# THE HUMAN FACTOR

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Mercury astronauts experienced weightlessness aboard aircraft.

NASA SP-4213

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## Biomedicine in the Manned Space Program to 1980

John A. Pitts

The NASA History Series

NASA Scientific and Technical Information Branch 1985
National Aeronautics and Space Administration
Washington, DC

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**Library of Congress Cataloging-in-Publication Data**

Pitts, John A.
The human factor.

(NASA history series) (NASA SP; 4213)
Bibliography: p. 211
Includes index.
1. Space medicine—History. 2. Space biology—History. 3. United States. National Aeronautics and Space Administration—History. I. Title. II. Series. III. Series: NASA history series; 4213. [DNLM: 1. Aerospace Medicine—history—United States. 2. Space Flight—history—United States. WD 750 P692h]
RC1125.P58 1985 616.9'80214'0973 85-21526

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC. 20402

# Contents

# Preface

Americans hailed the first manned lunar landing as an unprecedented technological achievement, a triumph of American ingenuity, inventiveness, and enterprise, and a symbol of the nation's return to world technological preeminence. This praise for American technology obscured a fundamental reality: that man, not the machine, was the critical variable in manned spaceflight and that a major responsibility for controlling this variable lay not only with engineers and mission planners, but with life scientists as well.

In 1958, the year in which Congress established the National Aeronautics and Space Administration, the human factor (the necessity for considering human well-being, health, safety, performance, and behavior as major constraints in engineering and mission planning) was the major concern for manned operations in space. The human factor injected into an otherwise purely engineering undertaking an array of variables that were, at the time, neither predictable nor easily specified. In a number of significant areas, normative values for predicting human physiological and behavioral responses to the conditions of spaceflight and the space environment and for providing specifications for the design and engineering of life support, protection, communications, and control systems were either nonexistent or of questionable validity.

Clinicians and biomedical scientists could not predict the limits of human tolerance to the actual and potential hazards of spaceflight. These hazards included "stress factors" of spaceflight (multiple G and impact forces, noise and vibration, isolation and confinement, alterations in day-night cycle, abrupt changes in demands on circulatory and respiratory systems), effects of exposure to a closed environment (artificial atmosphere, toxic contaminants, fuel leakage, humidity and thermal extremes), and hazards of the natural environment of space (weightlessness, radiation, thermal extremes, oxygen deprivation). The future of manned spaceflight hinged on the ability of biomedical scientists to identify limits of human tolerance to these environmental and operational factors.

Identification of tolerance limits was considered essential not only for the qualification of man for spaceflight, but also for engineering and mission planning. Engineers required precise information on human physiological and behavioral requirements in order to design and engineer space systems that would protect human passengers against these expected hazards, provide for effective monitoring of critical physiological functions, and, through proper placement and arrangement of communications, control, and display equipment, assure effective human performance. Precise human factor specifications were needed in order to avoid unnecessary weight (a major concern because of launch propulsion limitations) and unnecessary complexity. Mission planners also required exacting biomedical specifications in order to define mission profiles, establish mission durations, integrate biomedical monitoring into the overall mission, and provide for safe and efficient recovery operations for man (and machine). In short, the human factor created a need for active consideration of biomedical factors and active participation of life scientists in planning, evaluating, and implementing research, development, and operations in support of manned spaceflight.

Given the human factor, those charged with responsibility for planning the American manned space program recognized from the outset the need for a multidisciplinary approach to technical and operational decision making and for close and continuous interaction among life scientists, physical scientists, engineers, and mission planners. This had a direct bearing on space program organization and management. Recognizing the importance of biomedicine to the initial manned effort, NASA's first Administrator, T. Keith Glennan, established a biomedical group as an adjunct to the Space Task Group, which had technical and operational responsibility for Project Mercury, and created a special, high-level advisory group of leading human factors specialists to advise NASA on biomedical requirements for the manned space program. Later, as the scope of the space program expanded and as NASA began to plan for manned programs beyond Mercury, Glennan's successor, James E. Webb, saw a need to expand and diversify the agency's life sciences programs to meet the requirements of an expanded, diversified, and accelerated manned (and bioscience) space program.

Webb authorized a form of organization and management for the life sciences that turned out to be a source of enduring internal conflict and external controversy throughout the manned space program. He and his subordinates viewed the life sciences as activities that should be supportive of and subordinate to the agency's major space programs (space sciences, advanced research and technology, manned spaceflight operations). They favored a form of organization which aligned clinical medicine with the manned spaceflight program office, medical and human factor research with the advanced research and technology program office, and space biology ("biosciences") with the space sciences and applications program. This arrangement, in management's view, would encourage multidisciplinary coordination in areas where coordination was essential, while at the same time ensuring effective alignment of the elements of the life sciences programs with the respective major program offices. NASA's top management, which included no life scientists, made nominal provision for coordination among these three life sciences components. No direct effort was made to integrate the life sciences into a single office or to appoint a life scientist to a high-level administrative position. In the view of Webb and his top administrators, NASA had a critical need for life sciences support of its major space programs, but did not have a need for a major program in the life sciences.

This approach to the organization and management of the life sciences was logical, given the agency's major responsibilities in space and its obligation to achieve major manned spaceflight objectives in the most expeditious, efficient, and economical way. Nonetheless, this arrangement generated internal conflict and controversy and gave rise to a unique term, "biopolitics." Biopolitics refers to competition for life sciences funds, resources, and program authorities and occurred at several levels: among the three NASA life sciences offices, between NASA managers and public spokesmen for the scientific community, and between NASA and the U.S. Air Force.

Internally this arrangement and personalities combined to foster divisiveness among the agency's three life sciences offices. Dominated by physical scientists and engineers, NASA's top administrators believed that the life sciences could be compartmentalized along the same lines as the physical sciences, mathematics, and engineering, when in fact the biological sciences, behavioral sciences, medical sciences, and clinical medicine are to some degree interdependent and often had areas of overlap. Dividing and compartmentalizing life sciences management resulted in little active and regular interaction and cooperation among biologists, medical scientists, and clinicians (generally a normal activity in biomedical settings). In the process, management inadvertently invited factionalism and jurisdictional disputes associated with competition for funds, resources, and authority. The effective subordination of the life sciences to engineering and the physical sciences retarded the growth and development of a viable program of fundamental research in biomedicine and of an effective and integrated life sciences program, and discouraged life scientists outside NASA from actively supporting and participating in the manned space program.

Many articulate and influential scientists were hostile to the manned space program and viewed NASA's arrangements for the organization and management of its life sciences programs as justification for their hostility. These scientists, who viewed manned spaceflight as an unnecessary and unjustified investment of funds and a reckless and unnecessary risk of human life, favored a space program oriented toward scientific research in space rather than manned space exploration. They believed that the manned program used funds that could be better spent on unmanned space missions. Thus they looked upon NASA's arrangements for the life sciences as evidence of the agency's insensitivity to scientific research. The life sciences, they felt, could not make important contributions to scientific knowledge as long as they were decentralized, subordinated to physical science, engineering, and operational programs, and devoid of representation at the highest administrative levels. The subordination and decentralization of the life sciences, combined with the mission orientation of NASA, would, in their view, preclude the interaction among biologists, medical scientists, and clinicians that is normal in biomedical research settings, discourage the development of a program of fundamental biomedical research, and encourage the use of man as an experimental animal. Given these concerns, many scientists questioned NASA's ability to provide adequate biomedical support for manned spaceflight.

NASA's top management was repeatedly urged to free its life sciences programs from subordination to engineering and mission operations. Critics stressed the need for increased emphasis on fundamental research and a more traditional approach to the qualification of man for spaceflight (particularly, animal research as a preliminary condition of manned flights). Toward these ends, they recommended that NASA create a centralized life sciences research facility, an integrated life sciences program office, and a high-level life sciences administrative position.

External criticism of NASA's life sciences programs continued throughout the manned space program and resulted in several congressional investigations. Except when pressed by Congress, NASA's top administrators tended not to respond to the hue and cry from the scientific community. An integrated life sciences program, in management's view, was inconsistent with the agency's major responsibilities in space. Implementation of these recommendations, management believed, would necessitate a major increase in the space program budget and a major realignment of program responsibilities which could retard the pace of the manned program. NASA suspected that its critics among scientists wanted the agency to function as if it were a scientific research organization, comparable to the National Institutes of Health, rather than a mission agency charged with conducting manned and unmanned operations in space for scientific and technological development. With a mandate to place a man on the Moon before 1970 and to develop the nation's capabilities for manned operations in space, NASA could not afford, from management's perspective, the leisurely pace and autonomous structure of a scientific research organization.

NASA also, in the early 1960s, was not in a political position to build up its life sciences research capabilities and its life sciences program to the level required to satisfy these scientists. A major expansion of in-house capabilities in the life sciences ran directly counter to the aspirations of the Air Force. Air Force interest in manned spaceflight began in the late 1940s. By 1958, it had oversight responsibility for all space-related research and development within the Department of Defense and was well ahead of NASA and the other military services in planning for manned space operations. More important, the Air Force had pioneered in the field of aerospace medicine, had conducted or sponsored most of the extant research into the human factors aspects of high-altitude flight and spaceflight, was the nation's major employer of specialists in space medicine and biotechnology, and had facilities for research and development in aerospace medicine and biotechnology unmatched by any other government or private agency. As late as 1965, the Air Force was still the nation's leader in aerospace medical research and development and the training of specialists in aerospace medicine.

Given its own aspirations in space, the critical importance of biomedicine to manned spaceflight, and its unchallenged leadership in space medicine, the Air Force did not favor an expanded life sciences program within NASA. While Air Force officials had no objection to an increase in NASA's capabilities in space biology, they adamantly opposed any NASA buildup in biomedicine and biotechnology. Both political and practical factors underlay this opposition. Politically, Air Force officials feared that any reduction in its biomedical capabilities would justify a reduction in support for an Air Force manned space program. In practical terms, the Air Force feared that a major biomedical program within NASA would preclude full utilization of existing Air Force aeromedical research, development, and training facilities, make it difficult for the Air Force to attract specialists in aerospace medicine and biotechnology, and deprive the Air Force's aerospace physicians of the opportunity to gain experience in manned space operations. Accordingly, the Air Force and its supporters in Congress strove to deny NASA the funds and authority to strengthen its in-house biomedical capabilities at the same time that life scientists outside NASA were demanding that NASA increase these capabilities.

The history of the biomedical aspects of the manned space program is thus a multifaceted one. One facet is the technical and operational decision making that underlay biomedical research, development, and operations in support of the manned space program. What were the biomedical requirements and objectives at each stage of the manned space program? How, and by whom, were these requirements and objectives identified and ranked? What was the nature of the research and development projects undertaken to fulfill these requirements and achieve these objectives? How successful were the biomedical preparations for, and what were the biomedical results of, each of the manned programs? What role did the separate life sciences programs— space biology, human factors research, biotechnology, and space medicine— have in supporting the technical and operational objectives of the manned space program?

The history of biomedicine during the manned space program is also a history of administrative decision making. How did the technical and operational requirements of the manned space program affect the organization and administration of NASA's life sciences programs? What factors underlay management decisions concerning the allocations of life sciences resources, personnel, and authorities? What arrangements did management make to encourage coordination and timely resolution of jurisdictional disputes among the decentralized life sciences programs? What were the major organizational and management problems that emerged within the life sciences programs, and how were these problems resolved? What factors led NASA's top administrators, on several occasions, to make changes in the organization and management of the agency's life sciences programs?

The history of the biomedical aspects of the manned space program is also a study of biopolitics, that is, the effect of political factors on life sciences within the space program. What were the political considerations that influenced decision making in the space life sciences? To what extent, if at all, did these factors influence technical, operational, organizational, and management decisions? How successful were NASA's opponents and critics in influencing congressional decisions related to NASA's life sciences programs?

This historical analysis of biomedicine during the manned space program considers all these questions. The technical and operational problems that NASA's life scientists faced as they strove to provide biomedical support for both approved and advanced manned programs are discussed, as well as the administrative and political problems that emerged as NASA's life sciences programs expanded and diversified to meet the requirements of an accelerated space program. Together, the narrative and analysis illuminate the important contributions of NASA's life scientists to the nation's achievements in space, and record the difficulties and frustrations these scientists experienced as they tried to create a viable, integrated, and effective program in the space life sciences.

# 1
# Medicine, machines, and manned flight

The American manned spaceflight program officially began in November 1958, when the new National Aeronautics and Space Administration (NASA) received authorization to launch a man into Earth orbit. That effort, Project Mercury, was the first phase of a program that would lead to a series of manned lunar landings between 1969 and 1972 and the Skylab missions of 1973-1974, which qualified man for space missions lasting up to 84 days. Between Mercury (which included animal flights before single manned flights) and Apollo, the Gemini and Skylab projects successfully launched and recovered two and three men, respectively. The Skylab missions of 1973 and 1974 exposed men to a spaceflight duration of 84 days. That the space program moved so far so quickly is a testament to NASA's ability to harness and coordinate a diversity of talents and resources. It also testifies to the nation's capabilities in biomedicine and the behavioral sciences and to NASA's ability to encourage and sustain a working relationship among biomedical and behavioral scientists, clinicians, physical scientists, engineers, and mission planners.

This working relationship, though unusual, was not unprecedented. Within the military services, life scientists, engineers, and mission planners were accustomed to close interaction. For more than 50 years before the first manned spaceflight, these diverse specialists had worked together to solve human factors problems in aeronautics, to identify and measure human limitations at increasingly higher altitudes and speeds, and to develop equipment that would enable man to transcend these apparent limitations. Those charged with planning for Project Mercury and the subsequent phases of the manned space program were products of this experience.

## MEDICINE AND MANNED FLIGHT BEFORE 1958

A new phase in human exploration began on November 21, 1783, when two Frenchmen rose over the French countryside in a balloon.[1] Their flight introduced men to an era in which exploration would be inextricably bound to the machinery of exploration and to man's ability to cope with the conditions of unusual, and increasingly hostile, environments. Given the role of medicine in extending the frontiers of flight, it was fitting that one of the two persons on that first balloon flight was a physician. Numerous physicians flew on subsequent balloon flights. An American, John Jeffries, made several balloon flights after 1784 and may have been the first to investigate the effects of flight on man. He recorded a significant decrease in temperature, oxygen, and pressure with altitude and described a painful sensation in his ears. A contemporary, British surgeon John Shelton, discovered that nausea and irrational behavior can be effects of flight. Neither Jeffries nor Shelton understood the connection between diminished oxygen supply and diminished barometric pressure and the observed physiological effects.[2]

The manner in which Jeffries and Shelton investigated the conditions and environment of flight—using themselves as test subjects—became a tradition that continued into the period of powered flight. Steadily increasing speeds and altitudes and maneuvering capability raised new questions concerning human physiology and performance, and these questions naturally attracted the attention of flight-oriented physicians. These physicians, most of whom were military flight surgeons, generally were not research scientists, but more pragmatic, mission-oriented investigators. They sought to understand the factors that affected the health and performance of flight crews and to identify methods for reducing or eliminating ill effects.

Flight physicians often took heroic approaches to their investigations of the human factors problems of flight, using themselves as test subjects. Col. Randolph Lovelace II gave a dramatic demonstration of this approach in 1943. Lovelace hypothesized that the decreased density of the atmosphere at high altitudes would intensify the shock of parachute opening during emergency escapes. To test this hypothesis and evaluate several items of equipment intended to minimize the shock, he bailed out at an altitude of 12,195 meters. He proved his hypothesis and the value of the backup equipment: the shock nearly killed him, but the equipment saved his life.[3] Other flight physicians have made comparable heroic efforts. In most cases, their objective was to identify the causes of, and develop preventive measures against, specific problems, while developing a scientific understanding of the physiological and behavioral dynamics associated with flight operations.

Biomedical interest in flight was not entirely limited to flight surgeons, however. In the 1860s, French physiologist Paul Bert began to investigate systematically the physiological effects of diminished oxygen and barometric pressure. He realized that he needed to be able to simulate, on the ground, the flight environment. Accordingly, he constructed the world's first pressure chamber, in which he could simulate altitudes up to 10,980 meters. Using himself and dogs as experimental subjects, he conducted 670 experiments in which the percentage of oxygen in the air was constant and barometric pressure was the variable. He discovered that heart and respiration rates and digestive gases vary in direct proportion to altitude. Above 4,880 meters, he experienced nausea and dimming of vision. These symptoms of altitude sickness disappeared when he breathed air enriched with oxygen.

Bert followed these investigations with inflight research on two occasions. Two of his associates, both scientists, ascended to 7,991 meters in a gondola that was equipped with bags of oxygen having special mouthpieces. Both flights confirmed his belief that the use of oxygen-enriched air above 1,840 meters would eliminate the effects of altitude sickness. These experiments nearly ended in disaster, however, because Bert did not realize that the passengers would have to breathe oxygen continuously above the critical altitude.[4]

Bert had correctly identified the need for supplementary oxygen at high altitudes, but he failed to recognize that the critical factor was not the quantity of oxygen available, but the oxygen saturation within the blood, which in turn was a function of atmospheric pressure. Several European physiologists discovered this factor during balloon flights between 1900 and 1903. Their work led to conclusions that became part of the theoretical framework of aerospace medicine: man cannot survive above 7,930 meters without extra oxygen; oxygen must be force-fed through a closed mask in order to ensure optimum blood saturation; and man requires protection within a sealed structure or pressure suit at altitudes above 12,200 meters.[5]

The advent of powered flight and its rapid development after World War I augmented biomedical interest in the human factors of flight. Increased speeds and variable accelerations associated with maneuvering drew attention to the effects of these factors on physiology and performance, while developments in the machinery of flight raised concern over the possible clinical effects of noise, vibration, and toxic fumes. These and other factors gave increasing impetus to research in biotechnology—the application of information derived from human research to the development of life support and protective equipment to improve human performance in flight operations.[6] During the interwar period, aviation medicine came under the nearly exclusive control of the military services.

Research, development, and training facilities established by the Army and Navy remained the primary centers for aviation and space biomedicine through the mid-1960s. The activities at these facilities reflected the developing interaction among biomedical and engineering personnel and a pragmatic approach to aerospace medicine.[7]

The development of jet aircraft following World War II, like the advent of powered flight 30 years earlier, generated renewed interest in human factors. The jet age placed new emphasis on the identification of human capabilities and limitations, the design of systems and equipment to maximize these capabilities and minimize the limitations, and the definition of standards for selecting and training the individuals best qualified to endure the stresses and hazards of high-speed, high-altitude flight.[8] The development of jet flight strengthened and sustained the traditions of biomedical involvement in manned flight and mission-oriented biomedicine that had slowly emerged with propellor-powered flight.

While flight-oriented physicians and biomedical scientists gave primary attention to the human factors problems of aeronautics during the postwar period, interest in human factors aspects of spaceflight grew steadily during the 1950s. A cadre of German specialists in rocketry, biotechnology, and aviation medicine were the primary force behind this growing attention to space biomedicine. Between 1946 and 1948, the Army transferred 34 of these specialists to American military facilities, a few to Navy facilities.[9]

The dean and principal theoretician of the group was Hubertus Strughold, a physician and physiologist who had been engaged in aviation medical research since the mid-1920s. A Rockefeller Foundation Fellow, he gained international stature as a professor of aviation medicine and as director of the German Aeromedical Research Institute.[10] Strughold established the world's first department of space medicine at the Air Force School of Aviation Medicine in 1950. Under his leadership, the school became a major center for basic and clinical investigations into the physiological and behavioral effects of spaceflight and the space environment. During the 1950s, researchers at the school conducted (or sponsored) investigations into the biodynamics of spaceflight (physiological effects of stress factors and weightlessness), human performance (psychological, psychophysiological, and neurological effects), and metabolic, psychological, and other human requirements in space. The results of these investigations were regularly communicated to scientists worldwide through publications and symposia.[11]

Strughold contended that the distinction between space and atmosphere was artificial and misleading, at least as far as human biology was concerned. He maintained that man begins to experience "space equivalent" conditions at an altitude of 15,250 meters, where he is exposed to most of the hazards of the space environment and cannot survive unless protected by a sealed capsule or a pressure suit. For this reason, he argued, manned spaceflight is a natural extension of aeronautical flight, and space medicine a logical extension of aviation medicine. Biomedical investigations into the human factors of spaceflight, he concluded, must build on and extend knowledge already gained from aviation medicine.[12] Strughold's views had both practical and political value. They encouraged confidence in the nation's fundamental capability for proceeding with manned spaceflight, and they provided a rationale that Air Force officials would later use to justify the claim that the Air Force should direct manned spaceflight.

A number of other German scientists, particularly Otto Gauer and Henning von Gierke, were assigned to the Aviation (later Aerospace) Medical Laboratory at the Wright Air Development Center. Since the 1930s, this center had sponsored research into human physiological requirements in flight and had applied the results to the design and engineering of pressurized cabins, pressure suits, protective equipment (couches, restraints, cushions), and life support equipment (for example, oxygen masks for high-altitude flights).[13]

Like Strughold at the School of Aviation Medicine, Gauer and his associates introduced a theoretical approach to aerospace medicine at the Wright facility. Gauer theorized that multiple G acceleration followed by weightlessness could have serious physiological effects. He observed that the acceleration forces encountered during spaceflight launch and reentry would depress circulatory function and cause certain conditions that had been observed in high-altitude aeronautical flights: pooling of blood in the extremities and the brain ("redout") or insufficiency of blood supply to the brain (blackout). Weightlessness, he theorized, would compound the problem since, in the absence of gravity, the blood vessels would relax and would not perform the capillary action that normally aids the heart in the circulation of blood. Consequently, the heart, already overtaxed by multiple G acceleration, would be further strained by the loss of capillary action. This combination of factors, he believed, could lead to conditions such as heart failure, pneumonia (from pooling of blood and fluid in lungs), or severe muscle cramps (from pooling of blood in muscles). He suggested that this combination of factors could also disrupt the normal processes of the nervous system, through which the brain sends signals to the body systems in response to sensations. Because the sensations derive from pressure exerted at various points on the body, the multiple G and null G states, and their rapid succession, could cause the brain to receive and send mixed or conflicting signals. This, in Gauer's view, would affect balance, spatial orientation, and the body's efforts to compensate for circulatory dysfunction.[14]

In practical terms, Gauer's theories implied that these effects could be negated, or at least significantly reduced, if some means could be found to reduce the multiple G forces experienced during launch. Following this suggestion, researchers at the Wright center conducted tests of the relationship between body position and the physiological effects of G forces. After numerous tests with a centrifuge between 1952 and 1957, researchers concluded that maximum physiological tolerance results when the forces are applied transversely perpendicular to the head-to-foot axis.[15]

The Wright center was also responsible for designing equipment that would protect pilots of high-altitude, high-speed aircraft. This responsibility later included space crews, who would face similar, but more extreme, hazards. The major protective devices developed were pressure suits, couch and restraint systems, emergency escape hatches and seats, enclosed flight cabins, and life support equipment. By the end of the 1950s, scientists and engineers at Wright had become increasingly interested in the modification and redesign of aeronautical equipment for spaceflight.[16]

At the Aeromedical Field Laboratory (an extension of the Wright center) at Holloman Air Force Base, New Mexico, investigators conducted inflight biomedical investigations. Space-related biomedical research included exploration of the effects of weightlessness and radiation on small mammals and primates, human tolerance of the forces of acceleration and impact, physiological and performance effects of environmental extremes (cold, diminished oxygen, low barometric pressure), and human responses to brief periods of weightlessness. Biomedical operations at Holloman began in 1948 in a field then termed "space biology," the investigation of the space environment through observation of its effects on animals. On four occasions, rhesus monkeys in pressurized capsules were fired into the upper atmosphere aboard V-2s. In each case, the monkey survived the hazards of flight, but died when its parachute failed. From 1949 to 1952, in the Aerobee series, rhesus monkeys and mice were launched to altitudes above 70,000 meters on four flights. These animals were successfully recovered, with no adverse effects attributable to weightlessness and acceleration.[17]

The space biology program was terminated in 1952, when the Air Force began to give priority to ballistic missiles. By this time, Holloman had other biomedical commitments. Fritz Haber and Heinz Haber at the School of Aviation Medicine and Harold J. von Beckh at Holloman shared Gauer's anxieties about the potential hazards of weightlessness. A method for simulating weightlessness was obviously needed. The Habers, who were physical scientists and engineers, speculated that a brief period of weightlessness could be created by having an airplane make an abrupt descent following a sharp ascent. In 1951, test pilots flying such parabolic patterns proved the speculation to be substantially correct. They experienced about a half-minute of zero G and two to six minutes of low G. Von Beckh suggested a modification of the Habers' technique in order to assess both weightlessness itself and the pilot's reactions to reentry forces following weightlessness. He suggested that immediately following the half-minute of weightlessness, the pilot drop the plane into a steep downward spiral.

Missions between 1953 and 1958 using the combined Haber-von Beckh technique dispelled some concerns while raising new ones. The flights resulted in temporary disorientation and nausea (though it was impossible to determine whether this resulted from weightlessness or the nature of the flight pattern), but showed that humans quickly learn to perform in the new environment. The von Beckh trajectories provided concrete evidence that physiological tolerance of the forces of acceleration declines following exposure to weightlessness. This further confirmed Gauer's theories and reemphasized the need to keep G loads to a minimum.[18]

Holloman was also a center for investigations of the effects of linear acceleration and high-speed impact. Usually identified with Col. John Stapp, who rode the facility's high-speed "sled" a significant number of times between 1947 and 1955, these studies were intended to determine the limits of human tolerance to the multiple G forces of linear acceleration (straight-line, continuous force) and to high-intensity impacts. By 1958, these studies had revealed that humans have the potential to withstand 46 G and a force of 10,000 pounds for a quarter of a second, forces that were well in excess of those anticipated for spaceflight.[19]

Finally, Holloman was the center for the Air Force's Man-High high-altitude balloon flights between 1956 and 1961. Seven missions were flown to measure the intensity of cosmic radiation, test the effectiveness of a sealed cabin, and evaluate instrumentation for remote medical monitoring of a pilot's physiological responses above 30,500 meters. The most important results were in the areas of heat and humidity control and biomedical telemetry.[20]

While the Air Force was the unquestioned leader in aerospace medicine and biotechnology, the other military services made contributions. The Naval School of Aviation Medicine at Pensacola had responsibilities similar to, but narrower in scope than, those of the Air Force school. The naval school trained flight surgeons, but offered no specialized training in space medicine. The facility did sponsor research in areas that would later prove relevant to space medicine, such as designing and evaluating psychological profiles for the selection of pilots, and studying the effects of stress factors and extreme environments on the vestibular apparatus (components of the inner ear that control balance and orientation).

The Navy also sponsored biomedical research and development at its Aviation Medical Acceleration Laboratory in Johnsville, Pennsylvania, and the Naval Equipment Center in Philadelphia. The activities of these two centers together were similar to those of the Wright center. Johnsville had responsibility for human factors research, while Philadelphia oversaw biotechnology. As at Pensacola, these facilities were oriented toward aviation research and development with little direct interest in spaceflight before 1957.[21] Johnsville operated a centrifuge to study effects of acceleration and decceleration. The centrifuge, with NASA input, was modified to simulate interaction between the pilot and a control system that regulated centrifuge motion and G force. This dynamic motion simulator was used to develop the space reaction control system for the X-15 research airplane and later for tests of piloted reentries of the Mercury spacecraft.

The Army had no active program in aviation and space biomedicine, though it did staff a bioastronautics office at the Army Ballistic Missile Agency within the Wernher von Braun group at Huntsville, Alabama. The Army also had a major physiological research facility, the Armed Forces Institute of Pathology in Washington, D.C., which sponsored a wide-ranging program of basic research. Finally, the Army and Navy cooperated in 1958–1959 in a series of biological investigations in space with rhesus monkeys. These flights, launched by Jupiter missiles, provided additional evidence that higher organisms could endure the rigors of spaceflight if adequate life support was provided, and they were important for testing and evaluating biomedical monitoring techniques, instruments, and operational procedures.[22]

## SPACE BIOMEDICINE IN 1958

As the United States prepared to respond to the challenge presented by the Soviet Union's successful launch of *Sputnik 1* in October 1957, few within the American aerospace community doubted that the nation could place a man into orbit and return him safely, possibly in advance of the Soviets. The military services had the basic capabilities for launch, operations, and recovery. Biomedical investigators had evidence that man could tolerate the G forces and brief periods of weightlessness anticipated for an orbital mission. The hardware for sustaining man in near-space already existed and could be modified to meet the requirements of an orbital mission. Perhaps most important, the military services, the National Advisory Committee for Aeronautics, NACA (NASA's predecessor), the aerospace industry, and many universities collectively had the scientific, biomedical, and engineering talents and the research, development, and operations facilities required for the task.

Nonetheless, manned spaceflight remained a formidable challenge, and the human factor was a major element in that challenge. Adapting and modifying hardware, techniques, and knowledge derived primarily from aeronautical research posed significant engineering and operational problems, problems that were exacerbated by a dearth of hard data on human capabilities and limitations in space. While biomedical scientists were certain that humans could tolerate the conditions and forces of Earth-orbital flight, the precise short-term and long-range clinical and behavioral effects of spaceflight were not predictable. Nor could scientists provide the engineers with the baseline (normative value) specifications required for design and development of space capsule protective, life support, communications, and control systems.[23]

Physicians were particularly concerned about the environmental variables of space (radiation, weightlessness, magnetic fields), the spacecraft (toxic contaminants, fuel leakage, artificial atmosphere, abnormal pressure), and the spaceflight experience (acceleration, isolation, confinement, discomfort, disruption of day-night cycle). Among these, the most worrisome was weightlessness, because it could not be simulated effectively for sustained periods. So little was known about the effects of prolonged weightlessness that a broad range of possible debilities had been predicted, including disorientation and circulatory failure. Biomedical scientists were also worried about interactional factors, that is, the combined effect of two or more stress and environmental factors. The severe problems predicted by Otto Gauer were early examples. In addition, there was an apparent correlation between the level of oxygen in the bloodstream and tolerance to G forces. Biomedical scientists feared that weightlessness, by upsetting the normal rhythm of the circulatory system, would reduce tolerance to the multiple G forces of reentry. That, in turn, could degrade the ability of flight crews in a critical portion of any mission.[24]

In the absence of predictive values, space physicians realized that flight crews would have to be selected on the basis of exceptional physical and mental health and then carefully trained. Consequently, the selection and training of astronauts was a major area of biomedical concern. This would not be a simple task, however, given the absence of consensus on the physiological and psychological parameters that should be measured, and the unproved reliability of the instruments that would be used in making these measurements.[25]

The absence of hard biomedical data had a direct bearing on engineering and operations. To develop a space capsule that would meet human requirements without exceeding weight limitations and without unduly complicated systems, engineers required precise human factors values.[26] Mission planners, too, required precise biomedical data to ensure that the duration, configuration, and progression of missions would not exceed human tolerance. Since weightlessness was the major unknown variable and could not be simulated effectively, flight plans would have to be configured to increase gradually the duration of exposure. To do so, planners needed to know the levels of "acceptable risk" for each mission and decide which biomedical functions should be made part of overall monitoring procedures.[27]

The human factors requirements as known were fully documented by Dr. W. Randolph Lovelace II, a retired Air Force flight surgeon and international expert in aerospace medicine. Between February and October 1958, Lovelace chaired a Working Group on Human Factors and Training—a committee of aerospace physicians, human factors engineers, and test pilots who met under the auspices of the NACA-sponsored Special Committee on Space Technology (Dr. H. Guyford Stever, chairman). This group issued a report, authored by Lovelace, in which biomedical problems were cited as major obstacles to manned orbital flight. An "immediate requirement" exists, Lovelace wrote, for "detailed information on human tolerance limits" to prolonged weightlessness, isolation and confinement, linear and variable acceleration, and space radiation, as well as the application of this information to the "verification of space capsule design." This required, in Lovelace's view, a multidisciplinary approach to human factors research and applications and a coordinated national program of research in space biology and medicine.[28]

## COORDINATION OF THE MANNED SPACE PROGRAM

Although in early 1958 the United States had the resources and facilities needed to provide research, development, and operational support for manned spaceflight, these capabilities were dispersed among different agencies and the various space-related activities were largely uncoordinated. Between January and July 1958, President Eisenhower, key members of Congress, and leading scientists and spokesmen for the aerospace community became increasingly aware of the need for direction of the national space program by a single agency. In January 1958, Eisenhower authorized establishment of the Advanced Research Projects Agency within the Department of Defense to seek means for coordinating the nation's space programs and to recommend a single agency to carry out the task. Subsequently, the three military services and the NACA vied for authorization to manage and direct the space program, particularly the manned effort.

The Air Force seemed the likely choice, inasmuch as it had launch capabilities superior to those of the other military services, major launch sites on both coasts, and the most experience in launch operations. It was also the unquestioned leader in the field of aerospace medicine, with three times the biomedical personnel and four times the biomedical research and development budget of its closest competitor, the Navy.[29] Perhaps most important, the Air Force had shown more interest over a longer time than had any of the other claimants, and it could argue that this interest evolved logically from its historical role as the nation's principal aviation agency. The Air Force, as its space-oriented officials pointed out, had always been moving toward space: "From the first aircraft to enter the inventory to the futuristic X-15, Air Force goals have changed in degree only; the basics have been constant—greater speed, longer range, and higher altitude."[30]

The Air Force was also the most advanced in manned spaceflight planning and development. It had three separate programs at different stages of development, but each was conceived as an integral part of the overall Air Force space program. The X-15 rocket-powered research airplane, a joint NACA-Air Force project intended to "fly to the edge of space," was the most recent in a long series of high-performance research aircraft flown since 1947. Although it was plagued by development problems the X-15 was promoted by the Air Force as the first step in its plans to place a man in space.

The second Air Force program, Dyna-Soar, was still on the drawing board in 1958, but the Air Force argued that it was a logical extension of the X series of research aircraft. With design features similar to those of the X-15, Dyna-Soar was to be a lifting body. Launched into orbit by a missile, it would be capable of maneuvering in orbit briefly to set up its reentry and glide to Earth. The Air Force was also proposing a third manned program, Man-in-Space-Soonest (MISS), an extensive program that would achieve both military and civilian objectives in space. MISS was planned to begin with a series of unmanned biological satellites, proceed to a manned orbiting satellite (about 1960), a manned orbiting laboratory (about 1963), and conclude with a manned lunar landing in 1965.[31]

Neither the Army nor the Navy could set forth a comparable claim to the space mission. The Navy had excellent biomedical, human research, and biotechnology resources and facilities, but it lacked the Air Force's launch capabilities and lengthy experience in high-altitude and astronautics research, development, and planning. Moreover, the Navy's lone proposal for a manned spaceflight project, Project MER (for Manned Earth Reconnaissance), was overly ambitious, requiring the development of completely new hardware and systems. Further, the Navy's failure to place an unmanned satellite (Vanguard) in orbit cast doubt on its ability to sponsor a successful manned operation in space.[32]

The Army had launch capabilities and experience to match those of the Air Force. Its Ballistic Missile Agency, led by von Braun, probably had the best launch organization outside the Soviet Union and had been responsible for the United States' first successful orbiting satellite. However, the Army had limited capabilities in aerospace biomedicine and biotechnology, as was evident in its manned space proposal, Project Adam. Adam was simplistic in conception: a man would be hermetically sealed into a capsule atop a ballistic missile. The missile would launch the capsule into space; the capsule would orbit once and reenter as its orbit decayed. In terms of biomedicine, the plan required only that the passenger be protected against the more obvious hazards and forces. No effort would be made to monitor the passenger's physiological reactions in flight or to test human performance capabilities.[33]

The NACA was the least likely candidate for authorization to manage the manned space program. It had no launch capabilities or facilities, no biomedical resources, no tradition of space-related research and development, and no clearly defined proposal. What the NACA had, however, was an extensive and effective aeronautical research and technology development team, several decades of experience doing advanced research on the ground and in flight (i.e., the X series of research aircraft) in support of military and civilian aeronautical technology development programs, and an intense interest in expanding the scope of its activities to include astronautics. Perhaps most important, the NACA was a civilian agency.[34]

President Eisenhower, concerned that a national venture in space would nourish the growth of a politically powerful "military-industrial complex," was suspicious of military ambitions for a space program. Key members of Congress, leading scientists, and other influential public figures shared Eisenhower's concern. It was also believed that an open space program under civilian management would illuminate the contrast between the American and Soviet governments. Many scientists feared that a military space program would stifle communication among scientists and subordinate legitimate research to weapons systems development.[35]

On April 2, 1958 President Eisenhower recommended that Congress create a new agency, structured around the NACA, to manage the national space program. Congress did so on July 16. The National Aeronautics and Space Administration became operational on October 1, 1958 and received formal authorization to direct the manned orbiting satellite program (soon to be named Project Mercury) several weeks later.[36] How this new agency, with no biomedical personnel, no biomedical research facilities, and little experience in human factors research and engineering (with the exception of aircraft flight control), would manage a program that depended so much on biomedicine, remained to be determined.

# 2
# Human factors of Project Mercury

The salient features of NASA's biomedical program, as they were set down in Project Mercury and remained throughout the manned program, were summarized in 1963 by Dr. Charles Berry, chief of the Manned Spacecraft Center Medical Operations Office. "The nature of the challenge," Berry observed, required that "the simplest and most reliable approach be used." This involved, first, adapting biomedicine "to engineering and operations," using "off the shelf items wherever possible," basing medical operations on mission operations, and using "engineering analogies" to communicate biomedical information to engineers, astronauts, and mission controllers. Second, it entailed a "direct approach" to the qualification of humans for spaceflight: "thrusting" man into a "truly unknown environment," providing him with "the best protection and monitoring capabilities within the operational constraints of the mission," and using the observations of man in flight as "a means for evaluating the next step into space."[1] This approach was supported by NASA's engineering management and depended on the military services for the biomedical support of Project Mercury.

Initially, biomedical support requirements for Project Mercury could be satisfied through a small medical unit attached to the Mercury project office. However, as NASA began to look beyond Project Mercury, its administrators foresaw a need for a broadened biomedical program. This led to a reassessment of the initial organizational arrangements for biomedicine, and of the agency's dependence on the military services, which eventually brought NASA into direct conflict with the Air Force.

Concurrently, a small but articulate and influential group of scientists, including some life scientists, began to question the wisdom behind the manned space program and the adequacy of the biomedical support for

Project Mercury. Generally unfamiliar with the practical aspects of medical operations and strongly biased in favor of basic research, these scientists were disturbed that NASA did not intend to conduct an intensive biomedical research program (including an extended series of animal flights) before proceeding to manned flight. They were convinced that NASA planned to expose astronauts to unnecessary risks and that NASA management was more concerned with engineering and mission priorities than with human health and safety.

In Project Mercury NASA faced a fundamental question that would endure for some time as a source of controversy in the manned space program: How to organize and administer a life sciences program that would meet the technical and operational requirements of the agency's major programs, be consistent with the agency's overall program administration, and be acceptable to scientific interests outside NASA.

## BIOMEDICAL ADMINISTRATION OF PROJECT MERCURY

The requirements identified by the Working Group on Human Factors and Training (the Lovelace committee) and others posed challenges for NASA's management that were administrative as well as technical and operational. From the NACA the agency inherited personnel experienced in the physical sciences and engineering and facilities equipped for research in aeronautical engineering and the physical science aspects of aeronautics. It had no physicians or biomedical scientists on the staffs of its permanent headquarters or its centers.[2]

Nor did NASA have specific funds or authority to build capabilities in biomedicine. In the initial NASA authorization hearings, members of both the military and Congress had expressed opposition to any duplication of existing programs or facilities.[3] Given Air Force capabilities in bioastronautics, NASA could not expect support for a large program in human factors research and development. Moreover, NASA Administrator T. Keith Glennan opposed any major increase in the number of NASA employees or the size of the NASA centers. A fiscal conservative, he shared Eisenhower's view that the space program should be small in scale and limited in its objectives.[4]

Finally, those who had studied the agency's human factors requirements were recommending a biomedical program to support long-range objectives and underestimated the pressure on NASA to place a man in Earth orbit at the earliest possible time, preferably before the Russians. If many Americans shared Eisenhower's opposition to a "space race," many more believed that an active space program was essential to national prestige and security.

NASA therefore had little choice but to rely on the military services for biomedical support. The use of military personnel and facilities would provide the support required for manned spaceflight without creating conflicts with Congress or the military services and without exceeding the limits set by Glennan and Eisenhower. It would contribute to the achievement of Mercury objectives quickly and economically, and it would allow NASA to use NACA personnel and facilities without disrupting existing personal and organizational relationships.[5]

Because NASA's biomedical objectives at the outset of the space program were limited to technical and operational support for Mercury, Glennan established a biomedical team under the authority of the director of the Space Task Group (STG).* Since biomedicine was initially only an adjunct to spaceflight development and operations, both of which were the responsibility of the Space Task Group, this arrangement made good sense. It also did not require significant revision of existing authorities or transfer of NASA personnel.

The biomedical team for Mercury was composed entirely of military personnel on detached assignment. Initially, Glennan and his top administrators viewed this as a temporary arrangement and gave the team the designation "aeromedical consultants." Six months later, in April 1959, Glennan responded to advice from his staff and converted the biomedical team into a permanent operational component of the Space Task Group although it would continue to be staffed entirely by military personnel on temporary assignment.[7] The initial group of aeromedical consultants consisted of Dr. Stanley C. White, an Air Force lieutenant colonel, physician, and specialist in human factors engineering and biotechnology; Dr. Robert Voas, a Navy lieutenant, psychologist, and specialist in flight crew selection and training and human engineering; and Dr. William S. Augerson, an Army major, physician, and specialist in human physiology.[8]

Although NASA had no immediate requirement for biomedical administration outside the Space Task Group, Glennan and his staff needed input to ensure effective coordination with the military services, to accurately apprise Congress and the President of life sciences requirements and developments, to provide life scientists outside NASA with a point of contact within the agency, and to deal with the important and politically sensitive issue of astronaut selection. Since Glennan was averse to creating new programs or enlarging the staff, he sought to resolve the problem by using consultants. He also formed a Special Advisory Committee

*The Space Task Group was the project management center for Mercury. Although physically located at NASA's Langley Research Center in Hampton, Va., it was an autonomous organization. When manned spaceflight operations were relocated to Houston (1962-1963), the Space Task Group evolved into the Manned Spacecraft Center, later, Johnson Space Center.

for Life Sciences, which he hoped would substitute for a life sciences program office. As he saw it, this committee would give NASA regular expert advice from leading specialists in space biomedicine without increasing headquarters personnel or changing the organization. Toward this end, he selected as members of the committee persons who were recognized leaders in the field and who held high-level, full-time positions outside NASA— in short, persons who would have no compelling reason to carve niches for themselves within NASA or to promote a permanent life sciences office.[9]

The chairman of this committee, W. Randolph Lovelace II, was possibly the most famous specialist in space biomedicine; he was internationally recognized as an expert in both the theoretical and practical aspects of the field. He was influential, having extensive and important contacts in Congress, the military services, and the scientific community. Moreover, he had nothing to gain from a permanent NASA position; his political contacts ensured that he could influence space program planning whether he worked for NASA or not, while his position as director of his own research corporation provided a considerably greater income than he could have earned at NASA. Lovelace then had precisely the biomedical expertise required for Project Mercury, the political clout required to ensure that NASA received the level of biomedical support required for Mercury, and no ambition to create a position for himself. Collectively, the other members of the committee had status comparable to that of Lovelace, if none equaled his prominence in the field.[10]

The Life Sciences Advisory Committee assumed many of the responsibilities of a life sciences program office. Glennan expected it to provide liaison between NASA and the other government agencies, particularly the military services, and between NASA and the scientific community, while serving as a link between the biomedical staff at the Space Task Group and top management at headquarters. It would review biomedical planning for Project Mercury and make recommendations to Glennan and his key administrators, but it would have no line authority.

Glennan considered creating an official program-level life sciences position on the basis of recommendations from Lovelace, other scientists, and some members of his staff. Lovelace foresaw a continuing need for life sciences input into the space program and favored a high-level life sciences office and a centralized life sciences research facility.[11] Responding to this advice, Glennan directed a staff assistant, W. L. Hjornevik, to review NASA's capabilities and requirements in the life sciences. Hjornevik concluded that NASA was underestimating the importance of biomedicine. He pointed out that the reliance on consultants was in marked contrast to practices in the physical sciences and engineering, where consultants were used rarely. Hjornevik contended that the biomedical area was "potentially at least as important as the hardware development area" and that the "management concepts adopted in the engineering field" should be "applied in the aero-medical field." He recommended that Glennan appoint a "senior medical advisor" to his staff, create a permanent "biomedical unit in the space development headquarters organization," and establish "a small biomedical research laboratory" at one of the field centers.[12]

Although Glennan agreed to make the Space Task Group's aeromedical consultants team a permanent organizational component, he believed that the other recommendations required further study.[13] For the immediate future NASA could rely on the Life Sciences Advisory Committee for input at headquarters. From November 1958 through July 1959, administration of biomedicine remained the exclusive responsibility of Space Task Group management. The Life Sciences Advisory Committee continued to provide advice and recommendations, but played a major role only in the selection of the Mercury astronauts.[14]

## BIOMEDICAL SUPPORT FOR PROJECT MERCURY

The biomedical tasks for Project Mercury were in three primary areas: selection and training of astronauts; design, development, and evaluation of life systems; and provision of medical support for flight operations. Accordingly, NASA selected three military specialists in these areas as the biomedical consultants to Project Mercury. The nominal head of this group of consultants was Lt. Col. Stanley C. White, who was selected because of his acquaintance with key members of the Space Task Group staff and his activities as a member of the Man-In-Space-Soonest team at Wright-Patterson Air Force Base.[15]

A physician, White had more than 10 years of experience in human factors research and engineering. At the time of his detail to NASA, he was director of aeromedical research at the Wright Air Development Center, Wright-Patterson AFB, where he had been closely involved in research and development related to spaceflight life support systems and protective equipment. He was also serving as project leader of the spacecraft design group of the Air Force's Man-in-Space-Soonest planning group.[16] White selected Army Maj. William Augerson and Navy Lt. Robert Voas as his assistants.

Augerson, also a physician, was a specialist in human physiology and clinical medicine. Although he had very little experience with manned spaceflight, he had worked briefly with White at Wright-Patterson and had been involved in flight operations as part of the biological program of the Army Ballistic Missile Agency. In the latter capacity, he had monitored the physiological responses of monkeys in a series of Thor-Able flights.[17] Augerson's appointment assured representation from each of the services on the biomedical team; moreover, he was fully qualified for the position, bringing to NASA a strong medical background and an intense interest in the space program.[18]

Voas, a psychologist, also had a keen interest in the space program, especially the selection and training of flight crews. He began his career as a specialist in human engineering, a new field of psychology applied to the design of the workplace, procedures for improving worker motivation and satisfaction, and techniques for identifying and selecting management trainees. He came to NASA from the Naval School of Aviation Medicine, where he had devised a psychological testing program that had resulted in a sharp decrease in the rate of failure among pilot trainees.[20]

## ASTRONAUT SELECTION

The aeromedical consultants began their assignment during the first week of November 1958 and concentrated on two tasks: the development of environmental and life support systems, and astronaut selection. Following the ground rule that the selection program should identify "individuals who would require a minimum of training in order to fulfill the Mercury job requirements,"[21] they concluded that the job required persons with a high level of intelligence and physical stamina, exceptional health, advanced training in science or engineering, and psychological capabilities for effective performance under stress.[22] In addition, engineering constraints dictated that the astronauts be light in weight and not too tall. The consultants recommended the following basic requirements: maximum age, 40 years; maximum height, 5 feet 11 inches; excellent physical condition; bachelor's degree in engineering or a physical science; graduation from test pilot school; and a minimum of 1,500 hours flying time as a qualified jet pilot.[23]

The consultants then faced the task of identifying prospective candidates. Initially, they favored an open selection program, with applications sought and accepted from all interested persons who met the basic requirements. Volunteers were so numerous, however, that they soon decided to conduct a closed program and extend invitations only to carefully screened individuals. Ultimately, President Eisenhower directed that they limit their search to test pilots within the military services.[24]

The consultants first screened the medical records of 508 military pilots who had graduated from test pilot schools, identifying 110 who met the basic requirements. This group was reduced to 69 on the basis of recommendations from command personnel and instructors at the test pilot schools. These 69 were interviewed by a team that consisted of the aeromedical consultants, Space Task Group Associate Director Charles Donlan, civilian test pilot Warren North, two military psychiatrists, and a psychologist from NASA's personnel office. Thirty-two of those interviewed volunteered to undergo intensive testing.[25]

The final phase of the selection program began in February 1959. Testing included medical and clinical evaluations at the Lovelace Foundation for Medical Research and Education in Albuquerque, New Mexico, and physical and psychological stress tests at the Air Force's Wright Aerospace Development Center. The selection team wanted data that would show degrees of physical and mental soundness so that they could evaluate each candidate in comparison with the others.[26]

Before testing began, physicians at the Lovelace Foundation analyzed the medical histories of the candidates and established a composite picture of the clinical norms (baselines) that should be expected in the typical candidate. Norms were established for each of the body systems (e.g., circulatory, nervous, musculoskeletal), major organs (e.g., eyes, heart, lungs, ear-nose-throat), and primary physiological functions (e.g., blood pressure, heart rate, pulmonary function). Data for each of these areas were obtained by subjecting the applicants to a broad range of procedures, including tissue cultures, blood and urine chemistry, x-rays, examinations by specialists, and general internal medical examinations. Subsequently, each candidate was assessed in terms of his degree of deviation from each of the norms.[27]

In the second part of the testing program, Air Force personnel at the Wright Air Development Center conducted tests to measure "body efficiency" in terms of heart and pulmonary function, physical response to stress, and psychological performance. Stress tests included responses to acceleration, heat, isolation, depressurization, and extreme exertion. Psychological and psychiatric tests were intended to provide measures of intelligence and special aptitudes and assessments of personality and motivation.[28]

In late March 1959 the selection committee reviewed the test results and concluded that 18 candidates were comparably qualified in terms of medical and psychological factors. Instructed to reduce this number to 6, they reevaluated the medical results and individual technical qualifications, but could not reach a firm decision. Subsequently, final selections were made by NASA's top management.[29]

From a purely medical standpoint, the selection program ran very aircraft."[32] Vehicle weight and capsule design were the second consideration. Available launch vehicles made strict control on weight essential. Because of the pressure to achieve mission objectives at the earliest possible time, engineering design and development had to emphasize simplicity, with minimal use of new hardware. These two considerations dictated the approach to biotechnology. Wherever possible, life systems would be modifications of existing hardware. New hardware would be developed only if nothing was available to be modified, or the old hardware would not provide the "adequate margin of safety." Further, as long as the "risk hazard" was not in question, life systems would be selected on the basis of engineering considerations (weight and simplicity). Finally, life systems would be designed and developed with a minimum of redundancy.[33]

The off-the-shelf approach was most apparent in components that were related to flight stresses, that is, protection against acceleration, reentry, and impact forces. The capsule was to be designed so that the couch would hold the astronaut in a supine (back down) position with his lower extremities elevated approximately 20 degrees from the horizontal. This, White believed, would provide maximum protection against the multiple G forces expected during spaceflight. The couch, cushion, and impact restraints were to be modifications of similar equipment that had been designed for high-performance military aircraft and tested extensively in Air Force facilities.[34]

The pressure suit was a modification of a test pilot's high-altitude pressure suit, the Navy Mark IV. Evaluation by Mercury contractors resulted in numerous modifications. To minimize redundancy in the overall life systems, the suit would be designed to serve as the backup environmental system should the capsule life support system fail. This meant that it would have to provide for oxygen, atmospheric pressure, temperature and humidity control, and waste disposal. To meet weight limitations, it would be fabricated from a lightweight material. For the astronaut's comfort and performance, the suit would have to be flexible and capable of accommodating fittings for pressure gloves, helmet, and environmental control connections.[35]

The environmental control system of the capsule was not so much a modification of existing hardware as an amalgam of features and components of environmental systems from submarines and high-altitude aircraft. Like the pressure suit, the capsule would have to meet the environmental requirements noted above and be subject to the same basic engineering constraints related to weight and simplicity.

Those constraints were most apparent in the areas of atmospheric pressure and air conditioning. At the outset, there was disagreement about whether the capsule atmosphere should be "normal" atmospheric air at sea-level pressure or highly oxygenated. The former was preferable in terms of safety, as oxygen in high concentrations poses a serious fire hazard and can cause hyperoxia (oxygen intoxication) if the pressure is not properly adjusted. However, normal atmospheric air would complicate capsule engineering; heavier materials would be needed to hold in the higher pressure, and scaling the capsule would be more difficult. In addition, a normal atmosphere would increase the possibility of hypoxia (oxygen deprivation) in flight, necessitating the inclusion of sensors to monitor the partial pressure of oxygen in order to ensure an optimum level of blood oxygen.[36]

NASA's engineers were not alone in favoring an oxygen-rich atmosphere. White believed it had physiological advantages that outweighed the potential hazards. As a flight physician, he knew that hypoxia was a far greater problem at high altitude than hyperoxia. The low-pressure system would be within weight constraints, yet would provide a partial pressure of oxygen sufficient to maintain the proper blood oxygen level. He also reasoned that a pure oxygen atmosphere would ensure the availability of the oxygen required during emergencies. In particular, it would minimize the effects of emergency decompression.[37]

## MEDICAL SUPPORT FOR FLIGHT OPERATIONS

While White concentrated on human factors and biotechnology, Augerson worked on the design of a medical plan for Mercury operations. This involved three major responsibilities: medical maintenance of flight crews, preflight and inflight assessment of astronaut health and performance, and postflight evaluation of astronaut response to spaceflight and the space environment. Each of these supported a specific Mercury objective. Linked with astronaut training, medical maintenance should enhance an astronaut's ability to fulfill his responsibilities as a Mercury pilot. Preflight assessment and inflight monitoring would provide mission controllers with information needed to determine whether a mission plan should be followed or modified. Postflight evaluations would contribute to mission planning; physiological and performance data from one mission could be used by operations personnel in planning subsequent missions.

Although the Mercury missions involved more complex tasks and more sophisticated equipment, Mercury physicians had the same basic responsibilities as the flight surgeons for test pilots, and they could adapt tested techniques. Like their aeronautical counterparts, Mercury physicians would be maintaining, monitoring, and evaluating the physical and mental health of abnormally healthy individuals placed in an abnormally unhealthy environment and would not be able to base their assessments on normative physiological values derived from a general population. As former jet pilots, the astronauts had an abnormally high tolerance for physical and mental stresses. In addition, for most spaceflight stress parameters (e.g., cardiac function relative to null G) there were no validated normative values and hence no proven methods for determining whether an astronaut was approaching the threshold of tolerance.

Augerson and his colleagues could rely to some extent on procedures and techniques used by flight surgeons who monitored high-altitude flights in balloons and high-performance aircraft. However, the Mercury undertaking demanded greater sophistication. Augerson believed that physiological data derived from aeronautical flights would not provide adequate predictive values for Mercury missions. Rather, physiological norms would have to be derived for each astronaut and used in evaluating the inflight status of the individual astronauts. These norms were to be based on numerous measurements made during centrifuge runs and flight simulations and would encompass both the physiological factors to be measured in flight (heart action, respiratory performance, body temperature, urine output) and the clinical assessments to be made later. During flights, medical monitors would use the individual norms as a basis for inflight clinical assessments. After each mission, Augerson's team would use the norms to evaluate their postflight clinical findings.[38]

Augerson also foresaw a need for almost continuous monitoring of astronaut health and performance during missions, a task beset by both technical and nontechnical difficulties. In technical terms, spaceflight required remote clinical assessment with bioinstrumentation, which was not completely new, but few physicians had any experience with it. Some bioinstruments— such as pressure cuffs for taking blood pressure and sensors for recording changes in body temperatures— had been used during high-altitude balloon flights conducted by the Navy and the Air Force in the 1950s. While such instruments could serve as prototypes, their reliability was unproved and very few physiological responses could be measured with confidence.[39] Invasive techniques (implantation and insertion) were more likely to produce reliable measurements, but there was strong resistance to their use. Surgical implantation would cause discomfort and might introduce infection or interfere with pilot performance.[40] Moreover, the astronauts feared that a faulty instrument or misinterpreted data would be cause for grounding, while the engineers were concerned that elaborate instrumentation would complicate design problems, particularly those related to the pressure suit.[41]

Augerson decided to minimize the use of bioinstruments and to limit the number of inflight measurements to functions that seemed to be critical indicators of physiological distress and for which reliable, noninvasive bioinstrumentation existed or could easily be developed. These functions included (in the early flights) body temperature (measured rectally),* respiratory performance (monitored through an instrument implanted in the microphone pedestal of the flight helmet), and cardiac performance (measured through special electrodes and a pressure cuff linked to the helmet microphone). These measurements would be transmitted from capsule to monitoring sites by radio signal.[42]

Augerson planned to have specially trained medical monitors at each station of NASA's worldwide network of tracking sites. The monitors would record the biometric readings as the astronaut came into radio range and compare them with the known baseline values for the astronaut. If the monitor discovered significant deviations from the baseline, he would radio this information to the next monitor down the line and to the center medical operations team (White, Augerson, and Douglas). This pattern would continue until a decision was reached about the future of the mission. If the monitors did not discover significant deviations, the flight would continue and the recorded data would be retained for future reduction and analysis.[43]

The medical monitoring plan was based on the assumption that significant deviations would be accepted as justification for early termination of a flight mission, although Augerson knew that this was unlikely. He himself had little confidence in the reliability of bioinstruments and knew that it would remain open to question throughout the Mercury program. Moreover, he realized that guesswork would play a major part in operations, since it would be impossible in advance to establish precise correlations between degrees of deviation from baseline values and actual physiological dysfunction, and in any event the functions being monitored were not reliable indicators for all possible health problems that could develop in flight. Personally, Augerson favored a systematic program of basic medical research to establish these correlations before manned flights began; however, he accepted the fact that the time constraints and economics precluded this.[44] Thus, in fact if not in design, the principal value of the bioinstrumentation would be to test the instruments and monitoring procedures themselves and thereby contribute to the design and development of reliable devices for use in subsequent flight programs.

Because of the limitations of the bioinstruments and the likelihood that

*The use of the rectal thermistor bordered on being an invasive technique and was a source of tension between astronauts and physicians. At the beginning of Project Mercury, however, instruments for measuring temperature orally were unreliable, and rectal thermistors were used during the first four Mercury flights. An oral thermistor was developed for, and evaluated during, the later Mercury missions and became standard equipment for subsequent manned flights. This development is described in Chapter 4.

reliable instruments would not be available for use in the early Mercury flights, Augerson planned to rely primarily on health indicators for inflight medical assessments. Initially, he lobbied for inclusion of a television camera in the Mercury capsule so that physicians could make visual inspections. The idea was quickly rejected by the operations team because of the design problems it would introduce.[45] Instead, Augerson and his colleagues relied on voice assessments and medical interviews as health indicators. In the first mode, monitors would listen closely to the astronaut's voice for indications of physical distress (e.g., labored breathing) and neurological or behavioral dysfunction (garbled or slurred speech, disconnected word patterns). Besides being crude, this procedure was limited by distortions inherent in the communications system and by the high level of subjectivity involved. In the second mode, monitors would pose, at specified points during the flight, a series of questions that would lead the astronaut in making a personal assessment of his own physical condition. This had the obvious limitations that the astronauts were not physicians, and, more important, were not likely to volunteer information or admit to any problems that could lead to early termination of the mission.[46]

In an effort to minimize the biases of these modes, Augerson, in cooperation with Douglas and Voas, incorporated the training of medical monitors with the training of astronauts. First, the medical monitors would gain experience in procedures, familiarity with the astronauts, and a technical understanding of the Mercury missions by monitoring the astronauts during centrifuge runs and flight simulations. Second, in an effort to increase astronaut cooperation, basic physiology and clinical assessment would be made part of the astronaut training program.[47]

Following reentry and recovery, the astronauts would receive an extensive clinical evaluation. It would begin with an immediate assessment of the astronaut's present health. During the ensuing 24 hours, physicians would conduct a series of examinations to determine whether the spaceflight experience had caused physiological changes. These examinations would include urine and blood chemistry, vital signs (temperature, pulse, respiration, blood pressure), body mass and weight, body fluid volume, fluid intake and output, and general physical health and stamina. Physiological changes would be detected through comparison of these data with data obtained from similar examinations during preflight preparations.[48]

Augerson also faced a troublesome problem unrelated to medicine. It would be logical to draw medical monitors from the military services because military physicians could be mobilized and transferred easily, worked at a pay scale far below that of their civilian counterparts, and were accustomed to working in an operational environment. Moreover, few civilian physicians had a practical knowledge of flight medicine. The use of military physicians, however, posed a delicate diplomatic problem, since many tracking sites were on foreign soil. Augerson therefore proposed that NASA obtain some physicians from the Public Health Service. Although technically civilians, Public Health Service physicians were organized along military lines, holding rank and receiving pay equivalent to that of military physicians.[49]

Augerson's work was directly linked with that of the Astronaut Medical and Training Office. William K. Douglas, chief of the office, worked primarily as the astronauts' personal physician, providing medical care and coordinating with Augerson activities that involved the astronauts in tests and measurements.

