirements
- Housing for Research Subject
  - -provision of food and water
  - -suitable environment
  - -waste collection
- Measurements
  - -physiological
  - -environmental

Mission Constraints
- Size of Payload
- Weight of Payload
- Power Requirements of Payload
- Thermal Issues

Safety Considerations
- Biological Isolation
- Flammability/Offgassing of Hardware

Equipment/Science Verification Procedures
- Data Acquisition Capability of Hardware
- Biocompatibility of Hardware
- Feasibility and Value of Science
- Supporting Studies

Operations
- Crew Training
- Preflight, In-flight, and Postflight Procedures
- Ground Support Equipment
- Logistics

Table 3.1: Issues addressed during development of a flight experiment.

Hardware Development

Hardware must be specially built or modified to suit the space environment. Flight hardware is designed to meet stringent requirements pertaining to safety, mass, mechanical operation, structural features, electrical power usage, computer interfaces, and thermal properties. Safety standards must be verified and meticulously recorded. In addition, all flight hardware must be tested to verify that it can withstand the mechanical and acoustic vibrations encountered during launch, the acceleration forces (up to 3.2 g) during ascent into orbit, and the microgravity conditions in orbit.

Flight hardware includes equipment for housing the experiment subjects and monitoring their health and general well-being. Individual experiments sometimes require that special hardware be designed and fabricated (experiment unique equipment (EUE)), in addition to general purpose multi-user flight hardware. Hardware prototypes are fabricated during the experiment development phase. They must be compatible with the design and safety requirements of the STS and be able to withstand the stress of launch and re-entry. At the same time, appropriate system interfaces are designed and procedures for instrument verification developed. Prototype hardware designs are reviewed twice before flight hardware is fabricated. Existing ground hardware is also evaluated for potential transition to flight application at this time.

A formal review is conducted once the experiment and hardware design is completed and formally defined. After acceptance at this review, the experiment is ready to be incorporated into a payload.

Payload Development

Payload development is the process by which individual experiments are combined into a cohesive package. It is analogous to and frequently proceeds in parallel with the experiment development process. The results from individual experiment and hardware reviews provide input to the formal payload review processes.

Flight hardware is developed during this phase. Besides the items that are actually flown on the Shuttle, this hardware includes flight and ground data systems and special ground support equipment, such as checkout equipment for interface verification and functional tests. All flight hardware is subjected to verification testing and formal reviews.

A payload must undergo testing at the subsystem and system levels. Two main tests are conducted at the system level. The first is a Biocompatibility Test, so called because it is used to assess the compatibility of the hardware with the biological environment (including research subjects). The second is the Experiment Verification Test (EVT), which uses a simulated mission timeline and simulated flight conditions to verify the effective interaction of experimental procedures, hardware, and personnel.

In addition, the readiness of the payload for integration into a mission must be evaluated before it is shipped to KSC. Once it is demonstrated that the mandatory verification procedures have been performed, the payload is ready for physical integration into the Spacelab or the Shuttle middeck at the launch site.

Training of flight and ground support personnel is an important part of any space flight mission and is often conducted in specialized facilities. These may be equipped with flight hardware mockups, mathematical models, or payload simulators such as the Spacelab simulators provided for crew training at JSC and Marshall Space Flight Center (MSFC).

Payload Integration

Payload reviews generate results which provide input to the reviews held at the mission level. All requirements from various payloads must be combined to ensure mission success. During this period, hardware is fitted into the spacecraft, mission support personnel are acquired, and the crew is trained. The compatibility of the payload with the STS and with other payload elements, and overall system safety must be confirmed. Much of this activity takes place at KSC. ARC's involvement, and that of the investigators, is essential throughout this phase.

Investigator's Role

The investigator plays an important role during the entire payload development phase. Investigator Working Groups are established during the experiment definition phase to coordinate the requirements of different experiments. Investigator input is critical when evaluating the capability of the hardware to meet experiment requirements, and during biocompatibility testing. The investigator must help train crew members to familiarize them with experiment requirements and in-flight procedures. The investigator also assists in evaluating payload design in relation to the defined experiment requirements and in reviewing payload integration and checkout.

Science support facilities at ARC, KSC, MSFC, and JSC give investigators access to in-flight data while the mission is in progress. These facilities also enable investigators to communicate with crew members during the mission.