Robert Voas, Douglas's assistant and the astronauts' training officer, faced a major challenge in the astronaut training program. He was charged with training the astronauts to respond effectively to hazards that could not be predicted and preparing them for an environmental condition—weightlessness—that could not be simulated meaningfully. In addition, he had to develop procedures through which they could learn to operate a vehicle that was in the process of development. Since he could not anticipate or prepare them for all possible emergencies (with some notable exceptions, such as emergency decompression), he took the position that the training program should emphasize basic education and familiarization through repetition, including instruction in the sciences that underlay spacecraft design, spaceflight operations, and medical operations. In this way, he hoped to provide the astronauts with a body of information on which they could draw in an emergency, whether the emergency occurred in relation to spacecraft systems, the mission plan, or the pilot's health.[50]

Three aspects of the training program had the purpose of instilling in each astronaut an instinct for spaceflight, and each emphasized familiarization through repetition. The first was regular aviation flight training in high-performance aircraft to maintain basic skills. The second was "familiarization" with the "conditions of space flight," which was intended to acclimate the astronauts' nervous systems through repeated exposure to spaceflight stresses (G forces) and discomforts (vertigo, heat, pressure). Voas hoped that this aspect of training would help the astronauts learn to cope with the effects of spaceflight and prepare them to respond instinctively to emergency situations. The third aspect was flight simulation in the Mercury capsule. Again, the intention was to make vehicle operation an instinctive action and the astronaut a functioning part of a man-machine system.[51]

Voas applied his knowledge of human and industrial engineering in the training program. Realizing that workers are most comfortable in an environment which they understand and feel they control, he encouraged the astronauts to participate directly in the development and evaluation of the Mercury capsule and its component systems. In this approach, which became a standard feature of all subsequent manned programs, each astronaut monitored the development of a specific Mercury system or subsystem. He was expected to deal regularly with both contractor and NASA development engineers and to train the other astronauts in his specific system. This task had the primary purpose of giving the astronauts such a detailed understanding of the capsule systems that in the event of a systems failure, they could conceptualize the engineering problem, independently devise corrective action, and assist ground personnel in analyzing and solving the problem. Voas also believed that understanding the engineering principles involved in an emergency situation would reduce the astronaut's level of tension, since one fears most that which one cannot understand. In addition, he was convinced that many design and development problems could be avoided with the help of those who would be piloting the vehicle and would be alert to defects that might not be apparent to an engineer. In this sense, he was using an approach that was common in the aerospace industry, namely involvement of test pilots in engineering design and development.[52]

By mid-1959, Voas, Augerson, White, and the other members of the Mercury medical team had made significant progress in providing biomedical support for Project Mercury. They had identified the critical biomedical problems, implemented plans and procedures for dealing with these problems, and achieved an effective integration of biomedicine with the engineering and operations components of the project.

## PROBLEMS OF ADMINISTRATION

The arrangements for administering the Mercury medical program seemed sufficient, given the limited objectives of Project Mercury (i.e., to qualify man, life systems, and operational procedures for Earth-orbital missions lasting up to one day). But by early spring of 1959, NASA's top administrators were beginning to question the adequacy of these arrangements. First, the life sciences were not formally represented at the program level; input at NASA Headquarters came solely from the Special Advisory Committee for Life Sciences. Although able to review and make recommendations concerning the agency's life sciences programs, the members of the committee had no authority to issue directives or implement their recommendations. Stanley White, the nominal head of the Space Task Group biomedical team, did not have direct administrative access to the director of the Space Task Group and was subordinate to the two associate directors, both of whom were engineers. Further, the biomedical staff had no authority to deal with the external biomedical community, and so, in effect, was isolated from scientists and clinicians who had an interest in the biomedical aspects of spaceflight but who were not among NASA's life sciences advisors.[53]

NASA's top management—which included Glennan, Deputy Administrator Hugh Dryden, Director of Space Flight Development Abe Silverstein, and Silverstein's principal assistants, Homer Newell and George Low—consisted of engineers and physical scientists. The members of the Life Sciences Advisory Committee, which was intended to function as a headquarters life sciences program office, were highly respected in the rather narrow field of aerospace medicine. However, as government scientists their daily working relationships did not include the biomedical scientists in academia whose support could be important to the program.[54]

This organizational arrangement was based on the assumption that NASA's requirements in biomedicine would never extend beyond operational support for the one approved manned program. Thus it failed to take into account the advanced research and development that would be required to support manned flights after Mercury, if such flights were ever approved. A small operations-oriented group of clinicians, psychologists, and bioengineers on temporary assignment from the military services could not sustain the basic and applied research that would be required to support flights of longer duration. Further, these arrangements failed to meet NASARs responsibility to support basic research in the space sciences, including purely scientific investigations in space. While NASA's programs in the space sciences (then managed by the Office of Space Flight Development) were expanding, activities were limited to the physical sciences; a program in the "biosciences" was projected, but as late as March 1960 no such program had been implemented.[55]

Through advice from his staff and communications from outside scientists,[56] Glennan came to recognize that NASA was in danger of becoming totally dependent on the military services for biomedical research and development. While this posed no immediate problem for Project Mercury, it could reduce NASA's chances of receiving authorization to manage a post-Mercury manned program. Without its own biomedical program and research facilities, NASA would have to rely on the Air Force to conduct and sponsor extramural research and development in biomedicine, and this would make it difficult for NASA to establish independent ties to universities, research corporations, and industries in the area of biomedicine.

Glennan and his associates knew that the Air Force was girding to fight for authorization to manage the post-Mercury manned effort, should there be one, and was reorganizing its commands to provide more effective control over space-related activities. The Department of Defense had taken steps to improve coordination among the space-related components of the military services, which strengthened the position of the Air Force. When the Defense Department created the Advanced Research Projects Agency in early 1958 and gave it authority to coordinate the three manned military space programs and, eventually, to select one for official support, it was assumed that the agency would eventually tap the Air Force.[57]

Moreover, in early 1958 Secretary of Defense Neil H. McElroy gave the Air Force responsibility for reviewing, monitoring, and coordinating all military-sponsored research and development in support of advanced manned space programs. Although operational control of existing programs remained with the individual services, it was clear that in the post-Mercury era the Air Force would call the space shots for the military.[58]

The Air Force was also receiving some support from scientists. While many scientists had reservations about military control of the entire space program,[59] *Science* editor Philip Abelson and Jerome Wiesner of the Massachusetts Institute of Technology, among others, expressed the view that science would benefit if the scientific and manned components of the space program were divided, the former under civilian control, the latter under military. They reasoned that as long as NASA had charge of the manned program it would subordinate space science to manned flight, but if manned operations were transferred to the military NASA would be able to concentrate on science.[60]

The military services had much to gain and little to lose by providing biomedical support to NASA. Their personnel and facilities would be fully used and they could justify requests for expanded research and development capabilities. They would receive a steady infusion of funds from NASA, their personnel would receive valuable operational experience, and their support would be good for public relations. If Mercury failed, NASA would be blamed, but the services would still be able to push their own manned space plans; if it succeeded, the chances for an advanced manned program would be increased, and the services would be fully prepared to compete with NASA for authorization to manage such programs.[61]

In light of this situation, NASA would have to develop an adequate biomedical program if it was going to justify a role for itself. An "adequate" program in biomedicine for manned spaceflight would have to include support for basic research. Information on the biological effects of prolonged exposure to weightlessness, space radiations, and alterations of biological rhythms was badly needed and could be gained relatively quickly and inexpensively with subhuman organisms. Although NASA had a mandate to sponsor basic science in space, only the nonscientific aspects of the life sciences—biotechnology and medical operations—were receiving funds.[62]

By March 1959 Glennan realized that NASA's long-range interests indicated in-house capabilities in biomedicine and biotechnology and a diversified and expanded life sciences program. He appointed Dr. Clark T. Randt, an academic physician and clinical researcher, to his staff as special assistant for life sciences and authorized him to make a thorough study of NASA's long-range requirements and capabilities in the life sciences. Concurrently, he formed a Biosciences Advisory Committee composed of biologists and biomedical scientists with a basic research orientation to make recommendations concerning NASA's role and responsibilities in the life sciences and suggest organizational changes that would improve the management of biomedicine and the other life sciences. Their findings and recommendations laid the basis for NASA's life sciences program.

# 3
# NASA's life sciences program

*Two astronauts selected for the Skylab mission are assisted by scuba divers during a Neutral Buoyancy Simulator test.*

Laying the proper organizational foundation for life sciences at NASA presented special problems. Administrator Glennan realized that NASA needed to expand the scope of its life sciences activities if it was going to reduce its reliance on military personnel and facilities to provide biomedical research for future manned programs. The scientific community also looked to NASA to support biological investigations in space and basic research in biomedicine. At the same time, he was reluctant to increase in-house personnel and facilities or to disrupt existing personal and organizational relationships. Nor did he want to alarm the military services and Congress. To help him resolve this dilemma, he asked Clark Randt, a personal acquaintance, to join NASA as a special assistant and invited a group of prominent biomedical scientists to serve as a Biosciences Advisory Committee.

Randt was an excellent choice for life sciences advisor. A respected clinician, biomedical scientist, and medical administrator, he was believed to be an excellent choice to bridge the gap between academic life scientists and NASA's engineering- and physical science-oriented management. At the time of his appointment, Randt was director of the division of neurology at Case Western Reserve University Medical School in Cleveland and was recognized for his important contributions in sensory neurophysiology.[2] Glennan was also impressed by Randt's attitude toward science and the space program. As a clinician, Randt perceived the value of basic research in terms of its potential applications. His commitment to an expanded and strengthened program of basic biomedical research within NASA was firmly linked to potential clinical uses within the manned space program. Moreover, Randt was an enthusiastic supporter of manned spaceflight and believed that a successful program required the cooperation of life scientists, engineers, and mission planners.[3]

During the time he worked for NASA, from July 1959 to March 1960, Randt focused on three problem areas: NASA's needs and capabilities in the life sciences, liaison with other government agencies having biomedical research and development programs and facilities, and NASA's ability to attract the support of the academic community to the agency's long-range objectives in biology and medicine.

In February 1960, Randt recommended to Glennan that NASA implement a life sciences program that would provide for "sequential evolution" of life sciences "research, development and training" related to the biomedical requirements for manned spaceflight, the biological effects of the space environment, and the search for evidence of extraterrestrial life. He suggested that this evolution should proceed through three phases. Phase one, 1960 to 1963, should center on biomedical research and development related to manned flights of short duration (2 to 7 days) in Earth orbit (no more than 500 miles from the Earth). Biological research should be limited to ground-based facilities with the objective of identifying research problems requiring further investigation in flight. The second phase, 1964 to 1970, should focus on biomedical research and development related to human requirements during 10- to 30-day flights and biological investigations of subhuman organisms in support of manned flights (e.g., studies of the effects on cellular organisms of weightlessness, radiation, and alterations in body rhythms). Finally, in phase three, beyond 1970, biomedical research and development should address human requirements for flights exceeding six months in duration and one million miles in distance. Biological research in this phase would be essentially independent of manned spaceflight and centered on problems related to the origin and evolution of life and the search for extraterrestrial lifeforms.

To accomplish these objectives, Randt claimed, NASA needed to give high priority to basic biomedical research and to integrate all life sciences research and development. Noting that the life sciences comprise a continuum from basic research in biology to clinical practice, he suggested that the organization and management of life sciences programs should reflect this. In practical terms, this meant that the four primary life sciences activities—space biology, human research, biotechnology, and space medicine—should be administered within a single life sciences program office. He also urged the creation of a life sciences research center and an active program of grants and contracts to life scientists. The center and the program would fall within the jurisdiction of the director of the Life Sciences Programs Office.

Randt recognized that an expanded and strengthened life sciences program within NASA would be resisted by the military services and their supporters in Congress, but he believed this opposition could be quieted if

NASA clearly defined its legitimate areas of interest and pushed for authorization to develop in-house capabilities only where military programs were inadequate. He suggested that military capabilities were limited to biotechnology (development of life systems and protective equipment and the attendant human research) and that NASA was justified in developing capabilities in other life sciences areas. He further suggested that NASA establish a formal liaison in the life sciences between NASA and the Defense Department. This, he believed, would enable NASA to avoid direct confrontation with the Air Force while taking advantage of interservice rivalries. Finally, he urged Glennan to negotiate with the Space Science Board of the National Academy of Sciences for the formation of a life sciences committee that would be responsive to NASA's needs. This, in his view, would give NASA the same type of advisory service as the Air Force enjoyed through the Bioastronautics Committee.[4]

## THE KETY REPORT

While serving as Glennan's life sciences advisor, Randt represented NASA at meetings of the Biosciences Advisory Committee. Glennan had asked the committee to provide expert advice on life sciences programs and to respond to complaints from academic life scientists. He named as chairman Dr. Seymour Kety, a prominent neurologist and researcher with the National Institutes of Health, and instructed him to select as members of the committee "scientists of recognized stature in the bioscience specialties" who have had "diversified training and experience" and are as interested in "fundamental research" as in "applied research and technical development."[5] In short, Glennan wanted a biosciences committee that reflected the needs and interests of academic and other basic research-oriented life scientists.[6]

Glennan and his staff formulated 11 "functional objectives" for the Kety committee. These included determining NASA's present and future needs in the life sciences; the extent to which NASA should assume responsibility for life sciences research, development, and training; and the life sciences organization that NASA would need to meet its responsibilities. In setting forth these objectives, Glennan wanted specific guidelines for a life sciences program. He specified that the committee give evidence that NASA's biomedical objectives could be met through existing facilities and provide specifics about "the proportion of in-house to extramural effort . . . the rate of buildup for each— [and] the composition, organization, status and size of the NASA in-house capability." He also asked for hard data to justify a life sciences research facility.[7]

The Kety committee conducted its investigation from June to November 1959, presented a draft report to Glennan in December 1959, and submitted its final report in January 1960. The report urged increased emphasis on basic science and warned against making the life sciences program strictly an adjunct to manned spaceflight applications and operations. It identified two broad objectives: investigation of the biological effects of extraterrestrial environments "including the search for extraterrestrial life" and scientific investigations related to "manned space flight and exploration." While expressing unqualified support for the manned space program, it stressed that the ultimate objective was to expand opportunities for extraterrestrial science.[8]

To achieve these objectives, the report continued, NASA first needed to implement "an imaginative and long-range program" of biological, medical, and behavioral research with clearly identified scientific objectives and emphasis on the interrelationships among biological, biotechnical, and medical research and development. The report suggested three subdivisions for the life sciences:[9]

1. Basic biology; effects of extraterrestrial environments on biological systems, with special emphasis on "those phenomena associated with weightlessness, ionizing radiation, and alterations in life rhythms" and the search for organic molecules that "might be precursors or evidence of extraterrestrial life."
2. Applied medicine and biology: medical and biological research related to manned spaceflight, including "effects of weightlessness on human performance, radiation hazards, tolerance of force stresses, and maintenance of life-sustaining artificial environments."
3. Medical and behavioral sciences: "fundamental investigations" concerned with longer range human requirements in space and scientific investigation of the effects of space on human biology and behavior, including research into "metabolism, nutrition, blood circulation, respiration, and the nervous system control of bodily functions and performance in space equivalent situations."

A second requirement noted in the report was that NASA take responsibility for "leadership, coordination and operation of the biomedical aspects of the national space program." While avoiding sharp criticism of the military services, the authors did offer two reasons why a civilian agency was better qualified to manage this area of research and development. First, the military services were not in a position to achieve the objectives of investigating "fundamental biological questions relative to extraterrestrial environments and the scientific and technological aspects of manned space flight," because the services "must properly give primary attention to the development of weapons systems and the national defense." In contrast, NASA was "unhampered by such predetermined objectives" and therefore had the flexibility to pursue the broader life sciences objectives. Second, civilian control of biomedical programs would reaffirm America's "international role" as a "basically peaceful and benevolent power" that seeks to use manned spaceflight to symbolize "the scientific aspirations of all men" rather than "military strength."

However, the authors recognized the legitimate interests of the military services in space and their unique capabilities for supporting NASA's endeavors. NASA and the military services should form a "civilian-military liaison committee" for the biosciences, responsible for ensuring "maximum integration" and utilization of existing biomedical personnel and facilities and to provide mechanisms for sharing scientific and technical information.[10]

The final requirement for the achievement of biomedical objectives in space, according to the Kety committee, was a NASA organization with authority to plan and oversee the total life sciences program. The committee recommended an office of life sciences with "responsibility and authority for planning, organizing, and operating" a program that would encompass "intramural and extramural research, development and training." The director of this office should be "directly responsible to the Administrator of NASA in the same manner and at the same directional level as the other program directors." The report recommended that this office be divided into four sections, three related to the areas of research described above and the fourth to manage NASA's extramural life sciences program. The director should establish four advisory committees "made up of consultants outside of NASA" and corresponding to the four subdivisions of the office.[11]

The heart of this organization, however, should be a life sciences research center and several auxiliary facilities located at universities. The central facility, the authors suggested, should be colocated with Goddard Space Flight Center and serve as "the nucleus" for a "national undertaking" in space-related life sciences research, development, and training. The proposed center would be staffed by a small group of full-time "competent biological, medical and psychological scientists" who would conceive and direct "a broad and thoughtfully planned biomedical program of research extending from the most fundamental aspects to their most practical applications." It should be responsive to the director of the life sciences office and support and coordinate research at a network of auxiliary research institutes. The latter would be organized to conduct research along specific lines; for example, one center would be exclusively concerned with brain and nervous system research.[12]

The report of the Kety committee can be viewed as both a serious effort to give Glennan the advice he requested and an attempt to negotiate an active role for research-oriented life scientists within the space program. The committee gave Glennan good reasons for building up the life sciences, solid arguments in favor of civilian control of space life sciences, scientific justification for the manned space program, and detailed specifications for organizing and managing a life sciences program. However, all recommendations were predicated on the premises that the life sciences were of fundamental importance to the national space effort, that their value was founded on basic biological and medical research, and that the achievement of life sciences objectives depended on the use and development of academic life scientists and facilities and the active involvement of research-oriented life scientists in the space effort.

From Glennan's perspective, the report was satisfying because it gave him leverage in his dealings with representatives of both the scientific and military communities. To scientific critics, he could point to the Kety report as an "unbiased" justification of manned spaceflight. NASA's support for the report also demonstrated the agency's desire both to provide adequate life sciences support for manned flight and to give science status comparable to that already enjoyed by engineering and operations. At the same time, the Kety report gave Glennan fundamental arguments that could be used in efforts to convince the military services and Congress that NASA was justified in seeking internal capabilities in the life sciences. The most important aspect of the report, however, was that the recommendations were fully consistent with Glennan's own views of NASA. While it called for a vastly expanded program in the life sciences, it also emphasized that the in-house component should be small and should coordinate and manage, rather than conduct, research. Glennan could implement the major recommendations without a large-scale buildup in personnel and the increase in funds could be kept within manageable limits by transferring research and development allocations from military facilities to academic ones. Indeed, the authors of the report were not necessarily calling for a major increase in *total* life sciences funding, but simply in the amount being allocated to colleges and universities.[13]

Although Glennan was prepared to accept the report's recommendations concerning research objectives and headquarters organization, he doubted that NASA could obtain congressional support for a life sciences research facility in the near future. The Air Force and certain members of Congress would view it as a duplication of existing facilities, which Congress, on previous occasions, had directed NASA to avoid.[14] In light of this anticipated opposition, and because he did not believe the need for a life sciences research center was imminent, Glennan decided not to act on this recommendation until the new headquarters office had been firmly established. In this way, the new office could proceed cautiously with the development of a detailed and thoroughly justified plan before approaching Congress with a request to construct the facility. To avoid a premature confrontation, he did not announce the establishment of the Office of Life Science Programs until March 1, 1960, two weeks after the House of Representatives had completed its hearings on NASA's budget request for fiscal year 1961.[15]

Thus NASA's aspirations in the life sciences were not a source of contention during the House hearings and, in fact, were barely mentioned. NASA did not require congressional approval for an internal reorganization, but it did need authorization for the related operating funds. Glennan's staff accomplished this by including funds for biosciences as part of the overall request for research and development funds. The specific requests were innocuous: to transfer certain funds which had previously been approved for use in manned spaceflight to the "Directorate of Advanced Research" for support of "university research in the area of the biosciences," and to provide new funds for FY 1961 to support research in "bioscience" as part of the overall appropriation for support of university grants and contracts. The House approved the request with the understanding that the funds were to be used to encourage "the nation's biomedical scientists" to investigate "problems confronting man in traveling through space [in the areas of] biophysics, bioengineering, metabolism, behavior and space environment."[16]

NASA's intentions in the life sciences did become a matter of congressional concern after Glennan's March 1 announcement of the new Office of Life Science Programs, however, when the authorization bill passed to the Senate. Perhaps because Glennan included no information related to the new office in the materials he provided to the Senate committee before the hearings, there was little controversy,[17] but some members expressed reservations. Sen. Margaret Chase Smith (R-Maine) asked Glennan to elaborate on NASA's use of existing biomedical facilities and future plans in the life sciences. Sen. Stephen M. Young (D-Ohio), in questioning Gen. Bernard Schriever of the Air Force, implied that NASA was moving toward "an absolute duplication of the Air Force biomedical research activities." Nonetheless, the Senate approved the authorization, possibly because the funds involved were minuscule and would not be used for construction of new facilities.[18]

As mild as the hearings had been, it soon became apparent that key members of the House and Senate wanted to look more closely at the implications of NASA's recently announced plans. Concerned over the proliferation of biomedical activities throughout the government, and responding to public anxiety over Soviet advances in space and missiles—and aware that 1960 was an election year—both houses held hearings on biomedical activities of federal agencies in the summer.[19]

Certain key members of the House and Senate were convinced that NASA's seemingly modest plans would mushroom like the programs of other government agencies.[20] This, as Sen. Hubert Humphrey (D-Minn.) observed, could lead other agencies, such as the Federal Aviation Administration, to press for their own biomedical programs, and soon government support for biomedical research and development would be spread across so many offices that coordination would be impossible and duplications would be extensive.[21] Many members of Congress believed, with Rep. Emilio P. Daddario (R-Conn.), that NASA had no requirements in the life sciences that could not be met through the extensive and often underused biomedical laboratories of the Air Force and the Navy. Daddario argued that a NASA life sciences program not only would cause duplication and waste, but would generate intense competition for the limited supply of biologists, bioengineers, biomedical scientists, and clinicians.[22] Some questioned NASA's need for a biology-oriented program, observing that the National Institutes of Health already had the capability for sponsoring and directing research in the area.[23]

In short, the Office of Life Science Programs began formal operations faced with a dilemma. To satisfy its critics in the scientific community, NASA would have to press for a life sciences program whose scope and nature would be unacceptable to many in Congress and would be strongly opposed by the Air Force. Clark Randt, the first director of the office, would spend most of his time in an unsuccessful attempt to resolve this dilemma.

## OFFICE OF LIFE SCIENCE PROGRAMS

Organized along lines proposed by the Biosciences Advisory Committee, the Office of Life Science Programs was equal in status, on paper at least, to NASA's other program offices. The director held a line position equivalent to that of other program directors and, like them, reported directly to the NASA associate administrator.*

According to the official NASA statements, the life sciences office was to become "the focal point for a national and international effort" in the space life sciences.[24] Responsible for implementing the recommendations of the Biosciences Advisory Committee, the office's long-range functions were divided between basic research and research in support of manned flight. It was to develop a program of basic research with objectives that included knowledge of the biological effects of the physical factors of

* Relevant organizational charts are contained in the appendixes.

space, new information bearing on biological evolution, and the search for evidence of extraterrestrial life. It was also to establish a program of biological and medical research in support of long-duration manned spaceflights.

At first, Glennan and his staff gave Randt strong support and seemed to fully endorse the recommendations of the Biosciences Advisory Committee.[25] They generally supported Randt's efforts to make the Office of Life Science Programs a viable organization. In mid-March, Randt requested that all funds for bioscience grants and contracts ($2 million for FY 1961) be placed under his direct control. Heretofore, such funds had been administered through the Office of Advanced Research Programs. Following the recommendation of Associate Administrator Richard Horner, Glennan approved the request—a significant concession.[26]

Glennan also indicated that he approved of Randt's efforts to make NASA's life sciences programs independent of the military services. He agreed with Randt that coordination of life sciences matters with the military services should be at the Defense Department level, rather than with the individual services. Randt believed that this would improve overall coordination and help reduce Air Force influence within the space program. He also approved Randt's recommendation that NASA support the formation of a life sciences committee within the Space Science Board, a move that, in part, was also intended to reduce Air Force influence. In late 1959, the Air Force had backed the creation of an Armed Forces-National Research Council Bioastronautics Committee to facilitate communication between military agencies and life scientists in academia. Randt was pressed by key members of this committee to have the committee advise NASA as well. He rejected the idea and successfully avoided a situation that would have worked against NASA's independence in the life sciences.[27]

Glennan also encouraged Randt to locate an appropriate site for the life sciences research facility recommended by the Kety committee and to prepare a strong case for presentation to Congress. By late June 1960, Randt had identified the Ames Research Center and the newly constructed Goddard Space Flight Center as candidates for the facility. Although Glennan did not make a firm commitment, he indicated that he would do so in the near future and would select Ames as the site.[28]

During his first six months in office, then, Randt had reason to believe that the Office of Life Science Programs would evolve into the organization envisioned in the Kety report. Accordingly, he focused on the creation of an effective organization and the rationalization of a long-range life sciences research and development program.

Following the recommendations of the Kety committee, Randt divided the office into three parts: space biology, flight medicine and biology, and space medical and behavioral sciences. The division of space biology would be responsible for planning and implementing the biological research program, including developing the technology required for in-flight biological investigations. The flight medicine and biology division was to have, in the post-Mercury era, responsibility for applied research in support of manned spaceflight. It would sponsor and coordinate human factors research in support of the engineering and operational requirements of advanced programs and its activities would be directly linked to those of the agents responsible for manned spaceflight projects. The division of space medical and behavioral sciences would promote the basic research in human physiology and behavior which would identify man's qualifications and requirements for long-duration spaceflight and support efforts to plan for advanced manned programs.

Randt wanted the three divisions to function as an integrated unit. Ideally, information gained from biological research on subhuman organisms would guide those in space medicine in planning basic research in human biology and behavior. The knowledge gained from space medical research, in turn, would contribute to the planning of applied (human factors) research, which, in the end, would provide the basis for design and development of spacecraft and planning of mission operations. Randt was trying to give NASA's life sciences organization a pattern which was generally typical of biomedical research organizations such as the National Institutes of Health and university medical centers, and which reflected a view common among life scientists that biology, medical science, and clinical medicine were parts of an integrated and coordinated whole.[29]

Randt also oversaw the formulation of a "Ten Year Plan" for the Office of Life Science Programs intended to show how life sciences research and development would support the overall national space program, identify facilities required to support the program, and provide estimates of the costs involved. The bulk of the plan focused on the support the office would provide to the manned space program. While the plan for the space biology division called for activity in exobiology, it emphasized study of the effects of space on lower biological organisms, with specific attention paid to weightlessness, ionizing radiation, thermal extremes, electromagnetic fields, and alterations in biological rhythms (e.g., the day-night cycle).[30] Research in space medical and behavioral sciences would be directed toward assessing the effects on human physiological systems of long-term exposure to the space environment. Human metabolism would be studied to determine requirements for food and water, as would the disposal of solid and liquid wastes. Psychology was to be the third area of research, for such factors as isolation and confinement were likely to have significant effects on human behavior and performance during long-duration spaceflight. The final area of research, sociology, would explore interactional behavior in confined spaces.[31]

The research plan for flight medicine was premised upon a post-Mercury manned program leading to a circumlunar flight or lunar landing. The first objective would be to obtain enough information about human requirements in flights of "7 to 60 days" for engineers to design life systems so that "weight [would] be minimized and reliability maximized." Specific areas of concern would be control of atmosphere, temperature, and humidity; radiation; metabolic requirements; crew comfort and safety; and human requirements related to weightlessness and acceleration. Second, flight medicine would establish requirements for optimum integration of man and machine, such as the characteristics and placement of control and display systems and the nature and mechanics of human information processing. The goal was to ensure that the spacecraft operator would have no difficulty in determining what was happening at any given moment, the position of his vehicle in space and time, and what to do in an emergency. Finally, the flight medical area would sponsor research in the development of scientific instruments for flight crews.[32]

Randt emphasized in the Ten Year Plan that while he intended to "utilize to the maximum extent possible" existing military, industrial, and academic research facilities, the objectives set forth in the plan could not be realized unless NASA established a strong internal capability in life sciences. The heart of this capability would be a research facility to "provide the necessary internal competence for over-all management and program competence," ensure coordination among the "diversified" organizations conducting life sciences research for NASA, and stimulate research and training in the space sciences.[33] That capability depended as well on an adequate research and development budget, which he estimated would have to rise from the 1960 level of $2 million to $50 million in FY 1963 and $100 million by the end of the 10-year period. Likewise, the evolution of the program necessitated a buildup of in-house life sciences personnel. He estimated that by FY 1963 the Office of Life Science Programs and the life sciences research facility would require a staff of 75, about half of whom would be professionals.[34]

By late September 1960, Randt had completed his preliminary organizational work. He had filled the key positions and established channels of coordination with the military services and the Space Science Board. Most important, perhaps, he had presented a long-range program for the office, including a strong justification for a life sciences research facility. He was ready to move on with the development of the program. However, he was beginning to doubt Glennan's commitment to the program.

The first indication was a change in Glennan's support for Randt's staffing plan. In March, when Randt had projected a buildup of 32 to 38 staff persons by the end of FY 1961, and 60 by the end of FY 1962, Glennan had made no objections. Subsequently, Randt presented these numbers to congressional committees. In late July, however, Glennan advised Randt that the projection might have to be scaled down, and in September, Glennan said the total life sciences staff could not exceed 20 at the end of FY 1961 and 38 at the end of FY 1962. This effectively halved the capabilities for which Randt had planned, and he viewed this decision as stopping "the progress of this program soon after it was initiated."[35] At the very least, the life sciences Ten Year Plan might no longer be realistic.

Glennan's reasons for making this decision are not known.* It may have been a response to criticisms from members of Congress concerned with possible duplication of facilities and competition for personnel. Congressman Daddario, in particular, strongly opposed the staff projections; he doubted the need for so many people, and he was certain that, given the limited supply of scientists and engineers in space-related biology, medicine, and bioengineering, NASA could build up its life sciences staff only by attracting specialists from the military services.[36] There is no evidence that Glennan acted in response to such complaints, but he himself was not in favor of large-scale internal buildups.[37]

Randt continued to press Glennan for approval of his original staff plan and in October, at a staff meeting, he issued an ultimatum: that Glennan approve his requests or fire him. Glennan was inclined to release Randt, but members of the staff encouraged Glennan to work out a compromise. In the end, Glennan agreed to increase the staff complement to 30 in FY 1961 and 50 in FY 1962, which Randt found acceptable. Glennan relented because he realized that Randt "had a hard row to hoe because he had to deal with a bunch of engineers who had no real empathy for the life sciences."[38]

Randt was also beginning to wonder whether he would ever receive a firm commitment for the research facility that he considered the key to the whole program. Glennan had expressed support for the concept as early as March and had reaffirmed this support on various occasions.[39] His reluctance to make a firm commitment stemmed from factors unrelated to the life sciences.

At the time the Office of Life Science Programs was formed, it seemed to Glennan, his staff, and Randt that Ames Research Center would be the ideal site for the life sciences facility. Ames had personnel experienced in the area of biotechnology and hardware who would be useful in human factors research. Further, Ames was underused and its management made

*Glennan does not recall this specific decision and has no references to it in his diary. Available documents shed no light.

a strong bid for the facility. Most important, at least to Randt, Ames was located near many medical schools, medical research centers, universities, and major aerospace industries. By June, Randt, Associate Administrator Horner, and Glennan were all agreed that Ames was the logical choice.[40]

However, more was at issue than the location of the life sciences facility. From the outset, everyone involved had assumed that the facility would be near the principal manned spaceflight activity, to encourage regular interaction between those engaged in life sciences research and development and those involved in biomedical operations. Initially, this did not seem to be a problem, as Glennan suggested basing the Space Task Group in California.[41] He made no formal commitment, however, and directed Randt to continue investigating Ames as a possible site.

In the interim, Glennan learned from members of his staff that relocation of the Space Task Group and construction of the life sciences facility in California could encounter "political resistance." Virginia politicians were upset by rumors that the Space Task Group would leave Langley, and politicians from several states, including Massachusetts, Florida, Texas, and Maryland, had expressed an interest in having the manned spaceflight facility built in their respective states. Studies by Glennan's staff suggested that Ames posed a "political problem" due to a "rather large buildup of federal activities there in recent years." However, the staff assessment was that the life sciences facility could be moved to California without political repercussions, provided the manned activity went elsewhere.[42]

There being no obvious solution to the problem, Glennan tabled the matter for his successor to resolve.[43] He was preparing to resign, having agreed to serve as NASA administrator only until the end of the Eisenhower administration, and a new President would be elected in two weeks. It seems likely that he was also anxious to avoid any suggestion that he was allowing politics to influence his decisions. Glennan was a Republican and an Eisenhower appointee. The Republican candidate, Richard Nixon, was Vice-President and a Californian. A decision by Glennan to locate the two facilities in California might well have raised suspicions.

Randt, not surprisingly, was greatly upset. Not only did the future development of the life sciences program depend on this facility, his ability to devise a strong budget presentation was weakened. To be sure of congressional authorization for construction funds, he had to have a strong justification. He felt that the strength of that justification depended on his knowing where the facility would be located and how it would be related to the manned spaceflight center. He continued to press for a commitment from Glennan, but without success. When Glennan resigned in December 1960, the issue remained in limbo.[44]

A final source of frustration during this period was the relationship of the Office of Life Science Programs to the biomedical components of the Space Task Group. When Randt accepted the directorship of the office, he understood that biomedical preparations for Project Mercury were well under way, but he assumed that his office would have some involvement in the biomedical activities. The Biosciences Advisory Committee, which NASA had sponsored and whose recommendations Glennan appeared to endorse, had recommended that "the biomedical aspects of Project Mercury be placed squarely under the jurisdiction of the Office of Life Science Programs and that it be coordinated with other aspects of the life sciences program."[45]

Randt, however, quickly discovered that Glennan, Horner, Deputy Administrator Hugh Dryden, and Director of Space Flight Programs Abe Silverstein were firmly opposed to this recommendation. They believed that its implementation would disrupt established channels of communication and lines of authority, create internal dissention, and interfere with the progress of Project Mercury. Accordingly, Dryden, acting for Glennan, prevailed on Randt to cosign with Silverstein an agreement that "the interests of NASA are best served by retaining the full authority for the biomedical aspects of Mercury" in the Office of Space Flight Programs. In agreeing to this, Randt understood that his office would be consulted by the Space Task Group staff and that the arrangement would not apply to post-Mercury manned activities.[46] Nonetheless, his office had been shut out of NASA's only active life sciences project, one which employed 80 percent of its life sciences personnel and received nearly 70 percent of its life sciences research and development funds in FY 1961.[47]

In September 1960 Randt decided to press for more involvement in the biomedical aspects of the Space Task Group. Having discovered that Glennan's commitment to the life sciences program might be wavering, Randt began to doubt that his office would be allowed to participate fully in the biomedical aspects of post-Mercury manned programs. In July Congress had authorized NASA studies of a manned lunar project, and responsibility was allocated to the Office of Space Flight Programs and the Space Task Group. Since the biomedical aspects of this study would be conducted by the biomedical component of the Space Task Group, Randt saw that his office could be shut out of the biomedical aspect of the new program for the same reasons that it had been shut out of Mercury.[48]

A number of other events also alerted Randt to the deteriorating prospects for a life sciences program. First, Dr. Stanley White, the head of the Space Task Group's Life Systems Branch and nominal head of all Mercury biomedical activities, had told Randt that biomedical personnel were not being brought into the decision making.[49] Second, Randt was troubled by recent complaints from some prominent scientists that NASA was incapable of providing adequate biomedical support for Project Mercury. Fearing that NASA was "recklessly endangering" the lives of the astronauts, they succeeded in convincing the President's Science Advisory Committee to sponsor full-scale investigations of Project Mercury and the biomedical aspects of the space program.[50]

Randt was also disturbed by activities in the Air Force. Recently, the Air Force Systems Command had sponsored a study of the space program under the direction of Trevor Gardner. The resulting report had strongly favored a twofold space program, with NASA managing the scientific aspects and the Air Force managing the manned program. The Air Force had also instituted a major reorganization, one aspect of which was the centralization of Air Force bioastronautics (life sciences) programs within the Aerospace Medical Division of the Air Force Systems Command.[51] Clearly, the Air Force was planning a major effort to gain congressional approval to direct post-Mercury manned programs and was prepared to use its capabilities in the life sciences as part of its justification.

For these various reasons, Randt decided to press his case. In December 1960, he proposed four changes to the new associate administrator, Robert Seamans: granting the Office of Life Science Programs responsibility for "recruiting and productively employing human factors and medical personnel" prior to their assignment to the Space Task Group; consolidation of the four separate biomedical activities at Space Task Group within the Life Systems Branch; elevation of the Life Systems Branch to division status; and creation of a third associate directorship at the Space Task Group and placement of a life scientist in this position.[52]

Not surprisingly, Randt's proposals were unacceptable to Silverstein and Space Task Group Director Robert Gilruth. Commenting for himself and Gilruth, Silverstein reminded Seamans of the agreement Randt had signed the previous March, implying that Randt had already given up any claim to authority within the Space Task Group. Silverstein further advised Seamans that the Space Task Group had already made changes that satisfied Randt's second and third recommendations. The final recommendation was impractical. The associate directors, Silverstein noted, must be able to fill in for the director on occasion, and he claimed that life scientists lacked the "training and skills" to do so. The implication was that associate directors must be engineers.[53]

Seamans asked the NASA Office of Programs and Evaluation to investigate the matter. The resulting staff study seemed to endorse Silverstein's position, and it recommended retention of the status quo. However, the study was actually a victory for Randt, since it specified that he was to be consulted about all current biomedical planning for the

Apollo program and that, once the Apollo organization became separate from the Mercury organization, a biomedical associate director for Apollo should be appointed.[54]

This small victory, however, was insufficient to overcome Randt's sense of frustration. In January 1961, he was no closer to having a life sciences facility or the requisite budget than he had been in October 1960. The life sciences program was in limbo. Glennan had resigned, but a new administrator had not been appointed. The new President had yet to give any indication of his plans for the space program. A group of scientists, commissioned by President-elect Kennedy and chaired by Dr. Jerome Wiesner, had issued a report that was highly critical of NASA. Believed by many to reflect Kennedy's views, the report recommended that NASA be enjoined from any further expansion of its in-house capabilities and be denied authorization to prepare for further manned programs until it had completed Project Mercury. Though generally opposed to a large manned program, the Wiesner report stated that such a program, if authorized, should be under the direction of the military services.[55] Obviously, none of this boded well for the Office of Life Science Programs.

Randt's apprehensions increased as January passed into February. Kennedy had appointed an administrator, James Webb, but Randt had been unable to gain access to Webb's office. For all practical purposes, NASA management remained in the hands of Deputy Administrator Dryden, who in Randt's view, was unsympathetic to the life sciences and personally hostile to Randt. Moreover, Randt was beginning to suspect that someone on his staff was leaking information about life sciences budget plans to the Air Force, allowing Air Force personnel to come to NASA authorization hearings fully prepared to challenge NASA's requests.[56]

In spite of these frustrations, Randt made one final effort to salvage the life sciences program. In late February, he submitted to Seamans a detailed "Proposal to Consolidate the Total Life Sciences Program," which was essentially a restatement of the Kety recommendations and a reiteration of Randt's views about the program. He hoped his paper would provide NASA with leverage against the Air Force in the upcoming congressional hearings and would contribute to NASA's efforts to convince the new President to support a post-Mercury manned program under NASA auspices.[57] Seamans passed the report on to Dryden, but what happened to it thereafter is not known. Failing to receive an acknowledgment, unable to gain an audience with the new administrator, and believing that copies of his proposal were given to Air Force representatives, Randt handed in his resignation and made arrangements to return to academia.[58]

Future events would justify Randt's misgivings. In early March 1961, Congressman Daddario released a lengthy statement castigating NASA for its life sciences plans. He charged that NASA needed neither a life sciences program nor a life sciences facility, since the military services could meet NASA's requirements. Thus, he contended, NASA's impending budget requests related to the life sciences represented a waste of taxpayers' dollars. His comments were read into the NASA FY 1962 authorization hearings and he raised the same issues when questioning NASA witnesses.[59]

Nevertheless, Congress authorized funds for the Office of Life Science Programs and for the construction of a life sciences research facility at Ames. It did so primarily because the chairman of the House Committee on Science and Astronautics, Overton Brooks, was adamantly opposed to military control of the space program. Brooks had used his influence with Vice-President Lyndon Johnson, a fellow Texan, to gain a commitment from Kennedy that NASA would receive the post-Mercury manned program and a larger budget than it received in FY 1961.[60] The congressional authorizations, however, did not salvage NASA's faltering life sciences program.

The new director of the Office of Life Science Programs, Air Force Gen. Charles Roadman, was a hardworking bureaucrat, experienced aerospace physician, and dedicated supporter of the space program. He did not, however, share Randt's vision for life sciences. He was as dedicated to the military model of biomedicine as Randt had been to the academic model. A former flight surgeon and commander, he was mission-oriented rather than research-oriented. He recognized the importance and value of basic research in biology and medicine, but did not believe that basic research on animals had any relevance to manned spaceflight. Nor did he believe that NASA was the legitimate setting for research in medical science. Consequently, he favored a life sciences program that separated space biology from space medicine, and he recommended that the former be placed with the space sciences, the latter with manned flight programs.[61]

In April 1961 the committee selected by the President's Science Advisory Committee to investigate Project Mercury issued its final report. Its chairman, Donald Hornig, reported that the consensus among members was that NASA's biomedical preparations and capabilities for Project Mercury were fully adequate. Hornig was satisfied that NASA had considered all relevant human factors in designing the spacecraft and planning the mission operations and had taken every precaution to ensure the health and safety of the astronauts.* In the two months after Hornig's report, NASA conducted two manned suborbital flights; neither gave any reason

*Though satisfied with NASA's biomedical preparations for Mercury, Hornig considered them inadequate for longer duration manned missions and was sharply critical of NASA's use of the "aeromedical approach" to the qualifications of man for spaceflight.

to doubt the adequacy of NASA's biomedical preparations for Project Mercury.[62]

Thus NASA's Office of Life Science Programs was moribund during the last six months of its life. It had no strong supporters among NASA's top management, and it was directed by a man whose priorities in relation to the life sciences were completely different from those which the office was intended to promote. Finally, the pressure from the scientific community, which had provided much of the impetus for establishment of the office, had diminished, partly because NASA had demonstrated its ability to use the life sciences in support of manned spaceflight. Few mourned when, in August 1961, the Office of Life Science Programs passed out of existence.

Many reasons have been given for the short life of the office: inadequate funding, insufficient authority, inconsistent support from management, resistance from NASA's engineers and physical scientists, congressional and military opposition.[63] While these were contributing factors, the fundamental cause lay in the relationship of the office to the overall NASA organization.

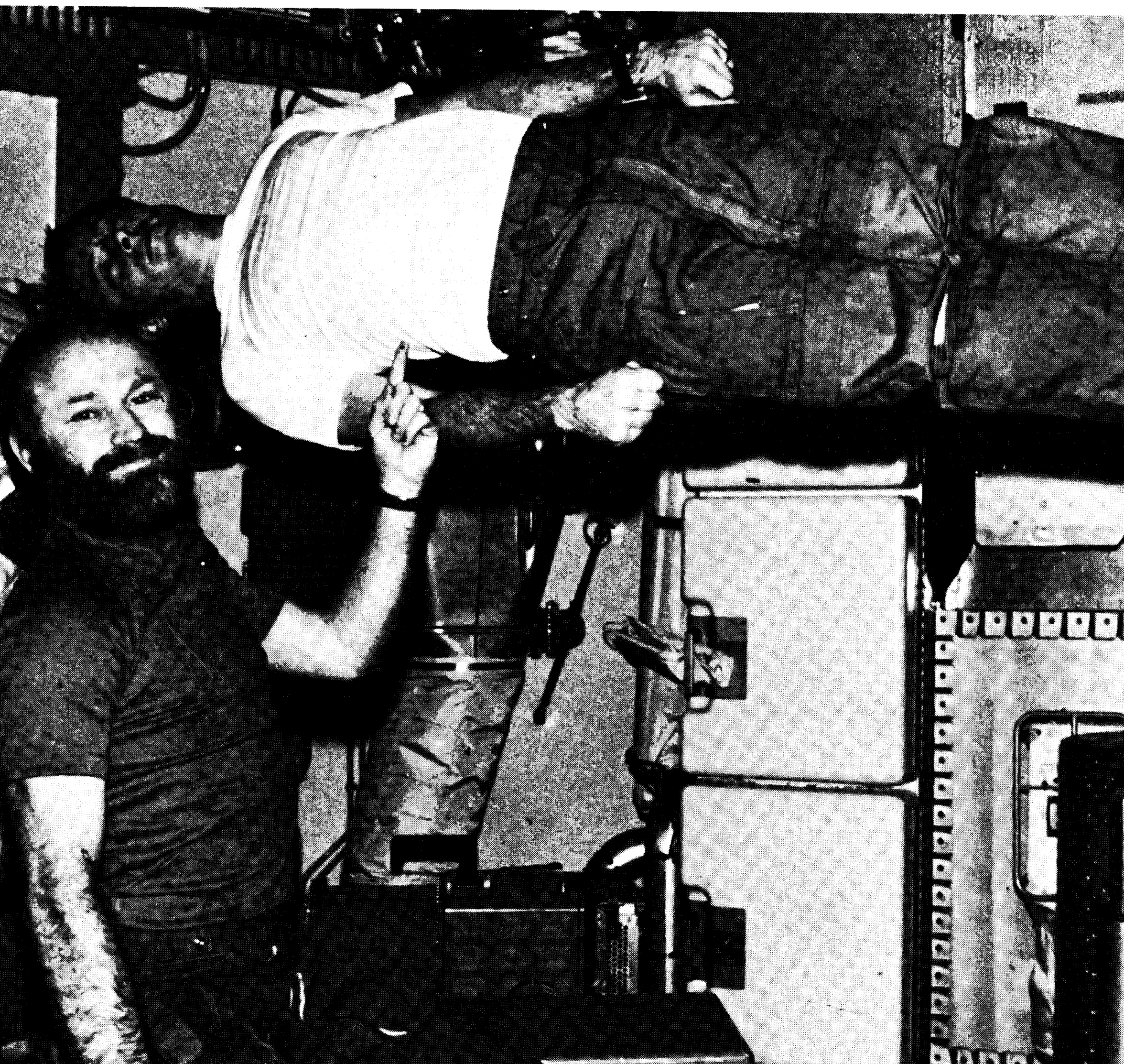
The rationale that underlay the formation of the office was inconsistent with NASA's immediate requirements. In 1960–1961, NASA's primary responsibility was to place a man in Earth orbit, and its requirements in the life sciences were basically operational. Although NASA gave considerable support to physical science and astronomy investigations in space, it showed little interest in the biosciences and had formulated no major inflight biological studies. Basic research in medical science and human factors, though recognized as important for the future, was not perceived as a pressing concern. Given the uncertainties about the post-Mercury manned program and the prospect that Mercury would be the primary manned effort over the next two or three years, there was no strong justification for extensive research in support of advanced manned programs. The human factors research and development required for Mercury were already under way in the Office of Space Flight Programs. In short, the Office of Life Science Programs met requirements that either did not yet exist (in relation to the approved Mercury program) or were so limited in scope that they did not justify a major commitment at the program level.

The organization and research programs were not attuned to the current orientation of the space agency. The office and its programs were basically patterned after a biomedical research center model, one more suitable to an umbrella research organization such as the National Institutes of Health or a university medical center. This model assumed that research and development priorities would be established by life scientists and that researchers would not be constrained by such matters as the applied value of their work or the necessity of meeting deadlines. NASA, of course, was patterned on the engineering research and development model of the National Advisory Committee for Aeronautics, in which engineers and physical scientists decided research and development priorities. Moreover, NASA's major mission depended ultimately on concepts developed by engineers and physical scientists; and it was under pressure to meet specific deadlines. In effect, the Office of Life Science Programs was a square peg trying to fit into a round hole.

The office was oriented more toward the interests of external scientists rather than to the needs of NASA. Biomedical scientists outside NASA preferred to expose humans to experimental or risk situations only after extensive research on lower organisms and mammals. Such an approach assumed that time and expense were not major factors; but for NASA time and expense were critical. In 1960–1961 NASA was engaged in a space race and was expected to compete, successfully, with a minimal investment of time and money. It could not afford to hold back the manned program until it obtained unequivocal evidence that man could endure the ordeal of spaceflight, especially when there was no direct evidence to preclude a manned mission of the Mercury class. Thus, NASA favored the approach long used by the Air Force, one in which carefully selected men were exposed to increasingly greater levels of risk for increasing durations, with data derived from each step used in planning the next step. For NASA the flight medicine approach to the qualification of man for spaceflight seemed to be the best compromise between the need to safeguard human life and the need to meet mission objectives.

# 4
# The human factor in long-duration manned spaceflight

*Astronaut Gerald P. Carr (left) and Edward G. Gibson (floating) demonstrate zero-g effects on weights, in the forward experiment area of Skylab 4. The crewmen lived in the weightless environment for 84 days.*



In the two years and five manned flights following the suborbital flight of Alan B. Shepard, Jr., in May 1961, the American space program underwent considerable change. Shortly after Shepard's flight, NASA responded to President Kennedy's call for a manned lunar landing before 1970 with its manned lunar landing program, which included two major series of manned flights, Projects Gemini and Apollo. By the time Gordon Cooper made the last Mercury flight on May 15, 1963, NASA's manned space program had changed from a small-scale project with limited objectives into a large-scale, multifaceted program representing a major national effort.[1]

This expanded program posed major challenges for NASA's biomedical staff. The Mercury flights carried a single man into low orbit, and the flights were no longer than one day. In Gemini and Apollo, life systems would have to accommodate two and three men for up to two weeks. The space capsule would have to provide protection against radiation and higher rates of acceleration sustained for longer periods than experienced during Mercury. Finally, longer flights would require attention to personal comfort, food, waste management, sleep, and physical mobility. Other concerns included prolonged exposure to weightlessness, 100 percent oxygen atmosphere, atmospheric contaminants, physical confinement, and altered circadian rhythms. While the Mercury flights gave some confidence in man's ability to survive and perform effectively in space, questions remained about long-duration flights.[2]

## BIOMEDICAL LEGACY OF PROJECT MERCURY

From a biomedical standpoint, Project Mercury was an unqualified success. Stanley White, head of aeromedical consultants, observed:

> The astronaut learns and adjusts quickly to his environment. His body senses of vision, hearing, smell, and touch appear to be unchanged. His kinesthetic sense is present. . . . Being inverted or flying backward has been described as being surprising but of no consequence to the astronaut. Motor sensations appear unchanged. . . . Eating, drinking, and urination appear normal. The performance of flight tasks by the astronauts has been highly successful on each flight. . . . gastrointestinal absorption and renal excretion have shown results comparable to preflight controls. In addition, no positive physical or significant biochemical change has been measured in the preflight-postflight studies.[3]

Dr. Charles Berry, from 1963 the director of Center Medical Operations at the Manned Spaceflight Center and the astronauts' physician, added that the Mercury flights revealed that, in spite of "numerous stresses," the spaceflight environment "produced no unmanageable physiological overload," and the missions indicated that weightlessness and acceleration forces would be of little consequence in subsequent missions.[4]

Project Mercury had two primary biomedical objectives. The first was to provide the medical support necessary to enable man to fly safely in missions that were not to exceed two days in duration. This objective was met through astronaut selection and training procedures, the environmental control system, and medical maintenance and monitoring programs. No significant problems related to astronaut health and performance, life systems, or medical operations arose during any of the Mercury flights.

The second objective was to investigate human physiological and performance reactions to spaceflight, which would contribute to planning future manned missions. Specifically, physicians wanted to know how long man can be exposed to the spaceflight environment without significant physiological or performance decrements, the causes of any observed changes, and preventive measures or treatments that should be used to counter any decrements.[5] Since Project Mercury had no provision for controlled inflight biomedical research or experimentation, the required data were obtained through medical evaluations before, during, and after flight.

Procedures for obtaining biomedical data changed little during the Mercury series. Preflight evaluations were used to determine the readiness for flight and to obtain medical data for comparison with postflight data. Three to five days before each launch, specialists in neurology, opthalmology, aviation medicine, psychiatry, and radiology conducted thorough physical examinations that included electrocardiograms, audiograms, electroencephalograms, biochemical studies of blood and urine, and tests to assess the condition of the astronaut's vestibular apparatus (control of balance and orientation by the inner ear). Results were compared with the astronaut's medical history, including data from simulations and centrifuge runs. On the day of launch, physicians made general assessments of the astronaut's mental and emotional state, measured his vital signs (pulse, blood pressure, oral temperature, and weight), and checked for changes in lungs, eyes, ears, nose, or throat since the previous examination. The same checks were repeated after the flight.[6]

Inflight monitoring was performed to keep mission control apprised of the medical status of the astronaut and also to provide medical data of research interest. Since Mercury physicians doubted the reliability of bioinstrumentation, they relied primarily on voice assessments and the astronaut's own personal observations for inflight medical evaluations. At the same time, attempts were made to improve the instruments, and bioinstrumentation was the only aspect of medical operations that underwent significant change as the Mercury missions progressed. The initial plan, which was followed during the suborbital flights of Shepard and Virgil Grissom, involved use of three bioinstruments: an electrode sensor applied to the chest to produce electrocardiograms, a respiration sensor mounted within a microphone in the helmet, and a rectal thermistor to measure body temperature. For the orbital flights, a decision was made to develop instrumentation for measuring blood pressure.[7]

At the very beginning of the Mercury project, Stanley White had hoped to measure blood pressure in flight, but acceptable instruments were not to be found. Available hardware "was either not compatible with the other data links or could not pass the qualification testing." Consequently, plans for blood pressure testing were "tabled temporarily," though arrangements were made to "review progress" at six-month intervals.[8] As events unfolded, the interest of biomedical spokesmen outside NASA forced an accelerated effort to develop the instrumentation that became known as the blood pressure measurement system (BPMS).

Before Alan Shepard's flight, some biomedical scientists had expressed concern over the rapid heart rates recorded during flights of the X-15 experimental aircraft and during astronauts' runs on the Johnsville centrifuge. These concerns led to an investigation by the President's Science Advisory Committee, which concluded that medical preparations for Mercury were adequate. Nevertheless, some investigators were disturbed by the heart rates (180+ beats per minute) and the absence of instruments for measuring blood pressure. Fearing that these concerns might cause a delay in the Mercury program, Space Task Group Director Robert Gilruth directed the Life Systems team to devise a reliable instrument for measuring blood pressure before the first manned orbital flight.[9]

The BPMS posed a major bioengineering challenge because the pressure suit and space capsule systems were not designed to accommodate such an instrument. Designing the pressure cuff itself was not a significant problem as it could follow the principles that govern the sphygmomanometer, an inflatable cuff that records systolic and diastolic pressure in the brachial artery of the left arm and is used to measure blood pressure under normal circumstances. The chief difference would be that a microphone, rather than a physician or nurse, would monitor the sounds.

A number of complications were involved in adapting the pressure cuff to Mercury systems: its effect on movement of the astronaut's arm, compatibility of the inflated cuff with the pressure suit, and addition of new leads into the telemetry channels without unduly complicating the electrical systems. In addition, physicians and engineers had to establish the accuracy of an instrument that is normally used on a passive subject in a quiet environment, but would now have to be adapted to work on an active subject in a noisy environment.[10]

Through a crash program, the BPMS was ready for the first American manned orbital flight. However, the instrument did not work because the astronaut, burdened with numerous inflight tasks, failed to turn it on. An automatic BPMS installed for the next flight was not accurately calibrated. Accurate readings depended on calibration matched to the baseline values for the individual astronaut. Exact calibrations were made for the last two Mercury missions, and excellent readings were obtained.[11]

As the flights progressed, a minor change was made in the method for measuring body temperature. During the first five flights body temperature had been measured rectally. Given the length of the final mission, planners decided that oral measurements should be used. This involved no changes in the electronic leads or telemetry channels; the thermistor was simply moved to an earmuff.[12]

In the four orbital missions, an effort was made to evaluate man's ability to absorb food in the weightless state. Toward these ends, each astronaut ate a cube of xylose (a sugar) during weightlessness. This test revealed that the astronauts could eat in flight, but that great care had to be taken to avoid crumbling the food. Xylose is quickly absorbed and excreted, and it was expected that urine samples would provide a measure of absorption rates during the weightless state. The test proved invalid for the first two flights, since it was impossible to separate the preingestion urine samples from those obtained after ingestion. Minor engineering changes made such separation possible in the final two flights, and resulting data demonstrated that the space environment does not interfere with intestinal absorption of food.[13]

Overall, the Mercury missions increased the physicians' confidence in man's physiological and psychological capabilities for long-duration spaceflight. However, some physiological abnormalities were revealed. First, in all four orbital flights the astronauts experienced dehydration; unusual amounts of water were needed and urine output was higher than anticipated. This was especially evident in the 10-hour flight of Walter

Schirra and the 1-day flight of Gordon Cooper. However, physicians were uncertain whether dehydration was an effect of weightlessness or a consequence of the artificial environment. White, for example, was convinced that it resulted from "inadequate control of the suit environment within the air-conditioning system," yet he and his colleagues recognized that other factors might have contributed to the problem.[14]

A second and potentially more serious abnormality appeared immediately after the Schirra and Cooper flights. When they first stood up after leaving the recovery craft, the astronauts experienced orthostatic hypotension. This syndrome involves fainting, or near-fainting, and is brought on by an abrupt drop in blood pressure and a sharp increase in pulse rate as the cardiovascular system fails to provide sufficient blood to the brain. Here again, it was impossible for physicians to identify with confidence the predisposing cause or causes of this condition. While unwilling to rule out spaceflight stress factors, they believed that the cause was prolonged physical immobility, since the syndrome had often been observed in persons who experienced prolonged bed rest. Nevertheless, the cardiovascular system would require close investigation during long-duration spaceflight.[15]

Physicians were also troubled by some minor indications of potential physiological and performance degradation. Cooper was so fatigued, apparently because of lack of sleep, that he required dextroamphetamine sulfate before reentry.[16] Lack of sleep could impair performance and the Gemini and Apollo missions would require far more crew involvement and control of the mission and spacecraft than was needed in Mercury. Fatigue would be a special concern during reentry.

Finally, postflight analyses revealed imbalances in blood and urine electrolytes (the chemical ions normally present). Calcium and phosphorus, the principal elements in the skeletal and dental systems, were present in unusually high concentrations. This indicated some demineralization of the bones and possibly the teeth and required further investigation.[17]

Thus, despite the success of Project Mercury, NASA's physicians faced the Gemini and Apollo missions with some apprehension. First, the anomalies just described indicated a need for more precise information on cardiovascular function, electrolyte changes, and performance decrements. Charles Berry convinced NASA management to make two changes in the projected Gemini program, increasing inflight experiments (perform controlled studies) related to the abnormalities observed during Mercury, and reducing the first manned Gemini flight from the planned eight-day mission. NASA changed the first manned Gemini flight to a four-day mission.[18]

There remained the need for more reliable bioinstrumentation. White concluded from the Mercury experience that the frequency of direct voice contact with astronauts would decrease in proportion to the length of the missions, and bioinstrument reading would become the primary means of evaluating inflight medical status. Since this would depend on periodic transmissions, he foresaw an associated requirement for improved methods of data handling and storage.[19]

Finally, physicians were concerned about new or magnified stress factors: longer exposure to acceleration forces, radiation fields, and the natural and artificial stresses of the spaceflight environment. These factors warranted a continuation of the incremental approach to qualification of man for spaceflight; improved (and approved) methods for gathering, storing, and analyzing biomedical data; and provision for inflight biomedical experiments.[20]

## BIOMEDICAL REQUIREMENTS FOR MANNED LUNAR LANDING

NASA had been studying the technical requirements for a manned mission to the Moon since 1959. By late 1961 the means of getting there had been selected: lunar orbit rendezvous, in which a compound spacecraft orbiting the Moon would separate, with one component (two men) going to the surface while the other (one man) remained in orbit. Later, part of the landing vehicle would rejoin the orbiting vehicle, after which the crew would return to the Earth. This scheme was selected over the direct flight of a single vehicle from the Earth to the Moon because the problems of rendezvous in space were considered easier to overcome than those of building the large launch vehicles (Earth and lunar) required for the more direct operation. Orbital rendezvous nevertheless posed significant engineering and operational challenges, not the least of which would be the need for the astronauts to control spacecraft maneuvers.

Project Gemini was authorized in 1962 to develop the equipment and procedures needed to rendezvous in orbit. It became an active project in 1963 and, though viewed as part of the lunar effort, was managed separately from Apollo. By the time Gemini became operational it had the specific objective of demonstrating that man could operate in space for up to 14 days, the time required for a lunar journey.[21] From a biomedical standpoint, Gemini was the key to the manned lunar program, since most of the biomedical stresses and variables that would affect the Apollo crews could be evaluated during the Gemini missions. Gemini and Apollo would differ in engineering systems, launch vehicles, crew size, and flight plans, but medical operations would be essentially the same, and stresses experienced by the Apollo crews, though somewhat different, in the main, would be represented by those experienced by the Gemini crews.

The critical variables that physicians anticipated for Gemini (and Apollo) included acceleration, weightlessness, radiation, space capsule environment, food and water, waste management, and performance factors (isolation and confinement, sleep, man-machine integration). Each was considered significant because of the mission configuration (higher orbits, longer exposure to acceleration forces), the mission duration, and the possibility that two or more of these variables could interact to degrade physiology and performance.

## ACCELERATION

The Mercury flights had revealed no decrement in physiology or performance that could be attributed to the acceleration forces experienced during launch and reentry. While the peak acceleration and deceleration forces anticipated for Gemini would not exceed those of the Mercury flights, they would be maintained longer to propel the capsule to the higher orbits, and due to the higher speed at reentry, would necessitate a longer period of deceleration.[22] Physicians were most concerned by the combined stress of the abrupt shifts from sustained launch acceleration to weightlessness and from weightlessness to sustained deceleration during reentry. Long before the first Mercury flight, physicians had been disturbed by the implications of the theoretical Henry-Gauer effect—that is, inability of the cardiovascular system to respond quickly to such abrupt shifts, causing astronauts serious trouble during reentry.

This syndrome had not appeared during Mercury, but then exposure to weightlessness had been relatively brief. NASA physicians feared that, for Gemini, longer periods of weightlessness could subject the cardiovascular system to serious stress in the launch and reentry phases. They also suspected this cardiovascular stress could contribute to more severe orthostatic hypotension when the returned astronauts resumed an upright position.[23] Medical preparations for these contingencies included the introduction of cardiovascular conditioning routines in the astronaut training program, expanded research into the cardiovascular effects of prolonged bed rest, efforts to develop bioinstrumentation that would function during launch and reentry, and design studies to improve the couch, restraint, and escape equipment. Physicians also devised inflight experiments to obtain more precise data on cardiovascular response to spaceflight. These were to be performed on all flights up to 14 days, but were considered most critical in the 4- and 8-day flights.[24]

Three medical experiments were planned to measure cardiovascular performance. A cardiovascular conditioning experiment (later designated M-1) was designed to test a procedure for minimizing the reduction in blood flow during weightlessness. A pair of pneumatic cuffs on the lower legs, inflated to 70 to 75 millimeters of mercury for two minutes out of every six, should increase venous pressure above the cuffs, thereby reducing "pooling of blood in the extremities" and increasing "the effective circulating blood volume" following exit from weightlessness. The cuffs were to be tested during controlled studies on subjects immersed in water for extended periods before the experiment was flown.[25]

A second experiment with an inflight exercise was intended both to measure cardiac function and to reduce the effect of prolonged immobility on cardiovascular performance. The exerciser consisted of two bungee cords connected to a handgrip and a loop for the feet. At prescribed intervals, the astronaut would place his feet in the foot loop and pull upward on the handgrip. Full extension of the handle (26.4 centimeters) would require 70 pounds of force. During exercise periods, heart and respiration rates and blood pressure would be recorded on magnetic tape and also telemetered to ground control.[26]

The third cardiovascular experiment was a combined electrocardiogram (electrical heart activity) and phonocardiogram (mechanical heart activity). A sensor for measuring electrical output and a transducer for measuring vibrations caused by heartbeats would be affixed to the astronaut's chest. Together, the instruments would provide data on cardiac function in flight and report the medical status of the astronaut from launch to recovery.[27]

Development of these experiments would require close coordination between physicians and other members of the spaceflight team. Major responsibility for development of bioinstrumentation and integration of instruments into spacecraft systems rested with the Life Systems (later Crew Systems) Division of the Manned Spacecraft Center. Interaction with this group was not expected to cause any difficulties, since the physicians and engineers in that division had been working together closely and effectively from the beginning of the space program. The real problem would be the reluctance of the astronauts to cooperate in the experiments. Besides the inconvenience and discomfort involved, the astronauts were concerned that the bioinstruments would uncover information that could lead to their being grounded. This was a continuous source of tension throughout the manned program, as the astronauts recalled how Deke Slayton, one of the original seven astronauts, had been grounded after it was found that he had a minor (to the astronauts) arrhythmia of the heart. The astronauts' cooperation was gained through diplomacy, tact, and appeals to higher authority from Charles Berry.[28]

## WEIGHTLESSNESS

The data from Mercury, though crude from a scientific perspective, suggested that the human body adapts to the weightless state and that man can perform effectively in null gravity. Physicians were more worried about the problem of readaptation to the Earth's gravity. They were concerned about changes in the cardiovascular system in particular, but also about changes in body fluid electrolyte balance, body fluid volume, and vestibular function. Consequently, they were anxious to investigate the physiological changes that occur during prolonged weightlessness and to measure the time required to return to normal.

Since weightlessness could not be effectively simulated on the ground, inflight experiments were the only means of investigating these problems. Toward this end, Berry and Lawrence Dietlein, the medical research director at the Manned Spaceflight Center, convinced NASA management to include medical experiments during the 8- and 14-day flights. The desired experiments included studies of the cardiovascular system, fluid electrolytes, fluid volume, bone demineralization, and vestibular function.

Three experiments were developed for the study of electrolyte changes. One (eventually designated M-5) involved preflight and postflight biochemical analyses of blood and urine and analysis of urine samples collected in flight (collection of blood samples in flight was considered impractical). The preflight-postflight analyses were intended to identify changes in the body fluid electrolytes that would indicate the "physiological cost to the crewman in maintaining a given level of performance during space flight." These analyses were also expected to reveal the length of time required for the astronaut's systems to return to normal, as blood and urine samples would be drawn at prescribed intervals during the 72 hours after the return to the Earth. The urine samples collected in flight would also be analyzed for electrolyte balance, to provide some indication of the physiological changes that occur during weightlessness, and their volume would be compared with fluid intake to help physicians understand the dehydration experienced by Mercury astronauts.[29]

Two other experiments to measure electrolyte balance as a function of changes in the muscular and skeletal systems were intended to assess "the effect of prolonged weightlessness and immobilization" and the length of time required for these effects to disappear. Experiment M-6, a study of bone demineralization, involved making a determination of changes in the density of two bones (one in the left foot, the other in the left hand) through analysis of x-rays taken at specified intervals before and after flight.[30] M-7 would be a biochemical analysis of the urine samples collected before, during, and after flight. Excreted calcium and nitrogen would be taken as indications of demineralization of bones and muscles. Controls for this experiment would be urine samples from subjects undergoing prolonged bed rest and samples from the individual astronauts before flight.[31]

Because the physicians were as much concerned with the astronauts' performance as with their physiology, two experiments were planned to investigate factors that might affect performance. Experiment M-8 would be an analysis of sleep patterns in flight. Electroencephalograms would be taken during preflight periods of sleep and used as baseline values.[32] In experiment M-9 the performance of the otoliths (the part of the inner ear most directly involved in balance and orientation) would be assessed by determining the ability of the astronauts to "estimate horizontality" in the absence of visual and gravitational clues. This would help predict the possible effect of prolonged weightlessness on otolith function.[33]

Here again, close cooperation and coordination—as well as tact and diplomacy—were needed to ensure the integration of experiments with space capsule systems and the cooperation of the astronauts. The sleep study in particular was anathema to some of the astronauts, who feared that the electroencephalograms were really intended to measure their psychological reactions. However, this experiment was planned for the 14-day mission, which was to be commanded by Frank Borman, who recognized the value of medical experiments and supported the medical program.[34]

## RADIATION

The Gemini and Apollo astronauts would encounter radiation from several sources: the Van Allen belt, outer space, and solar flares. Protecting them against radiation was primarily a problem for physical scientists and engineers, since it involved the development of shielding that would provide adequate protection, yet not impose severe weight penalties or be incompatible with spacesuit and capsule design. Biomedical personnel did have a role to play, however.

Before shielding could be developed, engineers required specifications on maximum permissible exposure (cumulated dose, intensity times duration) to the different types of radiation. NASA's biomedical personnel planned to approach this problem in two ways. First, in ground-based investigations different types of tissue would be exposed to radiation to determine how much could be absorbed before there was evidence of deterioration in the tissue mass or changes in the composition of the

*Astronauts Edward G. Gibson and Gerald P. Carr demonstrate zero-g effects on weights.*

chromosomes. Second, tissue would be flown into the Van Allen belt and changes would be noted. Subsequently, engineers would test different shielding materials to identify those which kept radiation beneath the maximum permissible level. In addition, mission planners intended to include dosimeters (instruments to measure radiation levels) on all flights to warn the astronauts of shielding failure. Physicians also hoped to identify drugs that would either provide protection against radiation or reduce the effects of exposure.[35]

## SPACE CAPSULE ENVIRONMENT

Like radiation protection, the environmental control system (the term encompassed capsule life support systems and spacesuits) was primarily a matter of concern to engineers. Physicians had to provide the specifications necessary to ensure integration of biomedical instrumentation into capsule and suit systems, maintenance of a 100 percent oxygen atmosphere at a pressure range of 3.5 to 5.0 pounds per square inch, and maintenance of suit and cabin temperature and humidity levels within comfort and health limits.[36]

Physicians were concerned, however, with matters associated with the environmental control system, specifically possible physiological and performance decrements resulting from prolonged exposure to the space capsule environment. The astronauts would be breathing 100 percent oxygen for up to 14 days, and the long-term effects were unknown. Ground-based studies had revealed some changes in blood volume and composition in subjects exposed to comparable environments for prolonged periods, and such changes could have serious effects during long flights. Discovering such decrements in the early Gemini flights would allow time to devise effective countermeasures before the problem became serious.[37]

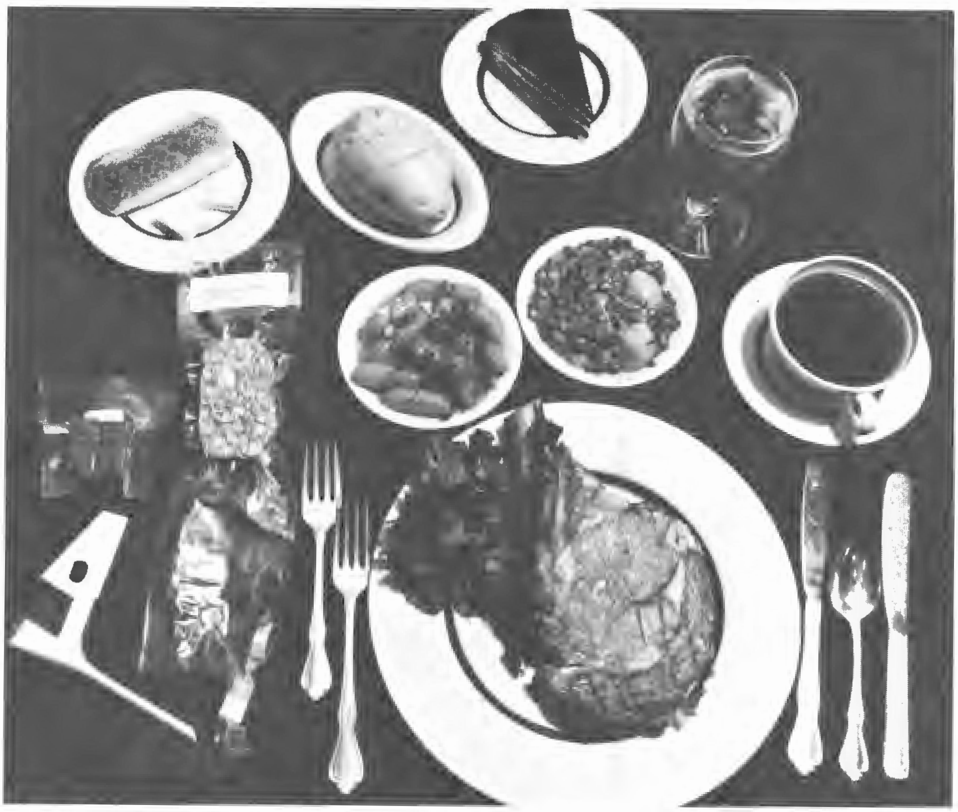
Another concern was the possibility of exposure to atmospheric toxins. The corrosive products of oxidation (especially the oxidation of heavy metals such as mercury, lead, and copper) can be highly toxic. Natural oxidation does not normally pose a health hazard because oxygen is only 20 percent of atmospheric air and the corrosion products quickly disperse. However, in the sealed environment of the space capsule with its 100 percent oxygen atmosphere, the oxidation rate would increase dramatically and the corrosion products (toxics) would quickly become highly concentrated.

Besides the oxidation of capsule materials, the other obvious source of atmospheric toxins was carbon dioxide from respiration. This was not expected to be a significant problem, since the Mercury experience had shown that the carbon dioxide could be removed by drawing it through a filter containing lithium hydroxide; the two chemicals interact, producing water and lithium carbonate.[38]

The identification of toxic corrosion products was a far more complex problem, since virtually every substance used in the construction of the space capsule could produce a toxic contaminant. For example, it was necessary to remove all the name plates from the interior of the Gemini capsule because the adhesive used to attach them combined chemically with the name plate and created a toxic product. The only clue to this was a slightly objectionable odor in the capsule. Physicians and chemical engineers had to identify potentially toxic substances and determine the levels at which they pose health hazards to humans. For this reason, toxicology became an area of major biomedical research interest.[39]

## FOOD AND WATER

Longer flights would require larger quantities of food and water, and here again, physicians had to work closely with design engineers and mis-



*Plastic containers of space food carried aboard the Apollo spacecraft equal the conventional meal in the foreground. A water gun is used to reconstitute the dehydrated food.*

sion planners. From a medical standpoint, the astronauts required sufficient food and water to ensure optimum performance. The food had to be nourishing, produce no undesirable physiological effects (nausea, diarrhea, or flatus), and have a composition so that it would be ingestible in flight. The engineers were interested in storing the food and water in as small a space as possible. Weights were also important.

The responsibility of physicians and biomedical scientists in this area was to establish precise metabolic requirements for men who would be largely immobile, but who had to be fully alert and physically capable of exerting the energy required for extravehicular activities. Physicians planned to develop preliminary specifications through metabolic studies on two different types of subject: those confined to prolonged bed rest and those made to perform strenuous work while immersed in water. The exact metabolic costs would be determined by giving the subjects carefully measured and analyzed quantities of food and water and quantitatively analyzing their urine and feces. These studies would provide only general guidelines; more precise information would have to wait until the first Gemini flights. Some of the experiments already described would yield the precise metabolic data needed to plan the food and water requirements of the later Gemini and the Apollo missions. In addition, the Gemini flights would provide an opportunity to test and evaluate different foods.[40]

## WASTE MANAGEMENT AND PERSONAL HYGIENE

Waste management and hygiene were not problems during Project Mercury because of the short mission durations. Fecal elimination was avoided by placing the astronauts on a low-residue diet for 7 to 10 days before launch. Provision for urination was necessary, but the weight and volume of urine collected would not affect vehicle design or weight. Likewise, personal hygiene was not an issue since the astronauts would return before soil on the body could lead to discomfort. In the longer Gemini and Apollo flights, defecation could not be avoided, the amount of urine collected would be quite large, and uncleanliness would be both psychologically troublesome and physically uncomfortable.

The issues in this area were fundamentally engineering ones and did not require much in the way of medical input. Engineers needed some information in order to predict the amount of fecal and urine output, and such information would become available from the metabolic studies and blood and urine analyses. They also needed to know how much provision should be made for hygiene in flight—for example, how often, if at all, the astronauts would have to wash to avoid skin ailments. With these exceptions, waste management was strictly an engineering problem.[41]

*Astronaut Charles Conrad, Jr., bathes in the shower facility in the Skylab 1/2 space station cluster. The shower curtain is pulled up from the floor and attached to the ceiling. Water flows through a push button shower head attached to a flexible hose, and is siphoned off by a vacuum system.*

## PILOT PERFORMANCE

Physicians and mission planners were concerned with pilot performance in long-duration flight, since the astronauts would be directly involved in spacecraft maneuvers during the Gemini and Apollo missions. There appeared to be four factors that could interfere with pilot performance: disorientation resulting from unanticipated effects of acceleration and weightlessness on vestibular function, serious dysfunction of a physiological system due to acceleration and weightlessness, psychological reactions to isolation and confinement, and inflight illness. The first two of these have been discussed in other sections of this chapter.

NASA's physicians recognized that psychological dysfunction due to prolonged confinement was possible, but they doubted that it was probable. Psychological testing and psychiatric evaluation had been critical parts of the astronaut selection process, and anyone with indications of emotional or mental weakness had been screened out. These tests included questions that were used in evaluating candidates for submarine duty. Moreover, physicians considered the test pilot background of the astronauts to be a reliable guarantee of their psychological fitness. Nonetheless, NASA sponsored some research in this area, including studies of airmen confined singly and in groups for periods up to 90 days and sociological studies of small-group interactions. None of this research yielded data of significance to the Gemini and Apollo missions.[42]

Inflight illness was a serious concern; it could be disastrous on flights that left Earth orbit because the spacecraft would have to loop around the Moon before returning to the Earth. No Mercury astronaut had experienced any significant inflight illness; but motion sickness had been a serious problem in Russian flights. In addition, many possible ailments could arise, and physicians insisted that the astronauts be able to treat the symptoms of the most likely ones. The medical kit on Gemini included 12 drugs for treatment of motion sickness, extreme fatigue, aches and inflammations, diarrhea, nasal and sinus congestion, irritation and inflammation of the eyes, bacterial infection, and severe pain. The kit also included creams for treating skin irritations and tapes and bandages for cuts.[43]

## ANIMAL RESEARCH

In their approach to these various challenges, NASA's physicians made no effort to investigate the assorted problems through systematic animal research. Many biomedical scientists outside NASA criticized this approach. In response to outside scientists' complaints, two monkeys had been flown in Mercury capsules prior to John Glenn's flight, but NASA rejected suggestions of an animal program in support of Gemini and Apollo. Although many scientists outside NASA found it difficult to understand this position, it made good sense to NASA's planners, engineers, and physicians.

NASA management opposed making animal research an adjunct to the manned program. President Kennedy had set an arbitrary deadline for a lunar landing and since there was no evidence that the incremental approach to qualifying man for spaceflight created unacceptable levels of risk, management saw no reason to further complicate the program. They were not opposed to animal research per se, but felt that such research should be conducted solely for scientific purposes and should be separate from the manned program.[44]

NASA's physicians opposed making the manned program dependent on animal research, in part, due to reflection of their background and experience; with few exceptions, the biomedical personnel at the Manned Spaceflight Center were either career military physicians on temporary assignment to NASA or civilian physicians who had come to NASA after separation or retirement from military service. Their flight medicine orientation favored using man as the measure of man's response to flight and viewed animal research as useful only in studying phenomena observed during manned flights.[45]

Animal research was important in the overall space program, however. Project Biosatellite, started in 1963, was projected to be a series of unmanned flights in which increasingly complex organisms would be flown for periods of up to 30 days. Although it was a scientific endeavor, it was also justified in some agency and outside scientific circles as having the ability of contributing information of value for manned flights. The Biosatellite program had three flights between December 1966 and June 1969. The first and last flights were judged unsuccessful. The second, a two-day flight in September 1967, provided some data on cells, plants, and animals.

Ames Research Center was also developing programs in basic biological and medical research that involved animals rather than humans. Ames life scientists hoped to link their research programs to the manned program, but met with little success.[47] Even at the Manned Spacecraft Center the medical research group established an animal program, but with the understanding that the animals would be used only for backup studies or for research that could not be conducted easily or safely on humans.[48]

## BIOMEDICINE AND ADVANCED MANNED SPACEFLIGHT

By 1963, both NASA and the Air Force were looking beyond Apollo. The Air Force was under pressure from Secretary of Defense Robert McNamara to cancel its only active manned space program, Dyna-Soar, and Air Force officials were seeking some type of manned program that would not duplicate NASA's efforts but would keep the Air Force involved in space activities. By early 1964, the Air Force had tentative approval to develop a program leading toward a Manned Orbiting Laboratory (MOL).[49]

NASA no longer had any need to engage in active competition with the Air Force, but agency officials did not want to be unprepared when the time came to push for authorization to conduct a post-Apollo manned program. During the year after the final Mercury flight, several planning groups investigated possible post-Apollo programs. NASA had tentative plans to conduct unspecified orbital activities with Apollo systems, provision for which was included in the authorizations for the Apollo program. One working group was set up to define the objectives and procedures for an Apollo Extension System (later designated Apollo Applications Program; still later, Skylab). Other groups were to study possibilities for a manned space station and a manned Mars landing.[50]

Biomedical input into advanced planning during this period (1963 to 1966) fell into three categories: biomedical specifications for an orbital laboratory, definition of biomedical experiments for advanced manned programs, and advanced human research. In October 1963, the NASA Office of Manned Space Flight set up a Biomedical Experiments Working Group to study the "design and operational requirements and constraints which would be imposed upon a manned orbital laboratory by the incorporation" of biomedical experiments to measure the effects of prolonged weightlessness.[51] The group identified cardiovascular deconditioning and musculoskeletal catabolism as the "greatest potential problem areas" related to long-duration weightless flight. It recommended that NASA approach these problems on two levels. First, NASA should institute a broad and intensive program of ground-based biomedical research related to 18 different aspects of human physiology and performance, compiling precise measurements of such functions as defecation, excretion, and metabolism. These measurements should constitute the "minimum safety package" that would be "integrated into any conceptual design." Second, these lines of research should be continued in flight. NASA should design the orbiting laboratory to include a physiology laboratory, a microscopy and chemistry laboratory, an x-ray facility, and a centrifuge and to accommodate "no fewer than four subjects," as this was considered the minimum number for orbiting valid biomedical data.[52]

The Office of Manned Space Flight established the Space Medicine Advisory Group in late 1963 to augment the work of the Biomedical Experiments Working Group. The advisory group was chaired by Dr. Sherman P. Vinograd, who was responsible for medical research within the office's Directorate of Space Medicine, but its members were drawn from biomedical research settings outside NASA. The initial purpose was to define the specific experiments that should be flown on an orbital laboratory. (Subsequently, the group was charged with reviewing and making recommendations concerning biomedical experiments proposals for Gemini and Apollo.) For the orbiting laboratory, the group designated 15 critical environmental factors: weightlessness, radiation, confinement, social restriction, monotony, threat of danger, artificial atmosphere, toxic substances, particulate matter, microorganisms, change in circadian rhythms, ultraviolet exposure, infrared exposure, noise, and thermal stress. It recommended the development of 14 experiments to measure the combined effect of weightlessness and each of the other stress factors and 6 more experiments to evaluate the combined effect of weightlessness and combinations of the other factors. The report called for the laboratory to remain in orbit for at least one year and have a crew of 6 to 12 persons. It also recommended an intensive program of preliminary biomedical research.[53]

In addition to these planning activities, NASA supported "fundamental and applied research in man's functions in relation to the space environment" with direct applicability to the design and engineering of spacecraft systems. Directed by the Office of Biotechnology and Human Research, this was an multidisciplinary undertaking in which man was viewed as a component of a man-machine system.[54] Activities in this area fell into four broad categories. First, man-machine integration studies were concerned with "critical points of contact of man with his vehicle," that is, with the man-machine interfaces that "involve man's health, comfort, survival, observation, decision-making, integrative and manipulative skills" and the ways "in which man's limitations may affect this system." Research in this area focused on such matters as the relationship of cabin arrangements to mission performance and the information and control links between space capsule systems and the human operator. The second category, biotechnology, covered design and development of advanced life support systems (e.g., artificial gravity and closed ecological environmental systems) and extravehicular equipment for planetary exploration and repair of spacecraft systems. The third area, applied research on animals, addressed the potential hazards of advanced spaceflight. The final area of research centered on development of advanced bioinstrumentation.[55] Although this research was directed toward problems related to manned spaceflight, the biotechnology and human research efforts were not conducted under the auspices of the approved manned space program; while the research was nominally applied in nature, its actual applications remained theoretical.

## SUMMARY

From 1962 to 1966 NASA's life sciences programs underwent major expansion and diversification. During the early years of Project Mercury, life sciences requirements were limited almost exclusively to medical operations, with very little research and development. By the end of the project, NASA's life sciences programs encompassed basic biomedical research and applied research and technology development as well as medical operations which expanded concurrently. In Mercury, the life sciences had a single objective: contribute to ensuring human health, safety, and performance in short-duration spaceflight. By the end of Mercury, the objectives included basic biological research; basic and applied medical research in support of both approved and advanced manned programs; planning of inflight biological and medical experiments; development, testing, and evaluation of life support and protective systems for approved manned flights; operational support for approved manned flights; and collection, reduction, and analysis of biomedical data obtained in flight.

These expanded objectives, combined with the priorities of the manned lunar landing program, had important implications for the organization and management of life sciences programs. The life sciences had to be organized to support the lunar landing program while meeting a diversity of new obligations. Coordination had to be arranged among biologists, physicians, psychologists, and engineers. In-house capabilities for supporting these activities had to be provided. Finally, in meeting its new obligations in the life sciences, NASA had to generate support—or at least minimize opposition—from Congress, the military services, and the scientific community.

# 5

# Life sciences management in an accelerated space program

The goal of placing a man on the Moon in nine years forced NASA to accelerate the pace and expand the scope of the space program. For the post-Mercury era, NASA would require an organization and a style of management that would be equally responsive to the research, development, and operations requirements of both approved (current) and advanced (long-range) manned programs; effect a balance between scientific investigations and manned spaceflight; and encourage integration of basic research, applied research and development, and manned operations.

On November 1, 1961, NASA Administrator James Webb announced a major reorganization that was intended to strengthen the agency's capabilities for satisfying these requirements. The new organization would remain fundamentally unchanged for the next 10 years and probably was a significant factor in attaining the lunar landing goal. The restructuring of the headquarters organization and implementation of new management procedures created unanticipated problems, however. Strong criticisms came from parts of the scientific community, tensions between NASA and the Air Force were aggravated, and internal factionalism increased. These problems were amplified in the life sciences programs.

## RESURRECTING THE LIFE SCIENCES PROGRAM

Webb decided to restructure the headquarters organization after concluding that existing arrangements were incompatible with NASA's new responsibilities. A compatible arrangement, he believed, would create a balance between centralized direction of the overall space effort and functional autonomy for specific space programs. Such a balance could be achieved by "placing increased emphasis and clearer focus" on NASA's major programs (space science, advanced research and development, manned spaceflight), by providing program directors with "the authority and freedom necessary to accomplish their program objectives," by encouraging close coordination between program directors and center directors in decision making, and by making NASA's top management (Webb, Deputy Administrator Hugh Dryden, and Associate Administrator Robert Seamans) responsible for directing the overall space effort and coordinating and integrating the major programs.

Webb abolished the existing program offices, which he considered too task oriented (e.g., focused on launch vehicle development, administration of grants and contracts), and replaced them with offices that were oriented toward major program functions. The program office directors were to have complete autonomy to plan, budget, and manage the program functions of their respective offices. The head of the Office of Space Science was given authority to direct the research, development, and operations required to support a program of basic scientific investigations in space. The Office of Advanced Research and Technology received jurisdiction over research and technology development in support of advanced aeronautical and manned spaceflight systems. Authority to plan and direct approved manned space programs (including development, testing, and evaluation of life support systems; selection and training of flight crews; and management of manned spaceflight operations) was vested in the Office of Manned Space Flight.*

Webb hoped, through this reorganization, to improve channels of communication between NASA Headquarters and the field centers, to clarify lines of authority connecting program and project elements, and to promote close coordination between program directors and center directors. Previously, NASA had followed management practices that had been established within the National Advisory Committee for Aeronautics. The centers, which managed research and development projects, had been virtually autonomous in technical decision making, but had not taken part in program decision making. Program directors had handled program budgeting and planning without directly involving the center directors and had rarely become involved in project management. This arrangement was satisfactory for the NACA, which was project oriented, primarily concerned with applied research and engineering, and generally not responsible for operational system design, development, and operations. It was

*Initially, Webb also created an Office of Applications, which had responsibility for communications and meteorological satellites, but this office was combined with the Office of Space Sciences in 1963.

also satisfactory for NASA during its early years, when the agency's project responsibilities were few and relatively narrow in scope. To Webb, the arrangement was not suited to an agency that had responsibility for major programs and a diversity of supporting research, technology, and development projects that included several large manned spaceflight projects. Those responsibilities, he believed, necessitated integration of program and project management.

To encourage close coordination between program offices and centers, Webb made the center directors line officials and authorized them to participate in program decision making. He assigned each center functional responsibility over research, technology, and development activities that corresponded to the functional requirements of the major programs. Each center director reported directly to one of the three program directors. In short, the center directors were to be directly involved in preparing program budgets and plans, while program directors were made accountable for monitoring the projects supporting their programs.

Dryden and Seamans were to provide overall direction and integration of space programs. Dryden became responsible for overseeing the management and coordination of technical activities. Seamans, as general manager, oversaw the day-to-day activities of the agency, including the coordination of program budgets and plans and the resolution of inter-program disputes.[1]

In authorizing the reorganization, Webb appeared to give no special thought to the life sciences. For all practical purposes, life sciences had lost program status in NASA with the departure of Clark Randt in March 1961. The life systems and medical operations staffs at the Space Task Group had been outside the authority of the Office of Life Science Programs. A few life scientists at Ames were trying to organize a project office, but were hindered by uncertainties concerning the approved, inadequate funding and the absence of a life sciences laboratory and of clear guidelines.[2]

Randt's successor, Air Force Gen. Charles Roadman, was a mission-oriented, practical-minded physician who did not share Randt's belief that space biology, human research, and space medicine belonged in a single program office. Instead, he saw three unrelated fields with different, often incompatible objectives. Believing that space medicine was the only life sciences activity of immediate importance to the space program, he made no real effort to strengthen the rest of the program. He urged the replacement of the Office of Life Science Programs by a Directorate of Space Medicine under the spaceflight programs office.[3]

Following the reorganization, the new program directors began to press for clarification of this ambiguous situation. Dr. Brainerd Holmes, head of manned spaceflight, responding to recommendations from Roadman, asked Seamans for authority to create a space medicine directorate. Holmes suggested that this directorate could absorb most of the staff, programs, and contracts of the defunct Office of Life Science Programs. He added that the space medicine director could easily function as the spokesman for NASA's life sciences programs.[4]

Concurrently, Dr. Homer Newell, head of the Office of Space Science, believing that space biology was being badly neglected, sought Seamans's approval for the establishment of a biosciences division, which would absorb the space biology staff and programs of the Office of Life Science Programs. Like Holmes, Newell believed that his own life sciences subordinate would be the logical point of contact for life scientists outside NASA.[5] The center directors at the Space Task Group (soon to be redesignated the Manned Spacecraft Center) and Ames were also interested in divining the future course of NASA's life sciences programs. Space Task Group Director Robert Gilruth had plans to elevate the life systems branch to division status and to appoint a space medicine coordinator to his own staff. He wanted to know how these offices would be connected with the program offices. Gilruth also wanted assurance that his group would retain authority over the biomedical research and development required for approved manned programs and would not have to go outside the manned spaceflight chain of command for critical biomedical support.[6]

Gilruth's counterpart at Ames, Smith DeFrance, wanted firm commitments from headquarters that would energize the moribund life sciences component at Ames. DeFrance feared that a buildup of biomedical research and development capabilities at the Manned Spacecraft Center would deprive Ames of an active role in the agency's life sciences effort.[7]

Seamans had to deal with these contradictory recommendations. Aware that key administrators wanted the life sciences problem resolved, that a disorganized and uncoordinated life sciences effort could retard the manned space program, and that the organization and management of the life sciences had to be compatible with the overall NASA organization, Seamans formed a group to study NASA's needs in the life sciences and to make recommendations about the organization and management of "an integrated Aerospace Biology and Life Support (Aerospace Medicine) program." Seamans appointed Bernard Maggin, from the Office of Programs, to chair this Life Sciences Working Group.[8]

Maggin's committee included representatives from each of the headquarters program offices and from the interested centers (Goddard, Manned Spacecraft Center, Ames). This group completed its study in March 1962 and issued a report that contained recommendations for reorganizing the life sciences programs. The report identified three life sciences program requirements: biological investigations in space, including research on the biological effects of the space environment and search for extraterrestrial life; human research, the "utilization and life support" of man in advanced aerospace systems and operations; and biomedical research, life support systems development, and medical operations in support of approved manned spaceflight programs. These requirements, the committee believed, coincided with the responsibilities, respectively, of the Office of Space Science, the Office of Advanced Research and Technology, and the Office of Manned Space Flight.

The Maggin committee noted that the overall effectiveness of these life sciences programs would require high-level coordination and a nominal degree of integration of the separate components. Otherwise, overlapping responsibilities, internal jurisdictional disputes, and duplication of efforts in the life sciences programs would ultimately reduce the effectiveness and increase the costs of the total space program. To make coordination possible, Maggin's committee recommended that the life sciences have a "programming capability" at headquarters, that is, a capability for planning and coordinating the overall life sciences effort. With this capability, the three life sciences directors could devise mutually acceptable procedures for allocating responsibilities and resources and resolving jurisdictional disagreements.

In the committee's view, the best way to do this would be to designate one of the three life sciences divisions as the office responsible for coordination of the overall life sciences program. That division would assume the former responsibilities of the Office of Life Science Programs: review and approval of research and development proposals, budgets, and plans; integration of life sciences programs; and liaison with life sciences components of the military services, industry, and universities. The Working Group report identified the Office of Advanced Research and Technology as the logical locus for life sciences program coordination. With responsibility for applied research and development related to advanced manned systems, the office was a middle link between scientific and manned operational programs.

The report also pointed to a need for "a reasonable technical capability in the field" and recommended that it be centered at Ames. NASA should triple its request for funding for facilities and make a commitment to expand and strengthen the existing life sciences component at Ames. This component, the report suggested, should have responsibility for managing all in-house life sciences research and technology development projects and for monitoring all related grants and contracts.[9]

Seamans approved the general recommendations of the Life Sciences Working Group. Between March and June 1962, he authorized Ames Director DeFrance to hire a life sciences director for Ames and directed the Office of Advanced Research and Technology to establish a Directorate of Biotechnology and Human Research. However, he did not give this new office the breadth of authority recommended by the Maggin committee. Its responsibilities were to include management of research and development related to "the fundamental understanding of man pertaining to and directly related to his utilization and life support in aerospace flight and operations," review of all life sciences research and development proposals, and representation of NASA's life sciences on committees coordinating the space-related research and technology development of NASA and the Defense Department. The director of the office would make recommendations to Seamans only on changes that should be made in the life sciences programs outside his jurisdiction.[10]

In limiting the authority of the new position, Seamans was responding to objections from the other program offices. Homer Newell and his director of biosciences, Dr. Orr Reynolds, doubted that an agency oriented toward applied research and engineering development would promote the growth and development of basic biological research. They also questioned the ability of the Office of Advanced Research and Technology to communicate effectively with biological scientists. Holmes and Roadman, from the Office of Manned Space Flight, feared that the pace of the approved manned space program would be retarded if its biomedical aspects were regulated by an outside group agency.[11] Seamans agreed with these objections, and further limited the office's program jurisdiction to research and development required for advanced, rather than approved, manned programs.

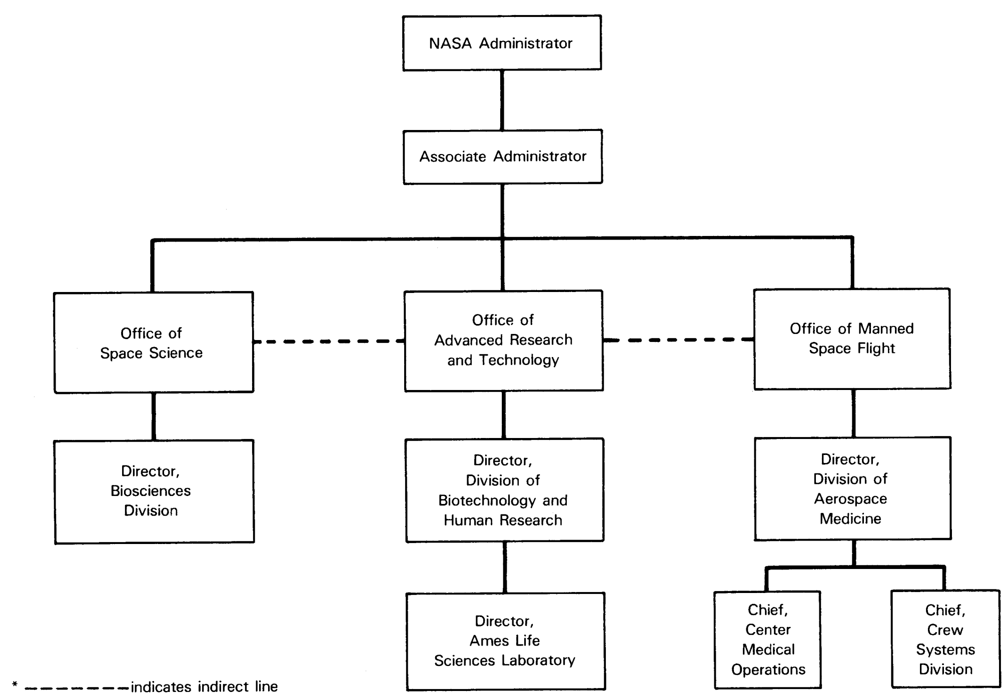
## ORGANIZATION AND MANAGEMENT OF LIFE SCIENCES PROGRAMS DURING THE PROJECT GEMINI ERA

NASA resurrected its life sciences programs in 1962, but did not revive its life sciences program office. The reorganization that followed the report of the Life Sciences Working Group created three separate, functionally independent life sciences components and placed them under the management jurisdiction of three program office administrators. The administrative arrangements in this new organizational scheme are depicted in the chart on the next page.

NASA management believed that this reorganization would augment life sciences support for each of the major programs while furthering the objectives of the NASA-wide reorganization of November 1961: functional autonomy for program offices and overall coordination of programming. The life sciences divisions were to function independently, and each life sciences director was to have autonomy in his own program. Ideally, each director would design a program that was compatible with the mission and objectives of his program office. The director of Biotechnology and Human Research would review the research and technology development aspects of all three programs to ensure that they were free of unnecessary duplication and did not overlap jurisdictional boundaries. Subsequently, the several program office administrators would review their respective life sciences programs and give final approval for their integration into the overall program office plan. Finally, the life sciences programs would be reviewed by Seamans and Dryden as part of their review of the major programs.

Management realities did not follow the management ideal, however. Genuine coordination of life sciences programs was difficult to achieve, and jurisdictional disputes were frequent and difficult to resolve. The life sciences directors did not work in harmony toward a coordinated program. NASA's top management did not give the human research division the authority it needed to enforce program coordination. Seamans alone had that authority, and he had neither the time nor the inclination to function as the de facto director of life sciences programs. Equally important, the life sciences program directors designed their programs to satisfy their

**Location of Life Sciences Elements within the NASA Organization, August 1962***



respective interests, rather than to achieve a coordinated program. When program office requirements conflicted with overall life sciences program interests, each life sciences director backed parochial concerns rather than support broader agency responsibilities. In short, the collective life sciences programs management system was plagued by the problem that had plagued the Office of Life Science Programs: responsibilities without authority.

While these organizational assignments and allocations of responsibility made sense in terms of overall space program requirements, they did not function effectively in the real operating environment and with the personalities within the life sciences. Management assumed that biology, medical science (human research), and clinical medicine could be easily compartmentalized; but these fields have broad areas of natural overlap. NASA management failed to issue guidelines that would clarify jurisdictional boundaries within these gray areas or provide any office or individual with the authority necessary to resolve questions and programs involving these boundaries.[12]

The problems emerging from this situation were most apparent in the relations between the human research-biotechnology and biosciences divisions. On paper, the responsibilities of each were clear. The former had responsibility for human research (basic and applied studies of man and his physiological and psychological reactions to spaceflight), human factors engineering (application of human research to man-machine integration), and biotechnology (application of knowledge gained from human research to design and engineering of life support, control, and protective systems). The responsibilities of the latter encompassed environmental biology (basic research into the effects of the spaceflight environment on physiology and behavior of subhuman organisms) and exobiology (search for extraterrestrial life). In theory, basic research in environmental biology would complement the applied research sponsored by Biotechnology and Human Research.[13]

In reality, the exercise of responsibilities was not so clear, and jurisdictional disputes developed. In part, these disputes can be attributed to the presence of two directors, Dr. Orr Reynolds and Dr. Eugene Konecci, who were strong-willed and highly motivated science administrators. Reynolds was a physiologist with experience in both basic research and administration. He came to NASA from a high-level position in the Department of Defense with the understanding that he would have a free hand to develop a bioscience program comparable to the DoD programs with which he was familiar. Reynolds assumed that his office would promote basic research that would both contribute to scientific knowledge and investigate problems of concern to "manned spaceflight and exploration." He also assumed that his program would encompass research on the entire span of subhuman organisms, from plants and lower animals to primates. He did not view basic biology as an isolated field of inquiry, but as the first link in a chain of research that culminated in clinical medical applications.[14]

Konecci, educated in medicine and engineering and experienced in working with both physicians and engineers in industrial settings, was strongly attuned to the biomedicine-engineering interface. He was also strongly oriented toward the systems approach to problem solving, and he believed that systems analysis was the logical way to approach life sciences problems of manned spaceflight. He did not view the life sciences as a continuum, but rather as modes for analyzing systems. In his view, the spacecraft was a total system consisting of numerous machine subsystems (e.g., environmental control system). Likewise, man consisted of numerous subsystems. The ultimate objective of life sciences research and development was to optimize the integration of man and spacecraft in terms of their subsystems.[15]

Konecci believed that each spacecraft subsystem should be designed with three sets of parameters in mind: human, environmental, and machine. The purpose of basic research was to increase knowledge of human parameters; of applied research, knowledge of human physiological and performance limitations relative to environmental factors; and engineering research, knowledge of the factors necessary to design machines that were compatible with human factors. For Konecci, the starting point for life sciences research and development was not a field of inquiry such as biology, or a style such as basic research, but rather a specific system (or subsystem) that required analysis. The end point was not clinical medicine or clinical applications, but the integration of man and machine in terms of the specific system or subsystem being analyzed.[16]

Given these differences in viewpoint and philosophy and failure to follow the intended division of activity between the two offices, conflicts between the two were inevitable. The most frequent disagreement concerned primate research. Reynolds, believing that his office had authority over all basic research on subhumans, insisted that ground-based research and inflight experiment involving primates fell within his jurisdiction. Konecci countered that distinctions between basic and applied research were irrelevant so far as man-machine systems were concerned. Moreover, primate research was a natural adjunct to human research and therefore within his jurisdiction.

These differences were really only surface manifestations of a more substantial and deeper problem: the two were struggling to create viable programs in the face of sharply limited resources. On paper, NASA's separate life sciences programs had a major place in the space program, but in reality they were treated as low-priority items. Reynolds, Konecci, and the director of space medicine (Charles Roadman, 1962; George Knauf, 1962–1964) were competing for limited funds, flight projects, and research facilities, and to a degree Reynolds and Konecci were also competing for control of a single flight project and a single research facility.

NASA's life sciences programs were grossly underfunded relative to other program areas. Some $8.5 billion was appropriated to the agency for research and development from 1962 through 1964. The amount for the three life sciences areas was $157 million, or 1.6 percent. Within the specific life sciences programs, this was broken down as shown in Table 1.[17]

NASA management did attempt to obtain larger sums for the life sciences, but Congress refused the requests. In 1964, for example, Congress reduced the total life sciences research and development request by 31 percent (from $67.1 million to 45.4 million). The space medicine request was reduced by 35 percent (from $16.7 million to 11.0 million), the human factors request by 28 percent (from $18.2 million to 13.2 million), and biosciences by 41 percent ($32.2 million to 21.2 million). No other area of research and development in any of the three major program areas had its budget request reduced by more than 18 percent, and on average the 20 other line items were reduced by 6 percent. Congress justified the reductions for space medicine and human factors on the basis of the availability of comparable capabilities in other government agencies and offered no explanation for reducing the biosciences request.[18]

It is not surprising that the life sciences directors engaged in intense competition for funds, or that they sought to tailor their funding request to the high-priority item of the 1960s, Apollo.[19] Reynolds's office, for example, had a total research and development budget of approximately $24 million for 1964 and pegged 67 percent of it for research in environmental and behavioral biology on problems directly related to manned spaceflight: weightlessness, acceleration forces, alterations in day-night cycle. Similarly, Konecci's office committed 53 percent of its $18.2 million to basic and applied research in environmental and behavioral studies.[20]

The work of the two offices overlapped, most obviously in the area of primate research. Reynolds believed that his office could, and should, examine environmental and behavioral problems systematically, moving from lower organisms to primates. Konecci assumed that primate studies were within the jurisdiction of his office, believing that primates were natural analogues for human research. Without top management resolution of the issue, the two offices pursued independent, often duplicative programs.[21]

This conflict carried over into the only approved, purely life sciences inflight research project, Biosatellite. Conceived by the Office of Space

**Table 1. Research and Development Appropriations, 1962-1964***
**(in Millions of Dollars)**

| Major program | Life Sciences Program | Life Sciences as percentage of total office program |
|---|---|---|
| Office of Manned Space Flight (5,600) | 42 | 0.8 |
| Office of Space Science (1,793) | 71 | 4.8 |
| Office of Advanced Research and Technology (1,120) | 44 | 3.8 |

* 1964 was the final year in which space medicine was listed as a line item. Subsequently, space medicine received funds from several different sources.

Science in 1962 and strongly supported by academic life scientists,[22] Biosatellite was to be a long-range project that would begin in 1966 with a package of biological experiments containing cellular organisms. Subsequently, three to six missions were to be flown, progressing toward primate flights of 15 to 30 days. The objective was to study the effects of weightlessness and acceleration forces on terrestrial organisms.[23] The human research and biotechnology directorate also wanted a flight program, but failing to obtain approval, insisted that it should have a major role in the management of Biosatellite. The rationale was that the development of advanced technological systems fell within its jurisdiction, that it had a need to test out biotechnological systems, and, most important, that it should have priority over inflight experiments involving primates.[24]

To resolve this issue and get Biosatellite moving, Seamans, Newell, and Raymond Bisplinghoff, the associate administrator for advanced research and technology, agreed to set up a joint Office of Space Science-Office of Advanced Research and Technology Biosatellite Working Group, which was to consist of the program associate administrators, directors of biosciences and human research and biotechnology, and representatives from Ames. The group began meeting in January 1963 and agreed that the Office of Space Science would manage the development of "basic spacecraft and recovery systems" for flights not involving primates and the basic research that did not involve primates. The Division of Biotechnology and Human Research would develop "advanced life support systems for later flights involving primates" and manage applied research related to biotechnology.[25]

This effort at cooperation failed. Newell and Reynolds claimed that Konecci refused to attend group meetings or to communicate with Office of Space Science representatives. The joint committee was dissolved and the two offices went their separate ways.[26] Because the Office of Space Science had responsibility for the early flights, it eventually gained primary control over the entire project. After Konecci's resignation in

1964, his successors lost interest in Biosatellite and began to plan a separate flight program with a frog's otolith as the object of study.[27]

Limitations of facilities also aggravated relations. Nominally, Goddard was within the jurisdiction of the Office of Space Science, Ames the jurisdiction of the Office of Advanced Research and Technology. This meant that the center responsible for unmanned flight operations was divorced from the center responsible for life sciences research and development. In practical terms, the Office of Space Science could control flight scheduling for unmanned flights and give priority to flights within its jurisdiction. Conversely, the Office of Advanced Research and Technology had jurisdiction over the center where the life sciences laboratory was located and could coerce Ames into supporting the type of research that would support its objectives. This, in fact, is what Konecci attempted to do; in early 1963, he made a major effort to have the Ames life sciences group concentrate on biotechnology and human factors research rather than biosciences.[23] This had the unintended effect of causing divided loyalties on the Ames staff.[29]

The difficulties at Ames were another manifestation of the absence of clear, integrated responsibility and authority for life sciences. The laboratory at Ames had been created as a biotechnology laboratory; it was expected to provide research and development for the manned space program, and the nucleus of its staff was to be drawn from specialists in human engineering and bioengineering.[30] However, after the dissolution of the Office of Life Science Programs, the management of the laboratory was placed in the hands of life scientists who were interested in basic biological and medical research. As a result, an internal division between bioscientists and bioengineers developed. This division was aggravated by the fact that the former were new to Ames, while the latter had been with Ames since the NACA years. The former tended to look to the Office of Space Science for direction, the latter to the Office of Advanced Research and Technology.

By early 1963, the Ames life sciences program was in disarray. The laboratory director, Webb Haymaker, was a brilliant scientist who avoided administrative involvement. His second-in-command, Siegfried Gerathewohl, had no authority to deal with the growing factionalism. As a result, the various factions went their separate ways.[31] When Konecci tried to direct the Ames staff to concentrate on biotechnology he was within his rights, since Ames was within the jurisdiction of his office; however, his efforts only aggravated the internal factionalism. This situation continued for more than a year. Resolution did not begin until early 1964, when Konecci resigned and Ames hired a director of life sciences, Harold Klein, who was both a scientist and an administrator.[32]

The second problem at Ames also stemmed from unclear lines of authority. Without decisive direction from headquarters, individual scientists initiated research projects based on interest rather than program value.[33] Some of the projects were poorly conceived. At the same time, Ames decided to go ahead with plans for an animal research program, including the creation of a primate colony. This raised the hackles of the Air Force and its allies in Congress, since Ames was violating an agreement accepted by Deputy Administrator Dryden a year earlier. During the FY 1963 authorization hearings, Dryden had assured Congress that NASA would forego development of its own primate colony and rely instead on the colony already operated by the Air Force. Although Ames was ordered to terminate its efforts in this direction, Air Force suspicions about NASA's intentions in the life sciences had been raised.[34]

The absence of effective coordination in the life sciences was also evident at the Manned Spacecraft Center. Since its inception as the Space Task Group in 1958, the center had enjoyed virtual autonomy and was not accustomed to seeking support or guidance outside the manned spaceflight chain of command. Its biomedical components reported to its director and had limited contact with headquarters. The space medicine directors at the Office of Manned Space Flight, Charles Roadman and George Knauf, were both satisfied with this arrangement. As a result, the biomedical staffs at the center proceeded as if they had the authority to pursue their own independent programs.

Expressing the view prevalent at the Manned Spacecraft Center, Richard S. Johnston, chief of the Crew Systems Division, asserted: "We are not flying man to determine biological effects . . . [but] to determine his capabilities in the space environment." With the exception of exobiology, Johnston claimed, the sole function of life sciences in NASA was to support manned spaceflight. Research along these lines belonged with those responsible for manned spaceflight, and "basic research in medical science, physiology, biology, etc., is the responsibility not of NASA, but the NIH."[35]

Accordingly, the Manned Spacecraft Center began to establish its own biomedical research program. In 1963, Dr. Lawrence Dietlein, a medical scientist, was hired to head a new Space Medicine Branch within the Crew Systems Division. Dietlein's office assumed responsibility for the basic and applied research required by crew systems and for designing the inflight medical experiments for the Gemini and Apollo missions.[36] Concurrently, the center allocated a major portion of its total aerospace medicine budget to research. Of $31.5 million allocated for aerospace medicine research, development, and operations for 1962–1964, 74 percent was allocated for basic and applied medical research and design and development of inflight medical experiments.[37] The program was larger than the related Office of Advanced Research and Technology program. By mid-1965, the center's biomedical research capabilities had become so significant that its director integrated all biomedical components into a division-level Directorate of Medical Research and Operations.[38]

The Manned Spacecraft Center steadily increased its medical research capabilities over the objections of the Ames life sciences staff and of the associate administrator for advanced research and technology. It was able to do so because, until late 1964, management had issued no specific directives outlining authorities for biomedical research. Moreover, it could easily justify this buildup on the basis of its need to investigate in a timely fashion the abnormalities discovered during the Mercury flights. Finally, it could pursue this independent course because no one in authority prevented it.

A final organizational weakness was the failure to identify an official life sciences spokesman for the agency. Nominally, the Office of Advanced Research and Technology filled this role. However, the key administrators were specialists in human engineering, flight medicine, and bioengineering and had industrial and military backgrounds. None was familiar with research problems of interest to biologists and medical scientists or sensitive to the concerns of academic life scientists. Consequently, life scientists from colleges and universities preferred to communicate with the Office of Space Science biosciences director, Orr Reynolds. This arrangement was such that NASA seemed to speak with two different voices, and it was frequently criticized by academic life scientists.[39]

The military services were also confused by this situation. Officially, the Office of Advanced Research and Technology represented NASA in dealing with the military. However, when the authority was given (June 1962), NASA's coordination with the services was limited to a single agency, the Aeronautics and Astronautics Coordinating Board, a single level of coordination (NASA and the Department of Defense), and a single area, supporting research and technology for manned spaceflight. Subsequently, NASA had occasion to deal with DoD on questions of space biology and with the Air Force on bioastronautics (space medicine). Reynolds assumed responsibility for space biology coordination, and George Knauf (Office of Manned Space Flight) dealt with the Air Force on matters concerning bioastronautics.[40]

The result was internal strife, particularly between Konecci and Knauf. NASA was under increasing congressional pressure from April 1962 to late 1963 to work out specific agreements with the Air Force that would preclude duplication in their space medicine and bioastronautics programs.[41] Since this issue concerned only manned spaceflight, Webb directed the Office of Manned Space Flight to negotiate with the Air Force Systems Command. George Mueller and his Air Force counterpart subsequently formed a Space Medicine-Bioastronautics Coordinating Committee to allocate research and development responsibilities between the two agencies, share personnel and facilities, and formulate a joint space medicine-bioastronautics budget.[42]

Konecci vehemently protested this arrangement, insisting that all NASA-military coordinations should go through the Aeronautics and Astronautics Coordinating Board. He did not want to provide Knauf and the Air Force with data on medical research contracts sponsored by the Office of Advanced Research and Technology, or Ames life scientists to engage in the coordination effort. He reasoned that the authority of the Space Medicine-Bioastronautics Coordinating Committee was limited to approved manned programs and that the committee had no legitimate authority over advanced research and development. Knauf replied, and management agreed, that coordination had to encompass the biomedical aspect of both approved and advanced manned programs, since the Air Force made no distinction between the two. In the end, Konecci cooperated fully.[43]

## TOWARD A COORDINATED LIFE SCIENCES PROGRAM

By late 1963, it was obvious to NASA's top management that some changes had to be made in the organization and management of NASA's life sciences programs. Clearly, the life sciences directors and offices were working at cross-purposes. Equally important, the disorganized state of the life sciences programs was impeding NASA's efforts to attract the interest and support of academic life scientists and to improve relations with the military services. Between February 1962 and February 1964, NASA's management of its life sciences programs was the object of increasing criticism from Congress and the scientific community.

Life scientists outside NASA conducted four reviews of NASA's life sciences programs during this period, and all reached the same general conclusions.* The programs were disorganized, and the disorganization stemmed from the absence of decisive leadership at the top management levels. Without decisive leadership, the programs lacked purpose and direction, were ineffective, and were incapable of promoting confidence among, or support from, high-quality scientists in colleges and universities. This situation would continue unless NASA appointed a respected

*The President's Science Advisory Committee conducted an investigation of biomedical programs during the summer of 1962. The Space Science Board of the National Academy of Sciences, supported by NASA funds, surveyed the agency's life sciences programs that same summer. In late 1963, Nello Pace, hired as a consultant by Webb, examined the agency's life sciences requirements.

life scientist to a high-level position (preferably as a deputy to the associate administrator) and gave him the authority to plan and direct the overall life sciences program and to represent NASA in its relations with life scientists outside the agency.[44]

Concurrently, Congress monitored NASA's efforts to effect a coordinated life sciences program with the military. Congress was particularly concerned that NASA and the Air Force work out specific agreements related to space medicine and bioastronautics in order to avoid unnecessary duplication of programs and facilities, prevent competition for the limited number of specialists in the field, ensure adequate military support for the biomedical aspects of the manned lunar landing program, and ensure that NASA would give fair consideration to proposals for inflight experiments submitted by the military services. Here again, lack of a single spokesman and lack of decisive internal leadership were cited as factors working against effective coordination.[45]

Seamans had anticipated the need for improvements in the management of the life sciences programs as early as March 1963, when he decided to hold periodic reviews of the programs. By requiring the life sciences directors to come together to explain and justify their programs to him, Seamans hoped to improve his capabilities for resolving internal disagreements and providing direction for the overall programs.[46] However, he lacked the time or the professional qualifications to serve as a de facto director of life sciences programs, so he urged the life sciences directors to begin meeting informally. At one meeting held in August 1963, the "Senior Biomedical Representatives" agreed on the need for a cooperative effort "to insure the development within NASA of a well-conceived, comprehensive, overall biomedical program."[47]

Program reviews and informal meetings did not solve the problem, however. Seamans was not particularly pleased with the program review presentations,[48] and the directors apparently were unable to meet regularly on an informal basis. Subsequently, Seamans authorized a formal Life Sciences Directors Group to be headed by the director of space medicine and gave him the authority to represent the associate administrator at meetings of the group. The chairman was to report directly to Seamans, rather than to his own program office administrator, on matters of concern to the life sciences program as a whole. The group was to devise a coordinated life sciences program, prepare a coordinated budget, resolve jurisdictional disputes, and recommend changes in the overall program. Decisions reached by the group were subject to Seamans's approval.[49]

The formation of the Life Sciences Directors Group can be seen as an attempted compromise between the centralized life sciences office desired by scientists and the decentralized arrangement that was most compatible with the program offices and the overall needs of the agency.[50] At the time the group was established (June 1964), W. Randolph Lovelace II had agreed to become the director of space medicine. Lovelace had the influence, personal and professional prestige, and experience to be an effective spokesman to both the scientific community and the military services. He could provide direction to the life sciences and encourage cooperation among the life sciences directors. Moreover, Lovelace had the personal authority necessary to keep the program office administrators from interfering in life sciences program decisions. Although nominally subordinate to the associate administrator of the Office of Manned Space Flight, he had a direct though unofficial line to NASA's top management. Finally, his influence extended to Congress and the military, so that he could be expected to promote NASA's interests successfully in negotiations with Congress and the Air Force. With Lovelace as director of space medicine and chairman of the Life Sciences Directors Group, NASA could maintain the integrity of its organization while having a de facto director of life sciences.[51]

In 1964, NASA management also tried to better coordinate the planning of experiments for manned flights. Proposals for inflight experiments were coming from three different quarters: the Office of Space Science (OSS) through its Space Sciences Steering Committee, the Office of Manned Space Flight (OMSF) through its Space Medicine Advisory Group, and the Manned Spacecraft Center (MSC) through its Space Medicine Branch. The OSS was proposing experiments in both the physical and life sciences, OMSF in the basic medical sciences, and MSC in medical experiments linked to specific operational problems. In addition, the military services, with no approved manned flights of their own, were pressing NASA to fly experiments related to military requirements.