Flight Phase

The flight phase begins at launch. Once the spacecraft reaches orbit, crew members follow a minute by minute schedule to accomplish the mission and experiment objectives. During these operations, the crew can consult with investigators via two-way voice communications, air-to-ground telemetry (data transmission), and television.

In-flight data is displayed simultaneously onboard and in the Science Operations Area at the MSFC. This data can also be transmitted to Test Monitoring Areas at ARC, JSC, KSC, and remote laboratories.

Operations that take place on the ground during the flight phase are as important as those that occur onboard the spacecraft. The Mission Control Center at JSC is responsible for monitoring and providing contingency support for orbiter payloads, two-way communications with the crew and onboard systems, and transmitting flight data to a central site. It also communicates with the Payload Operations Control Center (POCC) for coordinating flight operations between orbiter and Spacelab payloads. The POCC houses data monitoring facilities and commands payload elements in the Spacelab while maintaining communications with the Mission Control Center and the crew.

Pre/Postflight Operations

Preflight studies are frequently conducted several months before the mission to collect baseline data for flight experiments. Many investigators also require preflight collection of biosamples or data. During this period, investigators use laboratory facilities at various NASA centers to prepare experimental subjects for flight and to take preflight baseline measurements.

Special facilities are situated at launch and landing sites for harvesting and processing biospecimens, and for preflight data collection. For instance, the Life Sciences Support Facility at KSC is used for preparing and analyzing nonhuman biospecimens. Available resources include common laboratory supplies and analytical instruments, and animal maintenance facilities.

Experimental subjects are usually loaded into the Spacelab about 30 hours before launch and may be removed from the spacecraft as early as 3 hours after landing. Middeck payloads can be loaded about 18 hours before launch. Data collection commences at a facility situated at the landing site. Special arrangements are made if the orbiter is forced to land at a secondary or contingency site.

Experiments on Cosmos Biosatellites

U.S. scientists have conducted many experiments within the Soviet Cosmos biosatellite program. Experiments on the Cosmos biosatellite differ from those carried out on the Space Shuttle mainly because of one important factor. Since the biosatellite is unmanned, all in-flight experimental operations must be automated, as must all spacecraft subsystems and life support systems for experimental subjects. The biological subjects cannot be directly observed, although video viewing is possible. Repair or manual regulation of the life support system or the experiment hardware is not possible in flight, as are even the simplest of experimental operations. An unmanned satellite, therefore, has special demands for quality and reliability, especially in the equipment that provides automatic control and remote monitoring during the course of the flight experiments. This need for automation places some constraints on the types of experiments that can be performed on the biosatellite. Additionally, extensive shock and vibration testing needs to be carried out because of the impact of landing.

There are, nevertheless, distinct advantages to using unmanned vehicles for experimentation in space. The overall cost per mission is considerably less than for a manned mission. A wider range of materials can be used in hardware fabrication because crew safety is not a consideration. For the same reason, experiment design is more flexible. Missions can be terminated early if necessary or extended to maximize science return without concern for the requirements of the crew.

Experiment Development

Selection

Flight programs are developed by the U.S.S.R./Russia. The forum for presenting these program scenarios is frequently at meetings of the Joint Working Group for Space Biology and Medicine. At these yearly meetings, joint projects are discussed. Experiment proposals are invited from the U.S. and other participating countries. Once proposals are accepted and approved by Russian specialists, plans are exchanged on the best means of implementing the studies.

Definition

Experiments submitted by U.S. investigators are conducted jointly with Russian counterparts. Tissue samples and data are frequently shared between the two countries. In some cases, Russian and U.S. investigators perform complementary analyses of flight data, thus enhancing the science of both countries.

A key document, the Experiment Management Plan, is prepared for each experiment. This plan is a comprehensive summary of the experiment objectives, data, equipment, and operational requirements. It also outlines the agreements made between Russian and U.S. scientists with respect to data sharing and provision of equipment. The document is regularly updated, providing a means for recording the experiment's evolution to a state of readiness for flight.