Clearly, some method had to be found to select from the many proposals a finite number of experiments that could be flown on any one flight. Considerations of weight and space, engineering, time required of the crew, and the astronauts' reluctance to perform experiments were all limiting factors. In early 1964 Seamans directed Mueller to form within the Office of Manned Space Flight a Manned Space Flight Experiments Board.[52]

The board was actually inspired by the efforts of Homer Newell and George Mueller to establish guidelines for selecting and incorporating experiments proposed by the Office of Space Science into manned flights. Mueller had de facto veto authority over such experiments, since the Office of Manned Space Flight had authority over experiments packaging for manned flights. They agreed that OSS should select the experiments, and then OMSF would decide the order in which they would be flown. The board formalized the agreement reached by Newell and Mueller. In addition, a Defense Department representative was added to the board to ensure that the military would receive fair consideration.[53]

Subsequently, at the request of Lovelace, Mueller agreed to establish a Medical Experiments Panel within the board. Such a panel was deemed necessary by Dr. Sherman Vinograd, chief of medical research at the Office of Manned Space Flight, to ensure input from biomedical scientists outside NASA and coordination between OMSF and the Manned Spacecraft Center. Unofficially, Vinograd was worried that the center, with actual control over flight operations, would give preference to experiments proposed by its own staff and low priority to those recommended by the Space Medicine Advisory Group. The panel was also viewed as a means of drawing the astronauts into experiment planning.[54]

## SUMMARY

Management decisions related to the organization and management of life sciences programs had the primary objective of augmenting biomedical support for NASA's major programs within an accelerated and diversified space program. However, factors other than technical and operational requirements were significant in shaping these decisions. Internal disputes over jurisdiction and responsibilities showed that arrangements for organizing and managing the life sciences programs were defective. The evidence forced NASA management to develop a new management structure that would contribute to a better coordinated life sciences program while maintaining the integrity of the overall organization.

Management decisions concerning life sciences programs were also influenced by external forces—the scientific community, Congress, and the military services—particularly from 1961 to 1964. The role of these forces in shaping the organization and management, as well as the growth and development, of NASA's life sciences programs was significant throughout the entire manned space program.

# 6
# The biopolitics of manned spaceflight

NASA's efforts to establish a life sciences program to support the accelerated space program after 1961 produced conflict with two external groups. Certain spokesmen for the scientific community viewed the decentralized life sciences program as evidence that NASA was subordinating basic biomedical research to biotechnology and flight medicine. Air Force officials who were interested in space, and their allies in Congress, viewed the same phenomenon as an effort to build up NASA's inhouse biomedical capabilities at the expense of the Air Force's bioastronautics program. In short, NASA was caught between one group of critics who thought it was doing too little in life sciences and a second group who thought it was doing too much.

## NASA AND THE LIFE SCIENCES COMMUNITY

NASA's relations with the scientific community were generally satisfactory. Many scientists, particularly physicists and astronomers, saw in the space program genuine opportunities for expanding the scope of research in their fields. With physical scientists like Dr. Homer Newell in key administrative positions, their research interests early received high-level support.[1] In addition, prominent scientists served on advisory committees for the agency. Indicative of NASA's willingness to seek the advice of reputable scientists was the agency's support for the Space Science Board. The board operated under the auspices of the National Academy of Sciences, but received most of its financial support from, and provided most of its advisory services to, NASA.[2]

By contrast, scientists who viewed themselves as spokesmen for the scientific community in its dealings with federal agencies, the Congress, and the President were generally critical of NASA and its management of the space program. They most often expressed their views through formal bodies such as the President's Science Advisory Committee and ad hoc advisory groups such as the Wiesner committee. Although their views were not necessarily shared by the majority of practicing scientists, and groups like the Science Advisory Committee had no real authority over NASA, some of the critics were close to the President and the National Aeronautics and Space Council and their opinions received serious attention in Congress.

The President's Science Advisory Committee was the principal forum through which scientific criticisms of Project Mercury were aired. It supported several investigations into NASA's management of that project and made clear, early on, its position that the space program should be "geared to the interests of science" rather than manned flight and that NASA should function as a "research-oriented space agency" rather than one oriented toward engineering and operations.[3] Influential present and former science advisors, such as George Kistiakowsky and Jerome Wiesner, were opposed to the manned program and urged Presidents Eisenhower and Kennedy not to support it. In early 1962, the Science Advisory Committee played a major role in raising public concern over an alleged "bioastronautics crisis" and in the subsequent scrutiny of NASA's life sciences programs. Concurrently, NASA was reorganizing its life sciences programs to make them more responsive to major space programs.[4]

The bioastronautics crisis surfaced in February 1962 with the publication of a report by the Science Advisory Committee's Bioastronautics Panel. The panel had been organized in August 1961 in line with recommendations in a report prepared under the direction of Donald Hornig. Politically, the panel was created to answer questions raised by Congressman Emilio Q. Daddario in March 1961. Daddario, who favored a strong military space program, had called for a "central bioastronautics authority" and a "comprehensive national program" in bioastronautics. He had asked for a "prompt study" of the nation's capabilities and requirements in bioastronautics and had enjoined NASA to delay further expansion in this area until such study was completed.[5]

In spite of its scientific pretensions, the February 1962 report of the Bioastronautics Panel gave little attention to research and development issues. It focused on questions of organization, management, and coordination, and found NASA's life sciences programs "totally inadequate." Shortcomings included the decentralization of life sciences components, the absence of a biomedical administrator at "the highest administrative and decision-making levels," the "lack of coordinated use of government personnel and facilities," especially those in the military services, and reliance on "part-time advisory groups" as a substitute for "full-time effort by competent people." The panel recommended:

1. Appointment of "a national leader in biomedical sciences" as a deputy to the associate administrator, with "responsibility for long-range planning of the biological phases of a national program" in bioastronautics.
2. Coordination between NASA and the Department of Defense to ensure use of "DoD biomedical personnel and facilities in the conduct of project Gemini and Apollo."
3. Cooperation between NASA and the DoD to "build up national biomedical competence in fields essential to a long-range program," with the DoD having major responsibility to "fund and encourage the development of a long-range basic research program."[6]

The first and third recommendations were partly contradictory. Further, the timing of the report was unfortunate, as the agency was in the midst of a reorganization. Whatever the rationale, the report created a flap. Although it did not mention the National Aeronautics and Space Council, it implied that the council had been ineffective in overseeing the total space program. Like NASA, the council had no high-level biomedical scientists.[7] Its staff (which reported directly to the President, was chaired by the Vice-President, and was nominally responsible for overseeing both civilian and military space programs) was disturbed by the report and urged action to avoid "embarrassing council members."

The National Aeronautics and Space Council took no immediate action in response to the Bioastronautics Panel report, presumably because it preferred to keep out of the fray during annual authorization hearings. Congress could be expected to take up these issues soon. Because NASA was reviewing its life sciences program, the council may have preferred to see whether NASA would make an effective response. Finally, the council was aware that NASA and the DoD were engaged in informal coordination of bioastronautics when the panel report appeared; and it may have been reluctant to take any actions that might interfere with these negotiations.

NASA's management of its life sciences programs did not become an issue during the FY 1963 authorization hearings. Congress was more interested in overlaps between NASA life sciences and DoD bioastronautics programs. Nonetheless, several NASA witnesses sought to justify the decentralization of life sciences programs.[8]

Although Congress paid little attention to NASA's internal arrangements, the National Aeronautics and Space Council continued to do so. In June 1962 the council's executive secretary, Edward C. Welsh, asked Seamans what NASA was going to do about the Bioastronautics Panel's recommendations, particularly those related to appointment of a high-level biomedical administrator. To emphasize his interest, Welsh submitted a list of biomedical scientists whom he considered qualified to serve in such a position.[9]

Seamans reviewed the situation and concluded that finding an individual "with competence in fields ranging from fundamental biology to life support technology" was unlikely. Followed to the extreme, he argued, such a rationale would warrant deputy associate administrators for "propulsion, electronics, and a variety of other disciplines that cut across program lines." He decided the problem was not that a decentralized life sciences program hindered the agency's work, but that it gave NASA "a fragmented image" that was not "reassuring to the outside bioastronautics community." Biomedical scientists probably wanted a high-level biomedical position not to enhance the space program, but to represent their own interests. Consequently, in his reply to Welsh, Seamans temporized.[10]

Welsh let the issue rest for the time. In the interim, however, the Space Science Board joined the President's Science Advisory Committee in recommending a "focal point" for NASA's life sciences programs. In early August 1962 the board held a summer study in which "Life Sciences Management" was a matter of special interest. A special committee recommended that the NASA Administrator "appoint a scientist of highest competence and soundest reputation" in the life sciences to a position as a deputy to the associate administrator, with responsibility and authority to make decisions that would contribute to effective "internal and external coordination" in the life sciences and augment support for "research and technology relating to the life sciences."[11] The committee members doubted that NASA management would give serious attention to life sciences unless a life scientist held a high-level administrative position.[12]

In conveying these recommendations to Webb through Seamans, Executive Director Norton Nelson of the National Academy of Sciences apparently tried to minimize the scientific concern over this matter, but he did express the firm conviction that it would be in the best interests of both NASA and the biomedical community if the recommendations were adopted. At the least, appointment of a "senior biomedical advisor" to review all NASA "projects that relate to the life sciences" would defuse the criticisms expressed by a "rather small, but vocal group" of biomedical scientists.[13]

Webb, Seamans, and Dryden again concluded that a deputy to the associate administrator for life sciences was inconsistent with NASA's "broader programs." Webb informed Nelson that the absence of a life sciences office had "not proven to be an obstacle." Rather, existing arrangements had made the life sciences more "responsive to the needs of the program directors." However, Webb recognized a need to improve

NASA's relations with the scientific community and would give serious consideration to hiring a life sciences consultant.[14]

Additional pressure for a life sciences spokesman came from an unexpected quarter. In October 1962, David Vinson, executive secretary of the Texas Academy for the Advancement of Science, complained to Vice-President Johnson that, in the view of some members of the prestigious Aerospace Medical Association, NASA was accepting too much "guidance" from academic life scientists. Vinson urged that NASA pay more attention to the "industrial life scientists" who were acquainted with the "practical, operational" problems of spaceflight. In direct contrast to the Bioastronautics Panel, he criticized NASA for not making greater use of life sciences consultants. Although Vinson's views were repudiated by the president of the Aerospace Medical Association, Webb could not ignore the advice inasmuch as it had reached the Vice-President's desk.[15]

The concerns expressed by Nelson and Vinson reawakened the interest of the National Aeronautics and Space Council. In November 1962, Welsh again suggested to Seamans that NASA create a high-level life sciences position. This, Welsh said, "might accomplish the dual purpose of strengthening your staff and stilling criticisms" from the scientific community. Seamans refused, repeating earlier arguments, but added that he recognized that NASA's "relationship with the biological and medical professions is not altogether satisfactory" and conceded that "a consultant to general management" might be a "beneficial step."[16]

NASA's top management was still considering the matter when, in January 1963, an event at Ames tipped the balance. In late 1962, Webb Haymaker, life sciences director at Ames, had hired Ralph Gerard, a University of Michigan physiologist, as a life sciences consultant. By the time Gerard started work, Haymaker had resigned. After a month's investigation, Gerard concluded that the life sciences effort at Ames was a shambles and cited inadequate coordination, absence of direction from NASA Headquarters, and unjustified research as major problems. He sent copies of his report to Ames Center Director Smith DeFrance and to Seamans. Although DeFrance dismissed the report as the product of an "opportunist," it received Webb's attention and served as one more reminder that serious problems existed in the life sciences.[17]

In an effort to deal with these various criticisms, Webb hired (in April 1963) Dr. Nello Pace, a University of California physiologist, as a temporary consultant to the associate administrator. Webb asked Pace to examine NASA's overall life sciences program and make recommendations concerning organization and management.[18] Pace served in this capacity from July to November 1963.

Pace's findings and recommendations, contained in eight reports, differed little from the conclusions reached in earlier external reviews. Pace observed problems of communication between research-oriented life scientists and development- and operations-oriented engineers. He found that NASA's support for life sciences research in colleges and universities was minuscule compared with the support given to physical sciences and engineering.[19] He found that both the Manned Spacecraft Center and Ames had inadequate basic biomedical research capabilities and were led by biomedical scientists whose research abilities were in doubt.[20]

Pace's major recommendation was that NASA create a Directorate of Biospace Missions, whose director would be a deputy to the associate administrator and coequal to the program associate administrator. He would retain the Directorate of Space Medicine within the Office of Manned Space Flight, to be responsible for medical support operations. The biospace missions director responsible for life sciences research and development would represent NASA life sciences in dealings with external agencies, but would have no authority over medical operations in support of manned spaceflight.[21]

Pace made some useful observations, but failed to do his historical homework (a common failing among those who reviewed NASA's life sciences programs). The projected biospace missions office did not differ significantly from the Office of Life Science Programs and NASA's management viewed the record of the latter as one of failure. A comparable office would be "on the outside looking in" and would not "fit into the direct operating structure of the agency."[22] Equally important, Pace failed to indicate what this new directorship would mean for NASA's other two life sciences programs. The biosciences and biotechnology and human research offices were functioning, and NASA management was not willing to make an abrupt "about-face" and eliminate them. Seamans did not implement Pace's recommendations.

By the time Pace completed his assignment (November 1963), the "bioastronautics crisis" was over and NASA was receiving little criticism from the scientific community. NASA, the Defense Department, and the Air Force had made significant progress in their bioastronautics negotiations. This removed the major source of congressional concern over life sciences management. The opposition of the public scientists was further blunted by the success of Project Mercury. When Pace submitted his final report, NASA had completed six successful manned orbital missions in which biomedical support had obviously been adequate.

The scientific issue was also defused by internal changes. By November 1963, NASA had succeeded in separating its biological programs from its medical-operational ones. The biosciences office was established and under the leadership of Dr. Orr Reynolds. An exclusively biological flight program, Biosatellite, had been authorized. While the Manned Spacecraft Center was becoming the locus for medical research, Ames was emerging as the center for biological and medical investigations. Affirming this, NASA had appointed Dr. Harold Klein, a biologist, to head the Ames program. For these and perhaps other reasons, NASA enjoyed a hiatus from public scientific criticism from late 1963 to early 1967.

## NASA AND THE MILITARY SERVICES

NASA's relations with the military services might have been completely cordial had the Air Force had no aspirations in space and no bioastronautics program of any consequence. The National Aeronautics and Space Act of 1958 took account of military interest in space by directing NASA to refrain from unnecessary duplication of existing military facilities and provided for coordination between military and civilian space programs.[23] Moreover, NASA inherited from the NACA personnel who were accustomed to working closely with military personnel and to providing research and development support for military aeronautics projects.[24] Finally, NASA's managers recognized that they needed military support to achieve their objectives in space.

The Air Force, however, was determined to establish an active role for itself in space. Space-oriented Air Force generals, such as Bernard Schriever, Roscoe Wilson, and Thomas White, were adamant in their belief that a civilian space agency could not satisfy military requirements. They envisioned a program in which NASA would be responsible for unmanned, science-oriented space activities, while the Air Force directed the manned effort. Although they resigned themselves in 1958 to NASA management of Project Mercury, they continued to plan through 1963 for a military space program. Because the Air Force had unparalleled capabilities in bioastronautics, Air Force officials made space biomedicine the heart of their argument for a military manned program.

The Air Force had provided most of the biomedical support for Project Mercury and could reasonably expect to play a comparable role in subsequent manned programs. But as the Manned Lunar Landing Program evolved, the Air Force found it had no firm commitment that assured a role in it. Indeed, NASA was reluctant to rely too much on Air Force support and was striving to establish its own independent life sciences program.[25]

The Air Force, however, was not willing to be shut completely out of space. With the support of allies in Congress, it began in 1961 to press for a coordinated bioastronautics program. The initial impetus came during FY 1962 NASA authorization hearings, when, at the behest of Congressman Daddario, Congress directed NASA to fully utilize Air Force bioastronautics facilities. Daddario reviewed this issue in August 1961 and concluded that NASA's response could best be described as "an indisposition" to use the "skills and facilities already at hand." He reminded NASA Administrator James Webb that NASA was obligated to provide Congress with "a specific plan . . . to effectuate coordination of the civilian and military bioastronautics programs."[26]

For obvious reasons, officials of both the Air Force and NASA wanted to satisfy Congress. They disagreed about the level at which the agencies should coordinate joint concerns. Air Force officials favored direct negotiations with NASA, whereas NASA's managers preferred to negotiate at the Department of Defense level.[27] Seamans and Secretary of the Air Force John Rubel discussed bioastronautics on several occasions between October 1961 and February 1962, but were unable to agree on an appropriate course of action.[28]

Webb and Secretary of Defense Robert McNamara temporarily resolved this impasse when they signed a series of agreements that established procedures for coordinating NASA and Department of Defense space programs. One agreement was related to bioastronautics. Webb and McNamara agreed that NASA "should specify the operational characteristics and bioastronautics requirements" of the Manned Lunar Landing Program. However, NASA and the Defense Department were to "jointly determine and formulate the bioastronautics R&D plan needed to support the MLLP." Finally, the Defense Department, on the basis of "goals and requirements" prescribed by NASA, would "formulate detailed plans, manage, technically direct, and conduct" in-house bioastronautics research and development programs in support of the Manned Lunar Landing Program.[29] In short, the Webb-McNamara agreements provided for bioastronautics coordination at the Defense Department level.

Subsequently, Seamans directed Brainerd Holmes to work with his military counterparts to form a "joint DoD/NASA bioastronautics planning study group," which would prepare an "integrated NASA/DoD research, development, and operational support plan to meet the requirements of the Apollo, Gemini, and Dynasoar programs in the field of bioastronautics."[30] Although the agreement still indicated coordination at the Defense Department level, the emphasis was on areas of particular interest to the Air Force. Nevertheless, specific agreements concerning NASA-Air Force coordination in bioastronautics were not negotiated, or at least not quickly enough for Congress and the National Aeronautics and Space Council. When the FY 1963 authorization hearings commenced in late March 1962, Daddario and others were still not satisfied that NASA intended to fully utilize Air Force facilities. Several items in NASA's budget request seemed to unnecessarily duplicate Air Force capabilities.

One item that received an inordinate amount of attention was NASA's request for funds to establish a primate colony at Ames. This was a critical element in the center's long-range plan to establish a biomedical research capability and entice leading biomedical scientists to work there. It would satisfy scientists' repeated complaints that NASA was not adequately supporting its manned program with primate research. Internal biopolitics also underlay the request: Ames viewed the primate colony as a way to gain a lead over the Manned Spacecraft Center in the area of medical research.[31] Daddario reasoned that NASA could easily obtain all the primates it needed from the Air Force's major—and underutilized—primate colony at Holloman AFB, and Congress struck the request from the budget.[32] That the resolution of this basically technical issue had required congressional action reaffirmed the need for increased coordination and cooperation between NASA and the Air Force. Specific agreements between the two agencies would contribute to the timely and efficient resolution of such technical matters at a more appropriate decision-making level.

Members of Congress were also concerned that NASA's continuing efforts to build up its life sciences capabilities would intensify competition for a severely limited supply of available talent. Congress had expressed on earlier occasions (FY 1958, 1961, and 1962 authorization hearings) the fear that this would lead to two weak and inadequately staffed life sciences programs rather than one strong one. The Air Force and its congressional allies were also worried that NASA, with its lunar landing commitment, would appear more attractive than the Air Force to civilian biomedical scientists. They anticipated that, at worst, NASA would "pirate" Air Force civilians or, at best, obtain life sciences recruits who might otherwise have joined the Air Force. NASA's recruiting efforts in the late summer of 1962 seemed to confirm this fear, since it appeared to be making a special effort to recruit in areas where the Air Force had bioastronautics facilities (e.g., Dayton, Ohio). Although NASA was forced to back down in these efforts and was urged by Congress to work out joint recruiting with the Air Force, its recruiting efforts led to increased pressure for a coordinated civilian-military bioastronautics program.[33]

Negotiations between NASA and the Air Force continued to languish, and at the FY 1964 authorization hearings, Daddario again questioned NASA's continuing buildup in the life sciences. He recalled that in 1960 and 1961, NASA spokesmen had asked for only a "small nucleus" of life scientists who would complement, rather than compete with, the Air Force bioastronautics program. In 1958 Clark Randt had assured him that NASA's personnel complement in the life sciences (professional scientists and engineers) would not exceed 90. Yet in 1963 the agency was requesting authorization to increase that number to roughly 100. How, Daddario asked, could NASA do this, given the limited supply of bioastronautics specialists, except at the expense of military bioastronautics programs?

Answering his own question, he cited figures which revealed a high rate of attrition among military life scientists.[34]

Daddario was juggling statistics to make his case. He insisted that all of NASA's life sciences personnel be considered as a unit, though more than half were involved in biological and biomedical activities that did not contribute directly to manned spaceflight and did not duplicate military efforts. In addition, his attrition rates were drawn from all three services. Since the Army and the Navy had no need to maintain active bioastronautics programs, attrition among their bioastronautics personnel was to be expected. In reality, the Air Force, which had the only active bioastronautics program in the military, had experienced no attrition. Nonetheless, Daddario made his point, and Congress made significant reductions in NASA's FY 1964 budget requests in all three life sciences areas.[35]

The Executive Branch, too, expressed concern over the bioastronautics situation. Vice-President Johnson and the National Aeronautics and Space Council were particularly disturbed by the February 1962 report of the Bioastronautics Panel, which criticized NASA for failing to coordinate its life sciences programs with those of the military services. In August 1962, Johnson requested from both Webb and McNamara "a written statement . . . on the status of coordination" in bioastronautics.[36] NASA's reply, prepared by Dryden, and that of Air Force Secretary John Rubel, cited considerable informal coordination (high-level correspondence) but very little formal coordination. There was much talking and studying, but little action.[37]

In spite of Johnson's concern, the two agencies made little progress in forging agreements over the next five or six months. At the end of the year, Edward Welsh suggested that NASA's internal organization might be contributing to the problem. The appointment of a high-level life sciences spokesman, in addition to satisfying the scientific community, might speed up negotiations with the military services. NASA, in contrast to the Defense Department and the Air Force, he said, had no life scientists in positions of authority.[38] This, of course, was correct. None of NASA's three separate life sciences spokesmen had the authority needed to work out substantive agreements with other agencies.

By early summer of 1963, NASA management had accepted that direct negotiations with the Air Force and immediate, substantive agreements related to bioastronautics were imperative.[39] In June, NASA and the Air Force set up a joint committee on space medicine and bioastronautics. In August, negotiators agreed on the details for a joint coordinating committee. Both agencies agreed to use this committee as a basis for "integration" of life sciences activities related to "the approved flight program requirements of the X-20, Gemini and Apollo Programs." In addition, NASA and the Air Force agreed that the committee would work out plans for avoiding duplication in the use of facilities and awarding of contracts.[40]

This committee provided a forum through which the two bioastronautics programs were brought into alignment. Significant agreements included a computerized life sciences information exchange (ILSE), criteria for allocating research and development responsibilities and awarding contracts, procedures for coordinating the research of the separate NASA centers with those of the Air Force Aerospace Medical Division, policies for integrating the respective program budgets, and liaison offices in the respective organizations.[41] The negotiations were so successful that NASA and the Air Force presented joint space medicine-bioastronautics budgets to Congress for FY 1965 and 1966, with no public disagreements over priority in bioastronautics.

## SUMMARY

By the end of 1964, as NASA prepared for the first manned flight of the Project Gemini series, the agency had resolved its outstanding problems related to management of life sciences programs. Internally, it had established administrative arrangements that ensured life sciences support for major space programs. By establishing a Life Sciences Directors Group, the agency seemingly had found a way to maintain the integrity of its headquarters organization, while providing for coordination among its decentralized life sciences components. Management had reached workable arrangements for dividing life sciences responsibilities between Ames and the Manned Spacecraft Center, for providing decisive leadership at both centers, and for clarifying lines of communication with headquarters.

NASA had also survived trenchant criticisms from the scientific community. By placing the Ames program under the direction of a biologist and administrator, encouraging the development of biological programs at Ames, and assigning Ames project management authority for Biosatellite, NASA had given biological scientists an institutional focus for their research interests. In the decision to appoint Nello Pace as a consultant, the agency received specialized advice and indicated its willingness to listen to recommendations from the scientific community. It managed this without making any commitments to implement such recommendations or to alter the orientation of its overall programs. In short, NASA management dealt deftly and adroitly with its external critics, responding to their expressions of concern without letting those concerns undermine the agency's plans for organization.

Finally, NASA had concluded its conflict with the Air Force, while again maintaining its organizational integrity. It did so only under pressure from the legislative and executive branches of government. Yet the compromises to which it agreed did not significantly reduce its authority over space programs. Indeed, NASA actually benefited. While it formally recognized the Air Force's interests in bioastronautics and gave the Air Force primary control over human research and biotechnology, NASA received formal assurances of regular and timely support from the Air Force. In addition, NASA was freed from having to commit significant funds to advanced human research and biotechnology, and instead could fund the areas that were of most immediate public concern: space biology and space medicine.

While the agency benefited from these agreements, life sciences, as an integrated, cohesive program, did not. First, NASA endorsed compartmentalization of the life sciences, which created a gulf between the biological side of the space program and the medical-operational side. In effect, space biology and space medicine were to develop as separate, rather than complementary, programs. Second, by agreeing to accept Air Force priority in human factors and biotechnology, NASA stifled the growth of its third life sciences area. While the NASA biotechnology and human research program continued to operate, it had no major flight program on which to focus and no clear mission. Finally, by creating the Life Sciences Directors Group, NASA bypassed the thorny problem of top-level life sciences representation. While this decision reduced internal strife and promoted program coordination in the short run, it did not provide long-range viability to the life sciences program.

# 7

# Lunar trajectories: biomedicine in the Gemini and Apollo programs

Discussion of the organization and management of NASA's life sciences programs waned while Project Gemini missions were flown, March 1965 through November 1966. Like Mercury before it, Gemini was, in biomedical terms, an unqualified success. The Gemini flights demonstrated that man was fully qualified to perform effectively on 14-day missions, that he was capable of performing complex and arduous extravehicular activities, and that the life support systems were fully adequate for both purposes. In short, the Gemini flights gave assurance that NASA was ready for the next phase of the manned program, the lunar landing operations of Project Apollo.

Although Apollo depended to some extent on the Gemini experience, the projects were organized independently and overlapped in time. Biomedical personnel, planning operations and developing hardware, were nearly as active on Apollo during this period as those working on Gemini. Still other life scientists and bioengineers were attempting to define the biomedical requirements for the first post-Apollo manned program, Apollo Applications (which evolved into Skylab).

Concurrently, NASA's space biologists, though functionally separated from the manned program, were developing a flight program that they believed had an indirect bearing on manned spaceflight. In December 1966, NASA launched the first of a projected six Biosatellite missions. Unmanned and nominally oriented toward basic biological research, the Biosatellite flights were intended to provide data concerning the biological effects of space environment factors on living matter and animals. As Gemini came to a close, space biologists were preparing for a series of 15- to 30-day flights with primates. With these flights, they hoped to strengthen NASA's basic biology program and demonstrate its value to manned spaceflight development.

## BIOMEDICAL RESULTS OF PROJECT GEMINI

Project Gemini qualified man and life support systems for lunar operations in two stages. Through *Gemini 7*, biomedical interest centered on man's physiological and psychological reactions to, and the adequacy of the environmental control systems for, spaceflights of up to 14 days. Through the rest of the series, biomedical attention focused on the evaluation of human performance and life support related to extravehicular activities (EVAs).

Evaluation of the physiological and performance aspects of the Gemini flights involved standard clinical procedures (pre- and postflight physical evaluations, inflight monitoring) combined with selected medical experiments. Special emphasis was given to the cardiovascular and musculoskeletal systems. Measurements revealed that "some of the major human physiological systems exhibit consistent and predictable changes" during and after exposure to spaceflight lasting up to 14 days, but that such changes "are completely reversible." In addition, the data indicated that the "observed changes" would "not degrade human performance or crew safety during missions required to achieve the goals of the Apollo Program. "[1] Analysis of data related to "human functional systems" that physicians viewed as critical to manned spaceflight revealed no "flight-related changes" in the neurological, pulmonary, gastrointestinal, or genitourinary systems or in behavioral or metabolic functions. Physicians identified no serious decrements in these areas that could be correlated with the environmental factors that were of specific concern to physicians before the Gemini flights—acceleration forces, weightlessness, radiation, and space capsule environment.[2]

Similarly, observations of specific reactions to the spaceflight experience failed to reveal the adverse responses that many biomedical scientists predicted would occur during longer flights. Table 2 summarizes the predicted and observed reactions.

Equally important, physicians observed no significant decrease in astronaut performance during the Gemini flights. Visual acuity tests (inflight sightings and descriptions of ground views) and the absence of any evidence of vertigo or disorientation implied that long flights would not impair the functioning of the central nervous system and the vestibular apparatus. Data from electroencephalograms for nearly 55 hours of sleep revealed only minor variations in the four levels of sleep compared with baseline recordings obtained on the ground. Finally, the performance of

**Table 2. Human Response to Long-Duration Spaceflight: Predictions Compared to Observations during Gemini**

| Predicted | Observed | Predicted | Observed |
|---|---|---|---|
| Electromechanical delay in cardiac cycle | None | Stimulant need | Occasionally before reentry |
| Reduced cardiovascular response to exercise | None | Infectious disease | None |
| | | Fatigue | Minimal |
| (a) | Absolute neutrophilia | Dysbarism | None |
| Reduced blood volume | Moderate | Distribution of circadian rhythms | None |
| Reduced plasma volume | Minimal | | |
| (a) | Decreased red-cell mass | Decreased g-tolerance | None |
| Dehydration | Minimal | Skin infections and breakdown | Dryness, including dandruff |
| Weight loss | Variable | | |
| Bone demineralization | Minimal calcium loss | Sleepiness and sleeplessness | Interference (minor) |
| Loss of appetite | Varying caloric intake | | |
| Nausea | None | Reduced visual acuity | None |
| Renal stones | None | (a) | Eye irritation |
| Urinary retention | None | (a) | Nasal stuffiness and hoarseness |
| Diuresis | None | | |
| Muscular incoordination | None | Disorientation and motion sickness | None |
| Muscular atrophy | None | | |
| (a) | Reduced exercise capacity | Pulmonary atelectasis | None |
| | | High heart rate | Launch, reentry, extravehicular activity |
| Hallucinations | None | | |
| Euphoria | None | | |
| Impaired psychomotor performance | None | Cardiac arrhythmias | None |
| | | High blood pressure | None |
| Sedative need | None | Low blood pressure | None |
| | | Fainting postflight | None |

[a]Not predicted.

SOURCE: Charles Berry and Allen D. Catterson, "Pre-Gemini Medical Predictions versus Gemini Flight Results," in Manned Spacecraft Center, *Gemini Summary Conference*, NASA SP-138 (Washington, 1967), p. 199.

the astronauts during the complex inflight maneuvers of Gemini and during two emergencies provided unequivocal evidence that performance decrements should not be a factor in the Apollo program.[3]

The data obtained during the 4-, 8-, and 14-day Gemini flights did point to physiological anomalies in the cardiovascular and musculoskeletal systems, however. As anticipated, evidence of decrements in bone density, skeletal calcium, and muscle nitrogen was obtained, but the decrements did not approach clinical significance for the period in question, and all three conditions returned to normal within 50 hours of landing. That the peak decrements were observed in the 8-day flight and were significantly lower during the 14-day flight suggested that adaptation was occurring. This remained only a possibility, however, since the pertinent variables were not the same for the several flights. There was also a strong possibility that mission variables (such as exercise, diet, and fluid intake), rather than environmental ones, were the source of these changes and their fluctuations. The absence of clearly identifiable causes for the changes led NASA's physicians to conclude that intensive investigation of the musculoskeletal systems was essential before longer missions were attempted. However, they did not view these findings as matters of significant concern to Apollo operations.[4]

As expected, observations of the cardiovascular system also provided evidence of anomalies, some of which were considered insignificant. As in the Mercury flights, electrocardiograms revealed "rare" and "minor" irregularities in the heartbeat. Variations in blood pressure were observed, but in the critical 14-day flight, blood pressure and heart rate of both astronauts were within "the envelope of normality" during weightlessness and acceleration.[5]

However, the blood pressure and heart rate readings obtained during the 4- and 8-day flights caused some concern. Trends based on measurements along these parameters gave projections for the 14-day mission that were enough "to scare the pants off you." The fact that these projections were not borne out during the 14-day flight suggested cardiovascular adaptation to the conditions of spaceflight. Here again, the multiplicity of variables precluded certainty.[6]

Oddly, orthostatic hypotension, which had been a cause of serious biomedical concern following the Mercury flights, at first did not appear to be a problem during Gemini. It became evident only during postflight examinations with a tilt table (an examination table that can be tilted about three separate axes). Once again, the absence of uniform controls during the missions precluded precise correlation of this condition with specific spaceflight variables.[7]

NASA physicians were surprised by some of the cardiovascular data, which pointed to a potentially serious anomaly. Blood samples taken before, during, and after the *Gemini 4, 5,* and *7* missions revealed postflight deficits in red blood cell mass ranging from 5 to 20 percent. Adding to the concern was the absence of clear evidence indicating the specific cause. Oxygen toxicity (hyperoxia), immobility, diet, and weightlessness were all possible contributing factors. Since the deficit peaked during the 8-day flight (at 20 percent) and dropped significantly during the 14-day flight (to 5 percent), it seemed likely that the body was adapting. Since the anomaly did not appear to affect the health and performance of the astronauts during these flights and the condition reversed itself during the first 50 hours after flight, NASA's physicians did not believe it would pose a problem for the Apollo missions. However, as with the other anomalies, this loss in blood cell mass indicated yet another line of biomedical research required before longer flights.[8]

The Gemini flights also demonstrated the capability of the life support systems for 8- to 14-day flights. No significant problem developed in the functioning of the environmental control (atmosphere, humidity, temperature) or waste management systems. The astronauts encountered no unanticipated problems with drinking, eating, defecating, and urinating in flight. Finally, there were no indications that levels of radiation, atmospheric contaminants, or toxins in the spacecraft ever reached significant proportions.[9]

While NASA's biomedical scientists and physicians continued the program of pre- and postflight evaluations and inflight recordings, their major concern during *Gemini 8* to *Gemini 12* was the assessment of astronaut health and performance during extravehicular activities, in which one of the astronauts would leave the spacecraft and attempt various tasks. The spacewalks were spectacular; the astronauts put on a good show. But from a biomedical standpoint, extravehicular activity was deadly serious. The spacesuit had to maintain a pressure environment and provide essential levels of metabolic oxygen (i.e., oxygen actually absorbed by the body, as opposed to atmospheric oxygen), heat, and humidity. At the same time it had to allow the body-joint mobility and flexibility required for performance of tasks. As described by the engineers responsible for the suit, it

> . . . was a multi-layer fabric system consisting of a comfort liner, a gas bladder, a structural restraint, and an outer protective cover. To permit easy donning and doffing . . . quick disconnects were located at the wrists for glove connections, and at the waist for ventilation-gas connections. Suit entry and body waste management were provided by a structurally redundant pressure-sealing zipper. Internal to the suit, a gas distribution system directed a flow of oxygen to the helmet area for metabolic use and thermal control, and over the limbs and body for thermal control . . . [additional protective equipment] included: 1) extravehicular cover layer, 2) pressure thermal gloves, 3) visor temperature-control coating, and 4) sun visor.[10]

Spacesuit environmental control was provided through an Extravehicular Life Support System, consisting of a chest pack (which controlled heat through recirculation of gases), hoses and connectors for inlet and output of gases, and an umbilical cord and electrical cable that linked the suit to the space capsule oxygen and electrical systems. The functions of this environmental control system were to provide for metabolic oxygen, maintenance of suit pressure, removal of thermal load created by extravehicular effort, ventilation gas for removing carbon dioxide (respiration waste product), and emergency oxygen supply.[11] Although the equipment "operated satisfactorily within the design capabilities," three problem areas were identified. First, during extravehicular activity the pilots tended to become overheated due to design limitations in the thermal control system. As a result, engineers took steps to increase the "cooling and metabolic heat-rejection capabilities" in advance of the lunar landing mission. This was viewed as a relatively minor engineering problem. Second, certain design features related to attaching equipment (e.g., the sun visor) required an inordinate amount of work by the astronaut, and this pointed to the need for modifications in the positioning of equipment. Finally, the astronauts felt that the equipment packages were too bulky and interfered with their comfort and performance.[12]

From a clinical perspective, the overall response of the astronauts to extravehicular activity was satisfactory and indicated that with "careful planning of the workload" the efficiency of the astronauts would not be significantly reduced. However, in two of the flights (*Gemini 9A* and *Gemini 11*), pilots involved in extravehicular activity experienced extreme exhaustion and evidenced significant decrements in performance. Subsequent medical evaluations led to the conclusion that these decrements stemmed from operational procedures and design limitations, rather than from the extravehicular experience per se. The astronauts had not been trained to conserve personal energy or to relax tensed muscles. They became fatigued partly because they were tense and working harder than

*Astronaut John Glenn is fitted for a spacesuit, which is a prototype of space gear worn in actual spaceflights.*

necessary. In addition, the astronauts apparently were fatigued prior to extravehicular activity due to inadequate sleep, exhaustive preflight training, and elaborate pre-EVA preparations. In addition, the spacesuit environmental control system was designed to handle thermal levels below those actually created by the astronauts' activities. Prior to *Gemini 12*, the system was modified to increase its thermal dissipation capability, and changes were made in operational procedures to correct the problems noted above. As a result, the final extravehicular experience was highly satisfactory.[13]

To a great extent, NASA's physicians were making educated guesses when they tried to pinpoint the causes of exhaustion from extravehicular activity on *Gemini 9A* and *Gemini 11*. Engineering and operational considerations had precluded inclusion of the type of bioinstrumentation that would have been necessary to establish precise correlations between workload and metabolic cost. The bioinstrumentation for extravehicular activity was limited to one lead for electrocardiograms and one for respiration rates. While these provided gross indications of general physical condition, they could not accurately indicate body temperature or metabolic energy resources. Prior to *Gemini 12*, Manned Spacecraft Center physicians made a major effort to obtain accurate assessments of metabolic costs through ground-based simulations. Results were used in establishing the operational workload for *Gemini 12*.[14]

## BIOMEDICAL PREPARATIONS FOR THE APOLLO PROGRAM

Apollo was dependent on Gemini for assurance that astronauts could endure the rigors of the translunar flight and perform effectively in the lunar operations. Apollo, however, also had unique biomedical requirements. First, the Apollo missions would be the first in which clinical space medicine would be critical. As Apollo flights would take the astronauts out of Earth orbit, inflight illnesses could become serious problems. Once the spacecraft was en route to the Moon, an ill astronaut would have to complete the entire journey before he could return to the Earth for treatment. As a result, Apollo required a clinical program to minimize inflight illness and provide for inflight emergency treatment if illness occurred.[15]

The clinical program that evolved had three parts: preflight preventive medicine, preflight paramedical training for the astronauts, and an inflight medical kit. Prevention of illness was the major focus, and it included identification of latent illnesses during preparation for missions, reduction of contact with nonessential personnel, and determination of individual sensitivity to drugs that would be carried in the medical kit. The "health stabilization" program was planned to go into effect 30 days before each mission. It relied on intensive medical screening and physical examinations for early detection of infections. NASA's physicians recommended total isolation of the astronauts during this period; however, this was deemed impractical.* Preflight paramedical training was designed to enable the astronauts to recognize health abnormalities and select appropriate therapeutic measures. The program covered the cardiovascular, pulmonary, and neurological systems, vestibular and otologic functions, human behavior, pharmacology, and preventive medicine. This training also acquainted the astronauts with the emergency medical kit, which included 17 drugs for various respiratory, intestinal, eye, ear, nose, and skin infections.[16]

The need for a portable life support system for lunar surface extravehicular activity was a second unique biomedical requirement of the Apollo program. While Gemini had demonstated the basic capability of man and equipment, the duration of extravehicular activity had been a much shorter operation. The Apollo astronauts would have to carry their life support with them as they performed a variety of activities, so the environmental system had to be lightweight and not interfere with astronaut maneuverability.

To meet these requirements, NASA's engineers developed a Portable Life Support System that would operate as a backpack unit. Subsystems supplied oxygen for both spacesuit pressurization and metabolic consumption; cooled water for thermal control; filtered out carbon dioxide, odors, and trace contaminants; warned of malfunctions; and provided communications and telemetry. The life support system was a major component of the Extravehicular Mobility Unit, which consisted of the extravehicular spacesuit, a liquid cooling garment, an oxygen purge system, and special visor and overshoe assemblies.[17]

The third unique biomedical requirement of the Apollo program was the need to prevent contamination of the lunar surface, as well as contamination of the Earth's biosphere by possible lunar biota. Although most scientists considered the possibility of life (even at the subcellular or viral level) to be remote, back-contamination had to be considered. In 1963, the Space Science Board recommended that NASA ensure effective quarantine procedures during the Apollo program. Subsequently, NASA joined the Public Health Service, the Department of Agriculture, and the Department of Interior in forming an Inter-Agency Committee on Back-Contamination. Responding to the recommendations of this committee,

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*As discussed in Chapter 10, the frequency of infections in *Apollo 7* through *Apollo 13* led to implementation of a Flight Crew Health Stabilization Program that provided for complete isolation.

*Project Mercury astronaut candidates were put into a heat chamber for an extended period to measure their ability to function under the stress of heat. With the temperature at 130° F, Malcolm S. Carpenter spends the time reading.*

*Astronaut Edward H. White performs his spectacular space feat during the third orbit of the Gemini-Titan 4 flight. While floating, White is secured to the spacecraft by a 25-ft. umbilical line and a 23-ft. tether line, both wrapped together with gold tape to form one cord. White was the first American astronaut to egress his spacecraft while in orbit.*

NASA implemented a program with three objectives: preventing contamination of the lunar surface by human biological wastes, preventing contamination of the space capsule by astronauts returning from the lunar surface, and preventing contamination of the Earth's biosphere.[18]

To avoid contamination of the lunar surface, three vectors of contamination had to be contained: waste products (feces, urine, and residual food), terrestrial microorganisms released during lunar-landing module depressurization, and microorganisms present in the lunar module waste water system. Their containment posed an engineering problem—and meant that additional weight had to be lifted from the lunar surface. It was finally decided that the only feasible procedure would be to collect all wastes in special bags that would be stored in the equipment bay of the lunar module descent stage (which would remain on the lunar surface). These bags were not expected to leak, but if they did it was expected that the leakage would remain contained within the descent stage.

Of much more concern to biomedical scientists was the possibility of contaminating the Earth. NASA proposed to avoid this in three ways. First, special equipment would be included in the spacecraft to maintain cleanliness and reduce the amount of lunar dust returned to Earth. Second, a Mobile Quarantine Facility would be constructed to carry the astronauts from the recovery site to a fixed quarantine facility. Immediately after landing, the astronauts were to don special garments that included respirators to filter and sterilize their exhalations. They would wear the garment until they had entered the mobile facility. Waste products were to be transferred to the facility through special locks. The astronauts would remain in the mobile facility for an undetermined period of time (provision was to be made for 10 days) until transferred to a special quarantine facility.

Finally, NASA planned to construct a Lunar Receiving Laboratory to house both the returned lunar samples and the astronauts. This was to be both a containment facility and a testing facility. The astronauts would live there for 21 days, while scientists, using remote sensing devices and neoprene gloves, would conduct biological and biochemical analyses of the lunar samples and the astronauts. The receiving laboratory was constructed to match the specifications of the U.S. Army biological laboratories at Fort Detrick, Maryland, which was the nations's center for research on biological warfare.[19]

The kinds of biomedical data gathered during Mercury and Gemini would also be collected during Apollo. To further investigate the physiological anomalies discovered or studied during the earlier flights, detailed pre- and postflight assessments would be made. Special attention was to be given to the cardiovascular and musculoskeletal sysems, and a special effort would be made to obtain precise information on metabolic requirements. Bioinstrumentation had been refined during the Mercury and Gemini missions. Notable changes included an instrument for measuring overall body temperature through electrode sensors (as opposed to rectal or oral temperature) and provision for comprehensive measurements during extravehicular activity. To make the latter measurements, NASA's physicians and engineers cooperated in designing a biomedical harness that wrapped around the pelvis like a belt, rather than around the chest. This version was expected to reduce interference with operational performance.[20]

Initial biomedical planning for Apollo called for seven experiments that would measure reactions of the cardiovascular and musculoskeletal systems and metabolic function to the space environment. Following the *Apollo 204* accident, a fire which killed three astronauts and led to a 20-month delay in the Apollo program, the biomedical experiments were eliminated on the grounds that they were not critical to Apollo and could be postponed to a later program. Public attention after the fire focused on astronaut health and safety rather than science; in such a traumatic environment it was easy to emphasize medical preparedness rather than medical experiments.[21] Some biological and biomedical experiments were flown in the later Apollo missions, but they did not approach the comprehensiveness of the program that was originally planned.[22]

## BIOMEDICAL PLANNING FOR ADVANCED MANNED SPACEFLIGHT PROGRAMS

Reduction and analysis of the biomedical data derived from the Mercury and Gemini flights and from extensive ground-based research and simulations led biomedical scientists, both inside and outside NASA, to the cautious conclusion that man was qualified for spaceflights of 28 days.[23] Scientists were troubled by the physiological and performance decrements observed in these missions and were disturbed that precise measurements had not been obtained. However, the consensus was that the Apollo mission and support system changes would not jeopardize the health, safety, and performance of the astronauts. Biomedical scientists felt certain, however, that flights exceeding 28 days should not be attempted until the observed anomalies had received thorough investigation.

While NASA's post-Apollo manned missions were only vaguely defined at the end of Gemini, NASA management assumed that the manned program would continue to expand after the lunar landing. They expected that there would be missions of gradually increasing duration, so that human responses in one mission would indicate possible areas of concern for the next. Management hoped to begin with an orbiting laboratory, proceed to a permanent manned space station, and continue to a manned planetary mission.[24]

In 1966 a space station and a manned planetary mission were little more than visions on the horizon; however, studies of an orbiting laboratory and firm planning were moving forward. In 1963 NASA had received congressional authorization to establish design requirements for an orbiting laboratory, using Apollo systems, and had conducted several studies to determine both overall design requirements and specific biomedical requirements. Initially designated Apollo Extended Systems, the program was redesignated Apollo Applications Program in 1965. It subsequently flew as Skylab. The Apollo Applications Program was projected as a two-mission program in which flight crews would spend 28 and 56 days in orbit. Since the primary objective was to qualify man for even longer spaceflight, major emphasis was placed on biomedical investigations and life support systems.[25] In view of the anomalies already observed in manned flights, management recognized a pressing need for comprehensive biomedical planning well in advance of the actual missions. Toward this end, NASA asked the Space Science Board to investigate and make recommendations concerning the biomedical requirements for advanced manned programs.

The board presented NASA with its recommendations in February 1966. While satisfied with NASA's overall management of medical operations for Mercury and Gemini, the report noted the absence of acceptable and verifiable biomedical measurements and pointed out that reliable data were limited or nonexistent in several significant areas:

> . . . 1) the behavior of physiological and behavioral systems that respond slowly with time, such as metabolism and smooth muscle mass; 2) the extent to which physiological degradation or "deconditioning" may occur over an extended period of time; 3) the ability of man to adapt to the space environment, to attain a steady state of physiological and psychological adjustment, or, subsequently, to readapt to gravity and other planetary stresses; and 4) the possibility or likelihood of a combination of stresses producing a response greater than the sum of the responses to individual stresses. Finally, it cannot be ruled out that the space environment may induce totally unexpected responses.[26]

The report cited three sets of factors that NASA should consider in advanced biomedical research. All could have significant effects on astronaut health and performance as the duration of flights increased, even though none had yet compromised health and performance. The first set of factors, "medical and physiological," included weight loss, body fluid volume and electrolyte balance, calcium loss, change in blood volume and coagulation and in red blood cell mass, metabolic changes, compatibility of bacterial flora (i.e., tendency of normal human bacterial populations to undergo unpredictable and possibly adverse genetic changes when humans are in confined spaces), space radiation, readaptation to gravity, and combined stresses. The report recommended that investigation of these factors begin immediately with ground-based research in settings that simulate spaceflight and later be complemented by primate investigations in Biosatellite. This would provide a fundamental base on which a plan for inflight research on men could be structured.[27]

The report found that the second set of factors, "psychological and behavioral," was largely being "neglected" in the manned space program. In prolonged spaceflight, the psychological reactions of the crew could be more important than the physiological reactions. In spite of this, the report said, there were few data on the long-term effects of "isolation, confinement, monotony, social restrictions, threat of danger, noise and silence, and the enforced proximity of differing personalities." Research was recommended to correlate decrements in "crew motivation and performance" with mission duration and restricted environment, to identify physiological disturbances that might result from psychosocial factors, to define the "levels and types of activity" needed to maintain "physiological systems and behavioral skills," and to measure "the time required to perform tasks in space and the percentage of errors made."[28]

Finally, the report cautioned that the proven capabilities of "current life-support systems" did not justify confidence that those capabilities would extend to longer missions. NASA had developed effective life support systems quickly by compromising between the engineering and physiological requirements. This was satisfactory for missions that depended on "man's very considerable ability to adapt to adverse conditions." However, advanced missions would need a more substantial basis that stressed "clearly defined optimal conditions for effective performance" in space. In this regard, the report urged research and development into space cabin atmospheres (in particular, to explore the feasibility of a two-gas system), toxic contaminants, waste management, human engineering, biomedical data collection and data analysis, and inflight medical care.[29]

The findings and recommendations of the Space Science Board were consistent with those of NASA's own Biomedical Experiments Working Group and Space Medicine Advisory Group and provided the basis for the biomedical research that preceded Apollo Applications and the biomedical experiments package that was flown aboard Skylab. In addition, NASA management decided to adopt the board's recommendations concerning inflight animal experiments. Plans were made to use the Biosatellite primate flights to assess a two-gas atmosphere and the combined effects of weightlessness and radiation on primate circulation, metabolism, neurophysiology, and behavior.[30]

The increasing importance of inflight biomedical investigations warranted procedures for economically and efficiently designing and packaging biomedical experiments. However, it was difficult to define experiment packages with only vague indications of the types of missions that would be flown and virtually no information on the vehicles. Consequently, Dr. Sherman P. Vinograd and his associates concluded that NASA should design a flexible, modular biomedical experiments system capable of supporting a broad range of investigations, yet adaptable to any flight system that NASA selected. The result was the Integrated Medical and Behavioral Laboratory Measurement System.

The integrated measurement system was conceived in 1965, when a Technical Advisory Committee of NASA's life scientists considered ways in which NASA could accomplish the inflight biomedical research that various groups, such as the Space Science Board, had recommended. The committee identified two impediments. First, available bioinstrumentation was capable of providing gross evaluation of specific physiological responses, but not precise measurements. Second, traditional procedures relied on the use of individual items of equipment rather than comprehensive systems. The committee concluded that NASA should develop "a single biomedical support system that would integrate the required measurement, support and data-management facilities" and could function as both "a compact, miniaturized spaceborne medical center" and "a self-sufficient biomedical research facility."

As NASA's first attempt to apply engineering development principles to biomedicine, the integrated measurement system was conceived as a means for reducing lead times and preparing well in advance for the integration of biomedical systems with other spaceflight systems. Heretofore, the approach to biomedicine had largely been adaptive; that is, procedures were adapted to existing engineering arrangements and biomedical research requirements were often compromised. The system conceived by Vinograd and his associates would greatly facilitate the integration of biomedical research requirements with other systems and minimize the degree to which biomedical requirements had to be compromised. In 1966, however, the system was no more than a concept, and its development remained in doubt.[31]

# 8
# Directing the life sciences program

*Divers assist Skylab 2 mission commander Charles Conrad, Jr., submerge in the Marshall Space Flight Center's Neutral Buoyancy Simulator. The large water tank provided a simulated zero-gravity environment.*

The final 18 months of the Gemini era provided NASA's biomedical scientists with optimism and confidence. The Gemini missions dispelled any lingering doubts about NASA's ability to provide effective biomedical support for its flight crews and provided assurance that progress toward the planned lunar landing would not be retarded by human factors. The Gemini flights yielded biomedical data that greatly expanded knowledge of human reactions to spaceflight and the space environment and alerted NASA management to the need for a more comprehensive biomedical research program. Management's positive response to various recommendations from external and internal advisory groups and its tentative support for the Integrated Medical and Behavioral Laboratory Measurement System was evidence of this new awareness.

Increased emphasis on biomedical research and the biomedical requirements for advanced manned programs had ramifications for the management of NASA's life sciences program. Could NASA's decentralized life sciences program provide the necessary coordination among space biology, human research, biotechnology, and medical operations? Without a centralized point of contact for the life sciences, could NASA attract the active support of biomedical scientists with the knowledge and skills to make important contributions to the biomedical program?

During this period, the Life Sciences Directors Group managed to minimize internal factionalism, achieve a nominal level of coordination among NASA's decentralized life sciences components, and promote effective liaison with interested groups outside the agency. The achievements of the directors, however, were like those of the proverbial

Dutch boy with his finger in the dike; they could hold management problems in check for a while, but could not solve those problems. The question of the organization and management of NASA's life sciences program, dormant through most of the Gemini era, resurfaced as an issue early in 1966.

## LIFE SCIENCES DIRECTORS GROUP

The Life Sciences Directors Group functioned in lieu of a life sciences program office from June 1964 to August 1968. Established by NASA Associate Administrator Robert Seamans to improve the management of the overall Life Sciences Program, the group was charged with coordinating "those Life Science matters having Agency wide implications." Seamans hoped the arrangement would fulfill the management responsibilities of a life sciences program office without impairing the functional integrity of the major program offices. The group was strictly advisory, with no authority to involve itself in the internal management of individual life sciences offices or with individual directors in their liaison efforts with external scientific agencies in "their respective areas of cognizance."[1] The members of the group were expected to establish a "coordinated and integrated" life sciences program by "coordinating the planning, development and execution of life science activities"; reviewing and making recommendations concerning "problems and issues having agency-wide implications"; and proposing changes in "program activities . . . task assignments and relative priorities."[2]

The directors made recommendations through their chairman to Seamans. Authority to act on the recommendations rested with Seamans or the associate administrators heading the offices of Advanced Research and Technology (OART), Manned Space Flight (OMSF), and Space Science and Applications (OSSA). Top management viewed the Directors Group as a "strictly advisory" body that should have "no authority to direct action to be taken by its individual members or others."[3] Since NASA management had made no provision for a top-level life sciences administrator, above or equal to the program office associate administrators, real authority over the management of the Life Sciences Program rested with administrators who were not necessarily knowledgeable or involved day-to-day in the program.

In addition, the directives establishing the Directors Group did not specify the procedures by which they might reach a consensus on critical issues. The three directors were coequal. They were to share information related to their respective programs, eliminate program overlaps, and resolve internal jurisdictional disputes; but majority rule was not authorized, and the group could not force an individual director to submit to a majority decision. Disagreements could be resolved only by passing them on to higher authority.

Unanimous agreement was rarely possible, since each director naturally resisted proposals that would result in reducing the scope of his own program. This was particularly true of the directors of biosciences (in OSSA) and biotechnology and human research (OART), who were locked in conflict over a number of substantive issues.[4] Critical issues related to program jurisdiction usually had to be passed on to Seamans and the program associate administrators for resolution.[5]

The directors were also constrained by divided loyalties. Each director was responsible both to the Life Sciences Program and to his respective program office. Subordinate to the program office associate administrators, the directors, when considering matters of significance to the life sciences, had to take into account both the needs of the Life Sciences Program, and the requirements of the respective program offices. In practical terms, the Directors Group not only had to struggle to reach a consensus relative to the Life Sciences Program, but also had to be certain that such a consensus would be acceptable to the associate administrators.[6]

Finally, the Directors Group had no authority over life sciences activities at Ames Research Center and the Manned Spacecraft Center, both of which had major responsibility for life sciences research and development. The life sciences managers at the centers reported to the center directors, who in turn reported to one of the program office associate administrators. Ames and the Manned Spacecraft Center had an enduring disagreement concerning jurisdiction over medical research, but the Directors Group could not resolve it.[7]

These weaknesses in the program management of the life sciences program, though enduring in nature, were obscured for some time. At the time, W. Randolph Lovelace II had the personal authority, working as he did with top management, to overcome these weaknesses. Although frequently absent from meetings of the Directors Group and involved in many activities outside NASA, Lovelace had the respect necessary to gain cooperation among the directors and ensure management backing for decisions made, with his leadership, by the group. Internal weaknesses were also obscured because the life sciences budget, although spare,[8] continued to expand from 1962 to 1965 and was sufficient to support active programs in each life sciences area. Finally, the Gemini program and preparations for Apollo distracted management attention from internal problems affecting the long-term value of the life sciences effort. For NASA management, the important life sciences issues from 1962 to 1965 were technical in nature: life support systems, inflight experiments, long-range planning.

Between January 1966 and January 1967 some of the constraining factors disappeared. Lovelace, who had resigned from NASA a few months earlier, died in an airplane accident in December 1965. In March and April 1966 Congress reduced the funding for the space program, including the life sciences budget. In November 1966 the Gemini program came to a close, and NASA management began to look ahead to the post-Apollo space program, whose life sciences requirements remained to be defined. Finally, in January 1967, the *Apollo 204* fire raised serious questions about NASA's life sciences capabilities. Together, these factors forced an internal reassessment of the organization and management of the Life Sciences Program and the role of the Life Sciences Directors Group.

## QUESTIONS OF AUTHORITY AND JURISDICTION

The impotence of the Directors Group was epitomized by two issues that commanded management's attention in 1966. The growth of interest in life sciences experiments and inflight investigations was a major feature of the Gemini era. The emerging program of inflight experiments had two aspects: unmanned biological investigations in space and biomedical (i.e., man-oriented) experiments to be flown on manned missions. The former provided justification for the Biosatellite Project and required coordination between the offices of Advanced Research and Technology (OART) (biotechnology and human research) and Space Science and Applications (OSSA) (biosciences). The latter justified the Medical Experiments Program, which nominally was under the control of the director of space medicine (Office of Manned Space Flight) but, in practice, fell under the control of the director of medical research and operations at the Manned Spacecraft Center. In both cases, coordination of life sciences inflight experiments was a source of internal conflict, which the Directors Group was incapable of resolving.

Working relations between Biosciences and Biotechnology-Human Research had never been good because of biology and human research overlap. In creating the decentralized life sciences program, NASA management had not clearly identified authority over research involving primates. Biosciences viewed primate research as a natural extension of biological research; while Biotechnology and Human Research viewed the same area as a natural concomitant of human research. NASA management had assumed that the distinction between the two was clear: both divisions would support primate research, but Biosciences would have authority when the research objectives were strictly scientific in nature, and Biotechnology and Human Research when the objectives were related to advanced manned flight requirements.[9]

In practice, this distinction was not so clear, let alone enforceable, as the history of Project Biosatellite revealed. Biosciences had received authority over Biosatellite because the overall objectives of the project were scientific and the early flights were to include only biological experiments. However, OART had authority to review and approve requests for funding research and technology (research and development proposals in support of approved flight projects), including those in the life sciences.[10] In short, while OSSA had authority over Biosatellite planning, it was supposed to obtain approval from OART for Biosatellite development funds. In addition, OART had been promised a major role in later Biosatellite flights, which would carry primates and conduct both scientific and man-related investigations.[11] To satisfy these mutual requirements, NASA management placed Project Biosatellite under the general jurisdiction of the OSSA Biological Experiments Program but created a Biosatellite Project Office under the director of Ames Research Center. This arrangement was intended to ensure that Biosatellite would be responsive to the requests of both program offices.[12]

This arrangement prevented conflicts at the project level, but not at the program level. The headquarters program offices (OSSA and OART) were unable to reach agreement on their respective roles in biological flight programs for reasons that were "biopolitical."* They were competing for the same scarce resources—funds and flight projects. Life sciences funds were severely limited compared with funds in other areas and were in jeopardy of being cut back further, since Congress had indicated unwillingness to continue previous levels of funding for the space program. Likewise, life sciences flight projects were limited, Biosatellite being the only approved project for inflight biological investigations.

From the beginning of the space program, funds allocated for research and development in life sciences were minuscule compared with those in other areas.[13] The separate life sciences programs had always been in competition for scarce resources. Quirks in the life sciences budget intensified this competition after 1965 (when Congress began to reduce the space program budget) and centered the competition between OSSA and OART. The first quirk was the elimination of space medicine as a life sciences line item in the FY 1964 and subsequent budgets. Henceforth, space medicine would receive its funds from several different sources

*The term "biopolitics" was coined by an unknown source to refer to the NASA-Air Force conflict over control of space medicine-bioastronautics programs. Subsequently, it was commonly used in reference to internal disagreements among NASA's life sciences programs. Basically, it indicates that controversies related to life sciences programs, whether internal or related to NASA's interactions with life scientists in the military services, government agencies, and the scientific community, were as much political as they were scientific.

within the Office of Manned Space Flight and appropriations for space medicine would not be detailed in the budget requests. Biosciences and human factors (biotechnology and human research) would continue to appear as research and development line items. The second quirk was that Congress assessed funding requirements for the life sciences in two different ways: the separate life sciences requests were examined in relation to the budget requests of their respective program offices, and the separate requests were combined and assessed as a Life Sciences Program budget. Congress, following the lead of Congressman Emilio Q. Daddario, began to do this in 1961 (when space medicine was still a line item) as a means of comparing NASA's life sciences budget requests with those of the Air Force.[14] Congress continued this policy even after space medicine had ceased to be a line item.

The effect was to center competition for life sciences funds between OSSA and OART, and the former regularly received the lion's share. Bioscience appropriations for each fiscal year from 1965 to 1968 were twice those for human factors.[15] This disparity derived in part from Congress's tendency to view human factors as an adjunct to space medicine. Although space medicine was not a line item, the director of space medicine provided Congress with a survey of space medicine research and development projects as part of the Office of Manned Space Flight budget presentations, and Congress often trimmed the human factors budget request in the belief that OART was planning projects that would duplicate those already in progress in space medicine.[16] The disparity also resulted from the fact that Congress was more likely to consider OART proposals duplicative of military life sciences efforts. Since the space medicine budget was not directly visible, and NASA and the Air Force were coordinating their bioastronautics programs, space medicine did not come under scrutiny in this regard after 1964. Congress assumed that the Office of Space Science and Applications would not be duplicating military programs since the services had no significant bioscience programs. The Office of Advanced Research and Technology, however, had responsibility for biotechnology and human research, an area of assumed Air Force strength. It also had responsibility for advanced research, which in the mid-1960s was directed toward requirements for a manned orbiting laboratory. Since the Air Force, but not NASA, already had approval for a manned orbiting laboratory, OART's proposals were often viewed, mostly incorrectly, by Congress as duplicative of Air Force efforts.[17] This circumstance did nothing to promote harmony between OART and OSSA.

Competition between the biosciences and human factors divisions was also intensified by management decisions related to life sciences flight programs. NASA management authorized only two life sciences flight programs: the unmanned, biological Biosatellite, and the man-oriented, biomedical experiments program. It was assumed that the Office of Advanced Research and Technology, with its authority to review supporting research and development proposals and its ability to sponsor research and development in support of both manned and unmanned life sciences flights, would contribute to both the biological and biomedical flight programs. In addition, the office was expected to play a significant role in both the later Biosatellite flights (which would carry primates) and the Apollo Applications (Skylab) program.[18] At this time OART had approval to conduct preliminary studies for a single biotechnology flight that would use the instrumented inner ear (otolith) of a frog.[19]

For the time, however, OART had no direct involvement in the management of life sciences flight programs. It was virtually excluded from participation in the biomedical experiments program, since space medicine had moved on to conduct its own supporting research and development and already had more proposals for biomedical experiments than it could fly aboard the approved manned flights. Moreover, OART's life sciences division supported the use of animals in support of human research, while the space medicine group had little interest in animal research. This encouraged OART to view Biosatellite as a logical locus for inflight research in biotechnology and human factors.[20]

Personality differences and jealousies aggravated this situation. The director of biosciences, Orr Reynolds, had a strong orientation toward basic research. Reynolds and his staff of bioscientists viewed themselves as the guardians of pure bioscience against applied research, engineering, and mission operations. Since OART was an applied research and engineering office, they viewed it with suspicion and considered any extension of its authority over biological programs would lead to subordination of basic research to applied research and to the loss of the program.[21]

Reynolds was also the only life sciences director, after Lovelace, who enjoyed a measure of personal authority within his office. In contrast to the directors of space medicine and human research, Reynolds served continuously as a life sciences director from the inception of the biosciences division and had considerable independence due to his program office associate administrator, Homer Newell. Longevity in office and program autonomy gave Reynolds confidence that he could promote the growth of a bioscience program. This made him unwilling to support decisions or agreements which, in his view, would retard progress toward this goal.[22]

Biotechnology and human research had four separate directors between 1962 and 1966—Eugene Konecci, Frank Voris, Rufus Hessberg, and Walton Jones. Although the last three had experience in research and research administration and were medical doctors, none was a medical scientist. Rather, they had strong backgrounds in flight medicine and a primary research interest in the application of biomedical knowledge to human factors engineering.[23] Because of their backgrounds, they were not threatened by the NASA emphasis on engineering and operations and were not concerned with creating and guarding an independent life sciences program. They viewed Reynolds's efforts to safeguard the biosciences as self-centered empire building.[24]

The OART directors also did not enjoy Reynolds's level of independence. As "acting" directors, they had limited authority. More important, their associate administrators did not give them the autonomy that Newell gave Reynolds. On several occasions Seamans asked the associate administrators for assessments of their life sciences programs. Newell submitted assessments bearing Reynolds's name and covered them with memos indicating his endorsement of Reynolds's views. By contrast, the OART administrators, Raymond Bisplinghoff and Mac Adams, gave Seamans their own assessments and provided no indication that they had ever consulted their life sciences directors.[25] This obvious disparity in influence may have aggravated tensions.

These several differences precluded a harmonious working relationship between Reynolds and his OART counterparts and made it difficult for the Directors Group to reach agreement on critical issues that affected these two divisions. Reynolds, suspecting that a greater role for OART in the biological flight program would result in Biosatellite being changed from a biological to a biotechnology project, resisted efforts to increase OART's area of jurisdiction. The OART life sciences directors, believing that Reynolds was ignoring their responsibility for the review of life sciences research proposals, were suspicious of his intentions and anxious for formal agreements defining OART's role in life sciences flight programs.

The interest in life sciences flight experiments also brought to light a problem of coordination between the director of space medicine and the Manned Spacecraft Center Directorate of Medical Research and Operations. In this case, an imbalance of authority had developed between the headquarters life sciences office and the center medical office. In brief, the center medical director had more input into space medical decisions, including definition and selection of medical experiments, than did the director of space medicine at headquarters. This imbalance derived from the management relationship between the Office of Manned Space Flight and the Manned Spacecraft Center and the evolution of the MSC medical directorate.

Since the beginning of the space program, the Manned Spacecraft Center (and its predecessor, the Space Task Group) had enjoyed more autonomy than the other centers. This derived from the personal authority of the center's director, Robert Gilruth, and from precedents set during

T. Keith Glennan's administration. During Project Mercury, NASA's top management allowed Gilruth virtual autonomy to oversee the activities of the Space Task Group, and this carried over when the Space Task Group transferred to Houston and became the Manned Spacecraft Center.

The medical research and operations division shared this autonomy. The space medicine groups were initially placed under the jurisdiction of the Space Task Group director, and this link was strengthened when Office of Life Science Programs Director Clark T. Randt agreed to allow the Space Task Group to remain independent of his office. Following the dissolution of the Office of Life Science Programs in 1961, subsequent space medicine directors made no effort to change this arrangement. The first two directors, Charles Roadman and George Knauf, were Air Force officers on loan to NASA. Neither had any strong interest in strengthening his position at headquarters or in expanding the authority of his office. Both seemed to view the prevailing arrangement as the one most conducive to the achievement of manned spaceflight mission objectives.[26]

Knauf, in fact, agreed to two changes that reduced the authority of the office. The first involved the elimination of space medicine as a line item in the NASA budget, which Knauf viewed as a means of improving coordination between NASA and the Air Force and of making space medicine more responsive to three separate manned flight project offices: Gemini, Apollo, and Advanced Programs. The change, however, deprived the director of space medicine of direct input into budget planning. The second change involved the statutory definition of the space medicine office's responsibilities. From 1961 to 1963 the space medicine director was designated the "medical representative" of the administrator for manned spaceflight, and his responsibilities included reviewing and coordinating medical programs at the centers, coordinating NASA's medical programs with those of outside agencies, advising the manned spaceflight administrator on medical support programs, and reviewing and coordinating the total medical program. In 1963, however, the directorship of space medicine was changed from a line office in the Office of Manned Space Flight to a staff element on the OMSF administrator's staff, and it was "relieved of management responsibility for the medical development programs in support of Gemini and Apollo." This change reduced the director's responsibilities and limited him to advisory authority.[27]

Knauf's successor, Lovelace, had the personal authority to change this situation but made no effort to do so. He, too, had no compelling interest in strengthening his personal position or expanding the authority of his office. Moreover, his background in flight medicine and mission-oriented space medicine may have led him to support autonomy at the Manned Spacecraft Center.

The diminishing authority of the director of space medicine was paralleled by increasing authority in the Manned Spacecraft Center medical directorate. From 1962 to 1964 the center had two separate loci for space medical activities: the Center Medical Office and the Crew Systems Division. The former was a staff element in the center director's office, with responsibility for advising the director on medical operations and coordinating overall center activities in space medicine. Medical research (a small part of the program before 1964) and life systems development fell within the jurisdiction of the director of the Life Support Systems Division, a line office. With the increasing importance of medical research and its application to life systems and mission planning, the center's management recognized the need for improved coordination of these medical activities. In 1965, Manned Spacecraft Center Director Robert Gilruth approved a proposal prepared by Center Medical Director Charles Berry and created the Directorate of Medical Research and Operations.

The directorate was established as a line office, and the director was granted authority commensurate to that of the other division directors. His responsibilities included coordinating and integrating the medical research, human factors, and medical operations efforts; coordinating the space medical activities in support of the Gemini, Apollo, and Manned Spacecraft Center Advanced Program offices; preparing space medical budget recommendations; effecting liaison between the directorate and the Ames Life Sciences Directorate and between NASA and the Air Force Aerospace Medical Division; and coordinating the inflight medical experiments program.[28] Clearly, his authority, at least in regard to approved flight programs, exceeded that of the director of space medicine.

The Directorate of Medical Research and Operations did not have authority over medical planning for the post-Apollo manned programs. This authority remained with the Directorate of Space Medicine, which had a medical research division headed by a science-oriented physician, Sherman P. Vinograd. In contrast to the space medicine directors, Vinograd's background was in medical science rather than flight medicine, and he had strong ties to the academic biomedical community. In early 1964, Vinograd proposed to manned spaceflight administrator George Mueller and Lovelace that he be authorized to bring together a committee of biomedical scientists to study NASA's biomedical requirements for the post-Apollo period. Vinograd reasoned that this committee would help justify NASA's long-range involvement in manned space programs and improve its relations with the biomedical community. Mueller and Lovelace endorsed the proposal and established the Space Medicine Advisory Group.[29]

This advisory group had responsibility for identifying the biomedical requirements of, and the appropriate experiments package for, a manned orbiting laboratory. It addressed this matter during the first six months of 1964 and presented its findings in *Medical Aspects of an Orbiting Research Laboratory*. However, it had an impact that extended beyond this singular effort. First, the Space Medicine Advisory Group was organized to operate as a "working group," that is, a body backed by "a clear statement of methods, goals, and anticipated end products." It was authorized to define the requirements for a specific flight program and to make recommendations that would have a direct bearing on long-range policy decisions. The only previous NASA-sponsored, external advisory group with comparable authority was the Biosciences Advisory Committee, which provided the justification for the Office of Life Science Programs.

Second, Vinograd invited into membership scientists who would bring a balance between those who had no previous experience in the space program and those who had practical familiarity with spaceflight; whose backgrounds, collectively, spanned the entire range of life sciences fields that were relevant to the manned program; and who were noted for their contributions to their specific fields, rather than for their name recognition, political activities, and stature in the aerospace community. In contrast to normal advisory committees, the medical group was not dominated by either academicians or flight surgeons and bioengineers. Nor was it a body of stellar luminaries. While all the members were well known within their fields, only Loren Carlson was a frequent scientific advisor to NASA. Among the members were Ashton Graybiel, a physician, research administrator at the Naval School of Aviation Medicine, and internationally recognized space medicine researcher; Ross McFarland, a physiologist who pioneered in the effort to bring space medicine into medical school and public health programs; and James V. Warren, a physician and medical scientist who started the second academic program in space medicine (at Ohio State University) and who had served on the President's Science Advisory Committee panel that investigated NASA's biomedical programs in 1962.[30]

Given the eminence and diverse backgrounds of the committee members, their recommendations received serious attention from NASA officials and became the foundation for the Apollo Applications (later Skylab) biomedical experiments program. The activities of the group also enhanced the authority of the director of space medicine by providing a justification for a Medical Experiments Panel within the Manned Spaceflight Experiments Board.[31] This panel gave the headquarters space medicine office direct input into the planning of medical experiments for manned spaceflight, an authority previously within the exclusive jurisdiction of the medical office at the Manned Spacecraft Center. After the establishment of the Medical Experiments Panel, the MSC office had to submit its experiments for headquarters review, and its proposals were to be weighted against other proposals for biomedical experiments.[32]

These several events pointed toward an obvious need for clarification of responsibilities and authority in the area of inflight life sciences experiments. Because the Life Sciences Directors Group lacked the authority to implement necessary agreements, the resolution of contentious issues required the direct intervention of Seamans and the program office associate administrators. On January 24, 1966 these administrators directed the life sciences directors to review the life sciences experiments program and prepare recommendations for resolving specific issues related to the incorporation of medical experiments into manned spaceflight programs, the use of primates in inflight investigations, and the life sciences requirements for advanced manned programs.[33] With this authority, the life sciences directors were able to form an agreement concerning spaceflight experiments that would "satisfy the agency's long and shorter range needs" and "prescribe the procedures necessary for its accomplishment."[34]

The life sciences directors deliberated for three months before finally endorsing, on March 9, 1966, an "Agreement for the Management of an Integrated Life Sciences In-Flight Experiments Program." Subsequently approved by Seamans and the program office administrators, this agreement divided the life sciences experiments program into three parts: medical-behavioral experiments, involving "procedures performed on the spacecraft crew or passengers and designed to measure human capability or reaction"; biological experiments, "procedures designed to elicit an understanding of biological phenomena and functions by means of biological experimentation"; and biotechnology experiments, "engineering procedures designed to evolve advanced life science technology for support, protection or assistance to man in space flight." The agreement made the life sciences directors "executive agents" for these three areas and provided for review of life sciences experiments by the National Institutes of Health and a Medical Advisory Council. It also gave the Directors Group authority to "establish objectives, develop programs and define related efforts" relative to the experiments program.[35]

This agreement reduced, but did not eliminate, the coordination problems described earlier. While clarifying the division of authority between the biosciences and biotechnology offices, it did not resolve the issue of authority over primate experiments. By making the space medicine director the "executive authority" for medical experiments and providing for review of medical experiments by the National Institutes of Health and a Medical Advisory Council, the agreement strengthened the authority of the headquarters medical director relative to the Manned Spacecraft

Center medical officer in relation to long-range programs, but it did not change the prevailing authorities relative to Gemini and Apollo. It was a step forward, but one that the Directors Group had been unable to take on its own initiative.

The impotence of the Directors Group was also revealed in deliberations over the chairmanship of the Life Sciences Directors Group following Lovelace's death. The instructions that established the Directors Group had made provision for a permanent chairman to act as NASA's spokesman to life scientists outside NASA. The space medicine director was designated the permanent chairman both in deference to Lovelace's personal authority and as a compromise to avoid conflict between biosciences and biotechnology directors. Because the latter was a medical doctor, the biosciences director was designated as alternate chairman to ensure a balance between medical and biological authority. Here again, however, the decision treated the biotechnology director as the "odd man out."

Several problems marred this arrangement. First, since Lovelace rarely attended meetings of the Directors Group, the biosciences director, Orr Reynolds, normally presided over the meetings.[36] Second, although Lovelace had status within the scientific community, the Directorate of Space Medicine did not. The external scientific community tended to view NASA's space medical program as isolated from the community, unscientific in its approach, and flight oriented.[37] Finally, the Directors Group did not speak with a single voice, but with three voices—each director presented his own views to the external community, and each tended to seek out and address his own distinct scientific audience.

The overall effect was to further weaken confidence in NASA's life sciences program among external life scientists. For nearly two years following Lovelace's death, the space medicine directorship was filled by flight surgeons who had little standing in the scientific community and could not be considered NASA's life sciences spokesmen. The biosciences and biotechnology directors each tried to become the unofficial life sciences spokesman, with a tendency to seek support from science advisors favorable to their respective programs, in effect, using external life scientists to bolster their program positions. This led life scientists outside NASA to doubt that NASA had a serious interest in their recommendations.[38]

The role and authority of the Directors Group chairman emerged as an issue after Lovelace's death. Initially, Seamans appointed Orr Reynolds (the permanent alternate chairman) as acting chairman and directed Reynolds to serve in this capacity from January through June 1966, or until a permanent director of space medicine could be appointed. Possibly anticipating some disagreement from the biotechnology director, Seamans directed the program office administrators "to prepare thoughtful recommendations for coordination in the life sciences area."[39] Seamans specifically wanted suggestions concerning the role and responsibilities of the Directors Group and the procedures for designating the chairman of the group.

The program office administrators were in unanimous agreement that the role and responsibilities of the Directors Group should not be expanded, and that the group should remain a "strictly advisory" body. However, they disagreed on procedures for designating the chairman. Space science administrator Newell, endorsing recommendations from Reynolds, favored retention of the permanent chairmanship concept, arguing that this was the only sure means "to sustain rapport and maintain communications with the Life Sciences community.[40] Advanced research and technology administrator Mac Adams urged that the chairmanship be placed on a rotating basis to be consistent with the tripartite division of the program. Adams may have made this suggestion to ensure that Reynolds's temporary appointment as chairman would not become permanent. Adams apparently was concerned that any increase in the authority of the biosciences director would diminish the authority of the biotechnology director. Six months earlier, he had tried to convince Seamans to authorize the biotechnology director to replace the biosciences director as alternate chairman of the Directors Group.[41] Manned spaceflight administrator George Mueller initially favored retention of the permanent chairmanship; however, he later joined Adams in supporting a rotating chairmanship.[42]

The issue of the chairmanship gave further evidence of the impotence of the Directors Group. Clearly, the authority to define the role and responsibilities of the chairmanship and select the person who would fill it was not in the hands of those responsible for the life sciences—it was held by Seamans and the program office administrators. These administrators saw no value in expanding the authority of the Directors Group or strengthening the position of the chairman. The administrators, with Seamans's backing, declined to increase the authority and independence of the group. They issued new management instructions that stressed (as early instructions had not) the "strictly advisory nature" of the Directors Group, and specifically denied the group any "authority to direct action to be taken by its individual members or by others."[43]

## THE BOLLERUD REPORT

Although Seamans and the program office administrators refused to make fundamental changes in the authority of the Life Sciences Directors Group or to promote an expanded, independent Life Sciences Program, they could not ignore the reality that the life sciences program was fraught with problems. This was evident in the enduring conflicts among life sciences offices and in the difficulties in reaching agreement on medical and biological experiments and the Directors Group chairmanship. While Seamans backed the program office administrators and did not view life sciences as one of NASA's major program objectives, he did want to find a way to eliminate conflicts within the program. Accordingly, he asked the administrators to make a "thoughtful review" of the agency's life sciences programs.

The first response came from Col. Jack Bollerud, acting space medicine director, who presented his ideas in a lengthy report, "Staff Study of the Structuring of the Life Sciences Activities within NASA." Although Bollerud's background was in flight medicine and he had no strong contacts with academic life scientists, his report reiterated the findings and recommendations of earlier reports prepared by the National Academy of Sciences and the President's Science Advisory Committee.

Bollerud found the Life Sciences Directors Group totally ineffective, citing as evidence the tendency of the directors "backed by their Associate Administrators" to devote more effort to the "protection and fostering . . . of their own programs and interests" than to the needs of the Life Sciences Program, and the inability of the group's chairman "to recommend actions" that did not have the prior approval of the associate administrators. This encouraged the directors to become primarily concerned with "consolidating their positions and programs," which resulted in "duplicative" efforts and the tendency of the centers "to play one office against the other to augment their research budgets." The source of these problems, he claimed, was NASA management's insistence that the life sciences be organized according to "the often arbitrary and usually obscure divisions between applied, advanced, and basic research," a form of organization stemming more from "political considerations" and the requirements of "the overall NASA organization" than from the legitimate needs of the Life Sciences Program.

Restating the views of biomedical scientists outside NASA, Bollerud recommended that NASA establish a life sciences associate administrator and authorize him to "overview" all NASA life sciences activities; serve as NASA's "interface for life sciences with the scientific community"; define "areas of responsibility for each of the NASA life sciences activities and for resolving conflicts pertaining thereto"; review program and funding requirements for NASA's life sciences and recommend changes when duplicative efforts or jurisdictional overlaps became evident; review, approve, and direct changes in the missions of the NASA centers if "in the best interests of the total life sciences activities"; and make "final determination" of life sciences requirements for "facilities and items of equipment." He also recommended that the life sciences administrator be designated the "principal biomedical officer of NASA," be hired to serve as a "career officer" of NASA on a full-time basis, and "be selected" on the basis of his commitment to the Life Sciences Program rather than his "name recognition."[44]

Bollerud's findings and recommendations did not cause any immediate change in the organization and management of NASA's life sciences programs. However, coming from within the agency and from one who was not striving to create a power base (Bollerud was a career Air Force officer on temporary assignment to NASA), the report could not be dismissed as misperceptions by ivory-tower academics or as an internal power play. Bollerud's report and subsequent events over the next six months motivated Seamans to authorize a major internal review of life sciences organization and management within the agency.

# 9
# A new bioastronautics crisis

NASA's biomedical capabilities and management of its life sciences programs again became matters of public concern in 1967. The *Apollo 204* fire in January 1967 resurrected doubts about the agency's ability to safeguard the astronauts and complaints about its pragmatic "incremental" approach to the qualification of man for spaceflight. Concurrently, the President's Science Advisory Committee issued a report on post-Apollo goals in space in which it found NASA's biomedical program the chief impediment to extended duration manned spaceflights.

While NASA's top administrators had not been insensitive to the agency's requirements and management problems in the life sciences during the preceding four or five years, they had tended to minimize them. Again confronted by public scrutiny and criticism they decided to initiate their own review.

Between January 1967 and January 1970 NASA's biomedical requirements and capabilities and the organization and management of its life sciences programs were subjected to seven separate investigations: two internal, two by the President's Science Advisory Committee, one by the National Academy of Sciences, and two by congressional committees. Collectively, these investigations confirmed the recurring criticisms: NASA had failed to establish a sound scientific foundation for biomedical support of extended duration manned spaceflight, and its arrangements for administering its life sciences programs were a major cause of the problem. The recommendations of these committees, combined with a reduction of official and public support for manned spaceflight following the initial lunar landing, forced NASA management to reevaluate its approach to biomedicine and life sciences administration. This led, in late 1970, to a major reorientation of life science activities and reorganization of the life science programs.

## PUBLIC SCIENTISTS' PERSPECTIVES ON THE POST-APOLLO SPACE PROGRAM

As Project Gemini ended in late 1966, President Johnson and his advisors on the National Aeronautics and Space Council and the President's Science Advisory Committee (PSAC) began to take a serious look at the post-Apollo space program. PSAC, through its Space Science and Space Technology panels, had the task of reviewing civilian and military space programs and recommending priorities for the 1970s.

The committee completed its study on January 11, 1967. In a report titled *The Space Program in the Post-Apollo Period,* it advised the President that he could either follow the example set by President Kennedy in 1961 and declare a single major program objective, such as a Mars flyby or landing, or propose a balanced and diversified program that had many, but more limited, objectives. The authors clearly favored the latter, a "well-rounded" space program that would develop "a spectrum of national capabilities for operations in space."[1] To achieve a "substantial margin of flexibility" in objectives, the space program should have increased emphasis on scientific investigations, decreased emphasis on manned exploration, and more effective integration of manned and unmanned flight projects. The report proposed five "major objectives" for the 1970s:

1. Extension of the Apollo program "in order to exploit our anticipated capability to explore the Moon"
2. "A strongly upgraded program" of unmanned exploratory flights to the planets for both scientific investigation and planning of future manned missions
3. A program of scientific investigation and technology development to determine human capabilities and requirements in long-duration flight "in anticipation of manned planetary exploration"
4. The "vigorous exploitation" of space science and applications for purposes of "national security and the social and economic well-being" of the nation
5. The "exploitation of our capability to carry out complex technical operations in near Earth orbit" for the advancement of "science, particularly astronomy"[2]

The report found NASA's biomedical capabilities inadequate insofar as long-duration (more than 14 days) manned spaceflight was concerned, citing insufficient ground-based studies; inadequate bioinstrumentation; insufficient research in cell biology and mammalian physiology; "fragmentary and entirely inadequate" investigations of central nervous, metabolic, and endocrine system functions; and incomplete pre- and postflight assessments. In short, NASA's biomedical programs had not produced the fundamental knowledge of human physiology and psychology that would be essential for predicting human responses to long-duration flights.[3] A major manned program, such as a Mars landing, should be forestalled until the 1980s. NASA should concentrate in the immediate post-Apollo period on Earth-orbital flights of 28 to 100 days, using an orbital workshop and both primates and humans as test subjects. "Continuous medical observation" and controlled investigations of mammalian physiological and psychological reactions to spaceflight should be augmented by extensive, ground-based research to establish norms against which inflight responses could be measured. The Biosatellite program should be expanded to study effects of spaceflight on human analogues.[4]

NASA's only scheduled post-Apollo manned program, the Apollo Applications Program, was also criticized. The report questioned whether modification of Apollo hardware could provide the laboratory and workshop space necessary for comprehensive biomedical investigations. The tentative plan to have the astronauts construct the workshop in space was troubling, since NASA lacked the necessary data on human metabolic requirements to predict their ability to perform such work in space. The report recommended that NASA coordinate its plans for the Apollo Applications Program closely with the Air Force's plans for a Manned Orbiting Laboratory. NASA might be able to adapt the latter to its Apollo systems, while the Air Force could expand the scope of the orbiting laboratory to permit increased biomedical research.[5]

Not surprisingly, NASA's administrators were irritated by the Science Advisory Committee's report. While they conceded that the biomedical program was inadequate from a strictly scientific perspective, they contended that it was more than adequate to meet the specific (and nonscientific) objectives of the lunar program.[6] The report's emphasis on making animal research a "pacing item" for manned flights was unwelcome; NASA's biomedical scientists, engineers, and mission planners remained convinced that animal research had limited usefulness within the manned program.[7] Finally, NASA's administrators were not favorably disposed to linking the Apollo Applications Program to the Air Force's orbiting laboratory. Not only had NASA fought long and hard to make the civilian space program independent of the military, it had little to gain from the proposed affiliation. In 1967 the Air Force program was two years behind schedule, was plagued by political and funding difficulties, and was assigned a very low priority within the Department of Defense.[8]

The PSAC report had no direct effect, possibly because public attention was soon riveted on a far more serious matter, the *Apollo 204* fire.

Although subsequent congressional investigations absolved NASA's biomedical personnel of responsibility and traced the tragedy to an error in operational procedures (using a 100 percent oxygen atmosphere during ground-based simulations), the fire confirmed some scientists in their belief that NASA tended to be less sensitive to human health and safety than to engineering and operations. The President's Science Advisory Committee, "prompted by a growing unease . . . [concerning] NASA's biomedical effort . . . on the part of the interested scientific community,"[9] formed an ad hoc Panel on Space Biology and Medicine to investigate "NASA's current and proposed activities designed to qualify man for extended space flight."

In presenting its findings and recommendations in September 1967, the panel reaffirmed those contained in the January report. The second report reemphasized the need for a major and comprehensive program of fundamental biological and biomedical research to qualify man for long-duration flight. It went further, however, and stated that NASA, "as presently organized, does not appear to have the capability of developing a satisfactory program to study the effects of the space environment on man." The reason was that the agency lacked "the scientific leadership, program for needed manpower development, and method for allocating funds." The medical program at the Manned Spacecraft Center in particular, was found deficient "in scientific competence at both the leadership and operating levels" and "not capable of mounting or supervising a meaningful program that will qualify man for interplanetary flight."[10]

It appears that the authors (particularly the principal author, Dr. Eugene Stead) were interested not so much in stimulating NASA to reorganize the Life Sciences Program as in encouraging the agency to expand the role of external life scientists in biomedical program planning and to abandon the incremental approach favored by the Manned Spacecraft Center staff in favor of the approach favored by scientists who supported the PSAC's position. The report recommended no organizational changes, but stressed the need for "a formal in-house mechanism" to bring together "imaginative biomedical and physical scientists" to develop "new technologies . . . to exploit the demands of this new type of environmental medicine" and to generate "new programs" for the scientific investigation of such "environmental factors" as "the long-term effects of prolonged weightlessness."[11] Indeed, some within the committee went so far as to suggest that NASA replace the existing medical staff at the Manned Spacecraft Center with "a permanent group under Dr. Stead."[12]

NASA Associate Administrator Robert Seamans and Life Sciences Directors Group Chairman J. W. Humphreys viewed the report as self-serving. Nonetheless, they recognized that it could not be ignored. Seamans found the report "disturbing," especially in its references to the medical program at the Manned Spacecraft Center, and concluded that its finding "warranted" an internal investigation. Humphreys reached the same conclusion and suggested that "some input from a few non-agency biological and medical scientists" could have "a salutary effect" and dispel some of the concerns raised by the report.[13] Accordingly, Seamans asked two administrators within the Office of Programs, Bernard Maggin and Robert Bell, to conduct a preliminary investigation and recommend a course of action.

While Maggin and Bell were at work (September and October 1967), Stead's ad hoc panel was upgraded to a Biomedical Working Group and authorized by the President's Science Advisory Committee to conduct a thorough investigation of the biomedical requirements for, and long-term environmental effects of, long-duration spaceflight. Officially, this was part of a broad investigation of "the role of government agencies and universities in the study of the effects of the environment on man,"[14] and the Science Advisory Committee was interested not only in NASA's long-range biomedical capabilities but also in NASA's impact on health resources and medical manpower. President Johnson had established a Federal Interdepartmental Health Policy Council to recommend changes that would contribute to an improvement in health care funding and delivery. Some council officials believed NASA's medical manpower and medical research funds grossly exceeded its requirements, since only a handful of astronauts were beneficiaries. Consequently, the President's Science Advisory Committee study was inspired not only by the imminence of the post-Apollo space program but also by the interests of federal health policy.[15]

Stead's Working Group did not complete its investigation until May 1968 and did not publish its final report until November 1969. However, interim reports were issued and basically restated earlier arguments. The main thrust was that "life scientists continue to play a minor role in the affairs of NASA" because engineers and mission planners "are again setting the constraints." As a result, NASA's biomedical programs had contributed little to "the understanding of biological processes" and, as organized, would "never make major contributions to the life sciences."[16]

Stead summarized the Working Group's overall findings at a general meeting of the Space Science and Technology Panel in March 1968. First, he contended, "high level policy" within NASA "had not favored the creation of a significant biomedical program" due to the "test pilot-flight surgeon relationship" that characterized the Mercury, Gemini, and Apollo projects. Second, NASA's organizational arrangements had "resulted in poor communications between the various program offices in the biomedical area," a situation that had retarded the growth of the life sciences program at Ames and allowed the Manned Spacecraft Center biomedical program to isolate itself from scientific considerations. Third, "biomedical research" at both MSC and Ames was minimal and "totally inadequate to the future requirements of a significant biomedical program." Finally, the MSC biomedical staff lacked the scientific competence "to develop basic research programs, to use biological test systems other than man, or to develop meaningful research protocols for use in space flight."[17] Stead offered no recommendations for improving the organization of the life sciences programs, though he would do so in his final, published report.[18]

This report was not widely distributed, although the findings were presented to the President's Science Advisory Committee, the National Aeronautics and Space Council, President Johnson, and NASA's top management. Stead and his group held back from publishing the report, partly because they wanted it to be in final form and partly because they were awaiting the outcome of NASA's internal investigation.[19]

## INTERNAL ASSESSMENTS

Although NASA's administrators were aware of the management problems that hindered coordination of the life sciences programs, as long as these problems did not interfere with Gemini and Apollo or attract unfavorable publicity they had no incentive to take immediate action. The incentives came in the form of adverse publicity following the *Apollo 204* fire and of strong criticisms from the biomedical committees sponsored by the President's Science Advisory Committee. As J. W. Humphreys observed:

> With the culmination of short duration flights exhibited by Mercury and Gemini, attendant budgetary constraints, and the need to solve different and more complex problems (long duration manned flights), there was a requirement for a change in attitude and a need to reconsider goals and missions, responsibilities, and scientific objectives. It was not, however, until the rather critical Biomedical Subcommittee report of the President's Science Advisory Committee (1967) that a comprehensive study was requested which underscored: the degree of programmatic imbalance, the significance of inter-office organizational differences, and the validity of specific internal and external problem areas.[20]

Management's first response was to request a preliminary study in August 1967. The investigation conducted by Bernard Maggin and Robert Bell was the first agencywide life sciences review conducted by high-level administrators since 1962. Maggin and Bell presented their findings in the early autumn of 1967.[21] They recognized the existence of the internal problems to which many life scientists had alluded but which management had generally ignored. They cited "a deep-seated jurisdictional dispute" between the Biosciences and Biotechnology-Human Research divisions, the duration of which had "generated considerable frustration" on both sides. The dispute had undermined the confidence of the scientific community and encouraged views such as those expressed in the Science Advisory Committee reports, had generated confusion at the centers (particularly Ames, where the life scientists felt "that they are expected to have allegiance to one office or the other"), and had precluded development of "a single agency position and program plan" in disputed scientific and technical areas, the "classical example" being primate flights.[22]

Maggin and Bell also identified the problem of coordination between the OMSF Directorate of Space Medicine and the MSC Directorate of Medical Research and Operations. They noted that a "fundamental dispute over questions related to authority and responsibility" was "evolving" between headquarters and MSC medical officers. The sources of the dispute were changes in the nature of the two offices. While the headquarters directorate had been "somewhat out of the mainstream" of NASA's life sciences for many years, it was beginning to develop into an important office because of the need to prepare a comprehensive biomedical program for the Apollo Applications Program and to appoint J. W. Humphreys, an assertive administrator and former Air Force major general. Concurrently, the MSC directorate was expanding from an "operational support" office into one concerned with the "broader role" of medical operations, medical research, and clinical medicine. This, combined with the center's traditional autonomy, discouraged cooperation between the two space medical offices.[23]

Finally, Maggin and Bell identified the ineffectiveness of the Life Sciences Directors Group. "At best," they observed, the group had achieved "spotty coordination." Though expected to coordinate "the role and missions of the different organizational elements" and the "planning and programming process," the directors were unable to do so, largely because of the absence of any "mechanism for resolving the disputes" which are generated in these areas. Such mechanisms were lacking because NASA had virtually no "official documentation" delineating the roles and responsibilities of the life sciences components—no "policy directives," no "single functional statement," and only one management instruction (the one establishing the Directors Group). Maggin and Bell concluded:

> Since the responsibilities for the three offices have never been delineated, each member has proprietary interests to protect—not only those of his own, but also those of his boss. He has little precedent on which to yield or compromise on matters with jurisdictional implications. Is it reasonable, then to expect them to compromise their own interests or those of their bosses?[24]

These enduring problems, the authors suggested, were aggravated by competition for insufficient resources and by the "diversity of program practices within the three components." The three life sciences budgets were prepared separately. "They [were] never put together so that the resources required for the Total Life Sciences Program [could] be weighted against competing demands." This, in turn, minimized top management's interest in the life sciences since the overall program lacked "sufficient visibility." The diversity of practices hindered program coordination since each of the three offices had its own peculiar patterns of "program execution," "program planning," advisory committees, and research objectives.[25] "Specific management action" was necessary because life sciences activities were growing and changing at both headquarters and the centers. Maggin and Bell listed various suggestions for reorganization that had been made to them during their investigation. All the suggestions pointed to the need that had been identified in previous internal and external reviews of the Life Sciences Program—a centralized, high-level life sciences authority.[26]

NASA management ordered a more detailed and extensive review of the problem to identify specific management options. Seamans was aware that the Science Advisory Committee planned to follow up its "preliminary report" with a more detailed investigation, and he was concerned over growing friction between the Directorate of Space Medicine at headquarters and the Directorate of Medical Research and Operations at MSC.[27] Accordingly, he directed Humphreys to organize a task group to identify the specific areas where changes were warranted, formulate "options" for implementing those changes, and make specific recommendations on the "delineating of roles and missions."[28]

This Life Sciences Study Task Group held its first meeting on December 8, 1967, its twentieth on April 17, 1968. Maggin was executive secretary; the other 13 members were drawn from eight field centers and five program offices at NASA Headquarters. That the group had serious backing from NASA's top management was indicated by the terms of the appointments. There was one major constraint: recommendations would have to conform to existing organizational arrangements.[29] The group assumed that the Maggin-Bell study had substantiated the existence of major weaknesses and justified major changes.[30]

The first task was to define the objectives of the life sciences program and its components. Six objectives were defined:

*Exobiology:* investigations into the origin and evolution of life and the search for extraterrestrial life

*Contamination and Containment:* development of policies, procedures, and standards; conduct of research and development related to protection from and prevention of extraterrestrial contamination

*Bioscience:* biological investigations related to the space environment, but not directly related to problems of manned spaceflight
*Human Research:* biomedical research and development to increase knowledge of human physiological and psychological responses to spaceflight and to increase the effectiveness of man as a component of aerospace systems
*Biotechnology:* research and development related to life support, protective, and operational systems for all "biological activity"
*Flight Projects:* conduct of approved and assigned flight projects[31]

The group then proceeded to analyze the past, present, and projected future activities of each of the life sciences components in an effort to find a logical correlation between specific objectives and specific program activities. The overall goal was to identify the one life sciences office whose responsibilities were most often correlated with the objectives described above. From this effort, the group conceived a total of 20 possible management options.[32] It then assessed each option in terms of the following "evaluation criteria":

1. Clear delineation of authority and responsibility
2. Improved integrated program planning, execution, and review
3. Improved external relations
4. Degree of optimized use of resources (staff and funds)
5. Improved headquarters-field centers relationships
6. Consistency with NASA organizational philosophy
7. Minimal degree of disruption of organization
8. Provision of mechanism for resolving disputes[33]

On this basis, the task group decided on three management options. The first, which was favored by the majority of task group members and by the directors of space medicine and biotechnology and human research, called for designation of one of the existing life sciences offices as the "single office" for life sciences "research and technology." This option would place all "biology and medical science research and technology" in the Office of Advanced Research and Technology. It would allow the individual program offices control over respective flight projects, but would give OART responsibility for unmanned flights that were, entirely or in major part, life sciences flights.[34]

A minority, backed by the associate administrator for space sciences and the director of biosciences, favored an option that would make space biology independent of man-oriented research and development and would leave exobiology, contamination and containment, and basic bioscience under the jurisdiction of space sciences. The Office of Advanced Research and Technology would have jurisdiction over human research and biotechnology and the authority to coordinate the overall life sciences program and represent the life sciences in dealings with external agencies.[35]

The fact that the group could not agree on a single option reflected the reality that its members had not been able to set aside parochial interests. Indeed, when asked to review a selected set of contracts and determine the office that should have jurisdiction over them, the biosciences representative and the biotechnology-human research representative each claimed 60 percent of them.[36] Moreover, several officials attempted to bypass the committee and influence its decisions. Manned Spacecraft Center medical director Charles Berry proposed that NASA make the center the "lead center" for life sciences programs and grant it the authority to direct and coordinate the Life Sciences Program. The group rejected the suggestion as inconsistent with NASA management philosophy. Berry responded by contacting NASA Administrator James Webb. However, Webb demurred and the matter was dropped.[37]

More significant, the associate administrator for space sciences, John Naugle, and the director of biosciences, Orr Reynolds, sought to bypass the task group and undertake their own study of the problem. Naugle and Reynolds were concerned that the task group would propose a centralized life sciences office, that space sciences would not be the designated office, and that space biology would be retarded by emphasis on research and development directly related to manned flights. Naugle argued that the "concern over reorganization" was unrelated to the needs of space biology, but rather a response to recurring criticisms of NASA's medical programs in support of manned spaceflight. For this reason, he contended, reorganization would work to "the detriment of space biology," as fundamental biology would have a low priority in an integrated life sciences program.[38] Subsequently, Reynolds, with Naugle's backing, prepared several reports that were intended to bolster the space sciences position.[39]

Humphreys urged NASA Associate Administrator Homer Newell (Seamans had resigned in December 1967) to adopt the recommendation of the task group, but Newell did not comply. Possibly because of his former position as associate administrator for space sciences, he shared the concerns of Naugle and Reynolds and their preference for the option that gave autonomy to space biology.[40] Newell may also have been influenced by the views of external life scientists, which had been solicited by Reynolds in an effort to gain support for his position. These scientists encouraged Newell to maintain the autonomy and integrity of NASA's biological program.[41]

Humphreys and Walton Jones, director of biotechnology and human research, were not impressed by these arguments.[42] However, Newell rejected the task group's recommendations, although to ensure coordination he accepted the suggestion that the Life Sciences Directors Group be replaced by a body that had the authority to make and implement decisions. He also accepted the task group's view that the term "life sciences" was too nebulous and should be replaced by the designation "space biology and aerospace medicine." He agreed that this more accurately reflected the reality that NASA had two, rather than three, life sciences programs, one oriented toward fundamental biology, the other toward biomedicine.[43]

Accordingly, Newell established the NASA Space Biology and Aerospace Medicine Board in May 1968. It included the three program office associate administrators and the three life sciences directors as members and was chaired by the associate administrator for advanced research and technology. Its function was "to furnish the necessary coordination, review the direction of offices represented on the Board and to achieve a suitably balanced program free of wasteful duplication and conflict." Within this framework, the Office of Space Sciences would have jurisdiction over exobiology, fundamental biology, and "associated SRT"; the Office of Advanced Research and Technology over biotechnology, human research, human factors, environmental control, man-machine relationships, and medical research; and the Office of Manned Space Flight over manned spaceflight safety and operations. To ensure day-to-day coordination, the board would have a Program Management Council composed of the life sciences directors and representatives from the Manned Spacecraft Center and Ames. This council would have daily responsibility but, like the Directors Group, no authority.[44]

In effect, NASA management once again responded to evidence of a need for major reorganization of its Life Sciences Program by making minor adjustments to the existing organization. The Space Biology and Aerospace Medicine Board did make official what had previously been unofficial: real authority over the management of the life sciences programs rested with the program office administrators, rather than the life sciences directors. Nevertheless, the Program Management Council was really no more than a restructured Life Sciences Directors Group, and the allocation of program responsibilities was as nebulous as before. For example, the redefinition of program objectives still did not clarify the old problem of authority over animal research, which was a tool for both biology and biotechnology. In spite of two extensive internal reviews, NASA management made no more than cosmetic changes, and the long-standing management problems in the life sciences endured.

## CONGRESSIONAL BIOPOLITICS

NASA management's response to external criticisms of its biomedical programs in 1967–1968 was comparable to its reaction to similar complaints five years earlier. Its initial reaction was to mount a major internal review, an effort to defuse concerns as much as to identify and eliminate program defects. In both instances, management was willing to make changes so long as they did not entail a major reorganization or redistribution of program authority. Later, when public interest waned, management reacted by making some fine adjustments to the organizational machine, while minimizing the need for major modifications in the overall design. However, in 1968 public interest in the life sciences did not wane for long. The President's Science Advisory Committee continued its investigation of NASA's life sciences and issued a final report in 1969, at a time when Congress was already considering the need to review one aspect of the life sciences, the Biosatellite Project.

Congress had shown little interest in NASA's Life Sciences Program after 1963, when NASA and the Air Force resolved their disagreement over their respective Space Medicine and Bioastronautics programs. The resolution of that issue and the success of the Mercury and Gemini programs eliminated doubts about NASA's ability to provide adequate biomedical support for the astronauts. Even the *Apollo 204* fire did not motivate Congress to investigate NASA's biomedical programs, since there was no evidence that that tragedy resulted from biomedical inadequacies.

Ironically, Congress's renewed interest in NASA's biomedical programs was due to an event, *Biosatellite III,* that lay outside the manned space program and had only marginal relevance to biomedicine. *Biosatellite III,* an unmanned biological flight, was terminated on July 6, 1969, 9 days into its projected 30-day mission. The *Biosatellite III* capsule carried a primate named Bonnie. The mission was terminated after Bonnie developed dehydration and associated circulatory problems; she died eight hours after Earth recovery. Weighed against the accomplishments of the space program, the failure of *Biosatellite III* to achieve all its mission objectives was a relatively minor event and given the impending launch of *Apollo 11,* few Americans mourned (if they even noticed) the passing of the unfortunate primate. The loss was a great disappointment, however, to a small coterie of biologists within NASA and the community of biological scientists.

*Biosatellite III* was the last of a series of unmanned biological flights initiated in 1962 to conduct scientific investigations in space on subhuman organisms. From its beginning, the Biosatellite Project was plagued by funding problems, cost overruns, and mission failures.[45] Yet it was NASA's sole concession to scientists who believed that this type of basic biological research should have some priority in the space program as a support to the manned space program.[46].

For these scientists, *Biosatellite III* represented the last opportunity to convince NASA's management to reconsider its decision to terminate the

Biosatellite Project. In April 1969 NASA had announced its intention to end the project and had asked Congress to redirect Biosatellite funds to other projects. At the time, NASA planners were looking beyond the lunar landing missions toward the post-Apollo space program, and were hoping to receive authorization and support for a major objective (such as a manned Mars landing or an orbiting space station) that would be to the space program of the 1970s what the Manned Lunar Landing Program had been for the 1960s. A program of long-duration manned flight (28-plus days) would require, among other things, a greatly expanded program of basic and applied research into human requirements for space. From this perspective, it was believed by top management that continuing biological investigations in space would contribute little to the major long-range plans of the agency, and the extended manned flights would provide opportunities for a broader range of basic biological investigations than would be possible in Biosatellite flights.[47]

NASA's plans to terminate Biosatellite disturbed scientists who were closely tied to it. Biologists like Ross Adey and Nello Pace, who were linked to research settings outside NASA, had worked long and hard to convince NASA to support programs in space biology and to convince their academic colleagues that NASA had a sincere desire to support fundamental biological investigations in space. For these scientists, Biosatellite represented a realization that their efforts had not been in vain.[48]

The failure of *Biosatellite III* intensified the feelings of these scientists. From a scientific perspective, Bonnie's death seemed a strong justification for more intensive investigations into the biological effects of spaceflight, and unmanned biological flights in the Biosatellite mode were more conducive to these types of investigations than biological experiments flown on manned flights. From a practical standpoint, the biological problems that developed in *Biosatellite III* could presage the types of biological problems that would emerge during long-duration manned flights. Biomedical scientists and bioscientists argued that these problems warranted detailed study before extended manned missions were undertaken. NASA's critics in the scientific community viewed the agency's decision to terminate the Biosatellite flights, especially in view of *Biosatellite III*, as more evidence of indifference to the scientific aspect of the space program and of willingness to subordinate biomedical issues to engineering and operations considerations.[49] The other side of the coin was concern that the use of animals as a precurser to human flight clouded the biomedical issues. Data were difficult to evaluate and could give faulty information. The failure of *Biosatellite III* could have been due to handling of the subject, not "space environment" problems.

Scientists and congeries of persons and groups opposed to the use of animals in experimentation urged Congress to investigate the Biosatellite Project. This alone might not have moved Congress except that related events had already focused congressional attention on the space program. Following the successful flight of *Apollo 11,* Congress faced increasing pressure from groups and individuals who favored a reduction in the space budget. Articulate spokesmen for public interest groups were demanding less money for space and more money for social programs. At the same time, many scientists were calling for greater emphasis on unmanned scientific investigations and less emphasis on manned exploration. NASA's announced goals for the 1970s were contrary to both sentiments. A major manned program would entail a major increase in space program funding and severely limit opportunities for scientific investigations. In this light, the Biosatellite issue was significant, for NASA in effect was asking Congress to endorse a plan (termination of Biosatellite, transfer of funds to the Apollo Applications Program) that involved termination of a relatively inexpensive, science-oriented project in favor of a relatively expensive, exploration-oriented manned program.[50]

The final report of the Biomedical Working Group of the President's Science Advisory Committee appeared in October 1969. This report, *Biomedical Foundations of Manned Space Flight,* asserted that NASA had not laid "the necessary biomedical foundations for the design of optimum flight programs" and cited two reasons for this alleged failure. First, NASA's pragmatic approach to the qualification of man for spaceflight did no more than establish limits of human tolerance to the conditions of specific flight missions and did not involve the types of "innovative research" that would yield fundamental knowledge of the effects of spaceflight on human physiology and performance. This approach was adequate when human tolerance to the conditions of short-duration flights was at issue, but was inadequate for the prediction of, and preparation for, "modes and levels of effectiveness" in long-duration flights. Second, NASA had failed to develop mechanisms for encouraging communication and coordination between its space biologists and space physicians, on the one hand, and between "the life sciences and the engineering and management operations," on the other. As a result, NASA lacked essential integration of basic research, applied research, life systems development, and flight operations.[51]

The report concluded that NASA lacked the capability to mount a biomedical program able to support long-duration manned spaceflight and could not gain that capability without "a major modification of its approach to space biomedicine" to emphasize the "independence" and "unity" of the life sciences. Specifically, NASA should create an integrated "biomedical research program" that emphasized fundamental research and "environmental biological studies." Such integration, however, required that NASA "consider new organizational forms suitable to an expanded and upgraded biological-biomedical effort with biological and medical operations unified within the program."[52]

To Congressman Joseph Karth, chairman of the Subcommittee on Space Science and Applications of the House Committee on Science and Astronautics, the Science Advisory Committee report, scientists' concerns about the Biosatellite Project, and public reservations about the future courses of the space program justified a congressional review of NASA's "Biosciences Program." Accordingly, he scheduled hearings for mid-November 1969. Officially intended as an investigation of *Biosatellite III* and a review of NASA's plans to terminate the Biosatellite Project, the hearings actually became an investigation of NASA's management of its overall Life Sciences Program.[53]

Karth was disturbed by NASA's reluctance to reevaluate its Biosatellite decision in light of the results of *Biosatellite III*. Did these results, he asked, not have serious implications for manned flights of long duration? Should not NASA focus in on the effects of spaceflight and the space environment on animals before exposing man to these potential hazards? In short, Karth wanted an answer to the fundamental question that had divided NASA from many within the scientific community since the beginning of the space program: What is the best approach to qualifying man for spaceflight? The incremental approach followed throughout the 1960s, or the approach in which men would be exposed to the space environment only after a lengthy program of research on lower organisms and primates?[54]

Those who testified in favor of the latter approach were research-oriented, primarily academic, biologists and biomedical scientists, who urged that the circumstances of Bonnie's death be thoroughly investigated before any further plans were made for a post-Apollo manned program. The principal spokesman for the group was Ross Adey, a University of California biologist and the principal investigator for *Biosatellite III*. Adey felt that Bonnie's death resulted from a complex interaction between prolonged weightlessness and one or more space environmental factors and that there was a possibility of a comparable interaction in humans during long-duration flight.[55]

However, scientists like Adey were concerned with more than operational procedures for qualifying man for spaceflight. They viewed NASA's response to *Biosatellite III* and its decision to terminate Project Biosatellite as simply the latest in a long series of management decisions that revealed a disregard for the space life sciences. They presented an image of NASA as an agency that repeatedly subordinated the life sciences to engineering and operations, consistently ignored the need for a broad, basic research program in the life sciences, and repeatedly refused to implement recommendations from leading scientists to improve coordination among life sciences programs. They cited the oft-repeated recommendation that NASA combine its life sciences programs into a single program office and appoint a nationally respected life scientist to a high-level administrative position.[56] These claims bore the implication (not substantiated) that NASA's alleged failings in regard to the life sciences had contributed to the failure of *Biosatellite III*.

Not surprisingly, NASA's spokesmen viewed the issue from a different perspective. They did not question the scientific value of biological investigations, but they denied that *Biosatellite III* was a cause for major concern. Humphreys contended that Bonnie's death was a consequence of a phenomenon that had long been investigated by aerospace physicians. Weightlessness causes, through a complicated series of physiological mechanisms, a loss in body weight and a pooling of fluids. This had occurred in most manned flights, but had not had serious consequences and had quickly reversed on return to the Earth. The serious consequences in the monkey resulted from two factors that were not involved in manned flight: physical weakness resulting from implantation of bioinstruments, and the relatively small body weight of the animal. *Biosatellite III* had achieved its major objective of determining the effects of weightlessness on the systems of "a small sub-human primate" and represented "a laudable scientific goal." However, the results were of no significance to manned flight. "We did not and do not now believe," he affirmed, "that this experiment was a necessary precursor to a manned flight of any particular duration."[57]

Humphreys and Charles Berry, chief space physician at the Manned Spacecraft Center, strongly denied any need for NASA to change its approach to qualifying man for spaceflight. NASA needed to expand its basic research efforts in biomedicine, and steps in this direction were already under way. As an example, they cited plans to develop the Integrated Medical and Behavioral Laboratory Measurement System (see Chapter 7). They argued that animal experimentation could hinder advances necessary to manned flight, for example, by increasing the "lead times" required to progress from conceptual plan to final qualification of technology systems. The record of space medicine during the manned program, they contended, failed to show any defect in the approach followed during the 1960s or any evidence that preliminary animal flights would have made a substantial difference in the way the manned program was conducted.[58]

Finally, NASA spokesmen disputed the need for a unified biological and biomedical program and contended that the recently formed Space Biology and Aerospace Medicine Board would improve the overall management of the agency's life sciences and provide the coordination that had been lacking. NASA was considering other forms of organization in order to strengthen both its medical and biological programs. However, any consolidation of life sciences programs would provide autonomy for biological programs, that is, life sciences activities not directly related to manned spaceflight. Reynolds informed the committee of views he had previously expressed within NASA. He, along with Humphreys and Berry, favored an arrangement that would keep space biology in the Office of Space Science, but combine all human research, development, and operations with a single office.[59]

In the view of members of Karth's subcommittee, testimony taken during the hearing affirmed the complaints of scientists who were critical of NASA's management of space life sciences. The subcommittee recommended that the Biosatellite program "be reinstituted," that the "role of science be uprated as a mission objective," that NASA "conduct a new and higher level of biomedical experiments on the astronauts," and that NASA "examine with solicitude" and implement "to fullest practicable extent" the recommendations contained in the President's Science Advisory Committee report.[60]

Karth conveyed the sentiments of the subcommittee to NASA Deputy Administrator George Low, emphasizing its dissatisfaction with "inter-office relations *within* NASA." The testimony taken by the subcommittee, he said, showed that the program office associate administrators and the life sciences directors operated in ignorance of the others' plans, programs, and requirements in the life sciences. This, he said, was most obvious in the absence of coordination and meaningful communication between the biosciences and space medicine offices. The testimony also justified the belief that NASA had never made science a "mission objective" of its manned programs and had little interest in doing so in the future. He concluded that he and the other members of the subcommittee "will be interested in watching how this worthy objective is carried out" in the future.[61] Other members of Congress shared Karth's concern and wrote directly to NASA Administrator Thomas Paine for his views on the Science Advisory Committee's report and his assessment of actions that NASA would take in response to its findings and recommendations.[62]

These inquiries into NASA's life sciences programs between 1967 and 1969 drew public attention to the agency's need to reevaluate its approach to biomedical research, to reassess the role and status of basic biological and medical research within an engineering- and operations-oriented space program, and to reconsider prevailing arrangements for administering biological and medical programs. However, these assessments were already under way within the agency before Congressman Karth began his hearings. By late 1969 NASA's top administrators were reevaluating the scope and organization of space programs at all levels because of uncertainties about the types and numbers of manned missions that would be flown in the 1970s and because of the prospect of reduced space program funding in the 1970s. At the same time, these administrators and NASA's key life scientists had accepted the need for an expanded program of fundamental biomedical research and closer coordination among the man-oriented life sciences in order to qualify man and life support systems for extended duration spaceflights. Public scrutiny of the agency's life sciences gave NASA's key administrators a critical nudge in a direction toward which they were already leaning.[63]

*Air Force flight nurse volunteer is strapped down, with sensors attached to her temples, to be tested on the centrifuge. This test will help establish medical standards for candidates for flight on the Space Shuttle.*

# 10

# Lunar transit: biomedical results from Apollo and biomedical preparations for the post-Apollo space program

The *Apollo 11* mission was the watershed of the manned space program. For the American public *Apollo 11* was a symbol of the restoration of the nation's honor and technological preeminence. Within NASA, while *Apollo 11* was a political triumph and a source of immense relief, it was not the ultimate event in the space program. It was merely a prelude to even more interesting and significant space activities that lay in the future.

## A SPACE PROGRAM FOR THE 1970S

NASA planners had never viewed the Apollo program as simply a series of missions leading toward a manned lunar landing. They had conceived of it as a program that would achieve both the short-range political objective set by President Kennedy and long-range operational objectives. As George Low, then head of planning for manned spaceflight, informed Congress in 1962, "Apollo is the name of a spacecraft that will have a dual mission capability." It would carry men to the Moon, but would also be used in Earth orbit as an "orbiting laboratory." In the latter capacity, Apollo would be the first step toward "a manned permanent space station."[1]

NASA planners began to give serious attention to post-Apollo manned programs in mid-1962, when the agency asked the Space Science Board of the National Academy of Sciences to review NASA's present spaceflight capabilities and recommend space program priorities for the post-Apollo period. The board urged NASA to increase emphasis on scientific investigations in space and, "utilizing the unique capabilities of man as an observer and decision-maker," integrate the scientific and exploratory aspects of the manned program. The board also suggested that a manned Mars landing would satisfy both those interested in science and those favoring space exploration. Accordingly, it recommended that NASA make a manned Mars landing the primary space program priority of the 1970s.[2]

NASA's advanced mission planners were interested in a manned Mars mission, but they favored a manned orbiting laboratory or space station as an intermediate step, compatible with the phased development and gradual qualification of man for extended spaceflight preferred by NASA's top administrators. For this reason, they proposed to design a long-range program that involved a gradual extension of flight capabilities and gradual phasing of manned space objectives. This was also an economical approach, since Apollo systems could be used in the initial phase and could be coordinated with the Air Force's manned orbiting laboratory program.[3]

By late 1966 NASA planners had agreed that the initial phase of the post-Apollo program should be designed to use Apollo systems. Designated the Apollo Applications Program, the first phase would center on Earth-orbital flights of 28 to 100 days but would also include extended flights for lunar exploration. Objectives of the orbital flights would include advanced scientific investigations (e.g., a telescope mount for astronomical observations and laboratories for biological and medical studies), evaluation of life systems for long-duration flight, and qualification of man for spaceflights in excess of 14 days. This phase would be followed by an orbiting space station, which would serve as as staging area for advanced lunar operations (including construction of a permanent lunar base) and manned interplanetary flights.[4]

In spite of reductions in congressional appropriations, delays in the Apollo missions caused by the *Apollo 204* fire, and growing public disinterest in the space program, NASA planners continued to refine this basic post-Apollo space program. Between 1967 and 1969, planners at NASA Headquarters and at the centers examined NASA's present and future requirements and capabilities and proposed mission and program options.[5] These studies culminated in a long-range program for an Integrated Manned Space Flight Program for the 1970s, which had an overall objective "to build towards a manned planetary capability" by integrating "lunar mission capability" with the capability for a "long-duration manned space station." The mode of integration would be "low cost transportation" via a "reusable cislunar spacecraft system."[6]

This integrated program was divided into three subprograms: lunar, Earth-orbital, and planetary. The first would be a direct extension of the Apollo program and would include lunar flights through 1974 to permit surface exploration, deployment of scientific instruments, and surface mapping. The lunar program would lead after 1975 to construction of a permanent manned lunar base, which would be linked to an orbiting space station. The Earth-orbital program would begin with the Apollo Applications Program manned laboratory and would lead to a permanent manned space station. This orbiting station would provide opportunities for scientific investigations in the physical and life sciences relevant to lunar and planetary operations, while serving as a transfer point for flights between the Earth and the Moon. Finally, planetary missions would begin with unmanned explorations of the planets, asteroids, and comets during the 1970s and culminate in a manned interplanetary flight in the 1980s.[7]

This long-range plan gave continuing impetus to the life sciences. Interest in the planetary missions justified support for exobiology (search for extraterrestrial life, investigations into the origin and evolution of life in the universe), while the need to prepare for extended manned flights warranted efforts to develop a program of fundamental biomedical research and to define a coordinated series of inflight biomedical experiments. The need to qualify man for advanced programs and define his requirements in extended missions allowed NASA's space doctors to add basic and clinical biomedical research to their operational responsibilities.