Hardware

On the first three Cosmos missions with U.S. participation, most U.S. experiment hardware was in self-contained packages during the flight. Life support for the experimental subjects was provided mainly by the Soviet spacecraft environmental control system. These packages were delivered to the U.S.S.R. after flight qualification testing was performed in the U.S. The packages were installed in the spacecraft, flown in Earth orbit, and then returned to the U.S. Rodent and primate housing systems have always been provided by the U.S.S.R. In recent years, hardware development for the Cosmos experiments has become more of a joint effort. From the time of the first primate mission, Cosmos 1514, the U.S. began to supply hardware that required integration with Soviet equipment. On these later missions, U.S.-built hardware was often used to obtain physiological data. Such collaboration demanded joint verification testing and greater cooperation between the two partners.

U.S. flight hardware is subjected to extensive testing to ascertain that it can withstand launch, space flight, and the impact of biosatellite landing. Although testing is thorough, documentation is kept to a minimum.

Payload Development and Integration

Russia develops and integrates the payload. U.S. representatives are in frequent contact with Russian specialists. Experimental techniques are verified in the U.S. using animal subjects similar to the Russian flight subjects. Training sessions and development of detailed procedures are necessary since Russian and U.S. investigators collaborate closely in many of the preflight and postflight activities. Such activities include sensor implantation, biosampling, tissue preservation, and other experiment operations.

Complicated logistics and differences in language and metho dology sometimes hinder coordination of Russian and U.S. activities. A true cooperative spirit has been important in circumventing these difficulties.

Investigator's Role

U.S. investigators conducting experiments on the Cosmos biosatellite are not typically involved in mission logistics. Researchers base their experiments on the guidelines of the mission plan provided by the Russians. Investigators conduct preflight testing to ensure the suitability of techniques and hardware, which is essential to experiment success. In some cases Russian personnel are trained to conduct experimental procedures in the investigator's absence. Investigators frequently travel to Russia before the flight. Although they do not take part in any launch or landing activities, they are able to perform preflight/postflight testing on the flight animals during a certain window of time before launch and after recovery. Biosamples from experiment subjects are processed by U.S. investigators either in Russia or at their own laboratories.

The Flight Phase

In the past, the launch of the biosatellite has been a closed event and participation by foreign representatives has rarely been invited.

Flight duration is determined by the program of scientific studies. While in orbit, the onboard systems of the satellite operate in accordance with the flight program. Animals are allowed access to food and water according to a specific schedule. An automatic lighting system provides simulated day and night periods. Radio telemetry is used to control the flight subjects' environment and the spacecraft systems. Russian ground stations track the path of the biosatellite.

Pre/Postflight Operations

Preflight studies are conducted in the U.S. several months before the launch. U.S. investigators conduct some limited preflight and postflight operations, but in most cases Russian specialists handle flight animals.

Unlike the Space Shuttle, the Cosmos biosatellite does not land at a specific site. An automatic landing system controls the descent of the biosatellite's landing module. As the module moves through the Earth's atmosphere, a parachute system becomes operational, which cushions the impact of landing. Radio direction finding equipment is used to locate the biosatellite.

Once the biological subjects are recovered, immediate postflight operations are conducted in a temperature-controlled field laboratory erected at the landing site. Primates are examined upon recovery and then shipped to Moscow for testing.

Processing of other biospecimens begins three or four hours after landing. Tissue samples requested by U.S. investigators are preserved or frozen according to instructions, and later shipped to the U.S. If required, postflight testing is performed after the subjects have been transported to Moscow.

Additional Reading

American Institute of Biological Sciences. Experiment Survey Program. *Biosciences,* U.C. Berkeley, 1968.

Ballard, R.W. and K.R. Walker. Flying U.S. Science on the U.S.S.R. Cosmos Biosatellites. *American Society for Gravitational and Space Biology Bulletin.*, vol. 6, no. 1, October 1992, pp. 121–128.

Hypen, W. and J.C. Casas. *Flying a Scientific Experiment Aboard the Space Shuttle—A Perspective from the Viewpoint of the Experimenter,* unpublished report.

Ilyin, E.A. and G.P. Parfenov. *Biologicheskiye Issledovaniya na Biosputnikakh 'Kosmos'* (Biological Studies on the Cosmos Biosatellite). Nauka Publishing House, Moscow, in Russian, 1979.

Mains, R.C. and E.W. Gomersall. *U.S. Monkey and Rat Experiments Flown on the Soviet Satellite Cosmos 1514.* NASA TM-88223, May 1986.