## BIOMEDICAL ASPECTS OF APOLLO

In 1969 NASA decided to increase the number of Apollo flights to provide for lunar surface exploration. This decision increased opportunities to gather data on human physiological and behavioral responses to the conditions of spaceflight, including extravehicular activity, because the first three Apollo missions revealed unanticipated clinical anomalies. It also allowed NASA to restore some of the biomedical experiments that were abandoned after the *Apollo 204* fire.

## CLINICAL ASPECTS OF APOLLO

Although a few clinical anomalies were revealed, the Apollo missions collectively demonstrated NASA's ability to predict and prepare for the physiological and behavioral reactions of astronauts to spaceflight. With two exceptions, as Dr. Charles Berry observed, "almost every observation in the physiological realm" was identified during the Gemini program.[8]

The Apollo missions reaffirmed the belief of NASA's physicians that man was fully qualified for short-duration spaceflights and would not suffer irreversible physiological effects. Lunar surface operations showed that "man can perform very nicely in the one-sixth gravity environment"

*Skylab 4 Commander Gerald P. Carr gives a solo demonstration of the zero-g effects on weights.*

and that the metabolic costs of working in that environment were within acceptable limits. Finally, the Apollo experience affirmed the particular value and effectiveness of the general clinical program in quickly identifying inflight clinical problems and in coping with problems not identified before flight. The biomedical results from Apollo showed that man could endure the conditions of lunar flight and short-term lunar operations.[9]

The Apollo missions also contributed to the identification of clinical problems relevant to advanced manned missions. The physiological decrements that occurred in the final two Mercury flights and in the 8- and 14-day Gemini missions were also observed in the Apollo flights. As in the earlier missions, some of these anomalies—decreased red cell mass, orthostatic disturbance, and vestibular dysfunction—were found to be self-limiting and appeared to be adaptive responses to weightlessness. Data on other potentially adverse changes—dehydration, electrolyte imbalance, weight loss, bone demineralization—suggested problems that could be serious in long-duration flights.[10]

The need for preflight clinical monitoring and screening in order to minimize the risk of inflight infectious illness was also evident during Apollo. The crews of *Apollo 7* and *Apollo 9* developed upper respiratory infections, while one of the members of the *Apollo 13* prime crew was exposed to rubella (German measles). The *Apollo 7* crew members developed their infections in flight, while the *Apollo 9* crew was infected before flight and the launch date had to be delayed for several days. In the case of *Apollo 13*, a backup crew member had to be substituted for a prime crew member at the last minute.[11]

These illnesses would have caused serious problems in long-duration flights by placing an additional strain on physiological systems already struggling to adapt to spaceflight. In addition, weightlessness complicated inflight treatment of illness by impairing mucus drainage. As decongestants seemed to be ineffective, astronauts would run the risk of ruptured eardrums.[12]

These experiences underscored the need for a more strict preflight health maintenance program, one that included the families of crews in the screening process and provided for complete isolation of prime and backup crews for specified preflight periods. For this reason, NASA established a Flight Crew Health Stabilization Program before the *Apollo 14* flight. An extension of the traditional medical maintenance program, it included routine screening and monitoring, rapid diagnosis and treatment of illness affecting any astronaut or members of any astronaut's family, and serological tests and immunizations for all astronauts and members of their families. The new program also included "epidemiological surveillance" of the astronauts and their families, which entailed assessment of the health of those likely to have contact with prime and backup crews during the 90 days preceding a particular flight, and medical histories and medical examinations for those who would have contact with the astronauts during the 21 days before launch. During these 21 days, daily reports were taken on the health of all "primary contacts" and were correlated with information on general disease patterns from public health officials. The combined data were analyzed by computer. This surveillance effort was linked to isolation procedures. During the critical 21-day period, prime and backup crews were confined to strictly limited areas, and their primary contacts were limited to essential personnel and family members. Crew members were strictly isolated from potential disease carriers, such as transient populations, children, and launch site personnel whose medical histories were not known.

Although elaborate and confining and not without deficiencies, the health stabilization program was effective in reducing the incidence of

The clinical results from Apollo, then, underscored the need for fundamental biomedical investigations to support advanced manned missions. They reaffirmed the findings from the Gemini flights concerning the need for intensive investigation of cardiovascular, musculoskeletal, and endocrine systems and metabolic functions. In addition, they pointed to the need for controlled studies of vestibular and neurological functions and workload tolerances, and for improved procedures for minimizing the incidence of inflight illness and for treating such illness when it occurred.

## APOLLO BIOMEDICAL EXPERIMENTS

Biomedical experiments were flown during the last two Apollo missions, *16* and *17*. BIOSTACK and BIOCORE were experiments designed to measure the biological effects of various types of radiation that are screened out by the Earth's atmosphere. BIOSTACK was an experiment to assess effects of high-energy particles on the germination and growth of selected plant spores and on the embryological development of eggs of selected arthropods. BIOCORE measured the effects of high-intensity radiation on the organs and tissues of a pocket mouse. Both were primarily scientific investigations, but had the secondary objective of evaluating the biological effects of an environmental factor that could prove significant in long-duration manned spaceflight. Neither experiment produced results significant to planning for advanced manned missions.[20]

A third biomedical experiment, flown on *Apollo 16*, investigated the effects of radiation on the cellular physiology and genetic components of several types of microorganisms. The objective was to determine whether the levels of ambient high-intensity radiation in the space capsule had any significant effect on the viability of microorganisms. Since terrestrial microorganisms would be carried into space by men, it was important to know whether the radiation level in the space capsule would be sufficient to destroy them and, if not, whether they would undergo genetic changes that could cause them to become dangerous to man. This experiment revealed no significant differences in survival rates and rates of genetic change between the microbes flown aboard the spacecraft and those used as ground-based controls.[21]

The final experiment was designed to investigate a phenomenon reported by the crews of the *Apollo 11, 12,* and *13* flights. In each of these flights, crew members reported seeing light spots and light flashes

*Astronaut Joseph P. Kerwin is the subject for the lower body negative pressure experiment aboard Skylab 2, while astronaut Paul J. Weitz assists with the blood pressure cuff. This experiment provides information about cardiovascular adaptation during flight and orthostatic impairment of physical capacity expected on return to Earth.*

whenever the capsule was dark and the crew members' eyes were closed. NASA scientists hypothesized that the cause of the flashes was high-energy cosmic rays penetrating the space capsule and striking the crew members' retinas. To test this hypothesis, investigators had the crew members of *Apollo 14* and *15* count light flashes for specified periods while blindfolded. At the same time, test subjects on the Earth were doing the same. In the *Apollo 16* and *17* missions, the crew members wore a head device that contained special photographic plates which recorded cosmic-ray strikes while the crew members counted light flashes. The data from this experiment supported the original hypothesis.[22]

Although these experiments yielded no information of immediate concern in relation to manned spaceflight, they proved that cosmic radiation penetrates the space capsule. While the levels of ambient radiation in the space capsule were well below the acceptable tolerance level for short-term exposure, prolonged exposure could have unanticipated and unpredictable effects on physiology. Thus, low-level radiation, while insignificant in the Mercury, Gemini, and Apollo flights, might be a significant factor in long-duration flights.

## BIOMEDICAL OBJECTIVES OF THE POST-APOLLO SPACE PROGRAM

Planning for the post-Apollo biomedical program reflected two significant changes in the role and responsibilities of biomedicine in the space program. First, the biomedical program was no longer constrained by the requirements of specific manned missions or a single manned spaceflight objective. Although the scheduling and packaging of biomedical experiments and the operational support duties of space physicians would be influenced by the systems and flight profiles of the specific manned missions, the scope and direction of the biomedical program would no longer be determined solely by engineering and operational considerations. Second, the biomedical program for the 1970s reflected the increasing importance of basic research and clinical medicine in the space program. By 1970, space physicians had shed their flight surgeon image and were gaining recognition as medical scientists and clinicians. NASA's biomedical plans for the 1970s reflected the emerging need for comprehensive and fundamental research in biomedicine and for integration of the biological, biomedical, and bioengineering efforts.[23]

## RESEARCH OBJECTIVES

Various advisory groups examined and made recommendations concerning NASA's biomedical requirements in the post-Apollo space program. Those which had the greatest influence on NASA's biomedical planning for the 1970s were prepared by the Space Medicine Advisory Group in 1964 and by the Space Science Board of the National Academy of Sciences in 1965. The Space Medicine Advisory Group report focused entirely on the medical requirements and medical experiments for a manned orbiting laboratory. The authors determined weight experiments for a manned orbiting laboratory. Weightlessness was identified as the critical variable in long-duration spaceflight, and the authors proposed a series of experiments to test the effects of weightlessness on human physiology and performance, acting singly or in combination with other factors.[24]

The Space Science Board study was not limited to a particular type of mission and assessed NASA's broad requirements for a long-range integrated program of research in biology, medicine, and physiology. It concluded that biomedical preparations for long-duration spaceflight should center on fundamental investigations into the interactions between internal and external environments. "Physiology and behavioral processes" (internal environment), the authors stated, "respond to stresses slowly over time," so that the significance of these processes is directly proportional to mission duration. Of primary concern were cardiovascular response, bone and muscle metabolism, red blood cell concentration, blood clotting mechanisms, and long-term decrements in performance. The factors in the external environment that would influence these processes included physical factors (weightlessness, alterations in circadian rhythm, radiation, thermal stresses), behavioral factors (isolation, confinement, monotony, close quarters), and engineering factors (artificial atmosphere, toxic contaminants, noise, vibrations). Research on these interactions, according to the authors, should be conducted in an orbiting laboratory in which space crews and space capsule systems could be evaluated in missions of 28 to 1,000 days.[25]

In May 1969 the medical staff of the Manned Spacecraft Center prepared a detailed plan for a biomedical research and operations program for the 1970s. Strongly influenced by the studies noted above, the primary author, Dr. Charles A. Berry, noted that the "flight certification" approach to the qualification of man for spaceflight, which was required in the manned program of the 1960s, would not suffice for the 1970s and 1980s. "Major modifications" would be necessary in this approach and in "the level of investigative efforts" to make possible "unconditional qualification" of man for "extended space missions." Reiterating word-for-word the recommendations in the 1965 Space Science Board report, Berry said:

> Special emphasis must be placed on the physiological and behavioral processes that respond to stress slowly with time and are likely to become important during

> prolonged space flight. Of particular interest are weightlessness, cardiovascular function, bone and muscle metabolism, hematological changes, vestibular function, and long-term decrements in physiological and behavioral performance.[26]

This level of effort, Berry said, is required to enable exploitation of man's "unique capabilities" as both decision maker and observer. Since man will be an essential component of advanced flight programs and must be "accommodated" to any number of possible "program alternatives," the "investigative requirements" of the biomedical program of the 1970s must include efforts to obtain "greater knowledge of man's psychophysiological response to space flight"; expand "present understanding of design requirements for man/machine systems"; and develop "long duration flight systems and operation capabilities."[27] Berry stated that the biomedical program must concentrate on assessing the interactions between man's "internal environment" and the "stresses" imposed by the physical environment of space and the artificial environment of the space capsule.

"Degradation" in man's ability "to perform mental and physiological tasks," Berry said, results from "fluctuations in the physical properties and chemical composition of the internal environment." The human body seeks to "counteract" or "minimize" these fluctuations through "highly complex compensatory mechanisms." Short-duration exposure to stress produces "accommodative" changes which are "self-adjusting" and short-lived reactions that "possess defensive value to the organism" and "assure viability of the organism." However, when accommodative measures are prolonged, "acclimative processes" occur that allow an organism to adapt to extended exposure to stress factors.

Neither of these processes, as the Mercury and Gemini flights revealed, causes serious or irreversible changes in physiological and behavioral performance in the short run. However, without more intensive investigations it is impossible to determine their long-range effects. Acclimative processes, Berry said, worked to the advantage of the Gemini astronauts by allowing them to adapt to the weightless state. However, these processes are "operative at a level where detection is difficult." The threshold of acclimatization is unknown, and it is possible that the imposition of stresses over a long period may cause "these mechanisms to be overpowered." In such a case, the result would be "degradation of performance in vital functions."[28]

Given these uncertainties, Berry continued, the primary objective of the biomedical program must be to obtain fundamental data necessary "to permit confident extrapolation to major extensions in mission duration." This fundamental understanding must involve determination of "the precise nature, the ultimate severity, and the fundamental etiology of all changes in man's functional capabilities during and following prolonged space flight." To achieve this, the biomedical program must take account of "circumstances" that are peculiar to biomedical research. First, it is difficult to identify "normative functional capabilities" because individuals with similar physical and mental characteristics show "different physiological responses to some stresses," while a single individual may "respond differently to an identical stress imposed at different times." Second, stresses are "difficult to evaluate singly" since they tend to act in combination. Finally, it is often difficult to identify potentially serious physiological changes because "powerful compensatory mechanisms can mask" physiological decrements "until the conditions become critical."[29]

Given the requirements for advanced manned flights and these peculiarities of biomedical research, Berry contended, the biomedical program of the 1970s must seek answers to three critical questions: (1) whether physiological changes observed in spaceflight "reflect gradual adaptation" or "progressive deterioration of bodily functions," (2) whether the changes are "self-limiting" (i.e., do not lead to progressive deterioration) as mission duration increases, and (3) whether methods for evaluating changes "are sufficiently sensitive to detect all occurring accommodative and acclimative processes." The "primary goal" of the biomedical program then must be to qualify man by demonstrating that he can "acclimatize to the space flight environment" without serious and irreversible "physiological and performance decrements," can "withstand re-entry stresses" following these acclimatizations, and can "re-acclimatize successfully to normal earth conditions."[30]

Man's qualifications for extended space missions, according to Berry, would be established when "at least one crew" of "no fewer than three astronauts" successfully flew a "six-month mission" without any crewman having "medical problems referable to his flight experience." In this flight and in all preliminary flights, detailed investigations would have to be made of neurophysiology, pulmonary function and energy metabolism, cardiovascular function, endocrinology, hematology, microbiology, and behavior. If no serious decrements were observed in these areas during the six-month exposure, it could be assumed that "man can tolerate this environment for any length of time."[31]

Berry argued for an integrated approach to the study of human responses in each of these areas. Changes in physiological and behavioral systems and functions would have to be correlated with operative stress factors acting singly and in combination. Berry grouped these stress factors in four categories: "natural environmental factors"—weightlessness (affecting bone and muscle, cardiovascular function, psychomotor performance, and vestibular function), radiation, meteorites, altered periodicities, magnetic fields, extraterrestrial life; "spacecraft environment factors"—mechanical forces, linear acceleration, vibration, impact, noise and blast, microbiology, toxicology, enriched oxygen atmosphere, energy metabolism; "habitability factors"—cabin atmosphere, nutrition, thermoregulation, water management, waste management, personal hygiene and clothing, spacecraft architecture, crew selection, size and composition, work, rest, sleep, and recreation; and "operational factors"—oculovisual effects, extravehicular activity, artificial gravity, clinical medical care, data management, simulation.[32]

## MODALITIES

There were practical limitations to the implementation of this research program: the traditional problem of integrating bioinstrumentation and biomedical experiment packages into predetermined engineering and operational modes, and the new problem of developing medical and behavioral experiments that could be adapted to any of several types of spacecraft systems and flight configurations. The need to qualify man for extended duration flights aboard spacecraft that were yet to be defined led to the conception of the Integrated Medical and Behavioral Laboratory Measurement System. In the words of its chief architect, Sherman P. Vinograd, the system was designed as "a rack and module system" that could be "assembled into working consoles according to the requirements of the spacecraft and the experiments program for any particular mission." It would enable biomedical scientists to gain "sound scientific knowledge of human responses" while having "minimal or no impact" on the design or operation of the basic flight system.[33]

The first phase in development of the integrated measurement system began in June 1967, and it was hoped that the system would be ready for evaluation during the Apollo Applications Program. By 1969 Vinograd doubted that the system would be ready before 1973, though the fundamental principle of modularity would be incorporated into the Apollo Applications flights. The system would be adaptable to programs following Apollo Applications and would ensure an ongoing capability for measuring physiological, behavioral, biochemical, and microbiological functions during spaceflight and for effective "data management" of measurements recorded in flight. (The experimental objectives and measurement capabilities of this system are described in Appendix D.)

The integrated measurement system was only one mode for gathering data on medical and behavioral responses to spaceflight. Until its development was completed, medical and behavioral experiments would be conducted with experiment packages adapted to specific flight programs. Moreover, inflight research, regardless of the mode, could not be divorced from ground-based research. First, the instruments and techniques to be used in flight required prior evaluation and calibration; for example, a measurement of the effect of weightlessness on a function would be meaningless unless the instrument had been validated through measurements in normal gravity. Second, inflight measurements had to have some basis for comparison, so that all the functions to be measured in flight also had to be measured in controlled ground-based studies. Finally, an effort had to be made to determine whether inflight measurements could best be obtained through automated instruments controlled from the ground or through instruments managed by flight crews. Full implementation of the expanded biomedical research program and the qualification of man for extended duration missions required a thorough study of the efficacy of each of these modes.[34]

## AN INTEGRATED LIFE SCIENCES PROGRAM

The biomedical program described by Berry in May 1969 became the heart of an integrated life sciences research and development program for the 1970s. Since the space program of the 1970s would have no single major manned objective, all manned programs would be, in effect, advanced manned programs. Consequently, there was no longer a need to make distinction between advanced R&D and manned spaceflight programs. Likewise, the distinction between space biology and space biomedicine was losing significance. The successful planning of future manned programs depended as much on fundamental research in the biological sciences as it did on mission-oriented medical research and bioengineering. Moreover, in advanced manned programs the astronauts would be expected to function as scientific observers and experiment controllers as well as pilots and explorers.

Thus, NASA was moving away from compartmentalization of its life sciences activities into space biology, human research and biotechnology, and space medicine. For the 1970s, life sciences activities would have to accord with the uncertainties of the new space program. All research and development in biology, medicine, and biotechnology would bear directly or indirectly on the long-range goal of the agency: qualification of man as an operator, passenger, and scientific investigator in long-duration space missions. In short, the requirements for an indeterminate manned space program would force an integrated approach to biology and medicine.

The overall objective of the integrated life sciences research and development program was to obtain the fundamental knowledge necessary to make man "an effective and fully-protected operating element" of the systems required for the approved Skylab, tentatively approved Space Shuttle, and planned but unapproved space station programs. This would require understanding of the biological processes affecting human adaptation and tolerance to the conditions of spaceflight, the physiological and behavioral processes specific to man and having "paramount importance" in future manned missions, and the human factors involved in integrating man and machine in advanced flight systems.[35] The program required integration, rather than separation, of biology, medicine, and human factors engineering. This approach did not, however, take into account extraterrestrial life and its formation.

## BIORESEARCH

The principal aim of biological research in this integrated life sciences program was investigation of the basic biological processes related to "adaptiveness and tolerance" to spaceflight conditions for the purpose of identifying, measuring, and understanding "the mechanisms underlying functional adaptation of organisms in space." This program of "bioresearch" gave priority to research related to spaceflight factors that stimulate adaptive responses and the mechanisms of these responses at the cellular and clinical levels; genetic effects, if any, of space environmental factors, particularly long-duration exposure to low-level radiation; and biological effects of weightlessness, acting singly or in combination with other factors.[36] The bioresearch program was a modification of the old biosciences program, the major change being that biological investigations would be conducted to support the long-range manned program rather than for strictly scientific purposes.

The termination of the Biosatellite Project and cutbacks in space program funds precluded an independent biological program; however, integration into the manned flight program afforded new opportunities for biological investigations. Several biological experiments were scheduled for the Apollo Applications-Skylab missions, and one major unmanned biological flight was flown in late 1970. The latter, carrying the "orbiting frog otolith experiment," was designed to obtain information on biological response to weightlessness in a critical area, neurophysiology, that was difficult to study directly with humans. The experiment was selected because the otolith is the critical component of the vestibular apparatus—that part of the inner ear that influences balance and spatial orientation—and dysfunctions of the otolith can cause motion sickness and serious degradations in performance. The data from the otolith experiment revealed that the "basic neural control process" underlying vestibular function undergoes an accommodative response to weightlessness that is complete by the fifth day of exposure. Thus, this experiment supported the empirical conclusion based on manned flights, that man makes a positive adaptation to the weightless environment.[37]

The otolith experiment also yielded information on vestibular responses to noise and vibrations. Biomedical scientists had long assumed that noise and vibration were potential stress factors in manned flight. However, NASA physicians, having found no evidence of decrements attributable to these factors in the manned flights of the 1960s, considered them of secondary importance in the overall biomedical program. In the otolith experiment, the hair cells of the frog's otolith showed a significant response to noise and vibration. These results encouraged NASA's biomedical planners to investigate these factors in Skylab.[38]

The otolith experiment epitomized the emerging integrative approach to biomedical and life sciences research. It was intended to meet the needs of both pure science and applied (mission-oriented) research. It was carefully designed as an investigation of a phenomenon that was of interest to both biologists and space physicians, to both scientists and mission planners.[39] NASA life scientists hoped that this type of approach would be continued in the 1970s.

Toward this end, efforts were initiated to plan a series of similar flights for "definitive investigations of the effects of weightlessness." In coordination with the Naval Aerospace Medical Institute, NASA envisioned a series of missions that would culminate in a year-long study in an orbiting space station. In this final phase, several primates, attended by a veterinarian, would be experimental subjects in a special laboratory on the anticipated, but unapproved, manned space station. NASA planners saw this as a means to obtain the level of understanding of biological processes in flight that biomedical scientists had long demanded, while not interfering with the pace of the manned effort.[40] Budgetary cutbacks and the abandonment of plans for a space station stifled the further development of this project and of the integrative approach to biological investigations in space.

## BIOENVIRONMENTAL SYSTEMS RESEARCH (HUMAN FACTORS)

The requirements for advanced manned programs included the qualification of spacecraft systems, as well as man, for long-duration spaceflight, primary concerns being life support and protective systems. In long-duration flights, life systems would have to do more than sustain crews and provide minimal comfort for brief periods. They would have to "effectively and reliably" regenerate or recycle oxygen and water, provide for the "degradation" of solid and liquid waste materials, and ensure the cleansing and reconditioning of the space capsule atmosphere. Equally important, they would have to be engineered to provide for human comfort—personal hygiene, management of bodily wastes, thermal and humidity idity control, elimination of odors, and so on.[41]

In an effort to develop a life support system acceptable for long-duration manned flights, NASA sponsored the Advanced Integrated Life Support System. Basically, this was a closed environmental system simulator which would be used to "establish a technological base" for the "support, well-being, and efficiency of the crew" in advanced manned flights. Through "ground-based integrated operational manned tests simulating orbiting conditions," the AILSS would provide opportunities for testing the overall system and the integrity of the coordinated subsystems and for evaluating the reliability and maintainability of life support technology. The overall plan called for an extended series of tests increasing in duration from 90 to 180 days in which the focus would be on "advanced oxygen and water regeneration technology."[42]

The prototype simulator was available in early 1970 and the first test began on June 13, 1970 and extended to September 11, 1970—90 days. Four men were the test subjects for the entire 90-day run, and the test was conducted as if the simulator were an orbiting space station. The primary objective was to "demonstrate the capability to operate a multi-man life support system in a continuous regenerative mode for a 90-day period without resupply." The 90-day test demonstrated this capability, but revealed that maintenance would be a critical factor in advanced manned programs. In this test, 237 items had to be repaired and 242 man-hours were required for repairs. It was concluded that in advanced manned flights NASA would have to give major consideration to the maintainability and ease of repair of life support systems and subsystems and would have to include "scheduled and unscheduled maintenance" in the engineering and operational constraints. The test results also indicated that in the design of future life systems NASA would have to give maintainability priority over redundancy.[43]

The 90-day test of the simulator epitomized the integrated approach to life sciences research and development. Although the life support systems were the prime focus of the test, their evaluation was integrated with evaluations of capabilities for human performance, biomedical monitoring, and man-systems integration. The biomedical component included "constant medical attendance by licensed physicians, daily status checks, constant radiation exposure monitoring, biweekly clinical blood chemistries, and weekly electrocardiography and pulmonary spirometry." Emphasis was placed on "special studies" of constant exposure to "low-level stresses" which could be simulated, in this case, confinement and carbon dioxide levels. The overall results of the biomedical evaluation "revealed that the 90-day manned test was medically benign." No changes attributable to prolonged confinement were identified, though the carbon dioxide study "produced preliminary results suggestive of biochemical trends developing from exposure to carbon dioxide."[44]

The long-range plan for the Advanced Integrated Life Support System called for extension of simulations to 120 and 180 days and "final validation" in a 180-day "space flight experiment" aboard an orbiting space station. However, budget cutbacks and the curtailment of plans for a space station precluded implementation of this long-range plan.[45]

## BIOMEDICINE

The basic objectives of the biomedical effort within the integrated life sciences program were the same as those described by Berry in his program report of May 1969; identification of clinically significant physiological and behavioral reactions to the conditions of extended spaceflight and gradual qualification of man for spaceflight lasting 180 days. The inflight investigative effort was to begin with the Apollo Applications Program (redesignated Skylab in 1971) and conclude with a six-month evaluation aboard the projected space station. As the 1970s unfolded, however, Apollo Applications-Skylab became the final stage of the old manned program rather than the initial phase of a new manned program. Consequently, the program of inflight biomedical research had to be collapsed to accommodate the package of medical and behavioral experiments to three missions lasting 28, 59, and 84 days.

This reduction precluded the "level of investigative effort" that Berry had hoped for, forced elimination of some investigative categories, and caused a reduction in the number of experiments. Nonetheless, NASA life scientists viewed this as their first real opportunity to conduct controlled studies in space and proceeded with the development and packaging of experiments related to "areas which are judged to be most critical and most feasible at this time."[46]

The Apollo Applications-Skylab experiments were grouped in six categories. Category 1 (experiment M070), study of nutritional and musculoskeletal function, consisted of four integrated experiments with the collective objective of assessing inflight alterations in musculoskeletal status and evaluating biochemical changes and nutritive requirements as they differ from those in the Earth environment. The four correlated experiments were intended to provide "precise measurements" of the input and output of calcium, nitrogen, and other biochemicals, bone demineralization, and hormonal and electrolyte changes detected in studies of blood and bodily waste products.

The three experiments in category 2 concerned cardiovascular function and would measure the cardiovascular reflexes that normally regulate blood pressure and the distribution of blood in the body: the "onset, rate of progression, and the severity" of changes in cardiovascular function;

and changes in cardiovascular function "during given workloads on a bicycle ergometer."

Category 3, hematology and immunology, consisted of four experiments to determine physiological effects of spaceflight as indicated by changes in the volume, mass, and composition of the blood and blood elements and in the immune responses of the blood. Changes in immune responses would be indicated by alterations in the bacterial populations of the blood and the genetic makeup of the leukocytes.

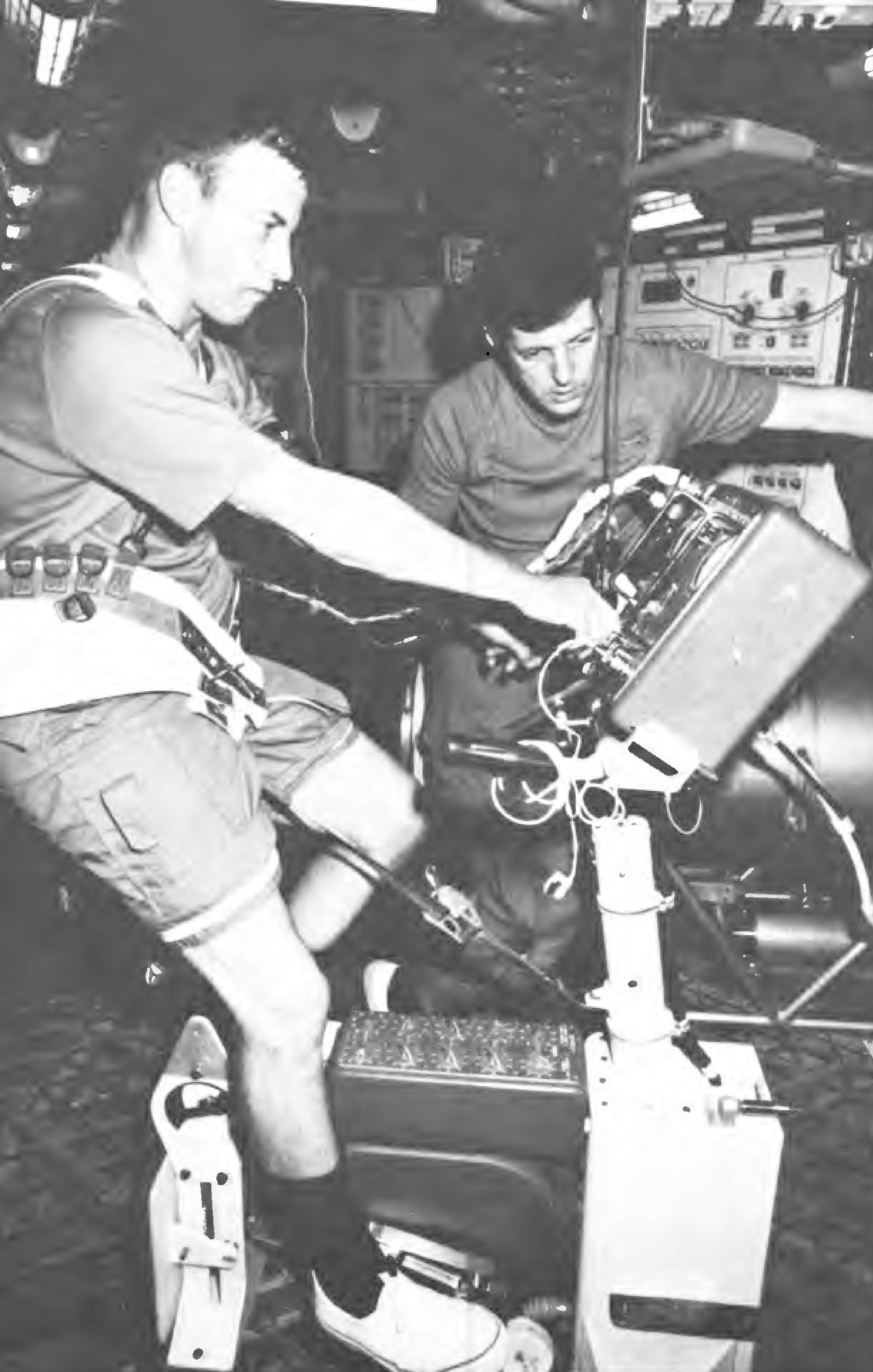
Category 4 was related to neurophysiology and consisted of two experiments to "evaluate central nervous system responses as a function of space flight." One experiment would investigate changes in vestibular function, while the other would utilize electroencephalograms to assess effects of prolonged spaceflight on patterns of "sleep and wakefulness."

The fifth category involved one experiment, a "time and motion study" to assess "behavioral effects." Its objective was "to evaluate the relative consistency between ground-based and inflight task performance" by observing films of the astronauts performing selected tasks in flight. The study was expected to yield information that would be useful in improving the design of space capsule subsystems and the training of astronauts for performance of inflight tasks.

The final category involved two experiments that were intended to measure pulmonary function and energy expenditure. Measurements obtained during rest, during "calibrated exercise" on the bicycle ergometer, and during selected "operational type tasks" would be used to determine whether a correlation existed between the "energy costs" of "mission-oriented physical activity" and alterations in "respiratory gas metabolism."[47]

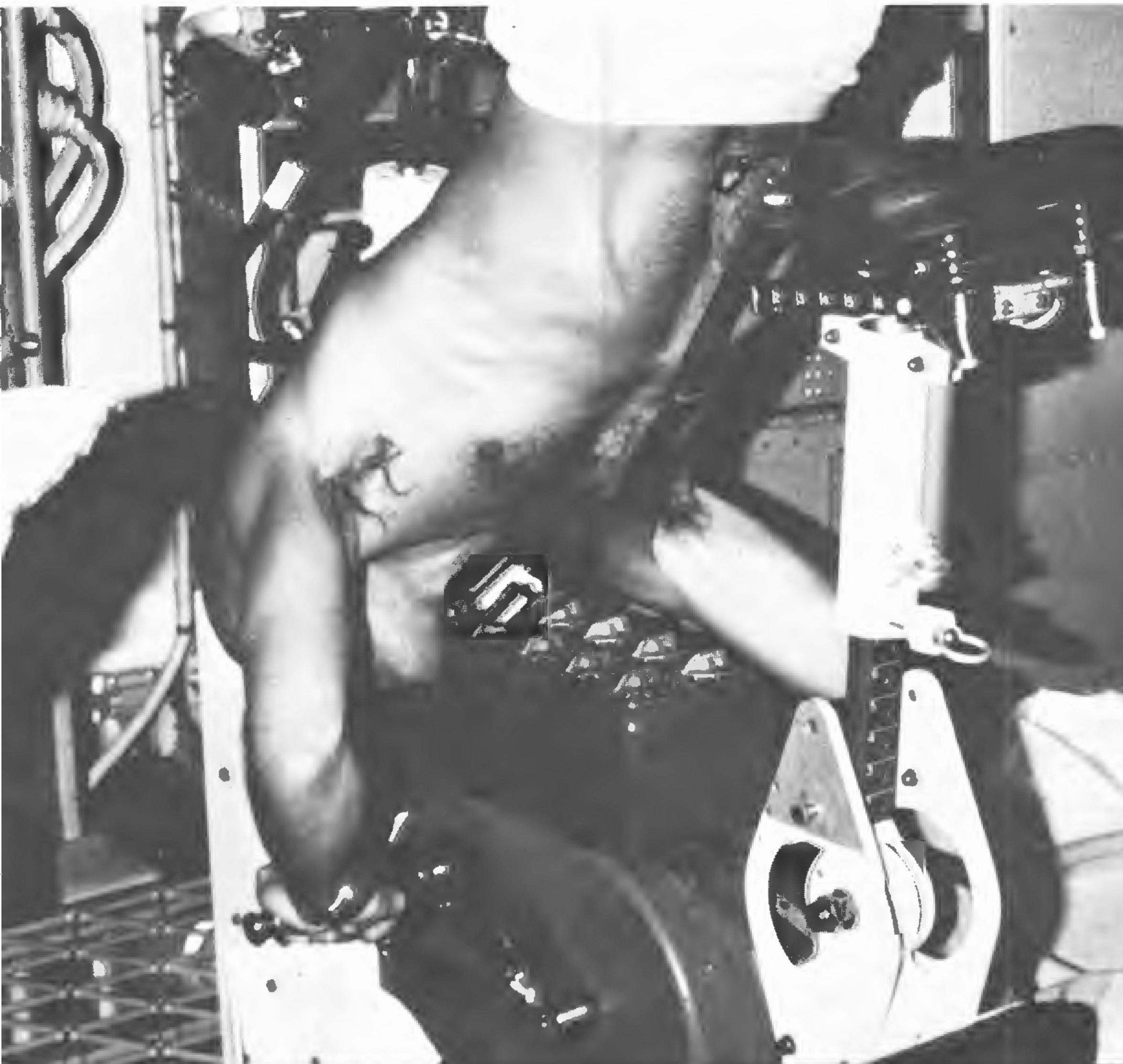
The diversity of NASA's biomedical programs would have been inconceivable in the 1960s, for the manned program of that decade required space physicians and life scientists to focus their efforts on mission-oriented research and mission operations and precluded the implementation of broad, research-oriented, and integrated biomedical programs. Yet, that same manned program provided a strong justification for specialization in space medicine and biology and medicine, the impetus for the emergence of space medicine as a distinctive field of medical specialization, and the opportunity for observation of the biological and physiological effects of a unique environment.

*Astronaut Paul J. Weitz checks out bicycle ergometer. The "bike" is part of equipment used to help determine if man's effectiveness in doing mechanical work is progressively altered by a prolonged stay in space.*



# 11
# Toward an integrated life sciences program

*Charles Conrad, Jr., is upside down pedaling the bicycle ergometer with his hands.*



Responding to external criticisms of its biomedical capabilities, to the need for improved coordination among its life sciences components, and to the requirements of the space program of the 1970s, NASA management announced a reorganization of its life sciences programs in December 1970. This included the integration of biomedical (manned flight-oriented) programs within a single office and the centralized coordination of all life sciences programs. It eliminated the long-standing division of space biology, biotechnology-human research, and space medicine into separate directorates, and established a new office, the NASA Division of Life Sciences, to coordinate all life sciences research and development. Located in the Office of Manned Space Flight, this division had direct responsibility for all life sciences activities directly related to manned spaceflight. Its director also had responsibility for coordinating life sciences activities remaining under the jurisdiction of other program offices: exobiology, which was integrated with the planetary programs division of the Office of Space Sciences; aeronautical medicine, under the jurisdiction of the Office of Advanced Research and Technology; and occupational medicine and environmental health, under the Office of Administration at NASA Headquarters.

This reorganization reflected a major change in space program priorities. It recognized the need for fundamental research in biology and medicine in support of extended duration manned flights, the integrity of the biological and medical sciences, and the value of centralized coordination of life sciences programs. However, it continued the practice of giving life sciences directors responsibility without authority. The new office lacked program-office status and did not create a top management position for a life scientist. Although he was responsible for centralized coordination of all life sciences activities, he was subordinate to the administrator for manned spaceflight programs and could not make life sciences program decisions without the concurrence of this administrator. At the same time, he was subordinate to the administrators of the program offices having direct responsibility for life sciences activities under their jurisdiction.

Therefore, the effect of the decision to reorganize the life sciences programs did not indicate a major change in management's perception of the life sciences or in the role and status of the life sciences within the space program. It simply reflected management's recognition of the need to change the organizational relationships and responsibilities of the life sciences programs and adjust to the priorities and requirements of the space program of the 1970s.

## THE REORGANIZED LIFE SCIENCES PROGRAM

Throughout the 1960s, NASA's top management did not act as if the agency had a pressing need or a major program requirement in the life sciences. As a result, an integrated life sciences program under the direction of a high-level administrator was not established. Several considerations underlay this attitude. First, NASA was not primarily a science agency. Its program obligations encompassed, in addition to space science, applications, technology development, space hardware design and development, and mission operations, and demanded a form of organization and management that reflected space program objectives and capabilities rather than scientific priorities alone. Management viewed recurrent demands for a centralized life sciences program as misguided efforts to force NASA to function as a scientific research agency similar to the National Institutes of Health.[1]

Second, life sciences investigations in space could not be conducted without a heavy investment in technology—launch vehicles, satellites, space capsules, biological and medical instrumentation. It would be more cost-effective to link each life sciences activity with related engineering and operational activities within program offices—for example, to place space biology in the same program office with other space sciences, so that biology, physics, astronomy, meteorology, and so on could share the same engineering and operational capabilities.[2]

In budgetary terms allocations for life sciences research, development, and flight programs were small relative to the overall agency budget. A single life sciences program office could not hope to develop independent engineering and operational capabilities or to provide sufficient research grants and contracts to build an effective program and to attract academic and research-oriented life scientists. Such scientists, in management's view, could seek support from agencies like the National Institutes of Health, which had more money to offer and did not require grantees and contractors to grapple with time-constrained programs and the development of complex instrumentation.[3]

This attitude prevailed in 1968, when the Life Sciences Study Task Group presented its recommendations for an integrated life sciences program, and it underlay Associate Administrator Homer Newell's decision to bypass the group's recommendation. Newell believed that NASA Administrator Thomas Paine and Deputy Administrator George Low would refuse to endorse the recommendations.[4]

NASA management was not alone in its opposition to an integrated and centralized life sciences program in 1968. Many life scientists in NASA, particularly those involved with the space biology (biosciences) program, shared this opposition. Orr Reynolds, director of bioscience programs in the Office of Space Science and Applications, doubted that space biology could survive within an integrated life sciences program. He was certain that in an integrated program stressing applied research, bioengineering, and manned operations, basic biological research would lose out in the competition for funds and flight space.[5] Reynolds's superior, John Naugle, associate administrator for space science and applications, also believed that space biology had much to lose and little to gain from integration. Moreover, Naugle believed that the Office of Space Science had unique capabilities in unmanned spacecraft development and operations which were particularly important to biological investigations in space. Its space biology program had a viable flight project, Biosatellite, which allowed space biologists to conduct biological investigations without competing for flight space. He doubted that the Biosatellite Project would survive within an integrated program.[6] The directors of space medicine and biotechnology and human research favored integration, and the reasons for their support justified Reynolds's and Naugle's opposition. Although J. W. Humphreys and Walton Jones saw the value of a space biology program, both believed that closer coordination among basic biology, human research, biotechnology, and space medicine would strengthen the agency's capabilities in the area of biomedical support for manned spaceflight.[7]

In the short space of two years these attitudes changed, and both top management and life scientists within NASA supported the establishment of an integrated life sciences program. The major factor in this shift was the change in space program priorities. By December 1970 the major objectives of the Apollo program had been achieved, and the life sciences research and development aspects of the only remaining approved manned program, Apollo Applications-Skylab, were essentially complete. NASA lacked a mandate to proceed with an advanced manned program comparable to Apollo and beyond the approved manned flights of Skylab. President Nixon (who wanted a reduced, multiple-objective, science-oriented space program for the 1970s) and Congress (which was losing interest in the space program) reduced the financial support for the space program and severely limited NASA's space program options. These constraints forced NASA to reassess its priorities, emphasizing unmanned planetary explorations, limited Earth-orbital manned operations, and research and development in support of unspecified and unapproved advanced manned programs. The change in emphasis shifted attention from manned operations and qualifying man for spaceflight to the design and development of a relatively short-duration, recoverable and reusable Space Transportation System (the Space Shuttle). Plans for manned operations in the 1980s would depend on the success of the Shuttle.[8]

This shift in priorities generated a subtle shift in NASA's management philosophy. Although manned spaceflight remained the focus of the space program, research and development in support of advanced manned programs would replace manned operations as the primary responsibility of the manned space program. In the absence of approved manned programs beyond Skylab, advanced research and development and manned flight operations had the same objectives, and there was no longer any need to make a distinction between the space-oriented research and technology development activities of the Office of Advanced Research and Technology and the Office of Manned Space Flight. There was also no longer a compelling reason to separate the activities of the human research and biotechnology directorate from those of the directorate of space medicine. An integrated biomedical program was now consistent with the agency's space program requirements.

Reductions in manned spaceflight activity were paralleled by increases in the field of planetary exploration. By December 1970, NASA had the engineering and operational capabilities for unmanned explorations of Mars, Venus, and the outer planets and congressional and executive authority to proceed with such flights. As a result, planetary exploration eclipsed lunar exploration as a major program objective. Since NASA did not have the authority to undertake manned exploration of the planets, unmanned capabilities assumed new importance, and the unmanned, science-oriented program of the Office of Space Science gained in importance relative to that of the Office of Manned Space Flight.

The shift in space program priorities and the emphasis on two objectives—unmanned planetary exploration and research and development in support of long-duration manned spaceflight—changed the agency's requirements in the life sciences. First, as noted before, it was no longer necessary to separate human research and clinical medicine or to give medical operations priority over biomedical research and development.

Second, the shift gave impetus to exobiology and, in so doing, established a distinction between the life sciences that were directly or indirectly supportive of manned spaceflight and those that had strictly scientific value. Finally, the agency no longer had to support an independent program of biological investigations in space. Most of the effort of the biosciences directorate in the 1970s had been directed toward exobiology or the investigation of biological phenomena with a bearing on manned spaceflight. Lacking the funds to support an exclusively biological flight program and program requirements for pure biological research, the agency could dispense with its biosciences program.

Yet, for reasons that are not clear, NASA's management apparently believed that it required an external review to justify changes in the administration of its life sciences programs. Accordingly, Homer Newell asked the Space Science Board of the National Academy of Sciences to form a committee to review the agency's requirements in the life sciences and to make recommendations concerning the organization and management of its life sciences programs. Chaired by H. Bentley Glass, a biologist at the State University of New York, Stony Brook, the committee issued its findings and recommendations in September 1970.

The committee's report, like all previous external reports on NASA's life sciences programs, found the agency deficient in basic science and fundamental biomedical research. It urged NASA to design a life sciences program for the 1970s that would give priority to exobiology; fundamental and clinical research in "human biology and space biomedicine" for the purpose of laying the scientific foundation for qualification of man for long-duration spaceflight; and terrestrial applications—transfer of biomedical knowledge and technology derived from the space program to Earth-based medicine.

The Glass committee warned that "it is folly to expect any major improvement in the implementation of goals and in the development of the life sciences within NASA" unless the agency accepts the necessity for "a thorough-going reorganization" in the "administration of its life science programs." It proposed several major organizational changes. To draw external life scientists into the program planning process and to prevent life sciences directors from exploiting life sciences advisory groups for biopolitical purposes, NASA should disband the advisory committees that served the three life sciences offices. In their place, the agency should create a permanent life sciences advisory board "at a high administrative level." The board, whose members would be drawn from life scientists who had no ties to NASA, would "review programs on a continuing basis" and "recommend policies and priorities."

Second, NASA should create "a new Office of Space Biology and Medicine" with authority over all life sciences programs. The director of this office should have authority equal to that of the program office administrators, should be either an associate administrator for life sciences or a deputy associate administrator within the office of the NASA associate administrator, and should be empowered to implement a reorganization of life sciences programs along disciplinary lines (space biology, human biology and medicine, exobiology) rather than in accordance with programmatic functions.[9]

The Glass committee's report basically endorsed the space program objectives announced by President Nixon. In contrast to President Kennedy, Nixon declined to set a major manned goal as the primary focus for the space program. Rather, stressing austerity and balance, he called for a space program that would give equal weight to space exploration, space science, and terrestrial applications of space technology.

NASA adopted, in principle, the recommendations of the Glass committee. It established a Life Sciences Advisory Committee composed of life scientists who had no ties to NASA and made this committee advisory to the associate administrator. It gave recognition, if not organizational legitimacy, to the life sciences disciplinary fields, and it combined all life sciences activities, save exobiology, in a single office. Exobiology remained within the Office of Space Sciences because its objectives were more compatible with the planetary science division of that office than with those of the other life sciences. The remaining life sciences fields—space biology, human research, biotechnology and space medicine—were all directly or indirectly supportive of the manned space program.

The most significant exception to the Glass committee's recommendations was the formation of a life sciences office at division rather than program-office level. NASA management chose to make the new integrated life sciences office a component of the Office of Manned Space Flight rather than a separate program office for several reasons. First, the new office did not encompass all life sciences. In management's view, exobiology, occupational medicine, and aeronautical medicine had objectives and priorities that were not compatible with those of the other life sciences; none of the three had a role to play in support of manned spaceflight, and all played critical roles in their respective program offices. Second, since the major components of the life sciences program would contribute directly or indirectly to the long-range requirements of the manned space program, it made sense to conduct the integrated life sciences program in the context of the overall manned space program. Finally, there was no good reason to create a deputy administrator for the life sciences in the associate administrator's office. This would set a precedent that could lead to other activities and components demanding their own deputy. Moreover, such a position was unnecessary since the Life

Sciences Division director was authorized to communicate directly with the associate administrator and since the Life Sciences Advisory Committee was established as an advisory body of the associate administrator's office.

It was in this context that Deputy Administrator George Low announced the reorganization of December 1970. The relevant directive established the "NASA Director of Life Sciences" and granted him "responsibility and authority to oversee the total NASA life sciences program." The director had "functions and responsibilities on two separate levels." As head of the Division of Life Sciences in the Office of Manned Space Flight, he was responsible for developing an integrated biomedical program to support the manned spaceflight effort. In this capacity he was expected to "provide biomedical flight operations support" and "direction of all life sciences research and technology programs" in the areas of "biomedical research, bioscience research, life support and protective systems, man-machine integration, advanced bioinstrumentation, and related flight experiment definition." As life sciences director, he was responsible for developing "an integrated life sciences program and the separate programs in exobiology, aeronautical medicine and occupational medicine-environmental health." In this capacity, he was expected to represent all the life sciences to the external scientific community, recommend persons to fill "key life sciences positions," and keep the Administrator apprised of "the conduct of the entire NASA effort" in the life sciences. Most important, he was responsible for preparing and proposing a single integrated program plan and budget for all the life sciences.[10]

In issuing this directive, Low reflected on the space program priorities described before. The old biosciences program would be eliminated, he said, because "budgetary restraints" and space program priorities necessitated giving "low priority" to life sciences activities that were not "directly related to man" or did not meet the requirements of the planetary program. Rather, the requirements of the manned program necessitated integration of man-oriented biological and medical activities within the Office of Manned Space Flight and allocation of exobiology and planetary quarantine efforts to the planetary program of the Office of Space Science and Applications.[11]

By December 1970 the earlier opposition of certain life scientists to the organizational alignments and responsibilities within NASA was no longer evident. The reorganization proposed by Low was consistent with the views of space medicine director Humphreys and biotechnology and human research director Jones as it would tie together biological investigations, human research, and clinical medicine and link them directly to the manned spaceflight program. The reorganization also was now acceptable to most space biologists. The separation of exobiology from the manned spaceflight life sciences assured them that they would have a field of purely scientific research and would not experience organizational dislocation.[12] Further, with the abandonment of the Biosatellite Project, the biosciences no longer had a flight project to support their research interests. Indeed, the quality of bioscience investigations had come under fire from the NASA Administrator and the associate administrator for space sciences, who felt that the bioscience experiments flown on Biosatellite were exploratory rather than scientific in nature and did not justify the expenditures involved, and believed that the biosciences program would benefit from integration into the biomedical program of the manned spaceflight office.[13] Finally, shortly before the announcement of the reorganization, the chief life sciences opponent of an integrated life sciences program, Orr Reynolds, announced his resignation. In his own view, this removed the main impediment to life sciences program integration.[14]

Although the announced reorganization did not implement the Glass committee's recommendations for independent program status for the life sciences, appointment of a life scientist to a top management position, and retention of the inflight biological experiments program, it met the spirit of the committee's recommendations and there were no further criticisms from the scientific community at that time. The reorganization acknowledged the integrity of the life sciences as they are related to man and affirmed the traditional view among biomedical scientists that basic research in biology and medicine should not be divorced from clinical medicine. And as a corollary, the reorganization implied acceptance by NASA management of the traditional approach to biomedical research, namely that fundamental research in biology and medicine should precede, or be closely coordinated with, research on man. Finally, the reorganization enhanced the role of academic life sciences in the space program and provided for increased input from, and more efficient utilization of the advisory capabilities of, academic life scientists. The several uncoordinated committees that had been advisory bodies to the old life sciences directorates were eliminated and replaced by a single life sciences advisory committee. Authorized to advise the NASA associate administrator, this committee provided some semblance of high-level life sciences input and coordination.

## THE INTEGRATED NASA LIFE SCIENCES PROGRAM, 1971–1975

The reorganization of 1970, though it did impose coordination of the biomedical programs and eliminate much of the internal factionalism that had existed, did not lead to a truly integrated life sciences program. The so-called integrated life sciences program was in truth a fractionated program with its major elements, biomedicine and exobiology, assigned to separate program offices. Moreover, it had the same administrative defect that had hindered the life sciences program since its inception in 1960—responsibility without commensurate authority.

The director of life sciences faced the same practical administrative problems that had confounded and frustrated the Life Sciences Directors Group and the director of the Office of Life Science Programs. The management instruction that authorized and defined his position made him responsible for overseeing all aspects of the life sciences program. Through "guidance, review, and recommendations" he was to coordinate and integrate the research and development budgets and program plans of the several components and effectuate an integrated overall program.[15] However, he lacked the authority to fulfill these responsibilities. As a line officer in the Office of Manned Space Flight, he was directly subordinate to the administrator of that office and on a level of authority below that of the program office administrators who had jurisdiction over the other life sciences elements. Like the chairman of the Life Sciences Directors Group, he could create an integrated life sciences program only if he had the support and approval of four separate program office administrators. Although the directive that authorized and defined his position authorized him to make recommendations directly to the associate administrator, he could not disregard the desires and interests of the manned spaceflight administrator or tread on the authority of the other program office administrators. Indeed, the relevant management instruction stated clearly that in carrying out his responsibilities he should "be ever mindful of the line responsibilities" of the program office administrators "over the people working in life sciences" under their jurisdictions.[16]

Because of this administrative arrangement, the life sciences director encountered frequent difficulties as he sought to carry out his responsibilities. Forming an integrated life sciences research and development program posed a major problem since he had direct authority over a relatively small part of the total budget. Within the Office of Manned Spaceflight, he had authority to formulate the biomedical research and development budget. As far as the remainder of the life sciences budget was concerned, his authority was limited to coordinating, reviewing, and making recommendations. If disagreements arose in the course of budget preparations, he had no authority to resolve them. Resolution of such disagreements rested with the program office administrators and top management.[17]

This weakness in the director's authority was aggravated by the reality that in the early 1970s the biomedical programs were no longer receiving the major share of life sciences research and development allocations. Exobiology, which had been poorly funded in the 1960s, grossed the lion's share of life sciences allocations in the 1970s. In FY 1973, for example, about 80 percent of the total life sciences budget lay outside the director's immediate jurisdiction. (Table 3 shows the FY 1973 budget in terms of activity and responsible office.[18])

The range of offices involved in formulating the various parts of the total life sciences budget suggests the magnitude of the problem the director faced as he sought to formulate an integrated budget. This situation led one observer to conclude that the life sciences program, rather than being integrated, was "hampered by fragmentation of elements," and that the Director of Life Sciences lacked the degree of authority required to carry out this responsibility.[19]

Limitations on the director's authority were also evident in program planning. The director had responsibility for effecting an integrated life sciences research program, that is, one in which the research projects supported by the several life sciences components were devoid of duplication and overlap, complementary where necessary, and actually addressed to the agency's requirements. Toward this end, he was authorized to review research plans and projects proposed by the several offices and to make recommendations related to these proposals to the associate administrator. However, because he had less authority than the program office administrators and was directly subordinate to the manned spaceflight administrator, he was constrained in the exercise of this authority.

Complicating this problem, program administrators and life sciences administrators outside the Office of Manned Space Flight were concerned about the life sciences director's objectivity. They viewed him more as a line officer in that office than as the agency's chief administrator for life

**Table 3. Integrated NASA Life Sciences Program Budget, FY 1973**

| Activity | Office | Allocation | Percentage of Total |
|---|---|---|---|
| Life support and protective equipment | MSC DLS[a] | $10.2 M | 14.0 |
| Skylab | MSC DLS | 8.0 M | 11.1 |
| Medical and biological research | OMSF DLS | 10.7 M | 14.9 |
| Human factors and bioinstrumentation | OMSF DLS | 4.6 M | 6.4 |
| Aeronautical life sciences | OART | 3.0 M | 4.2 |
| Medical applications and technology utilization | OART | 2.2 M | 3.1 |
| Occupational medicine and environmental health | HQ administration | 4.6 M | 6.4 |
| Planetary biology | OSSA | 3.9 M | 5.4 |
| Planetary quarantine | OSSA | 2.2 M | 3.1 |
| Viking[b] | OSSA | (22.6 M) | (31.4) |

[a] MSC DLS = Manned Spacecraft Center Directorate of Life Sciences.
[b] A small part of this planetary program was associated with life sciences.

sciences. These administrators—and probably the manned spaceflight administrator as well—assumed that the director would give priority to manned spaceflight plans and projects when making recommendations concerning the integrated life sciences program. This assumption was based in part on the fact that the first life sciences director planned to use Office of Manned Space Flight standards and procedures for reviewing all life sciences research proposals and urged the other program officers to use that office's project review procedures in preparing their research program plans. Naturally, the administrators of the Office of Space Science and Applications and the Office of Advanced Research and Technology were reluctant to abandon their own procedures, which they had used before 1970, and they suspected that the application of manned spaceflight standards and procedures to the review of all research proposals in the life sciences would convey an advantage to the Office of Manned Space Flight's own sciences division.[20]

Whether this assumption was justified is difficult to determine. It is certain, however, that the nature of the administrative arrangements for integrating the life sciences may well have disposed the life sciences director to favor the life sciences component of the Office of Manned Space Flight. The research program of that office's life sciences division was his own program and the one for which he was directly accountable. Moreover, he was in a relatively weak position to make recommendations on the total life sciences program that were not acceptable to his boss, the manned spaceflight administrator. Finally, the background, experience, and allegiance of those who were appointed to the life sciences directorate undoubtedly biased them in favor of the Office of Manned Space Flight.

Both of NASA's life sciences directors between 1971 and 1975, J. W. Humphreys (1970–1972) and Charles A. Berry (1972–1974), were flight-oriented clinicians who held key positions in the manned spaceflight office before their appointment. While both recognized the importance of basic research in biology and medicine and supported the goals of the other life sciences, neither had significant experience or interest in fundamental research. Humphreys, whose career had been primarily devoted to the practice and teaching of surgery, was the Office of Manned Space Flight director of space medicine from 1967 to 1970. He had been an Air Force flight surgeon before joining NASA. Berry had served as head of medical operations at the Manned Spacecraft Center from 1962 to 1972, as a member of the Mercury aeromedical team from 1959 to 1962, and as an Air Force flight surgeon before joining the space program. In short, the reorganization of life sciences programs placed responsibility for integrating all the life sciences components in the hands of men who were by experience disposed to favor the objectives, priorities, and standards of the Office of Manned Space Flight, which had authority over only one of the life sciences components.[21]

Whether justified or not, the administrators of the other offices—Space Science and Applications and Advanced Research and Technology—were unwilling to place their trust in the objectivity of the life sciences director. Shortly after the reorganization of 1970, they decided, without consulting the director, to adopt new standards and procedures for reviewing project proposals, which they employed rather than those recommended by the director. In spite of the director's objections, they used their own procedures for the FY 1972 budget. Subsequently, they agreed to some modifications, but only after negotiation among the program office administrators. The life sciences director was impotent to resolve this problem, even though resolution was essential to the fulfillment of his responsibilities. This, and other comparable situations, led the chairman of the Life Sciences Advisory Committee to complain to NASA Associate Administrator Homer Newell that the director of life sciences could not be expected "to discharge his functions in a fully effective fashion" so long as "decisions are being made and programmatic actions are being taken without [his] knowledge and concurrence." The only solution to this problem, in his view, would be "further consolidation" of the life sciences program.[22]

The life sciences director also was hampered by bureaucratic inertia. In order to gain internal support for the reorganization of 1970, NASA's top management had had to provide assurances to the affected life sciences administrators and staffs that the reorganization would not cause serious disruptions of existing organizations, loss of authority for key personnel, or disruption of personal and organizational relationships. Every effort would be made to ensure that "established relationships" were maintained.[23] At the same time, Civil Service regulations prohibited significant changes in the responsibilities and authority of individual employees without congressional approval or strong justification. Consequently, the reorganization proceeded with the misunderstanding that, insofar as possible, organizational arrangements would remain intact when transferred and no key administrators would suffer loss of authority.

In practical terms, this meant that the life sciences administrator had to create an integrated life sciences program responsive to the agency's requirements and priorities in the 1970s, while using key administrators and staff personnel whose philosophies and perceptions were formed during the quite different space program of the 1960s. Although the primary requirement of the manned space program of the 1970s would be fundamental biomedical research in support of advanced manned flights, the life sciences director was forced to rely on administrators and staff who had not worked in terms of an integrated life sciences program. For example, the new program depended on a reorientation of the life sciences program at the Manned Spacecraft Center toward basic biological and medical research and away from applied research, biotechnology, and mission operations. However, the life sciences director at NASA Headquarters had to work with an individual appointed to the Manned Spacecraft Center life sciences directorship who had a degree in the physical sciences, no training or research experience in the life sciences, and a career that had been devoted entirely to development and evaluation of life support systems. While this individual had performed exceptionally in his various capacities and was a highly respected administrator, he was not qualified through experience to direct an organization expected to focus on biological and medical research.[24] This made it very difficult for Humphreys and Berry to establish the type of research-oriented program recommended by the Glass committee and envisioned at the time of reorganization.

By late 1972 NASA Administrator James Fletcher and Deputy Administrator George Low were dissatisfied with progress in the development of the Life Sciences Program. Disturbed by negative comments from the Life Sciences Advisory Committee and their own convictions that life sciences director Charles Berry had not developed a headquarters life sciences research component and had not kept top management apprised of developments within the life sciences program, they began to question whether these problems stemmed from the nature of the organization or from the individuals involved. While both agreed that "the person in the job is more important than where he is organizationally situated," there seemed to have been a lack of awareness of the administrative constraints that made it virtually impossible for the life sciences director to do his job.[25] Both Humphreys and Berry were forceful and assertive individuals, capable and experienced administrators, and respected members of the NASA community, yet neither succeeded in forming an effective and viable life sciences program.

## TOWARD COMPLETE INTEGRATION

In early 1973 Fletcher appointed Dr. William Barry as a special assistant to conduct a review of the agency's life sciences programs. The ostensible purpose of this review was to determine their adequacy for the Space Shuttle program, but the fundamental reason was his desire to know whether problems in the management of the agency's life sciences program derived from administrative arrangements or from the capabilities of the individuals involved. In effect, both purposes were complementary and related to the same question: What arrangements are most consistent with the fulfillment of the agency's requirements in the post-Skylab space program?[26]

Barry presented his findings to Fletcher in February 1974. The primary weaknesses in the program, according to Barry, were those that have already been discussed—and had persisted from the start—fragmentation of programs, responsibility without commensurate authority, bureaucratic inertia. In regard to the last of these, he concluded that the age and longevity in office of key administrators engendered conservatism in the management of the program and precluded innovative and imaginative approaches to solving the problems peculiar to the space program of the 1970s.[27] Although the old biosciences, human research-biotechnology, and space medicine directorates were supposedly integrated into the Office of Manned Space Flight division of life sciences, in practice integration was never effected. Within the division of life sciences, biology and medicine were in separate branches, each staffed by carryovers from the old programs; consequently, the biology and medicine programs, though in the same office, were not truly integrated. Those responsible for managing the bioresearch division (biological sciences), he believed, maintained the old bioscience orientation in which biological research was conducted for purely scientific reasons and without regard for the requirements of the manned spaceflight program. Likewise, the bioengineering and medical research branches continued to function as if they were the old biotechnology-human research and space medicine directorates, rather than as integrated units. This, he believed, was due to the fact that key administrative and staff positions in the new organization were largely filled with persons who had been with the agency since the beginning of the space program.[28]

Moreover, although space medicine was essentially a specialized branch of environmental medicine and the space medicine and occupational medicine-environmental health branches had many common concerns, the reorganization made no provision for integrating the latter into the life sciences division. This resulted from the conservatism of the life sciences administrators, who had grown within a program in which space medicine and occupational medicine were totally segregated. Barry contended that in the Shuttle era, with its emphasis on space transportation and on utilization of space passengers who were not drawn from test pilots, occupational medicine and environmental health would assume increasing importance.[29]

These observations led Barry to conclude that NASA was in need of a life sciences organization in which the director had substantial authority and "a youthful, middle-management point of view."[30] However, the problems, he said, were not limited to headquarters, but extended to the centers as well. Reiterating the findings of the Life Sciences Study Task

Group in 1968, the Maggin-Bell Study of 1967, and the Bollerud report of 1966, he found that communications between the life sciences offices at Johnson Space Center and Ames Research Center were minimal and that duplication of efforts remained a serious problem.[31] He also noted a marked contrast between the capabilities of the two centers. Ames, in his view, was under the direction of a highly qualified scientist, Hans Mark, who was also an excellent administrator and who had built on Ames's already "excellent ties" with local universities. By contrast, Johnson had "an obvious lack of scientific leadership," and virtually no ties with major universities. Among the deficiencies that he observed at Johnson Space Center were key life sciences administrators who had no professional credentials in the life sciences, severe "fragmentation" of the life sciences (12 separate branches), an overabundance of veterinarians, and a tendency to depend on life sciences support from personnel drawn from life sciences agencies outside NASA.[32] The irony in this, according to Barry, was that the center least qualified to support biomedical research in support of manned spaceflight, Johnson Space Center, was the agency that NASA Headquarters looked to for primary biomedical support for advanced manned programs, while the center best qualified to provide this support, Ames, was generally overlooked by headquarters insofar as biomedical research was concerned.[33]

Barry concluded that these arrangements were totally inadequate for the Shuttle—or any other—era, when the "major issues of important future significance" would be (1) "technology development to support the search for and identification of extraterrestrial life," (2) "defining the physiological parameters for space shuttle scientist-passengers, and developing appropriate selection techniques," and (3) "definition, preparation, and coordination of payloads for the Space Shuttle."[34]

These considerations, Barry contended, justified reorganizing the NASA Life Sciences Program. First, he recommended that occupational medicine-environmental health be integrated into the life sciences program and that the life sciences office divide its activities along the following lines: aerospace medicine and biology, bioenvironmental engineering, and occupational medicine-environmental health. Second, he urged that NASA establish the directorship of life sciences as an independent office, separate from the Office of Manned Space Flight and "reporting directly to top management." This directorship should have "independent budgetary authority" and independence of the program office associate administrators.[35] Third, he recommended that all the headquarters life sciences components be consolidated within a single office and placed under the jurisdiction of the life sciences director. Finally, he urged that NASA reorganize the life sciences activities at the centers. The life sciences elements at Johnson Space Center, he said, should be fully integrated into a single office and placed under the direction of a research-oriented scientist. The life sciences director at Johnson should have responsibility and authority for developing the fundamental biomedical research capability required for the Shuttle era. Ames life scientists engaged in basic biological and medical research and research in bioengineering should be transferred to Johnson, while Ames should remain the center for exobiology and aeronautical life sciences research.[36]

Barry's report reiterated findings and recommendations that Fletcher had received from the NASA Life Sciences Advisory Committee over the preceding two years.[37] However, these recommendations were never fully implemented, for their complete implementation was not considered practical. Any effort to make a major shift of personnel and facilities from one center to another would have been thwarted by internal and external opposition. Moreover, even if there were solid evidence that old-line life sciences administrators were retarding the growth of a truly integrated life sciences program, those administrators could not have been easily removed from their positions.

Nonetheless, Fletcher recognized the need for some improvements. He and his deputy, George Low, had been dissatisfied with the pace of the life sciences program under the direction of Charles Berry. Although they did not question Berry's capabilities, they doubted his commitment to the creation of an expanded and diversified life sciences research program.[38] Berry's background in mission-oriented medicine and lengthy experience with space medical operations may have made it difficult for him to appreciate the value of fundamental research in biology and of basic medical research that was not mission oriented.[39] Moreover, with Berry as NASA Headquarters life sciences director and Richard S. Johnston as director of life sciences at Johnson Space Center, the two most important (traditionally, at least) life sciences administrative positions were held by persons wedded to the Manned Spacecraft Center-Johnson Space Center mode of mission-oriented biomedicine.

In an effort to inject new life into the headquarters life sciences office, Fletcher acted on one of William Barry's recommendations. Barry had suggested that Johnston be replaced by David Winter, or that Winter be appointed headquarters life sciences director. Winter, a medical scientist and clinician and specialist in neurophysiology, was at the time deputy director of life sciences at Ames and had no background in manned spaceflight operations. Fletcher accepted Barry's alternative recommendation and appointed Winter director of life sciences at headquarters in September 1974.

Fletcher made no further changes in life sciences organization until September 1975, by which time he had determined that a major reorganization of all headquarters programs was in order. He believed that a reorganization would effect "a more logical realignment of responsibilities as we move into the Space Shuttle operations." He identified these responsibilities as "launching space vehicles and conducting shuttle operations" and planning for "the science to be performed on these flights." This necessitated closer coordination among the research, development, and operations offices at both headquarters and the centers. To achieve this coordination, he abolished the old program offices and created two associate administratorships, one for headquarters administration and one for centers administration. Within the jurisdiction of the former, he placed three program offices—one for aeronautics, one for space transportation systems and operations, and one for space sciences. The space transportation systems office assumed most of the responsibilities of the old Office of Manned Space Flight and had primary responsibility for development of Shuttle systems and conduct of Shuttle operations. The Office of Space Science received responsibility for planning the scientific activities of Shuttle operations.[40]

This broad reorganization led to a change in the organization of the life sciences and one that met the spirit, if not the form, of the organization recommended by Barry and others. By creating the position of associate administrator to coordinate the activities of the centers and by removing the centers from the jurisdiction of individual program offices, Fletcher essentially met the spirit of Barry's recommendation. In theory at least, the basic research conducted by Ames life scientists would be closely coordinated with the efforts of the Johnson life scientists—and without any major relocation of personnel, facilities, and programs. At the same time, the existence of an associate administrator responsible for program office coordination should ensure effective coordination among life sciences research, development, and operations at headquarters without the need for a high-level life sciences administrator. Finally, by making a distinction between spaceflight development and operations and space science, Fletcher created a framework for integrating all the life sciences within a single office. Fundamental research in biology and medicine and definition of life sciences payloads for Shuttle flights now clearly fell within the purview of space science, and the life sciences office was placed under the jurisdiction of the Office of Space Science. In addition, because the Shuttle flights were expected to carry passengers in addition to the flight crews, occupational medicine and aeronautical medicine were added to the life sciences office.[41]

This reorganization was authorized 18 months after the termination of the Skylab program and 3 months after the Apollo-Soyuz flight, which was in effect the last American manned flight in the mode that had begun with the first Mercury flight and that had reached its apogee with the first manned lunar landing. The reorganization, in terms of both overall and life sciences administration, symbolized a major shift in the space program orientation and management approach. The old mode of spaceflight in which missions were conceived in the same terms as the testing of experimental aircraft was over and a new mode was emerging. Spaceflight as a mode of transportation and a medium for commerce would replace spaceflight as a means of "testing the envelope"; expendable space systems would be replaced by reusable ones; and the experience of spaceflight would no longer be limited to a few uniquely qualified, highly selected individuals. This shift in orientation had significant implications for NASA's life sciences.

*The Skylab vestibular function experiment tests the crew's susceptibility to motion sickness in the Skylab environment.*

# 12

# NASA life sciences from the Shuttle into the future

In the 1970s, NASA's life scientists acquired an opportunity to develop a life sciences program that was not constrained by the practical requirements of specific manned missions. They were free to devise an integrated approach to biological and medical research, to design meaningful inflight investigations, to emphasize fundamental research in biomedicine, and to replace the pragmatic incremental approach to human research with the traditional mode of biomedical investigation. Biomedical aspects of Skylab and long-range planning for Space Shuttle operations reflected this shift in the role and responsibilities of the life sciences program.

Yet the life sciences program was not without problems. While the end of the Apollo program released life scientists from the pragmatism of the manned program of the 1960s, it also deprived them of certainty (i.e., clearly defined, readily identified mission objectives) and an important justification for life sciences activities. Moreover, the shift cast an old dilemma into a new mold: how to achieve a balanced life sciences program that would satisfy the demands of both the manned spaceflight program and the space sciences program. The history of the life sciences in the 1970s shows the efforts of life scientists to take advantage of new opportunities while resolving this dilemma and while maintaining and justifying their activities in the absence of a major national manned objective in space.

## BIOMEDICAL ASPECTS OF SKYLAB

The Skylab program, which consisted of three manned missions flown between May 25, 1973 and February 1974, was both an ending and a beginning. In operational terms, the Skylab missions were logical extensions of the manned programs of the 1960s and the concluding phase of the manned missions that had begun with the first suborbital flight of Project Mercury. At the same time, Skylab represented the first U.S. step toward a space station. The mission durations were chosen to extend the incremental approach to the qualification of man for spaceflight, and most of the biomedical investigations and experiments were designed in response to physiological and behavioral situations identified in the earlier flight programs.

Yet Skylab was also a major departure. The Skylab missions were the first in the American space program in which scientific investigations had the same level of priority as operational tasks and in which the astronauts had a fundamental responsibility to function as scientific investigators. Further, the Skylab program was not limited by specific short-range mission objectives; its objective was to evaluate man's capability for enduring flights up to 84 days in length, to understand some of the mechanisms underlying physiological adaptation to weightlessness, and to identify countermeasures that would permit man to perform effectively in flights of longer duration. The clinical studies and biomedical experiments of the Skylab flights were designed along classical lines of biomedical research and involved correlated studies of major body systems to determine the dynamics of physiological and behavioral responses to spaceflight.[1] Skylab, then, was the first American effort to make fundamental research in biology and medicine an integral part of manned spaceflight operations and to give operational reality to the integrated life sciences program.

The complete history of Skylab, including its biomedical aspects, has been detailed in other studies and will receive only summary treatment here.[2] The following survey of its biomedical investigations and findings will show the range of biomedical activities within the Skylab program and the expansion in scope of the biomedical aspects of manned spaceflight from the beginnings in Project Mercury. The Skylab program was significant in two ways. First, the missions qualified man for flights up to 84 days long and provided medically acceptable evidence of man's qualification for flights of longer duration. Second, the biomedical experiments and clinical investigations yielded important information on human physiological adaptation to weightlessness and affirmed the value of fundamental and coordinated biomedical investigations to long-range manned operations.

The Skylab biomedical program encompassed six areas: general clinical evaluations, neurophysiology, musculoskeletal functions, body fluid biochemistry and hematology, cardiovascular function, and nutrition and metabolic function. Experiments within these areas reflected clinical and research concerns derived from earlier manned missions: crew health stabilization and the prevention of inflight illnesses; vestibular function

*Astronaut Joseph P. Kerwin, crew member of the first manned Skylab mission, examines the Human Vestibular Function, while astronaut Paul J. Weitz reads a checklist. The experiment will help establish the validity of measurements of specific behavioral/physiological responses influenced by vestibular activity under one-g and zero-g conditions.*

and motion sickness; bone demineralization and muscle atrophy; red cell mass and blood volume losses; cardiovascular adaptations to weightlessness and orthostatic hypotension; and the metabolic costs of workloads in null gravity. These investigations consisted of a broad range of pre- and postflight clinical studies and 13 biomedical experiments to study a variety of physiological functions and test the reliability of new bioinstruments.

## CREW HEALTH STABILIZATION

The Skylab program for reducing the probability of inflight illness followed the basic procedures established in the latter stages of the Apollo program (see Table 4). A 21-day preflight isolation period was imposed, during which the number of primary contacts was strictly limited and the health of those contacts closely monitored. The 21-day period was selected because it covered the incubation period for the majority of infectious disease organisms.[3]

In Skylab a seven-day postflight isolation was added to protect returning crewmen, who might have increased susceptibility to infectious diseases due to the extended duration of the flights. This added period of isolation would also reduce the possibility of postflight infection interfering with the scientific evaluation of medical data and would prevent transfer of infections between flight crews.[4]

The program for prevention of inflight illnesses was closely linked to a series of microbiological investigations to detect the presence of potentially pathogenic microorganisms on the crewmen and in the spacecraft and to gain an understanding of the response of these organisms to the spaceflight environment. The procedure entailed collecting samples of

**Table 4. Skylab Flight Crew Health Stabilization Program**

| | | | | |
|---|---|---|---|---|
| | | *Primary Contacts* | | |
| | | Class A and Class B | | |
| | | Illness reporting (voluntary) | | |
| | | ↑↓ | | |
| *Crew* | | *Medical Surveillance Office* | | *Primary Work Areas* |
| (Crew Surgeon) | | Program coordination | ⇄ | Active surveillance |
| Living quarters | ⇄ | Training | | Security |
| Mobile trailers (JSC) | | Records and data | | Preventive measures |
| Crew quarters (KSC) | | Medical status reports | | Surgical masks |
| Food | | ↑↓ | | Biorespirators |
| Travel | | *Clinic* | | Air filters |
| | | Medical examinations | | |
| | | PC qualification—disqualification | | |
| | | Badge control | | |

SOURCE: Johnston and Dietlein, *Biomedical Results from Skylab.*

*Ames's Dr. Patricia Cowings straps laboratory assistant Leah Schafer into vertical acceleration device used to induce motion sickness in human volunteers. Dr. Cowings trains subjects to use biofeedback to prevent motion sickness.*

microbial flora from 12 separate sites on the bodies of the crewmen before and after each mission and 16 days before the termination of each mission (see Table 5). Analysis of these data demonstrated gross contamination of the Skylab environment, but failed to show that any of the inflight diseases during the Skylab missions was caused by this contamination or that the contamination posed a significant hazard for long-duration spaceflight.[5]

Overall, the Skylab health stabilization program appeared to significantly reduce the incidence of inflight infections. While upper respiratory infections and gastroenteritis were relatively common during the Apollo missions, they did not occur during the Skylab missions. Table 6 compares the occurrence of infectious diseases before the health stabilization program with that after the introduction of the program.

**Table 5. Crew Sample Collection Sites[1]**

| *Sample designation* | *Area sampled* |
|---|---|
| Neck | 13 cm² below hairline at base of neck. |
| Ears [2] | Right and left external auditory canals with two revolutions of each swab in each ear canal. |
| Axillae | 6.5 cm² below hair area on each side. |
| Hands | 6.5 cm² on right and left palms. |
| Navel | The internal area of the umbilicus, and a surrounding 13 cm² area with at least two revolutions made with each swab. |
| Groin | 5 cm strip from rear to front on right and left inguinal area between legs. |
| Toes [2] | Area between the two smallest toes of each foot. |
| Nares [2] | Both nostrils. |
| Throat swab [2] | Surfaces of tonsils and posterior pharyngeal vault swabbed with each of two dry calcium alginate swabs. |
| Gargle | 60 cm² phosphate buffer used as gargle and washed through oral cavity three times. |
| Urine | 60 cm² midstream sample. |
| Feces | Two samples of 100 mg each taken from center of the fecal specimen. |

**Table 6. Effect of the Flight Crew Health Stabilization Program on the Occurrence of Illness in Prime Crewmen**

| Health stabilization program absent | | | | Health stabilization program operational | | | |
|---|---|---|---|---|---|---|---|
| Mission | Illness type [1] | Number of crewmen involved | Time period [2] | Mission | Illness type [1] | Number of crewmen involved | Time period [2] |
| Apollo 7 | URI | 3 | M | Apollo 14 | | | |
| 8 | VG | 3 | P, M | 15 | | | |
| 9 | URI | 3 | P | 16 | | | |
| 10 | URI | 2 | P | 17 | SI | 1 | P |
| 11 | | | | Skylab 2 | | | |
| 12 | SI | 2 | M | 3 | SI | 2 | M |
| 13 | R | 1 | P | 4 | SI | 2 | M |

[1] Illness type:
URI, Upper respiratory infection.
VG, Viral gastroenteritis.
SI, Skin infection.
R, Rubella exposure.

[2] Time period:
M, During mission.
P, Premission.

## NEUROPHYSIOLOGY

Investigations in neurophysiology had two objectives: to test methods for predicting and controlling motion sickness and to identify the nature and cause of the vestibular changes that contribute to motion sickness. The investigations consisted of a three-part vestibular function experiment and a postflight evaluation of balance.[6] The findings from these studies were basically inconclusive. Tests of susceptibility to motion sickness successfully predicted motion sickness events in only 22 percent of the cases and led to the conclusion that susceptibility on the ground is not an accurate indicator of inflight susceptibility. Rather, prevention of motion sickness involves adaptation and use of appropriate medications. Likewise, while these studies indicated that "otolith function is profoundly influenced by null gravity," the etiological factors connecting otolith function to motion sickness could not be identified. The general conclusion was that the "central memory network" is programmed to respond to a 1-G environment and requires "repatterning" through training to prevent distortion of "sensory inputs" in the null G environment.[7]

## MUSCULOSKELETAL FUNCTIONS

As noted earlier, bone demineralization and muscle atrophy were anomalies observed in the Gemini and Apollo flights and were of significant concern to physicians. In Skylab, several investigations were conducted to measure the extent of musculoskeletal changes, to determine whether they represented a self-limiting adaptive response, and to test the reliability of instruments for measuring them. In one experiment, the dietary intake of the crew members was carefully monitored and compared with analyses of urine samples taken each 24 hours. A significant increase was observed in calcium and creatinine in the urine, both indicative of bone demineralization, and in nitrogen and phosphorus in the urine, indicative of muscle degeneration. These changes continued to increase throughout each of the three manned missions, suggesting that a self-limiting adaptive response was not occurring. As these changes occurred in spite of inflight exercise regimens, the findings indicated that musculoskeletal function could be an area of significant concern in longer duration flights.[8] Other studies confirmed changes in bone density and muscle mass, but indicated that exercise programs could reduce atrophy in muscle strength.[9] Overall, these investigations showed that weightlessness was the principal factor in bone and muscle atrophy in spaceflight and that there was a need for intensive investigations to understand these phenomena and identify effective countermeasures.[10]

## BODY FLUID BIOCHEMISTRY

Early theories and practical experiences in the manned flights of the 1970s suggested that weightlessness causes, through a complex biomedical reaction, a loss in body fluid. In simplest terms, weightlessness causes a reduction in total circulating blood volume, which reduces hormones controlling excretion and leads to elimination of body fluids. It was theorized that this change was a response to the space environment. To test this idea, determine the scope of this change, and identify the mechanisms involved, Skylab investigators conducted experiments to measure changes in blood volume, body fluid output, and the biochemistry of body fluids.[11] Their findings confirmed that changes occur in blood and body fluid volume and body fluid chemistry in direct response to weightlessness, that these changes appear to be self-limiting and successful adaptations to the spaceflight environment, and that the specific dynamics are uncertain.[12]

## HEMATOLOGY

Data gathered during the 4-, 8-, and 14-day Gemini flights indicated a significant loss in red cell mass. However, physicians could not determine whether this was a self-limiting adaptive response or a condition that would become worse as the duration of flights was extended. They also could not identify the precise cause of this change, though they suspected that it was a toxic reaction to prolonged exposure to highly oxygenated atmospheres. In the Skylab missions, medical scientists sought to measure the duration of the change and determine whether it was an adaptive response or a reaction to oxygen toxicity.[13]

The findings confirmed that the decrease in red cell mass "is a constant occurrence in space flight," but that the phenomenon is self-limiting. The effect did not increase steadily as mission duration increased. However, a 30-day delay occurred before the change began to reverse itself. The success of the 83-day mission suggested that this rather lengthy recovery, though a matter of clinical concern, would not pose a hazard in longer duration missions. Efforts to identify the cause of this change were unsuccessful, though the relevant experiment indicated that it was not a response to oxygen toxicity. Rather, some unidentified factor was believed to cause a suppression in bone marrow activity and a consequent decrease in red cell mass.[14]

## CARDIOVASCULAR STUDIES

The Mercury and Gemini flights revealed a significant decrease in postflight orthostatic tolerance and suggested that the body makes cardiovascular adaptations to weightlessness that interfere with cardiovascular function on return to a 1-G environment. Skylab investigations were conducted to determine the extent and time course of changes in orthostatic tolerance in flight, to determine whether data collected in flight could be used to predict postflight orthostatic intolerance, and to determine whether changes in orthostatic tolerance can be minimized by inflight exercise.[15] The findings confirmed that the cardiovascular system changes to adapt to weightlessness, that this adaptation stabilizes in four to six weeks, that the change does not impair inflight physiological function or performance, and that it does not affect exercise tolerance in flight. Further, the change appeared to be a result of undetermined factors that reduce circulating blood volume, although this was not confirmed. Postflight studies showed that orthostatic tolerance decreased only after return to the Earth and was directly related to inflight exercise. This finding pointed to the need for an effective inflight exercise program.[16]

## BIOMEDICAL PLANNING FOR THE SPACE SHUTTLE ERA

The biomedical results of Skylab justified the objectives of the integrated life sciences program and generated optimism that the program would continue to grow and develop within the context of a space program based on use of a Space Shuttle. NASA initiated the development program for the Space Shuttle after two years of study and President Nixon's call for a reusable space transportation system that would offer "less costly and less complicated ways of transporting payloads into space."[17] Although the Shuttle would be the prime focus of the manned spaceflight program through the early 1980s, it was to be the first component of an eventual multistage space transportation system, which would include the Shuttle, a space tug, and a space station. The Shuttle would transport passengers and payloads from the Earth to low Earth orbit; the space tug would ferry them from low orbit to higher orbits or to the space station; and the space station would function as a staging area for interplanetary flights and as a site for extended spaceflight operations and scientific investigations. In the interim between initial operations and completion of the system, the Shuttle, the tug, a space lab, and various automated satellites would serve as the modalities for both operations and inflight investigations.[18] However, at the close of the Skylab program, NASA had full approval and funding only for the development of the basic Space Shuttle and its initial operational tests. NASA had authorization to proceed with planning for the development of the other components, but the time frame for full funding, final design development, and actual operation was uncertain.

In spite of the uncertainties, life scientists were confident that the Shuttle and subsequent developments would be boons to the space life sciences. They were most excited about the prospect of carrying out life sciences experiments in space in laboratories under conditions approximating those on the ground.[19] Previously, life scientists had been forced to use bioinstruments of questionable reliability in remote monitoring of biological processes and to design their experiment packages with engineering constraints, thus compromising scientific objectives. With a reusable system, experimental payloads could be designed as closed units which could be returned to the Earth for analysis if required, weight and space would no longer be major constraints, and life sciences experiments would not have to be designed as one-shot operations but could be carried on over a series of flights.

Life scientists also saw in the Shuttle an opportunity to use trained scientists as inflight investigators and obtain data on the physiological effects of spaceflight from a diversity of passengers. Previously, data were drawn from flight crews who were well suited and carefully selected for space missions. At the same time, a large body of data was obtained from a very small sample of human beings. With the Shuttle flights, scientists could study passengers who were more representative of the general population and obtain data from a broad sample.[20] Many life scientists were especially interested in the opportunity to study the effects of spaceflight on women and wished to know the degree to which sex is a factor, if at all, in adaptation to weightlessness and if special countermeasures are necessary to protect women astronauts from the effects of extended duration spaceflight.[21]

A third advantage that life scientists saw in Shuttle operations was the opportunity to study physiological changes during the first three to five days of spaceflight, the critical period during which physiological adaptations begin. In Mercury, Gemini, Apollo, and Skylab, this was not possible because of the short duration of the missions or the need for the astronauts to devote themselves exclusively to operational tasks during the first days. After the initial Shuttle qualification flights, operational tasks would not monopolize the time of the flight crews, and some of the Shuttle passengers would have no involvement in operational tasks. Consequently, data could be obtained on this critical period of adaptation.[22]

Finally, life scientists were buoyed by the prospect of a permanent orbiting space station. This would provide opportunities to conduct controlled studies over very long periods to evaluate human responses, to conduct long-range, uninterrupted biomedical experiments, and to conduct biological investigations at all biological levels. Equally important, they viewed the space station as an opportunity to move toward biological investigations of the planets.[23]

Anticipating that the space transportation system would become fully operational by 1985, life scientists in NASA and the National Academy of Sciences devised long-range plans for biomedical research for the Shuttle era from about 1982 to 1991. These plans followed traditional life sciences categories and divided the Shuttle life sciences programs into space biology, biomedicine, planetary biology, and man-machine relationships. These four subprograms were to (1) further investigations into the origin of life and the search for extraterrestrial life, (2) continue research on mechanisms of adaptation to spaceflight and identify criteria for developing countermeasures, (3) continue the refinement of advanced technology for life support, protective systems, and work aids, and (4) implement techniques for studying in animals and lower organisms physiological changes observed during manned flights that cannot be easily or safely studied through experiments with man.[24]

However, life scientists understood the realities of the space program and recognized that implementation of this long-range research program could be delayed until well beyond 1985. Consequently, they also focused on designing life sciences payloads for the early Shuttle flights. The life sciences investigations would be conducted in low orbit with the Shuttle itself and automated subsatellites. Life scientists anticipated that this arrangement would prevail through the early 1990s. Accordingly, they established somewhat modest short-range goals, emphasizing weightlessness as the variable of fundamental concern to both space biologists and space physicians. Their two short-range goals were to study "basic biological and physical mechanisms . . . and . . . changes over time in biological systems," and to gain information for developing "countermeasures and support systems to extend man's capability to live and work in space." Life scientists planned to meet these objectives in three ways. First, they planned to develop an automated life sciences research module that would contain an array of biological specimens and would remain in space for extended periods. This module would be ferried into low orbit by the Shuttle, and subsequent Shuttle flights would retrieve and return packages from the module. Basically, the module would be used to study the long-term effects of weightlessness, radiation, and altered circadian rhythms. Other biomedical experiments would be conducted in a laboratory designed for incorporation in the Shuttle and through experiment payloads flown according to a predetermined schedule. The operation of the laboratory and the monitoring of the payloads would be the responsibility of trained scientists carried as passengers on the Shuttle.[25]

## LIFE SCIENCES MANAGEMENT IN THE SHUTTLE ERA

Designing a long-range research program was one matter; implementing it in the face of political and administrative constraints was quite another. Responsibility for effecting the transition from a life sciences program oriented almost exclusively to support for manned spaceflight operations to one stressing fundamental research in biology and medicine fell to Dr. David L. Winter. Winter, a physician, medical scientist, and specialist in neurophysiology, was deputy director of the life science directorate at Ames from 1971 to 1974. He was appointed to the life sciences division at NASA Headquarters by Administrator Fletcher following recommendations that NASA place the division under the direction of a research-oriented, rather than flight-oriented, medical scientist.[26]

Winter came into a situation where, at the time of his appointment, the life sciences director reported to the administrator for manned spaceflight. Thus, he was responsible for developing a life sciences program that would support fundamental research in biology and medicine while functioning within a program office that had a strong traditional orientation toward applied research, biotechnology, and medical operations and that was staffed by personnel who favored that orientation.[27] After devoting a year to devising a life sciences program directed at balancing the differing requirements of manned operations and space science, Winter and his office were transferred to the space sciences program office. The administrators of that office were primarily physical scientists who had no tradition of involvement in the manned program, and who were as devoted to basic research and theoretical science as the manned spaceflight administrators had been to manned spaceflight applications. Moreover, several key administrators in the space sciences office had a low opinion of the life sciences program. They believed that it had failed to achieve the same level of scientific excellence as the physical science and astronomy programs.[28] Winter was in the unenviable position of having to shift from an office where he strove to justify a balanced and integrated life sciences program to administrators who had little interest in basic science, to an office where he had to justify such a balanced program to administrators who had little interest in applied research, biotechnology, and medical operations.

Winter, at the time of his appointment, understood that he was to design a life sciences program that would define the standards for passengers on the Shuttle, determine human requirements and man-machine requirements for Shuttle era operations, and devise biological and medical experiments that would form the life sciences payloads for Shuttle operations.[29] However, the space science administrators had somewhat different objectives. When he announced the reorganization of

September 1975, Fletcher specified that the space science office would have responsibility for defining the scientific parameters for the Shuttle era (see Chapter 11). The key space science administrators, Noel Hinners and John Naugle, interpreted this as meaning that the space science office would focus exclusively on science and would not be constrained by the requirements of the manned space program. Accordingly, they directed Winter to design a life sciences program that would be acceptable to research scientists and that would attract as much respect and support from academic life scientists as the physical science and astronomy programs had. They specifically did not want a life sciences program that was justified primarily by its applications to manned spaceflight.[30]

As a scientist with no strong identification with the manned space program, Winter shared the desire for a program that would make scientific contributions and would be respected by life scientists outside NASA. However, although he shared the overall goal of the space scientists, his conception of the responsibilities of science was different from theirs. As a medical scientist, Winter was heir to a different scientific tradition than that inherited by Hinners and Naugle. Medical science has never been totally divorced from human applications; its theories are formulated with the expectation that they will have eventual application in clinical situations. Physical scientists have a tradition of science for science's sake, a belief that scientific theories can be formulated without regard to practical applications. To a large extent, biological scientists (as opposed to medical scientists) share the latter tradition. Winter's medical orientation, combined with his understanding that he was responsible for establishing a balanced life sciences program, caused him to work toward the formulation of a life sciences program that, though scientific in orientation, gave major attention to the role of life sciences in support of manned spaceflight.[31] Hinners and Naugle viewed this as a repudiation of their directives to Winter.[32]

In addition, bureaucratic inertia complicated Winter's attempts to develop an appropriately balanced program. Although the life sciences division had been transferred to a new program office, the loyalties of many of the key administrators and staff remained fixed in the manned spaceflight program. The staff that followed Winter in September 1975 included Dr. Stanley Deutsch, a psychologist and human factors specialist, Dr. Sherman Vinograd, a physician, medical scientist, and specialist in space physiology and clinical space medicine, Dr. Rufus Hessberg, a physician and retired Air Force flight surgeon, Dan Popma, a bioengineer and life systems specialist, and Dr. Richard Young, a biologist. All but Hessberg had been with NASA since the early 1960s; Hessberg had joined NASA in 1966 after a career in aerospace medical programs in the Air Force. Only Young had a background in basic research and the biological sciences and strong connections with academic life scientists. Thus, the "new" life sciences program within the space science office was to be defined and implemented by personnel whose careers were linked to the manned space program of the 1960s and who justified the agency's work in terms of its applications to manned spaceflight. A similar situation prevailed at the NASA centers. The Johnson Space Center life science division, which would have primary responsibility for life sciences support of the Shuttle at project level, was appropriately, overwhelmingly oriented toward manned spaceflight applications. The director of the life sciences office, Richard S. Johnston, was a chemist with a background in the development, testing, and evaluation of environmental control systems. His staff consisted primarily of physicians, veterinarians, and bioengineers, most of whom had been with the space program since the early days and few of whom had any strong interest in fundamental life sciences research and development that were not linked to manned spaceflight.[33]

If Winter had a failing, it lay in his unwillingness to replace these people with others oriented toward the more fundamental aspects of life sciences research. He valued the experience they brought to the program, respected their credentials—and their loyalty to the agency—and shared their assumption that life sciences research should have an ultimate application to manned spaceflight.[34] Moreover, Winter would have encountered problems had he tried to remove them. Besides being protected by Civil Service regulations, their removal could be expected to cause widespread unrest and undermine morale.

Within this context, Winter proceeded to develop a life sciences program that was closely linked to the future of manned spaceflight. Following guidelines set down in various studies of the life sciences aspects of the Shuttle era, Winter directed a program that had a number of notable accomplishments. Under his direction, the life sciences office supported the first studies of the physiological requirements for space passengers who were not test pilots, including the first American effort to determine whether women differed from men in their response to the conditions of spaceflight and whether they had special requirements beyond the obvious (e.g., special adapters for waste disposal). Other accomplishments included the development of flight suits to meet the diversity of requirements in the future space program, development of experiment protocols to extend study of physiological and behavioral data derived from Skylab and to evaluate changes occurring during the first three to five days of spaceflight, and design of experiment packages to study mechanisms of long-duration biological changes as manifested in lower organisms. Perhaps, to some degree, the most important accomplishment of Winter's administration was diplomatic rather than scientific: he played a major role in establishing and maintaining U.S.-Soviet interactions in the life sciences, which led to the sharing of vital life sciences data between the two nations.[35]

In spite of these accomplishments, the space science administrators did not believe Winter was taking the life sciences program in the direction they desired. They concluded that he was not developing a truly scientific program and was continuing to justify the life sciences in terms of manned spaceflight applications.[36] To some extent, this view was supported by the findings of a study of NASA's life sciences program undertaken by the Life Sciences Advisory Committee in 1978 (though overall, the report was generally favorable).[37] Winter's superiors were also disturbed that he had not made a greater effort to replace old-line administrators and believed that he was an ineffective administrator.[38] Given these differences, a conflict gradually developed between Winter and space science administrator Hinners, and Winter resigned under pressure in 1979.

## THE LIFE SCIENCES AND THE FUTURE

In 1981 the future of NASA's life sciences program was unclear, primarily because the future of the American space program was uncertain. Throughout the 1970s NASA's life scientists rested their hopes in the Space Shuttle and the transportation system that would follow. It was no longer certain that the Shuttle would lead to a reactivated manned space program in the near future or generate support for crash efforts to place a space station in orbit or conduct manned interplanetary flights.

Devising a life sciences program that would be ready to respond to whatever contingencies emerged was the objective of the new NASA life sciences director, Dr. Gerald Soffen. The appointment of Gerald Soffen as David Winter's replacement may have signified a commitment by NASA management to free the life sciences completely from the constraints of the manned space program. Soffen was the first life sciences administrator in NASA's history who did not have a background in medicine. He has a doctorate in biophysics and undergraduate and graduate training in biology. One of the first scientists professionally committed to exobiology, Soffen has been involved in exobiology with NASA since the early 1960s and was project scientist for Viking.[39]

Soffen admired Winter and respected his efforts and accomplishments; nonetheless, he was committed to eliminating the problems that led to Winter's departure. Soffen's first effort was to encourage old-line life scientists to retire and to identify younger life scientists who would be able to make imaginative contributions to "new" life sciences planning. He was committed to developing a life sciences program oriented toward the basic biological sciences as impacted by the environment of space, and to making the most of whatever opportunities emerge as the future space program evolves rather than toward solving specific biomedical problems of specific types of manned missions. In this light, he believed that Winter's major error lay in his efforts to design a science-oriented life sciences program within a philosophical framework of manned spaceflight carried over from the 1960s. That philosophy was one in which the focus was on the problems that lay in the way of manned flight and the search for solutions to those problems. With that emphasis, Soffen believed, NASA's life scientists never took full advantage of the opportunities for research that were available.

In line with his own philosophy, Soffen did not intend to devise a long-range life sciences program, but rather to lay the groundwork on which a continuously evolving program can be built. He believed that the heart of the program should be the formation of a team of imaginative scientists able to identify specific, attainable scientific goals, and find ways to take advantage of whatever spaceflight systems are available for achieving those goals. He hoped that such a team would be able to pursue answers to meaningful scientific questions and, in so doing, lay the groundwork for life scientists who follow. One of the more intriguing questions which NASA has the capability for answering, Soffen believed, is how biology fits into and interacts with larger systems. He saw this as the type of question that can be answered through research in space, has implications for both global ecology and spacecraft ecology, and links problems of the terrestrial environment with those of the spacecraft environment.[40]

## CONCLUSION

NASA's approach to the "human factor"—or life sciences research—resulted to a large degree from the engineering requirements of placing man in space, for limited periods of time, to demonstrate U.S. technological capabilities. The content of a coherent life sciences program within the agency would depend on the differing attitudes of scientists and engineers toward qualifying and supporting humans in space, scientific study of the effects of the space environment on biological matter, and a search for extraterrestrial life.

One fundamental issue was whether the manned space program should be directed by scientists or by engineers who would pursue its development as they had the development of a research airplane (incremental exploration and expansion of capabilities with human operators). Resolution of this issue would govern the agency's strategy for qualifying man for spaceflight and would decide whether it should seek increased funding for "space biology" as distinct from human factors research. The argument proceeded to the accompaniment of recurrent complaints that the manned space program was draining excessive resources from space science.

NASA's development of a life sciences program suffered not only from philosophical differences but also from inconsistent direction and management. NASA life sciences research was no less subject to the fiscal and political fluctuations that affected the space program than any other part of NASA. NASA's own study of the "human factor" finally fell victim to a human factor: personalities and competing aspirations combined with managerial failure to specify objectives, to delegate authority along with responsibility, and to insist on timely implementation of its objectives to undermine the development of a strong and effective program. Notwithstanding the triumphs of NASA's Mercury, Gemini, Apollo, Skylab, and Shuttle programs, the agency still had to demonstrate its ability to fully integrate life sciences into the U.S. venture into space.

The close of NASA's first quarter-century proved critical for the nation's space program. As the successful space transportation system achieved nearly operational status with ever more frequent flights, the agency won in January 1984 President Ronald Reagan's endorsement of a new initiative to develop a permanently manned Earth-orbiting space station, and to have such a station operational by the centennial year of Christopher Columbus's voyage, 1992.

A successful space station program will provide the United States and its international partners space-based facilities enabling routine, continuous use of space for science, applications, technology development, commercial exploitation of the unique space environment, and space operations. None of this can be achieved, however, unless NASA develops and exploits the synergism of the man-machine combination in space. Moreover, one or more of the space station's proposed habitation, logistic, service, and laboratory modules will be dedicated to research and technology development pertinent to the life sciences. This will provide the life sciences community with its first opportunity for continuous, detailed study of man, and other biological matter, in the space environment.

Of longer term significance to the life sciences is the fact that the presence in Earth orbit of a space station will enable the agency to consider more extensive lunar exploration and possibly lunar colonization. The possibility of extended stays in space, whether on the space station or for lunar and planetary visits, will have profound impacts on life sciences research. Not only will the effects of zero gravity be of concern, but the synergistic effects of a combination of space environmental factors will pose special problems: How will different levels of gravity, when combined with different radiation exposures, different atmospheric constituents, and different day-night and seasonal cycles, affect humans and other biological matter? What will new generations look like, and what will be the nature of their mental and intellectual growth? How will we sustain and house humans and provide them with the tools to function effectively in these distant, hostile environments? These are difficult questions that must be resolved by life scientists and engineers in the coming decades, supported by effective and coherent strategies of program management with a full appreciation of the increasingly complex research and development challenges of future decades.

# Bibliography

This bibliography has six sections: general historical studies, archival sources, congressional reports, technical reports, original books and articles, and interviews. The first four sections and part of the fifth are in essay form. The fifth section concludes with a list of selected books and articles on the technical and operational aspects of aerospace biomedicine. Persons whose interviews formed part of the research base for this study are listed in section six.

## 1. GENERAL HISTORICAL STUDIES

Books and monographs on the historical aspects of aviation and space biomedicine are few in number, generally authored by nonhistorians, and commonly narrative in form. The history of aviation medicine has received more extended attention than has the history of space medicine. The best histories of aviation medicine are R. J. Benford, *Doctors in the Sky* (Springfield, Ill.: Charles C. Thomas, 1955); Jeremiah Milbank, Jr., *The First Century of Flight in America* (Princeton: Princeton University Press, 1943); and Douglas H. Robinson, *The Dangerous Sky* (Seattle: University of Washington Press, 1973). Though short on interpretation and analysis, each of these is a useful reference source for names, dates, and significant events and each is entertaining reading.

The history of space medicine is recorded in only two books. Eloise Engel and Arnold Lott, *Man in Flight: Biomedical Achievements in Aerospace* (Annapolis: Leeward, 1979) is a comprehensive book that examines the history of space medicine and traces its many roots in aviation medicine. Written for a general audience by authors who are neither historians nor specialists in aerospace medicine, *Man in Flight* is an entertaining narrative history in which highly technical information is presented in a clear, concise, and accurate manner. This book's strength rests with its detailed examination of the history of research and development in specific areas, for example, weightlessness, acceleration forces, high-altitude physiology. Its weaknesses include an overemphasis on anecdotes, infrequent source citations, and a pedestrian bibliography.

Mae Mills Link, a historian, is the author of the only previous study of biomedicine within NASA's space program. Her *Space Medicine in Project Mercury,* NASA SP-4003 (Washington, 1965) is a useful reference source for names, dates, and events and for its summaries of technical information. However, the book is too brief and tends to treat technical matters superficially. The source citations are extensive, but they are marred by the fact that the author does not inform the reader of their location. Link also prepared a lengthy manuscript on NASA's overall life science programs which reflects a sincere effort to analyze this important, and often quixotic, subject. However, this manuscript has not been published, possibly because it lacks thematic coherence and is rife with personal judgments that are not supported by documentation.

The majority of studies of the historical aspects of aviation and space biomedicine are narrative histories in textbooks and journals, technical histories, and sections within broader aviation and space histories. The narrative histories emphasize names, dates, and events and have little interpretation and analysis. A typical narrative is Col. George Zinneman, "Aerospace Medicine—Present, Past, and Future," the introductory essay in Hugh W. Randel, ed., *Aerospace Medicine,* 2d ed. (Baltimore: Williams & Wilkins, 1971), pp. 1–21. Zinneman chronicles the "milestones" in aerospace medical research and traces the evolution of professional organizations and professional training. Similar narratives appear in the first edition of this text (1961) and in other texts on aviation and aerospace medicine. Comparable narrative histories have appeared at various times in such journals as the *Armed Forces Journal of Medicine* and the *Journal of Aviation, Space and Environmental Medicine* (originally, *Journal of Aviation Medicine;* later, *Journal of Aerospace Medicine).*

Technical histories focus on the history of research and development. The best technical history of aviation and space biomedicine is David Bushnell, *History of Research in Space Biology and Biodynamics, 1946–1958* (Holloman AFB, N.M.: Air Force Missile Development Center, 1958), which is a comprehensive and detailed examination of research and development activities conducted under the auspices of the Air Force Aeromedical Field Laboratory. The history of research and development activities in each of the human factors areas is examined in David Bushnell and James S. Hanrahan, *Space Biology: The Human Factors of Space Flight* (New York: Basic Books, 1960). Though published by a commercial publisher, this book builds on Bushnell's 1958 work, emphasizes technical history, and relies on information derived from technical reports.

The history of aviation and space biomedicine also receives attention from authors of space histories. Loyd S. Swenson, James V. Grimwood, and Charles C. Alexander, *This New Ocean: A History of Project Mercury,* NASA SP-4201 (Washington, 1966) includes detailed examination of such biomedical matters as the astronaut selection program, the development, testing, and evaluation of Mercury life support systems and pressure suits, the Mercury medical monitoring program, and the medical results of each of the Mercury flights. The authors also give some attention to NASA's relations with the military services and the scientific community, though without discussing the life sciences in particular. Follow-on histories of Gemini and Apollo, unfortunately, do not give comparable consideration to biomedicine. Barton Hacker and James Grimwood, *On the Shoulders of Titans: A History of Project Gemini,* NASA SP-4203 (Washington, 1977) barely mentions biomedicine, even though the evaluation of human physiological and performance capabilities in longer duration flights and during extravehicular activities was a primary objective of Gemini. Similarly, Courtney Brooks, James Grimwood, and Loyd Swenson, *Chariots for Apollo: A History of Manned Lunar Spacecraft,* NASA SP-4205 (Washington, 1979) contains very little information on biomedicine. A forthcoming book on Skylab, authored by David Compton, may rectify this situation. Preliminary drafts of the manuscript indicate that the author will devote several chapters to medicine and biology.

Aspects of medicine and biology not directly related to manned spaceflight receive some attention from the authors of two other NASA histories. Homer Newell, *Beyond the Atmosphere, Early Years of Space Science,* NASA SP-4211 (Washington, 1980) includes a chapter on NASA's Life Sciences Program. Newell discusses the bioscience program of the Office of Space Sciences, the problems of administering a life science program, and the involvement of external scientists in the formulation of policy relative to the life sciences. Edwin P. Hartman, *Adventures in Research: A History of Ames Research Center, 1940–1965,* NASA SP-4302 (Washington, 1970) describes briefly the organization of the life science program at Ames, research activities in the biosciences and exobiology, and Project Biosatellite. However, the treatment is superficial and does not include any reference to the biopolitical problems that retarded the growth of the Ames life science program. A NASA contract historian, Elizabeth Muenger, is preparing a new history of Ames and plans to devote several chapters to its life science activities. In spite of its central role in space medicine, the history of the Manned Spacecraft Center (Johnson Space Center) remains unpublished. A history exists in manuscript form, but its publication is in doubt.

The context of NASA's interactions with the military services and the scientific community is established in several general histories, none of which specifically addresses the life science issue. John M. Logsden, *The Decision to Go to the Moon: Project Apollo and the National Interest* (Cambridge: MIT Press, 1970) includes a detailed analysis of the competition between NASA and the Air Force for control of the manned space program and of the sources of scientific criticism of NASA's role and activities in manned spaceflight. The politics of space policy making, especially in relation to scientific activities, are analyzed in R. Cargill Hall, *Lunar Impact: A History of Project Ranger,* NASA SP-4210 (Washington, 1970). Two monographs, Charles M. Atkins, "NASA and the Space Science Board of the National Academy of Sciences," NASA Historical Note HHN-62, Sept. 1966, and Pamela Mack, "NASA and the Scientific Community: NASA-PSAC Interactions in the Early 1960's;" unpublished paper prepared under auspices of the NASA History Office, May 4, 1978, examine NASA's relations with the respective scientific organizations.

2. ARCHIVAL SOURCES

Archival collections of documents in aviation and space biomedicine are widely scattered and occasionally difficult to locate. Documents related to the history of aviation medicine and space-related medicine before 1958 are in both military and civilian archives. Most of the important records related to military aerospace medicine are in Air Force custody. The majority of these records related to NASA and the civilian space program are declassified and are in one of three depositories. The Office of the Historian, Air Force Systems Command, Andrews AFB, Md., has records management responsibility for documents concerning Air Force experimental aircraft, missile, and space programs. Through this office, researchers can gain access to documents related to Air Force aerospace medical and bioastronautics programs through 1960 and can locate relevant documents generated by the Aerospace Medical Division, Brooks AFB, Texas, and the Wright Aerospace Development Center, Wright-Patterson AFB, Ohio, since 1960. The Division Historian's Office, Aerospace Medical Division, Brooks AFB, is the point of access for documents related to Air Force aerospace medicine since 1960, and this division also maintains important documents predating 1960. With the assistance of the historical staffs, Air Force documents can be located with relative ease. NASA-Department of Defense documents concerning life sciences and bioastronautics can be located through the Office of the Historian, Office of the Secretary of Defense, the Pentagon, Washington, D.C. Copies of many of the documents contained in these several depositories are in the files of the NASA Historical Archives, NASA History Office, Washington, D.C.

The Federal Aviation Administration, Washington, D.C., has records related to civil aeronautics dating from the 1920s; however, these are often difficult to locate as they have been retired to Federal Records Centers and are not necessarily inventoried as medical documents. The Medical Department, Wright State University, Dayton, Ohio, is creating an archive of aerospace medicine. The centerpiece is a collection of the papers of Dr. Ross McFarland, a pioneer researcher in aviation physiology. With the official backing of the Aerospace Medical Association, this archive promises to become a central depository for the history of aerospace medicine. The Aerospace Medical Association, headquartered at Washington National Airport, Washington, D.C., has a small collection of documents on both aviation and space medicine. It includes many books on aviation and space medicine, copies of relevant journals since the 1920s, and records of the Aerospace Medical Association since its founding in 1928.

The role of scientists in the formulation of space policy and the definition of research and development objectives in space is documented in records of the Armed Forces-National Research Council (AF-NRC) Bioastronautics Committee, the Space Science Board of the National Academy of Sciences, and the President's Science Advisory Committee. Minutes of committee meetings, copies of correspondence, and reports of formal study groups of the Bioastronautics Committee and of the Life Sciences and Man-in-Space committees of the Space Science Board are in the archives of the National Academy of Sciences (NAS), Washington, D.C. The academy does not encourage use of its archives by nonmembers, though it will open its records to accredited researchers who submit a letter of application accompanied by a letter of sponsorship and who are willing to pay a $15 per hour user's fee. Fortunately, the NASA Historical Archives, NASA History Office, contains copies of most of the pertinent records in the academy archives, including extensive records of the AF-NRC Bioastronautics Committee and unpublished records of deliberations of the Space Science Board groups that periodically reviewed NASA's life science program. The records of the President's Science Advisory Committee are scattered among presidential libraries; however, the NASA Historical Archives has copies of all relevant published and unpublished reports of this committee and an extensive collection of relevant correspondence.

The major studies of NASA's biomedical and life science programs undertaken by the Science Board and the Advisory Committee were either published or widely disseminated in manuscript form. The published versions are useful though sanitized. The draft versions, which are available in the NASA Historical Archives, provide insights into the inner workings of these committees, attitudes and opinions that do not appear in published versions, and the biopolitics of the space program. Pertinent studies undertaken by the Space Science Board include *A Review of Space Research,* report of a summer study at the State University of Iowa under the auspices of the Space Science Board of the National Academy of Sciences, NAS-NRC Publication 1079 (Washington, 1962), which contains sections on biology, space probe sterilization, and the scientific role of man in space (draft versions in three bound volumes shelved in NASA Historical Archives); *Space Research—Directions for the Future,* report of a study by the Space Science Board, 3 vols. (Washington: NAS-NRC, 1965), with volume 3 devoted to biology, medicine and physiology, and physiology of man in flight (draft versions in author's files); H. Bentley Glass, ed., *Life Sciences in Space* (Washington: NAS-NRC, 1970), a study sponsored at NASA's request (draft versions in author's files); and *Human Factors of Long-Duration Spaceflight* (Washington: NAS, 1972).

The President's Science Advisory Committee issued two unpublished reports on NASA's biomedical programs: Donald Hornig, Chairman, "Report of the Ad-Hoc Mercury Panel," April 1961, and Donald Beeson, "Report of the Bioastronautics Committee," July 1962. Both reports received wide dissemination; copies are in the author's files and in the President's Science Advisory Committee files, NASA Historical Archives. Published Advisory Committee reports bearing on biomedicine and the life sciences include *The Space Program in the Post-Apollo Period* (Washington: White House, 1967) and *The Biomedical Foundations of Manned Space Flight* (Washington: Office of Science and Technology, 1969). Draft versions of the latter prepared on several different dates are in the author's files and in the President's Science Advisory Committee files, NASA Historical Archives.

NASA, of course, has the major archival collection of documents related to the biomedical aspects of manned spaceflight and to life science programs. These documents are dispersed among separate depositories, however, and only those maintained by the NASA Historical Archives are easy to locate and readily accessible. These archives contain approximately six cubic feet of primary and secondary documents filed under "Life Sciences" and "Life Science Programs." These include assorted correspondence, minutes of committees, technical reports, and official records of the Office of Life Science Programs. An additional nine cubic feet are maintained in assorted files: documents related to biomedical operations are in files of the separate manned spaceflight projects; those related to external scientific relations are in President's Science Advisory Committee and National Academy of Sciences files; those related to NASA-Air Force and NASA-DoD bioastronautics and life science coordination are in the Air Force, Aeronautics and Astronautics Coordinating Board, and DoD files. Other pertinent documents are in the files of the Manned Spacecraft Center, the Office of Manned Space Flight, the

Office of Advanced Research and Technology, and the Office of Space Science and Applications. Some useful documents are in the files of key administrators, particularly T. Keith Glennan, James Fletcher, and Homer Newell. The Biography files contain biographical information on key life scientists and copies of their published articles. Also useful are the Budget files, which document the history of appropriations for the life sciences.

Many documents related to biomedicine and the life sciences have been retired to the Federal Records Center, Suitland, Md. These are all inventoried in record group 75, NASA records, and inventories of these records are available through the NASA History Office. It is a tedious and time-consuming process to identify and locate specific documents through these inventories, however, because life science documents have not been retired as a group but rather as portions of batches of documents retired by accountable program offices. These offices prepare inventories for each batch of retired records, but the records management specialists do not always specify in detail the nature of the records contained in each batch. Consequently, to locate life science documents, one must go through the inventories sheet by sheet and often must retrieve an entire file box to determine whether it contains any important life science records. Generally, documents related to specific life science programs—biosciences, biotechnology and human research, and space medicine—can be located by reviewing the inventories of records retired by the respective program offices—Space Science and Applications, Advanced Research and Technology, Manned Space Flight. Documents related to life sciences program management, interagency life sciences coordination, congressional relations, and NASA interactions with scientific organizations are in document collections retired under the designation Central Administrative Files. The complete list of all record subgroups that contain life science materials encompasses approximately 100 separate accession numbers. To facilitate future research in this area, the author has made copies of all useful documents contained in these retired files and is organizing them into a new file, which will have a distinct accession number.

The Headquarters History Office has some records related to life sciences activities at the NASA centers; however, the majority of relevant documents are in the National Archives or regional Federal Records Centers. Johnson Space Center in Houston is the only NASA center that has an active history office and history archives. Records related to biomedicine and the life sciences are not easy to locate in the Johnson files, however, which are organized into daily chronologies, center histories and interviews, and project histories and interviews. To use the Johnson materials, researchers in the life sciences must be familiar with names and dates, and be prepared to invest considerable time in drawer-by-drawer, folder-by-folder searches.

Ames Research Center at Moffett Field, Calif., which had primary responsibility for research in biotechnology, medical science, and bioscience, and Langley Research Center, Hampton, Virginia, which played a minor role in life science research and technology, do not have formal history offices or active history archives, though both have "historical monitors" who will assist researchers in using the center archives. A NASA contract historian, Dr. Elizabeth Muenger, is writing a history of Ames and, in the process, identifying and establishing the location of life science materials in the Ames archives. NASA recently hired Dr. James R. Hansen to write a history of the Langley Research Center, and in the course of his work he undoubtedly will locate relevant life science records in those archives.

Many documents related to space biomedicine and the space life sciences are in the private collections of former life scientists and life science administrators. Unfortunately, it is not known how many of these private collections exist. Army Gen. William S. Augerson has approximately nine cubic feet of documents related to the medical aspects of Project Mercury, 1958-1961, most of which concern medical monitoring. Dr. Robert Voas, currently with the Department of Transportation, has a collection of comparable size, primarily on the Mercury astronaut selection and training programs, 1958-1963. Dr. Sherman P. Vinograd, chief of medical research in the Directorate of Space Medicine from 1961 to 1975, has approximately 20 cubic feet of documents related to NASA Headquarters space medicine and life science programs, 1961-1978. Vinograd may donate this collection to the aerospace medicine archives at Wright State University. Although it is useful to know of the existence of these private collections, researchers should be aware that 90 percent of the documents in them are copies of records that are accessible through the NASA Historical Archives.

## 3. CONGRESSIONAL RECORDS

Congress periodically reviewed NASA's life sciences programs and the agency's relationships with the military services and the scientific community. Each year both the House and Senate held hearings on NASA's authorization requests for the ensuing fiscal year. The published reports of these annual hearings appeared in two forms: transcriptions of the separate hearings, and follow-up reports summarizing the findings and actions taken by each body. The information in these reports includes details of life science research, development, and operations, requested and approved budgets, congressional justifications for budget decisions, and questions and testimony concerning relations between NASA and, respectively, the military services and the scientific community. Outside the authorization hearings, congressional interest in the space life sciences was sporadic.

Congressional interest in NASA's life sciences before 1960 was limited to the biomedical aspects of Project Mercury. This interest is recorded in a House Report, *Jupiter Missile Shot—Biomedical Experiments,* report of the Committee on Science and Astronautics, 86/1, June 3, 1959; and a Senate report, *Project Mercury: Man-in-Space Program of the National Aeronautics and Space Administration,* report of the Committee on Aeronautical and Space Sciences, 86/1, Dec. 1, 1959. House members also expressed interest in possible conflicts between the Air Force program in bioastronautics and NASA's requirements in space medicine in the initial NASA authorization hearings, which were published as *Astronautics and Space Exploration,* Hearings of a Select Committee on Astronautics and Space Exploration, 85/2, April 15–30 and May 1–12, 1958.

In 1960 both sides of Congress investigated the biomedical capabilities and requirements of NASA and the military services in response to open conflict in this area between NASA and the Air Force and to publicized scientific doubts about the adequacy of NASA's biomedical capabilities in support of Mercury. The most extensive and detailed study ever made of the nation's overall capabilities in space biology and medicine is reflected in U.S. Senate, *Space Research in the Life Sciences: An Inventory of Related Programs, Resources, and Facilities,* report of the Committee on Aeronautical and Space Sciences, 86th Cong., 2d sess. (hereafter 86/2), July 15, 1960. House interest in medicine and the life sciences is reflected in three reports of hearings held by the Committee on Science and Astronautics, 86/2: *Life Sciences in Space,* Oct. 4, 1960; *Medical Research for Space Travel,* June 15–16, 1960; and *Space Medicine Research,* June 15–16, 1960. The House also examined life sciences in the context of the total space program in *Review of the National Space Program,* Hearings of the Committee on Science and Astronautics, 86/2, Jan. 20–Feb. 18 and Feb. 23–Mar. 7, 1960.

Apart from the annual authorization hearings, Congress did not give special attention to NASA's life science programs from 1961 to 1968. However, both the House and the Senate conducted hearings on matters that bore on the life sciences. The House investigated NASA's relations with the military and military interests in space and reported its findings in *Defense Space Interests,* Hearings before the Committee on Science and Astronautics, 87/1, March 17–21, 1961, and *The NASA-DoD Relationship,* report of the Subcommittee on NASA Oversight, Committee on Science and Astronautics, 88/2, 1964. The Senate investigated NASA's overall research and development programs, its overall manned spaceflight objectives, and scientists' views on the space program and published its findings in three reports: *NASA Scientific and Technical Programs,* Hearings of the Committee on Aeronautical and Space Sciences (hereafter CASS), 87/1, Feb. 28 and Mar. 1, 1961; *Manned Space Flight Programs of the National Aeronautics and Space Administration,* staff report of the CASS, 87/2, Sept. 4, 1962; and *Scientists' Testimony on Space Goals,* hearings of the CASS, 88/1, June 10–11, 1963.

Congressional interest in NASA's life science programs flared briefly in 1969, largely in response to scientific criticisms of NASA's management of Biosatellite and biomedical research in support of long-duration manned spaceflight. NASA management's decision in early 1969 to terminate Project Biosatellite generated widespread criticisms from academic and research-oriented bioscientists. This combined with adverse publicity following the aborted mission of *Biosatellite III* (June 1969) and the subsequent death of its monkey-passenger led to two House investigations. The testimony and findings of these investigations are recorded in *Biosatellite Program,* Hearings before the Committee on Science and Astronautics, 91/1, Nov. 12–18, 1969, and *Future of the Bioscience Program of the National Aeronautics and Space Administration,* Hearings of the Subcommittee on Space Science and Applications, Committee on Science and Astronautics, 91/1, Dec. 24, 1969. Although the agency's life sciences activities were criticized by scientists during the 1970s, Congress has not found a need to investigate the life sciences program (apart from authorization hearings) since 1969.

## 4. TECHNICAL REPORTS

Since 1968, American biomedical and behavioral scientists, clinicians, and human factors engineers working in government, industry, university, and private research settings have produced more than 10,000 technical reports on research, development, and operations in aerospace medicine and biology. All the published reports and most of the unclassified and unpublished reports since 1953 have been catalogued in *Aerospace Medicine and Biology, An Annotated Bibliography* (vols. 1–6, 1952–1958, by the Department of Commerce; vols. 7–9, 1958–1963, by the Library of Congress) and *Aerospace Medicine and Biology, A Continuing Bibliography* (nos. 01–214 by NASA as NASA SP-7011). All the entries in this continuing publication and all classified and unclassified reports on aerospace medicine and biology sponsored by NASA and the military services are computer-catalogued through the RECON program, which is open to use (with minimal restrictions) to all researchers. Both of these sources contain, in addition, citations of all unclassified reports on aerospace medicine and biology prepared by researchers in the Soviet Union since 1964. Most of these reports have been translated by the staff of the Science and Technology Division, Library of Congress.

Articles and monographs on technical aspects of aerospace medicine and biology have appeared with regularity in a number of continuing publications. The *Journal of Aviation, Space and Environmental Medicine* (*Journal of Aviation Medicine,* 1927–1958; *Journal of Aerospace Medicine,* 1958–1972) is the official journal of the Aerospace Medical Association and has been a forum for research communications in the field since 1927. The Air Force School of Aerospace Medicine, Brooks AFB, Texas, has held annual symposia in aerospace medicine since 1951, and the papers presented at these conferences have been published annually as *Lectures in Aerospace Medicine.* Reports on aerospace medicine have also appeared at various times in other journals, most notably the *Proceedings* of the American Astronautical Society (each annual volume bears a different title), *Human Factors,* and the *Armed Forces Journal of Medicine.* Reports on space biology have appeared on various occasions in the *AIBS Bulletin,* a publication of the American Institute of Biological Sciences.

NASA has published technical reports on the biomedical aspects of the major spaceflight programs through its scientific and technological information program. The biomedical preparations for and biomedical results of the Mercury and Gemini flights are recorded in publications that encompass the overall aspects of the two projects. The biomedical aspects of Mercury are covered in articles contained in *Conference on the Medical Results of the First Manned Sub-Orbital Space Flight* (Washington, June 6, 1961); NASA Manned Spacecraft Center, *Results of the First Manned Orbital Flight* (Washington, 1962); *Results of the Second Manned Orbital Flight,* NASA SP-6 (Washington, 1962); *Results of the Third Manned Orbital Flight,* NASA SP-12 (Washington, 1962); and *Mercury Project Summary, Including Results of the Fourth Manned Orbital Flight,* NASA SP-45 (Washington, 1963). The medical aspects of Project Gemini are in *Gemini Mid-Program Conference,* NASA SP-121 (Washington, 1966); *Gemini Summary Conference,* NASA SP-138 (Washington, 1967); and *Summary of Gemini Extra-Vehicular Activity,* NASA SP-149 (Washington, 1967).

The medical aspects of Apollo and Skylab were published separately from the other program summaries. The biomedical aspects of Apollo are in Richard S. Johnston, Lawrence S. Dietlein, and Charles A. Berry, eds., *Biomedical Results of Apollo,* NASA SP-368 (Washington, 1975), while those of Skylab are in Richard S. Johnston and Lawrence Dietlein, eds., *Biomedical Results from Skylab,* NASA SP-377 (Washington, 1977). Both are extremely detailed studies that cover experiments, preparations, and findings and include extensive citations of relevant technical literature.

Several related technical reports also deserve notice. The history of

Project Biosatellite and the technical aspects of the three Biosatellite flights (many of the experiments of which had direct relevance to manned flight) are examined in detail in J. W. Dyer, Project Manager, *Biosatellite Project: Historical Summary Report* (Moffett Field, Calif.: NASA Ames Research Center, 1969). Research and planning for biomedical support of advanced manned programs are examined in Sherman P. Vinograd, ed., *Medical Aspects of an Orbiting Research Laboratory,* NASA SP-86 (Washington, 1966); Langley Research Center, *Preliminary Results from an Operational 90-Day Test of a Regenerative Life Support System,* NASA SP-261 (Washington, 1971); and an unpublished report prepared by the NASA Manned Spacecraft Center, "A Biomedical Program for Extended Space Missions" (Houston, 1969). A program of biological research in support of advanced manned programs is described in American Institute of Biological Sciences, "Bioscience Research during Earth-Orbiting Missions: Manned Orbital Research Lab/Manned Orbital Space Station," NASA Contractor's Report NASA-132, 1966.

5. ORIGINAL BOOKS AND ARTICLES

Textbooks on aviation and space medicine, while not numerous, have appeared with regularity since World War I. Possibly the first text on the subject was *Air Service Medical* (Washington: War Department, 1919), which covered all the fundamental issues that would concern aviation and space physicians during the ensuing 50 years: selection and training of flight crews, physical and mental examinations of flight crews, operational role of flight physicians, man-rating of machines and machine-rating of men, and medical research problems of manned flight. At least two texts appeared during the 1920s: Philippe Maublanc and V. Ratie, *Medical Examination of Airmen* (New York: William Wood and Co., 1921) and C. H. Bauer, *Aviation Medicine* (Baltimore: Williams & Wilkins, 1926). The classic text, Harry O. Armstrong, ed., *Principles and Practices of Aviation Medicine* (Baltimore: Williams & Wilkins), appeared in 1939, with subsequent editions in 1943 and 1952. A later version also edited by Armstrong appeared in 1961 under the title *Aerospace Medicine,* and a second edition with this title, edited by Hugh Randel, was published in 1971 (both editions, Baltimore: Williams & Wilkins). All these editions encompass the same general subjects: history of aerospace medicine; examination, selection, and training of flight crews; physiological and psychological problems of flight; and human factors problems of machine design. Each edition also includes extensive citations of relevant literature.

Books, monographs, and articles on specific aspects of aviation and space medicine are too numerous to receive comprehensive examination in this context. The titles listed here, samples of the literature, cover most issues of concern to specialists in aerospace medicine from 1958 to 1980 and are themselves sources for significant contributions to the literature of aerospace medicine.

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## 6. INTERVIEWS

A. *By the author:*

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Dr. Lawrence F. Dietlein, Aug. 19, 1980
Gen. Donald K. Flickinger, Oct. 18, 1979
Dr. T. Keith Glennan, Feb. 19, 1980
Dr. Siegfried Gerathewohl, July 3, 1979
Col. Rufus Hessberg
Gen. J. W. Humphreys, May 2, 1979
Richard S. Johnston, Aug. 18, 1980*
Dr. Walton Jones,* May 22, 1979
Bernard Maggin, Oct. 17, 1979
Dr. John Naugle, Feb. 21, 1980
Dr. Homer Newell, Feb. 22, 1980
Dr. Clark Randt, Aug. 14, 1979, Sept. 24, 1979
Dr. Orr Reynolds, Nov. 14, 1979
Dr. Gerald Soffen, Feb. 28, 1980
Dr. Sherman P. Vinograd, June 2, 1979
Dr. Robert Voas, Oct. 19, 1979
Dr. James V. Warren, June 19, 1979
Dr. David Winter, May 8, 1981

B. *By NASA Headquarters History Office staff:*

Dr. George Knauf, 1963
Dr. Eugene Konecci, 1963
Dr. Randolph Lovelace, 1964
Dr. Clark Randt, 1961
Gen. Bernard Schriever, 1961

C. By Johnson Space Center History Office staff:

Dr. Charles A. Berry, Mar. 18, 1968
Dr. Lawrence F. Dietlein, Mar. 22, 1968
Richard S. Johnston, Mar. 21, 1968

# Source notes

CHAPTER 1

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2. Engel and Lott, *Man in Flight,* pp. 33–34.
3. Ibid., pp. 212–15.
4. Ibid., pp. 34–37.
5. Ibid., pp. 38–41.
6. Ibid., pp. 41–61. See also Mae Mills Link, *Space Medicine in Project Mercury,* NASA SP-4003 (Washington, 1965), pp. 13–14.
7. Mae Mills Link and Hubert A. Coleman, *Medical Support of the Army Air Force in World War II* (Washington: Office of the Surgeon General of the Air Force, 1955), pp. 230–51.
8. Link, *Space Medicine,* pp. 14–18.
9. Engle and Lott, *Man in Flight,* pp. 112–16.
10. Official biography, Office of Information, Aerospace Medical Division, Air Force Systems Command (AFSC), Brooks AFB, Tex., 1962, copy in Biography files, NASA History Office (hereafter NASA HO). Biographies of Strughold are numerous.
11. Harry G. Armstrong, "Origins of Space Medicine," *U.S. Armed Forces Med. J.* 10 (1959): 390–95, "Historical," in Harry G. Armstrong, ed., *Aerospace Medicine,* pp. 1-17. The general lines of research conducted at, or sponsored by, the school are reflected in *Lectures in Aerospace Medicine,* published annually from 1948 under various editors and containing papers presented at the school's annual symposia in aerospace medicine, and in published reports of papers presented at special symposia sponsored by the school in 1951, 1958, 1964, and 1968. The first collection was published as *Physics and Medicine of the Upper Atmosphere;* the later collections all have the title *Bioastronautics and the Exploration of Space.*
12. Strughold's articles include "Basic Environmental Problems . . . Seen by a Biologist," and "Atmospheric Space Equivalence," both in *J. Aviat. Med.* 25 (1954): 420–24.
13. Link and Coleman, *Medical Support,* pp. 230–40.
14. Otto Gauer and Heinz Haber, "Man under Gravity-Free Conditions," in U.S. Air Force, *German Aviation Medicine, World War II* (Washington: Office of the Surgeon General of the Air Force, 1950), pp. 641–45.

15. James H. Hanrahan and David Bushnell, *Space Biology: The Human Factors in Space Flight* (New York: Basic Books, 1960), pp. 76–77. See also Engel and Lott, *Man in Flight,* pp. 200–202.
16. Interview, Stanley C. White, June 14, 1979.
17. David G. Simons, "Use of V-2 Rockets to Convey Primates to Upper Atmosphere," Air Force Techn. Rpt. 5821, Air Materiel Command, Wright-Patterson AFB, Ohio, May 1959, copy in Files, HQ AFSC, Andrews AFB, Md.; James P. Henry, "Animal Studies of the Sub-Gravity State during Rocket Flight," *J. Aviat. Med.* 23 (1952): 421–23; Hanrahan and Bushnell, *Space Biology,* pp. 139–49.
18. A complete survey of research undertaken at Holloman during this period is in David Bushnell, *History of Research in Space Biology and Biodynamics, 1948–1958* (Holloman AFB, N.M.: Air Force Missile Development Center, 1958).
19. Bushnell, *History of Research,* pp. 10–13; Hanrahan and Bushnell, *Space Biology,* pp. 86–88, 93–94; John P. Stapp, "Biodynamics of Space Flight," in Kenneth F. Gantz, *Man in Space Program of the U.S. Air Force* (New York: Duell, Sloan, and Pearce, 1959), pp. 63–68.
20. Engel and Lott, *Man in Flight,* pp. 18–27; David G. Simons, "Observations in High-Altitude, Sealed-Cabin Balloon Flights," in Gantz, *Man in Space,* pp. 133–160.
21. Senate Committee on Aeronautical and Space Sciences, Space Research in the Life Sciences, 86th Cong., 2d sess. (henceforth 86/2), July 15, 1960, pp. 128–65.
22. Ibid., pp. 173–88.
23. W. Randolph Lovelace II, chairman, "Report of the Working Group on Human Factors and Training to the Special Committee on Space Technology," Oct. 27, 1958; copies in various locations including Administrator's (Glennan) Correspondence and Files, NASA HO.
24. The many sources that describe the state of biomedicine and the principal biomedical problems are listed in the bibliography. Significant sources include the House Committee on Science and Astronautics, Space Medicine Research, 86/2, June 15–16, 1960; Senate Committee on Aeronautical and Space Sciences, *Project Mercury: Man in Space Program of the NASA,* 86/1, Dec. 1959, pp. 30–51; S. B. Sells and Charles A. Berry, "Human Requirements for Space Flight," in Gantz, *Man in Space,* pp. 161–77.
25. Sells and Berry, "Human Requirements," p. 161; Robert Voas, "Project Mercury: Astronaut Training Program," in Bernard Flaherty, ed., *Psychophysiological Aspects of Space Flight* (New York: Columbia Univ. Press, 1961), p. 96; Senate, *Project Mercury,* pp. 44–45.
26. Senate, *Project Mercury,* pp. 35–36; Sells and Berry, "Human Requirements," p. 161.
27. Charles A. Berry, "Aeromedical Preparation," in *Mercury Project Summary,* NASA SP-45 (Washington, 1963), p. 199.
28. Lovelace, "Report of Working Group on Human Factors"; similar concerns were expressed by members of the Armed Forces-National Research Council (AF-NRC) Committee on Bioastronautics, which included representatives from the academic community. Complete minutes of this group are in the archives of the National Academy of Sciences (NAS); minutes of some meetings are in NASA HO files.
29. Senate, *Space Research in the Life Sciences,* pp. 59–60, 69, 128–29, 173.
30. Gen. Thomas D. White, "The Inevitable Climb to Space," in Gantz, *Man in Space,* p. xiv.
31. Gen. Donald G. Flickinger, "The U.S. Air Force Human-Factors Program," and Gen. Homer A. Boushey, "Blueprints for Space," both in Gantz, *Man in Space,* pp. 238–58; "Outline History of the USAF Man-in-Space Research and Development Program," *Missiles and Rockets* 10 (1962): 145–50; House Committee on Science and Astronautics, *Missile Development and Space Sciences,* 86/1, Feb.-Mar. 1959.

32. "MER II: Navy Manned Satellite Study," Dec. 1958, contract prepared by Convair Division, General Dynamics Corp. tech. rpt. extracted from NASA RECON. See also Loyd S. Swenson, Jr., James M. Grimwood, and Charles C. Alexander, *This New Ocean: A History of Project Mercury,* NASA SP-4201 (Washington, 1966), pp. 100–01.
33. "Project Adam Chronology" and "Development Proposal for Project Adam," undated manuscripts in Manned Spaceflight files, NASA HO; Gerathewohl interview; Link, *Space Medicine,* pp. 26–27; Swenson, Grimwood, and Alexander, *This New Ocean,* pp. 99–100.
34. Details of the evolution of NACA's interest in astronautics are given in Swenson, Grimwood, and Alexander, *This New Ocean,* pp. 55–106.
35. The politics of these decisions is discussed in several studies, including Swenson, et al., *This New Ocean,* and John M. Logsdon, *The Decision to Go to the Moon: Project Apollo and the National Interest* (Cambridge: MIT Press, 1965).
36. Swenson, Grimwood, and Alexander, *This New Ocean,* pp. 96–106.

## CHAPTER 2

1. Charles A. Berry, "Aeromedical Preparations," in *Project Mercury Summary,* NASA SP-45 (Washington, Oct. 1963), p. 199.
2. Staff lists are in the Administration, Project Mercury, and Office of Manned Space Flight files, NASA HO. Biographical details on NASA Headquarters and Space Task Group personnel are in Biography files, NASA HO, and in Loyd S. Swenson, James M. Grimwood, and Charles C. Alexander, *This New Ocean: A History of Project Mercury,* NASA SP-4201 (Washington, 1966), pp. 109-14.
3. For congressional and military opposition to a buildup in in-house biomedical capabilities, see House Select Committee on Astronautics and Space Exploration, *Astronautics and Space Exploration,* 85th Cong., 2d sess. (hereafter 85/2), April 15–30 and May 1–12, 1958, pp. 1216–33.
4. Glennan interview.
5. Ibid.
6. For a survey of the patterns of organization and management within NACA and their relationship to NASA organization and management, see Swenson, Grimwood, and Alexander, *This New Ocean,* p. 55–108.
7. W. L. Hjornevik, memo to Glennan, "Bio-medical Interests of NASA," Jan. 2, 1959, copy in Administrator's Correspondence and Files—Glennan, NASA HO.
8. Mae Mills Link, *Space Medicine in Project Mercury,* NASA SP-4003 (Washington, 1965), p. 44; Stanley C. White interview, June 14, 1979.
9. This is based on information provided during interviews with Randt, Glennan, Vinograd, Naugle, Reynolds, and others. Biographical details on Lovelace are in the Biography files, NASA HO. He is also discussed by Link, in *Space Medicine,* pp. 3–7.
10. The other members of the committee are identified in the appendixes.
11. See "Report of the Working Group on Human Factors," Oct. 1958, in Administrator's Correspondence and Files, NASA HO.
12. Hjornevik, "Bio-medical Interests of NASA."
13. Glennan interview. This was implemented via Special Orders A-1157 (DAF), Apr. 1, 1959, "Agreements between the Departments of Defense, Army, Navy, and Air Force, and the NASA Concerning the Detailing of Military Personnel for Service with NASA," signed by Glennan on Feb. 24, 1959, and approved by Eisenhower on Apr. 13, 1959.

14. Link, *Space Medicine,* p. 63.
15. Ibid., p. 44; White interview.
16. White interview and Biography files, NASA HO. See also Swenson, Grimwood, and Alexander, *This New Ocean,* pp. 25–28; Link, *Space Medicine,* pp. 24–25.
17. Augerson interview and Biography files, NASA HO. See also Swenson, Grimwood, and Alexander, *This New Ocean,* pp. 160–61; Link, *Space Medicine,* pp. 28–29, 45–46.
18. Politics was a factor, but its significance should not be exaggerated. Augerson said his command pushed him toward special training to ensure that the Army had qualified space medical personnel available. This is substantiated by several pieces of correspondence in his personal files, which he allowed the author to read.
19. Augerson's biography is in Biography files, NASA HO.
20. Voas interview and Biography files, NASA HO. See also Swenson, Grimwood, and Alexander, *This New Ocean,* pp. 161–63; Link, *Space Medicine,* pp. 45–46.
21. Robert Voas, "Project Mercury: Astronaut Training Program," in Bernard Flaherty, ed., *Psychophysiological Aspects of Space Flight* (New York: Columbia Univ. Press, 1961), p. 97.
22. Ibid. and interviews with White, Augerson, and Voas. See also Senate Committee on Aeronautical and Space Sciences, *Project Mercury: Man-in-Space Program of the NASA,* 86/1, Dec. 1959, pp. 42–45; Voas, "Astronaut Training," in *Project Mercury Summary;* Charles L. Wilson, *Project Mercury Candidate Evaluation Program,* Wright Air Development Center (WADC) Tech. Rpt. 59-505, Dec. 1959.
23. Voas, "Project Mercury: Astronaut Training Program," p. 97.
24. Ibid. and Voas interview. See also Swenson, Grimwood, and Alexander, *This New Ocean*, pp. 161–63.
25. Voas, "Project Mercury: Astronaut Training Program," p. 97; Senate, *Project Mercury*, pp. 40–44; William K. Douglas, "Selection and Training of Space Crews," in *Lecture in Aerospace Medicine* (Brooks AFB, Tex.: School of Aviation Medicine, 1960), pp. 32–41; Voas interview. Voas said very few were actually rejected; most of those who did not participate declined to volunteer for fear that their regular careers would suffer.
26. Senate, *Project Mercury*, p. 42.
27. Ibid., pp. 42–55; W. Randolph Lovelace II et al., "Selection and Maintenance Program for Astronauts for the NASA," *Aerosp. Med.* 33 (1962): 667–84. Link, *Space Medicine*, pp. 45–58, includes a detailed summary of these tests.
28. Senate, *Project Mercury*, pp. 45–49; Link, *Space Medicine*, pp. 45–58.
29. Swenson, Grimwood, and Alexander, *This New Ocean*, pp. 161–66.
30. Extracts of articles describing these clinical, psychological, and psychiatric evaluations are appendixes to this study.
31. These changes are documented in Space Task Group records, Project Mercury files, NASA HO, and are also described in Link, *Space Medicine,* p. 70.
32. "Project Mercury Animal Program, Status Report of July 10, 1959," document in personal files of William S. Augerson, author and distribution unknown; testimony of Donald Flickinger, in Senate, *Project Mercury*, p. 36; Flickinger interview.
33. White interview.
34. Ibid.
35. White and Flickinger interviews; Senate, *Project Mercury*, pp. 40–41; White et al., "Review of the Biomedical Systems for the MR-3 Flight," in *Conference on the Medical Results of the First U.S. Manned Suborbital Flight* (Washington: NASA, 1961), pp. 29–46; Frank H. Samonski, "Project Mercury Environmental Control System Technical History," draft, undated, Project Mercury files, NASA HO.
36. White interview; White, "Present Status in Major Systems; Environmental Systems,"

Feb. 1959, in Project Mercury files, NASA HO; Richard S. Johnston and Edward Michel, "Mercury Life Support Systems," in *Life Support for Space Vehicles* (New York: IAS, 1960).

37. White interview. See also Swenson, Grimwood, and Alexander, *This New Ocean*, pp. 125-26.
38. Augerson interview and unpublished report, "Medical and Biological Research Aspects of Project Mercury," drafted by Augerson and Voas, Sept. 8, 1960. Those who cooperated with Augerson in the development of the medical operations plan included White, William K. Douglas, James P. Henry, George Knauf, and Rufus Hessberg—all on detail from the military services. Later, Charles A. Berry and William R. Turner, Air Force physicians, joined the team.
39. Engel and Lott, *Man in Flight*, p. 78
40. Augerson interview; Augerson to project director, "Medical Monitoring for Project Mercury," Oct. 3, 1959, in personal files of Augerson; Charles A. Berry, "Aeromedical Preparations," p. 199-209. See also Link, *Space Medicine*, pp. 85-111.
41. Voas and Augerson interviews.
42. Augerson, "Medical Monitoring."
43. Ibid.
44. Augerson, "Medical and Biological Research Aspects of Project Mercury."
45. Augerson interview; Berry, "Aeromedical Preparations," p. 204. TV cameras were included in the final two Mercury flights, but their value was minimal due to ineffective placement within the capsule.
46. Augerson interview; Augerson, "Medical Monitoring"; Berry, "Aeromedical Preparations," p. 206.
47. Transcripts of many of these runs and simulations, in Augerson's personal files, were made available for the author's review. Medical aspects of astronaut training are described by Voas in "Project Mercury: Astronaut Training Program" and "Astronaut Training."
48. These procedures are reviewed in Augerson and L. Patrick Laughlin, "Physiological Response of the Astronaut in the MR-3 Flight," in *Conference on Medical Results*, pp. 47-59, 71-86; Duane Catterson et al., "Aeromedical Observations," in *Mercury Project Summary*, pp. 299-326; Berry, "Aeromedical Preparations," 199-209.
49. Augerson, "Medical Monitoring."
50. Voas interview; Voas, "Project Mercury: Astronaut Training Program."
51. Voas interview; Voas, "Project Mercury: Astronaut Training Program."
52. Voas interview; Voas, "Astronaut Training."
53. Interviews with White, Augerson, and Randt. Problems of communication between biomedical personnel at Space Task Group and the larger biomedical community were cited in many critical reports of NASA's biomedical programs, including "Report of the National Aeronautics and Space Administration Biosciences Advisory Committee," Jan. 25, 1960; copies are in many locations, including the Administrator's Correspondence and Files, NASA HO.
54. White, Augerson, Randt, and Reynolds interviews; report of Biosciences Advisory Committee.
55. NASA, Director for Space Science, memo for general distribution, "National Space Science Program," Apr. 10, 1959, in "Papers of Dr. Homer Newell," NASA HO.
56. Glennan interview; Hjornevik, "Bio-Medical Interests."
57. For a summary of these developments, see House Committee on Science and Astronautics, *Defense Space Interests*, 87/1, Mar. 17-23, 1961, pp. 93-96, 211-19. See also John M. Logsdon, *The Decision to Go to the Moon: Project Apollo and the National Interest* (Cambridge: MIT Press, 1970), pp. 46-48.

58. House, *Defense Space Interests*, pp. 9-11.
59. The President's Science Advisory Committee (PSAC) was the focus of scientific opposition to military control of the space program. See Logsdon, *Decision*, pp. 18-19; PSAC, *Introduction to Outer Space* (Washington: Executive Office of the President, 1958).
60. See Abelson's comments in Senate Committee on Aeronautics and Space Science, *Scientists' Testimony on Space Goals*, 88/1, June 10-11, 1963, pp. 3-24, which are representative of views he expressed in various contexts and at various times between 1958 and 1960.
61. Flickinger interview.
62. NASA Director for Space Science, "National Space Science Program," and 1959 and 1960 "Estimates of Appropriations," in Budget files, NASA HO.

## CHAPTER 3

1. "Interview with Dr. Clark T. Randt," conducted by Dr. Eugene Emme, Mar. 30, 1961. Transcript in files of NASA HO.
2. Ibid.; Randt biography in Biography files, NASA HO.
3. Glennan interview. Randt's commitment to the manned space program is evident in a letter to Glennan, Dec. 16, 1958, in Administrator's Correspondence and Files, NASA HO.
4. Randt, memo to Glennan, "Development of a Life Sciences Program," Feb. 25, 1960, and draft of notes for authorization hearings, dated Feb. 25, 26, and 29, 1960, both of which are in Life Sciences Program files, NASA HO. See also Randt, letter to Glennan, Dec. 16, 1958.
5. Glennan interview; Glennan, "Memorandum for Headquarters Staff," July 7, 1959, in "Staff Meetings and Reports," Administrator's Correspondence and Files, NASA HO.
6. The members of the committee are identified in Appendix C.
7. Glennan, "Memorandum for Headquarters Staff," July 7, 1959, and "Proposed Charter for an Advisory Committee on NASA Bio-Technical-Bio-Science Programs," June 30, 1959, both in "Staff Meetings and Reports," Administrator's Correspondence and Files, NASA HO.
8. "Report of the National Aeronautics and Space Administration Bioscience Advisory Committee," Jan. 25, 1960, p. 1.
9. Ibid., pp. 7-12.
10. Ibid., pp. 22-27.
11. Ibid., pp. 14-15.
12. "Report of Biosciences Advisory Committee," pp. 16-20.
13. Glennan interview; Randt interview, Aug. 2, 1979.
14. House Committee on Science and Astronautics, *1960 NASA Authorization*, 86/1, Apr. 20-29 and May 4, 1959, pp. 185-201.
15. Glennan interview; Randt interview, Aug. 2, 1979.
16. Reported in Senate Committee on Aeronautical and Space Sciences, *NASA Authorization for Fiscal Year 1961*, 86/2, Apr. 29, 1960, pp. 26, 28.
17. Senate Committee on Aeronautical and Space Sciences, *NASA Authorization for Fiscal Year 1961*, 86/2, Mar. 28-30, 1960, p. 36.
18. Ibid., pp. 36-38, 548-49.
19. House Special Investigating Committee on Science and Astronautics, *Space Medicine Research*, 86/2, June 15-16, 1960; Senate Committee on Aeronautical and Space Sciences, *Space Research in the Life Sciences*, 86/2, July 15, 1960; Senate Committee on

Government Operations, *Coordination of Activities in Biomedical Research*, 86/2, Aug. 11, 1960.

20. Daddario comments in House, *Space Medicine Research*, pp. 16–17. Daddario would continue for many years to be the chief congressional proponent of a strong military manned program and a consistent critic of NASA's efforts to develop internal capabilities in the life sciences.
21. Senate, *Coordination of Biomedical Research*, pp. 169–70.
22. See, e.g., questions posed to Randt by Daddario and Congressman Moeller in House, *Space Medicine Research*, pp. 2–19.
23. Senate, *Coordination of Biomedical Research*, pp. 168–72.
24. This statement appeared in various contexts, including Senate, *Space Research in the Life Sciences*, pp. 33–34.
25. Ibid.; House, *Space Medicine Research*; Senate, *NASA Authorization for Fiscal Year 1961*.
26. Randt to Richard E. Horner, "Grant and Contract Management in the Office of Life Sciences," Mar. 16, 1960; Glennan interview.
27. Randt, correspondence with author, Sept. 24, 1979; Randt to Glennan, "NASA Relationship to the Armed Forces-National Research Council Committee on Bioastronautics," Mar. 28, 1960; Randt interview, Aug. 2, 1979.
28. Glennan to Homer Joe Stewart, June 6, 1960; Glennan to Smith J. DeFrance, Mar. 15, 1960.
29. Randt interview, 1979.
30. Randt, "Office of Life Science Programs Ten Year Plan," Sept. 15, 1960, pp. 21–23; copy in Life Sciences Program files, NASA HO.
31. Ibid., pp. 18–20.
32. Ibid., pp. 1–17.
33. Ibid., pp. 24–27.
34. Ibid., unnumbered page attached to front of file copy and dated Oct. 13, 1960.
35. Randt interview, 1961.
36. House, *Space Medicine Research*, pp. 12–18.
37. Glennan interview.
38. Ibid.
39. Glennan to Stewart, June 6, 1960; Glennan to DeFrance, Mar. 15, 1960.
40. Ibid.; Randt to Glennan, "Proposed Establishment of a NASA Biotechnology Laboratory," June 3, 1960; Homer J. Stewart to Glennan, June 15, 1960; Randt interview, 1979.
41. Glennan to Stewart, June 6, 1960.
42. Bruce Lundin and Donald Heaton, "Report of the Special Working Group on Location of the Manned Space Flight Activity," Oct. 14, 1960.
43. Glennan interview.
44. Randt interview, 1979.
45. "Report of Biosciences Advisory Committee," p. 15.
46. Randt interviews, 1961, 1979; Randt and Silverstein to Horner, "Biomedical Aspects of Project Mercury," Mar. 23, 1960.
47. Senate, *Space Research in the Life Sciences*, pp. 27–36.
48. Randt interview, 1979.
49. Randt interview, 1961; White interview.
50. PSAC, "Report of the Ad Hoc Panel on Man-in-Space," Nov. 14, 1960, and "Report of the Ad Hoc Mercury Panel," Apr. 12, 1961; copies of both reports are in many different locations.
51. Trevor Gardner, "Air Research and Development Command Bioastronautics Capability

and Requirements for Manned Space Operations," Dec. 15, 1960; Gen. Bernard Schriever to Trevor Gardner, Oct. 11, 1960, and to Glennan, Jan. 11, 1961; USAF Historical Div., "Chronology of USAF Man-in-Space Activity," Feb. 1965.

52. Randt to Glennan, Sept. 12, 1960; Randt to Seamans, Dec. 6, 1960.
53. Silverstein to Seamans, "Recommended Reorganization of the Life Systems Branch, Space Task Group," Jan. 3, 1961.
54. Jack Young to Seamans, "Organization of the Life Systems Activities in the Space Task Group," Jan. 30, 1961.
55. "Report to the President-Elect of the Ad Hoc Committee on Space" (Wiesner report), Jan. 1961.
56. Randt interview, 1979; Randt to Seamans, "NASA-Air Force Relationships," Feb. 9, 1961; Randt to Lt. Gen. Roscoe C. Wilson, Feb. 10, 1961.
57. Randt, "A Proposal to Consolidate the Total Life Sciences Program," Feb. 2, 1961.
58. Randt interview, 1979.
59. House Committee on Science and Astronautics, *1962 NASA Authorization*, 87/1, Mar. 13-23, and Apr. 10-24, 1961, pp. 151-56.
60. Swenson, Grimwood, and Alexander, *This New Ocean*, pp. 209, 325.
61. Charles Roadman to Seamans, May 10, 1961; Roadman, "Redirection of the NASA Life Science Programs," Nov. 22, 1961; Roadman biography, Biography files, NASA HO.
62. "Report of the Ad Hoc Mercury Panel," Apr. 12, 1961; *Conference on the Medical Results of the First U.S. Manned Suborbital Space Flight* (Washington: NASA, June 6, 1961).
63. Explanations appear in many different contexts, e.g., W. L. Hjornevik, "A Summary Look at the Headquarters Organization Problem," staff rpt. for James Webb, Feb. 27, 1961, and "Report of a Life Sciences Study Task Group," Apr. 18, 1968.

## CHAPTER 4

1. For the decision to make manned lunar landing the focus of the space program, see John M. Logsdon, *The Decision to Go to the Moon*; Amitai Etzioni, *The Moon-Doggle* (Garden City, N.Y.: Doubleday, 1964); Barton C. Hacker and James M. Grimwood, *On the Shoulders of Titans: A History of Project Gemini*, NASA SP-4203 (Washington, 1977); Courtney G. Brooks, James M. Grimwood, and Loyd S. Swenson, Jr., *Chariots for Apollo: A History of Manned Lunar Spacecraft*, NASA SP-4205 (Washington, 1979).
2. House, *Authorizing Appropriations for NASA*, report of the Committee on Space Science and Astronautics, 88/1, July 25, 1963, pp. 46-47; comments of George Knauf, in Senate, *Manned Space Flight Programs of the National Aeronautics and Space Administration: Projects Mercury, Gemini and Apollo*, staff rpt. of the Committee on Aeronautics and Space Science, 87/2, Sept. 4, 1962, pp. 17-18; Charles Berry, "Aeromedical Preparations," in *Mercury Project Summary*, NASA SP-45 (Washington, 1963), p. 199; Stanley C. White, "Biomedical Data Collection for Space Programs," speech at the Manned Spacecraft Center in 1963, copy in the bibliography files, Johnson Space Center (hereafter JSC) history archives.
3. White, "Biomedical Data Collection," p. 7.
4. Berry, "Aeromedical Preparations," p. 199; Berry interview, Mar. 18, 1968, in JSC history archives.
5. Berry, "Space Medicine in Perspective: A Critical Review of the Manned Space Program," presented to the American Medical Association Clinical Convention, Nov. 28, 1966, p. 3.
6. Berry, "Aeromedical Preparations," pp. 201-03; Howard A. Minners et al.,

"Aeromedical Preparations and Results of Postflight Medical Examinations," in Manned Spacecraft Center, *Results of the First United States Manned Orbital Space Flight* (Washington: NASA, Feb. 20, 1962), pp. 83–92; Howard A. Minners et al., "Clinical Medical Observations," and Earnest P. McCutcheon et al., "Physiological Responses of the Astronaut," both in Manned Spacecraft Center, *Results of the Second United States Manned Orbital Space Flight*, NASA SP-6 (Washington, May 24, 1962), pp. 43–62; Charles Berry et al., "Aeromedical Analysis," in Manned Spacecraft Center, *Results of the Third United States Manned Orbital Space Flight*, NASA SP-12 (Washington, Oct. 3, 1962), pp. 23–36; A. D. Catterson et al., "Aeromedical Observations," in *Mercury Project Summary*, pp. 310–21.

7. Berry, "Aeromedical Preparations," p. 201; R. S. Johnston et al., "Life Support Systems and Biomedical Instruments," in *First Manned Orbital Results*, pp. 41–43; J. H. Boynton, E. M. Fields, and D. F. Hughes, "Spacecraft Systems Development and Performance," in *Mercury Project Summary*, pp 38–52.
8. White, "Biomedical Data Collection," p. 6.
9. Berry interview, Oct. 30, 1967; Johnston interview, Apr. 17, 1968, in JSC history archives; Lawrence Dietlein interview, Aug. 19, 1980.
10. Johnston et al., "Life Support Systems and Biomedical Instruments," pp. 41–43; Johnston interview, Apr. 17, 1968, JSC history archives; Johnston interview, Aug. 18, 1980.
11. Berry, "Aeromedical Preparations," p. 203.
12. Ibid.
13. Ibid., p. 202; Catterson et al., "Aeromedical Observations," p. 315.
14. White, "Biomedical Data Collection," p. 7.
15. Berry, "Aeromedical Preparations," pp. 206–07; Catterson et al., "Aeromedical Observations," pp. 299–326; Senate, *Manned Space Flight Programs,* pp. 17–30; Berry interviews, Oct. 30, 1967 and Mar. 18, 1968, and Dietlein interview, Mar. 22, 1968, all in JSC history archives.
16. Berry and Dietlein interviews, Oct. 30, 1967 and Mar. 18 and 22, 1968, in JSC history archives; Dietlein interview, Aug. 19, 1980.
17. Ibid.
18. Berry interview, Mar. 18, 1968.
19. White, "Biomedical Data Collection," pp. 9–11.
20. Ibid.; Berry, "Aeromedical Preparations," pp. 201–07.
21. Senate, *Manned Space Flight Programs*, p. 115.
22. Ibid.
23. Dietlein interview, Mar. 22, 1968; Charles Berry and A. D. Catterson, "Pre-Gemini Medical Predictions versus Gemini Flight Results," in *Gemini Summary Conference*, NASA SP-138 (Washington, 1967) pp. 197–99.
24. Charles Berry et al., "Man's Response to Long-Duration Flight in the Gemini Spacecraft," in Manned Spacecraft Center, *Gemini Mid-Program Conference*, NASA SP-121 (Washington, Feb. 25, 1966), pp. 235–40.
25. Lawrence F. Dietlein and W. V. Judy, "Experiment M-1, Cardiovascular Conditioning," ibid., pp. 381–91.
26. Dietlein and Rita M. Rapp, "Experiment M-3, Inflight Exercise—Work Tolerance," ibid., pp. 393–94.
27. Dietlein and Carlos Vallbona, "Experiment M-4, Inflight Phoniocardiogram," ibid., pp. 397–402.
28. Berry interviews, Oct. 30, 1967 and Mar. 18, 1968; Dietlein interviews, Mar. 22, 1968 and Aug. 19, 1980; Johnston interview, Aug. 18, 1980.

29. Dietlein and E. Harris, "Experiment M-5, Bioassays of Body Fluids," in *Gemini Mid-Program Conference*, pp. 403–06.
30. Pauline B. Mack et al., "Experiment M-6, Bone Demineralization," ibid., pp. 407–15.
31. G. D. Whedon et al., "Experiment M-7, Calcium and Nitrogen Balance," ibid., pp. 417–21.
32. Peter Kelloway, "Experiment M-8, Inflight Sleep Analysis," ibid., pp. 423–29.
33. Eaerl Miller, "Experiment M-9, Human Otolith Function," ibid., pp. 431–35.
34. James Waggoner interview, July 8, 1966, in JSC history archives.
35. Senate, *Manned Space Flight Programs*, pp. 21–23.
36. Richard S. Johnston interview, Aug. 18, 1980; Dietlein interview, Aug. 19, 1980.
37. Berry and Catterson, "Pre-Gemini Medical Predictions," pp. 209–10.
38. R. L. Frost, J. W. Thompson, and L. E. Bell, "Environmental Control System," in *Gemini Mid-Program Conference*, pp. 71–77; R. S. Johnston interviews, Apr. 17, 1968 and Aug. 18, 1980.
39. James Waggoner interview, July 8, 1966; Senate, *Manned Space Flight Programs*, pp. 24–28.
40. Senate, *Manned Space Flight Programs*, pp. 25–26.
41. Ibid., p. 26; R. S. Johnston, "Performance of Gemini Spacecraft Systems," in *Gemini Summary Conference*, pp. 29–31. For a detailed discussion of engineering problems of waste management, see Norman Belasco and Donald M. Perry, "Waste Management and Personal Hygiene for Extended Spacecraft Missions," presented at the American Industrial Hygiene Conference, Apr. 26–30, 1964.
42. Berry, "Space Medicine in Perspective," p. 14; Berry and Catterson, "Pre-Gemini Predictions," pp. 215-61; George E. Ruff and Edwin Z. Levy, "Psychiatric Evaluation of Candidates for Spaceflight," *Am. J. Psychiat.* 116 (Nov. 1959): 385–91.
43. Berry and Catterson, "Man's Response to Long-Duration Flight," p. 244. Specific drugs included cyclizine HC1, dextro-amphetamine sulfate, APC, meperidine HC1, tripolidine HC1, pseudoephedrine HC1, diphenoxylate HC1, atropine sulfate, tetracycline HC1, methylcellulose solution, parenteral cyclizine, and parenteral meperidine HC1.
44. The essential NASA position is contained in a letter from D. Brainerd Holmes, director of the Office of Manned Space Flight (OMSF), to Christian Lambertsen, a prominent academic life scientist, Nov. 20, 1962.
45. Berry interviews, Oct. 30, 1967 and Mar. 18, 1968; Holmes to Associate Administrator Robert Seamans, "OMSF Position on Animal-Biological Experiments in Space," Nov. 22, 1962; Robert Gilruth to Charles Roadman and Holmes, "The Role of Animal Experiments," Jan. 18, 1962.
46. House, *Authorizing Appropriations for NASA*, 1963, p. 48; Charles E. Campbell, "Project Development Plan: Biological Investigations of Space," planning document prepared at NASA Goddard Space Flight Center, Sept. 1961.
47. Smith J. DeFrance to Charles Roadman, Feb. 21, 1962; Roadman to DeFrance and Thomas Dixon, "Policy Statement Regarding Animal Experiments," Feb. 28, 1962.
48. Gilruth to Roadman and Holmes, "Animal Experimental Work Supporting Manned Space Flight," Jan. 18, 1962.
49. For details concerning the USAF Manned Orbiting Laboratory (MOL), see MOL folders in Skylab files, NASA HO.
50. Reports of meetings related to the Apollo Extension System, space station, and Mars flight are in Skylab files, NASA HO.
51. The working group was established by OMSF Inst. M-IA 8115.281, Oct. 10, 1963.
52. See "Report of the Orbital Research Laboratory Biomedical Experiment Working Group," June 1, 1964, in NASA HO. An earlier study, "A Program for the Study of the

Effects of Prolonged Weightlessness on Man," was prepared in July 1963 by the Manned Orbiting Laboratory Team at Ames. Life sciences aspects of an orbiting laboratory were also considered by Alfred Mayo, director of biotechnology and human research, as reflected in a draft manuscript, "Requirements for NASA Activity in the Life Sciences," Feb. 2, 1962, in the "Mayo Folders," Office of Advanced Research and Technology (OART) files, NASA HO.

53. Background to and recommendations of the SPAMAG report are in *Medical Aspects of an Orbiting Research Laboratory*, NASA SP-86 (Washington, 1966). Also, Sherman P. Vinograd interview, May 10, 1979.
54. Eugene Konecci, "Human Research," in *Life Sciences Program Review Document*, 1963, pp. 95–105; Frank Voris, "Medical Aspects of Manned Space Flight," 1963, pamphlet published by the NASA Office of Scientific Information.
55. Alfred M. Mayo and James P. Nolan, "Bioengineering and Bioinstrumentation," in K. E. Schaefer, ed., *Bioastronautics*, (New York: Macmillan, 1964), pp. 227–73.

## CHAPTER 5

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2. See Elizabeth A. Muenger, *Searching the Horizons: Ames Research Center, 1940–1976*, NASA SP-4304 (Washington, D.C., 1985).
3. Interviews with Reynolds, Nov. 14, 1979; Naugle, Feb. 21, 1980; Gerathewohl, July 6, 1979; Randt, Aug. 14, 1979.
4. D. Brainerd Holmes to Seamans, "Responsibilities of a Directorate of Aerospace Medicine," Nov. 20, 1961; Charles Roadman, "Aerospace Medicine Briefing for Dr. Holmes," Nov. 13, 1961.
5. Interviews with Newell, Naugle, and Reynolds.
6. Newell, Naugle, and Reynolds interviews; Robert Gilruth to D. Brainerd Holmes, "Manned Spacecraft Center Expected Effort in Aerospace Medicine," Dec. 15, 1961; Newell and Holmes to Seamans, "Redirection of NASA's Life Science Programs," Nov. 22, 1961; Alfred Mayo, "Management of Advanced Research and Technology Programs," Jan. 22, 1962.
7. Smith J. DeFrance to Seamans, Aug. 22, 1961.
8. Thomas Dixon to project directors, "Formulation of a NASA Aerospace Biology and Life Support (Aerospace Medicine) Program," Jan. 9, 1962.
9. "Report of the NASA Working Group on the Life Sciences," Mar. 1962, unpublished study prepared under direction of Bernard Maggin for Seamans, pp. 36–41; R. F. Bohling to Maggin, "Comments Regarding Report of Working Group on the Life Sciences," Feb. 26, 1962; Richard S. Johnston, "MSC Comments on Report of NASA Working Group on the Life Sciences," Feb. 1962.
10. Seamans to Maggin, "Report of the Working Group on Life Sciences," Apr. 12, 1962; Thomas Dixon to multiple addressees, Mar. 20, 1962.
11. Johnston, "MSC Comments," Feb. 1962; interviews with Newell, Maggin, and Naugle.
12. This is brought out in a number of internal reviews, including Jack Bollerud, "Staff

Study of the Structuring of the Life Sciences within NASA," 1966, and Bernard Maggin and Robert Bell, "Management of the Life Sciences," Oct. 1967.

13. W. Fred Boone to Seamans, June 17, 1964; *Twelfth Semi-Annual Report of the NASA to the President*, 1963.
14. Reynolds interview; Orr Reynolds, "Bioscience Programs," in Life Sciences Program Review Document, 1963, transcript of presentations made to associate administrator.
15. Interview with Eugene Konecci, Aug. 14, 1964; Konecci biography in Biography files, NASA HO.
16. Eugene Konecci, "Biotechnology and Human Research," in Life Sciences Program Review Document, 1963; Konecci, "Human Factors in Electronics," paper presented to the 5th Annual Conference on Human Factors in Electronics, May 5, 1964.
17. "Budget History for Fiscal Year 1964," pp. 4, 14, 38, in Budget files, NASA HO.
18. Senate, *NASA Authorization for Fiscal Year 1964*, report of the Committee on Aeronautics and Space Sciences, 88/1, Aug. 2, 1963, pp. v, 49, 116.
19. Interviews with Reynolds and Naugle.
20. "Biosciences" and "Human Factor Systems," in "Budget History for Fiscal Year 1964," pp. RDO 12-1 to 12-5 and RDO 17-1 to 17-6.
21. See Bollerud, "Staff Study," 1966; Maggin and Bell, "Management of Life Sciences," 1967.
22. See NAS, Space Science Board, "Report on the Organization of the Life Sciences in NASA," Aug. 7, 1962; Nello Pace, "Report Nr. 6 of the Special Life Sciences Consultant to the Administrator," Nov. 1963.
23. J. W. Dyer, *Project Biosatellite: Historical Summary Report* (Moffet Field, Calif.: NASA Ames Research Center, 1969).
24. Jones interview.
25. Newell and Raymond Bisplinghoff to Seamans, "Establishment of a Joint OSS/OART Committee on Biosatellite," Jan. 1963; Newell to Bisplinghoff, Jan. 17, 1963; Benny B. Hall to Seamans, "Minutes of the First Meeting of the Joint OSS/OART Biosatellite Working Group," Jan. 24, 1963.
26. Hall to Seamans, Newell, and Bisplinghoff, Apr. 9, 1963.
27. Naugle, Newell, and Jones interviews. Jones claims that the failure of the joint effort was due to unwillingness of Office of Space Science (OSS) personnel to cooperate.
28. Eugene Konecci to Bisplinghoff, Oct. 25, 1962; Konecci to Smith DeFrance, "Headquarters Survey of Life Sciences Activities," June 1, 1963; Gerathewohl interview.
29. Gerathewohl interview; Ralph W. Gerard to DeFrance, Feb. 28, 1963, enclosing Gerard's "Report on the Life Sciences at Ames," Feb. 20, 1963.
30. Clark Randt to Keith Glennan, "A Bio-Technology Laboratory at Ames," June 6, 1960.
31. Gerathewohl interview; Gerard, "Report on the Life Sciences at Ames"; Thomas Dixon to Seamans, Jan. 17, 1963.
32. Earl D. Hilburn to John F. Parsons, Sept. 10, 1964; Edwin P. Hartman, *Adventures in Research: A History of the Ames Research Center*, NASA SP-4302 (Washington, 1970), pp. 321-23, 441-44.
33. Gerard, "Report on the Life Sciences at Ames"; DeFrance to Seamans, Mar. 21, 1963.
34. Fern Pickens to Seamans, July 18, 1962.
35. Richard S. Johnston, "Comments on Report of the NASA Working Group on Life Sciences," Feb. 1962.
36. Interviews with Charles Berry, Oct. 30, 1967 and Lawrence Dietlein, Aug. 19, 1980.
37. "Aerospace Medicine," in 1963 NASA Budgetary History, p. 14.
38. Berry interview, Oct. 30, 1967.
39. PSAC, Life Sciences Panel, "Report of the Bioastronautics Panel," Feb. 15, 1962; NAS,

Space Science Board, "Report on the Organization of the Life Sciences in NASA," Aug. 7, 1962.

40. Seamans to Maggin, Apr. 12, 1962; Thomas Dixon to multiple addressees, Mar. 20, 1962.
41. George Knauf to J. S. Brown, "Discussion with Congressman Daddario" and attached "Coordination of Space Medicine Programs," Sept. 10, 1963; interview with George Knauf, undated, transcript in NASA HO.
42. "A Proposed Plan to Implement NASA/AF Coordination of the FY 1964 Space Medicine-Bioastronautics Design, Development and Test Program to Support Approved Flight Program Requirements," signed by John M. Talbot and George Knauf, Aug. 5, 1963, and endorsed by George Mueller and Gen. Roscoe C. Wilson, Aug. 7, 1963.
43. Konecci, letter to DeFrance, June 1, 1963; memo to Knauf, Jan. 3, 1964; memo to Seamans, "Coordination in the Life Sciences Field," Aug. 12, 1964; letter to Paul F. Bilke, Apr. 22, 1964.
44. PSAC, "Report of Bioastronautics Panel," Feb. 1962; NAS-Space Science Board, "Organization of Life Sciences in NASA," Aug. 7, 1962; Norton Nelson, letter to James Webb, Nov. 27, 1962; Robert Seamans, memo to Newell, "Special Assistant for Life Sciences," Sept. 18, 1962; Nello Pace, report of the special consultant to the Administrator, No. 6, "Reorganization of NASA Life Sciences Activities," Oct. 4, 1963.
45. George Knauf, memo to J. S. Brown, Sept. 10, 1963; Congressman Emilio Q. Daddario, letter to James Webb, Aug. 29, 1962; comments and testimony, in House, *1964 NASA Authorization*, Hearings before Subcommittee on Manned Space Flight, Committee on Science and Astronautics, 88/1, Mar. 6–27, Apr. 1–29, May 1–21, June 6, 1963, pp. 1037–1189, passim.
46. "Program Review Life Sciences," transcript of presentations to Seamans, Apr. 6, 1963.
47. George Low, memo to Seamans, July 1, 1963; Charles Roadman, memo to Seamans, "Biological Program," Aug. 3, 1963.
48. Seamans, memo to Raymond Bisplinghoff, Apr. 21, 1964.
49. Seamans, memo to program administrators, "Life Sciences Coordination," July 9, 1964. Because the management issuance system was in the process of revision, the formal instruction establishing the LSDG, NASA Management Issuance 1152, was not issued until June 24, 1965.
50. James Webb, letter to Norton Nelson, Nov. 14, 1962.
51. Interviews with Naugle, Jones, and Newell.
52. NASA Management Issuance M 9000.002, "Establishment of a Manned Spaceflight Experiments Board," Feb. 10, 1964.
53. Ibid.; "George Mueller-Homer Newell Correspondence," in Manned Space Flight Experiment Board files, NASA HO.
54. NASA Management Issuance MM 7000.026, "Establishment of Medical Experiments Panel of Manned Space Flight Experiments Board," June 1, 1964; George Mueller, memo to Randolph Lovelace, "Medical Experiments," May 8, 1964; interviews with Sherman P. Vinograd; Lawrence Dietlein, Aug. 19, 1980; and James Waggoner, July 8, 1966.

## CHAPTER 6

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3. Meg Greenfield, "Science Goes to Washington," *The Reporter*, Sept. 26, 1963, p. 26. See also Mack, "NASA and the Scientific Community"; John M. Logsdon, *The Decision to Go to the Moon: Project Apollo and the National Interest* (Cambridge: MIT Press, 1970), pp. 1-87.
4. Logsdon, *Decision to Go to Moon*, passim.
5. George Alexander, "Panel to Probe Bioastronautics Effort," *Aviation Week*, Aug. 21, 1961; editorial, *Aviation Week*, Mar. 6, 1961; comments of Emilio Q. Daddario, *NASA Authorization for FY 1962*, Hearings before the House Committee on Science and Astronautics, 87/1, Mar. 6- Apr. 27, 1961.
6. PSAC, Life Sciences Panel, "Report of the Bioastronautics Panel," Feb. 15, 1962, pp. 11-13.
7. R. W. Hale to Vice-President Johnson, "Bioastronautics Crisis," Feb. 28, 1962.
8. Charles Roadman, comments in *NASA Authorization for FY 1963*, Hearings before the House Committee on Science and Astronautics, 87/2, Mar. 6-29 and Apr. 2-10, 1962, p. 954.
9. Edward C. Welsh to Robert Seamans, "Bioastronautics," June 29, 1962.
10. Seamans to Albert Siepert, NASA Office of Administration, July 6, 1962; Siepert to Seamans, "Coordination of NASA's Interests in Bioastronautics," July 19, 1962. Seamans's reply to Welsh could not be located; Siepert's memo contains recommended points that Seamans should include in his reply.
11. NAS, Space Science Board, "Report on the Organization of the Life Sciences in NASA," Aug. 7, 1962.
12. Ibid.; W. W. Kellog to Norton Nelson, "Some Expressions on NASA Life Sciences Management," Aug. 5, 1962.
13. Nelson to James Webb, Aug. 9, 1962; Homer Newell to the Administrator, Aug. 29, 1962; Seamans to Newell, "Special Assistant for the Life Sciences," Sept. 18, 1962; Nelson to Seamans, Oct. 2, 1962.
14. Webb to Nelson, Nov. 14, 1962.
15. David B. Vinson to Vice-President Johnson, Oct. 11, 1962, conveying "An Opinion in Regard to a Recommended Aerospace Medical Association Expression"; Johnson to Webb, Oct. 16, 1962; Seamans to Webb, "Use of Consultants," Oct. 30, 1962; Raymond Romatowski to Bernard Maggin, Oct. 24, 1962; Eugene Konecci to Maggin, Oct. 26, 1962; Orr Reynolds to Maggin, Oct. 26, 1962; Charles Roadman to Maggin, Oct. 25, 1962.
16. Edward C. Welsh to Seamans, Nov. 9, 1962; Seamans to Welsh, Nov. 20, 1962.
17. Ralph W. Gerard, "Report on the Life Sciences at Ames," Feb. 20, 1963; Gerard to Smith DeFrance, Feb. 28, 1963; DeFrance to Seamans, Mar. 3, 1963; Gerathewohl interview, July 3, 1979.
18. Webb to Nello Pace, Apr. 30, 1963.
19. Pace, "Establishment of a Bioastronautics Training Program," rpt. 1, July 17, 1963.

20. Pace, "Ames Life Sciences Research Laboratory," rpt. 3, Sept. 17, 1963.
21. Pace, "Reorganization of NASA's Life Sciences Activities," rpt. 6, Oct. 4, 1963.
22. Albert Sipert to Seamans, July 19, 1962.
23. "National Aeronautics and Space Act of 1958," sec. 102(c)(8).
24. For this background, see Loyd S. Swenson, James M. Grimwood, and Charles Alexander, *This New Ocean: A History of Project Mercury*, NASA SP-4201 (Washington, 1966).
25. George Knauf interview, undated, transcript in NASA HO.
26. Daddario to Webb, Aug. 29, 1961.
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28. Rubel to Seamans, Feb. 12, 1962.
29. "Agreement between DoD and NASA Relating to Bioastronautics Research, Development, Test and Evaluation in Support of the Manned Lunar Landing Program," signed by James Webb and Robert McNamara, Feb. 10, 1962.
30. Seamans to Rubel, Mar. 23, 1962; Seamans and Rubel to Charles Roadman and John Talbot, "Joint DoD/NASA Bioastronautics Planning," Feb. 12, 1962.
31. G. Dale Smith to Smith DeFrance, Jan. 18, 1962; DeFrance to Seamans, Jan. 19, 1962; Fern Pickens to Seamans, July 18, 1962; George Low to Seamans, July 1, 1963.
32. House, *NASA Authorization for FY 1963*, pp. 171-79.
33. Seamans to Brockway McMillan, assistant secretary of the Air Force, Sept. 5, 1962.
34. Daddario comments, in *1964 NASA Authorization*, Hearings before the House Committee on Science and Astronautics, 88/1, Mar. 6-27, Apr. 1-29, May 1-21, June 6, 1963, pt. 2(b), pp. 1037-89.
35. Senate, *NASA Authorization for Fiscal Year 1964*, report of the Committee on Aeronautics and Space Sciences, 88/1, Aug. 2, 1963, pp. v, 49, 116. See also Senate, *NASA Authorization 1964*, Hearings before the Committee on Aeronautical and Space Sciences, 88/1, June 12-18, 1963, pp. 909-13.
36. Edward C. Welsh to Webb, "National Aeronautics and Space Council Meeting, August 3, 1962," Aug. 6, 1962; Franklyn Phillips to Hugh Dryden, "Request of the Vice President for a Written Statement of Bioastronautics Programs," Aug. 7, 1962.
37. John Rubel to Welsh, Aug. 13, 1962; Dryden to Welsh, Aug. 15, 1962.
38. Welsh to Seamans, Nov. 9, 1962.
39. Comments of George Knauf, in *NASA Authorization*, Hearings before the House Committee on Science and Astronautics, 88/2, Feb. 18-26 and Mar. 3-10, 1964, pt. 2, pp. 705-31. Knauf says, "This action occurred I must say, in response to some rather positive urging . . . [from] this committee."
40. "A Proposed Plan to Implement NASA/AF Coordination of the FY 64 Space Medicine-Bioastronautics Design, Development, and Test Program to Support Approved Flight Program Requirements," signed by John M. Talbot and George Knauf on Aug. 5, 1963, by D. Brainerd Holmes and Roscoe Wilson on Aug. 7, 1963, and by Robert Seamans and John Rubel on Feb. 10, 1964.
41. Eugene Konecci to George Knauf, "Recommendation for Utilization of U.S. Air Force Aerospace Medical Divison Manpower and Facilities at Brooks Air Force Base," Jan. 3, 1964; Knauf, draft of statement prepared for the Subcommittee on Manned Space Flight, Committee on Science and Astronautics, House, Feb. 26, 1964; Harold Klein to Konecci, "Coordination of Ames Life Sciences and the School of Aerospace Medicine

6. For a thorough analysis of the problem, see reports and correspondence in "Report of the Life Sciences Study Task Group to J. W. Humphreys," Mar. 1968, in the Life Sciences Program files, NASA HO; Humphreys interview.
7. For example, see Harold B. Klein, memo to Charles A. Berry, "Liaison between the Manned Spacecraft Center and the Ames Research Center in the Life Sciences Area," Sept. 1, 1966.
8. For a comparison of the life sciences R&D budget and R&D budgets for other areas, see Chap. 7. This disparity is also discussed in Nello Pace, "Report Nr. 6 of the Life Sciences Consultant to the Administrator," Oct. 1963. Pace contends that the life sciences receive less than 2 percent of the total R&D funds.
9. Details in Chap. 7.
10. Refer to Seamans memo, "Coordination in the Life Sciences Field," July 9, 1964, and NASA Management Instruction 1152.18, June 24, 1965.
11. Refer to reports and correspondence in the Biosatellite files, NASA HO.
12. Ibid.
13. Nello Pace, "Report Nr. 7 of the Life Sciences Consultant to the Administrator," Nov. 1963.
14. Daddario first insisted on this during the FY 1962 authorization hearings. See House, *NASA Authorization for FY 1962*, Hearings before the Committee on Science and Astronautics, 87/1, Mar./Apr. 1961.
15. Senate, *Authorizing Appropriations for NASA*, report of the Committee on Space Science and Astronautics, 88/2, June 2, 1964, p. 2; Senate, *NASA Authorization for Fiscal Year 1966*, report of the Committee on Aeronautics and Space Science, 89/1, p. 4; Senate, *NASA Authorization for FY 1967*, report of the Committee on Aeronautics and Space Sciences, 89/2, May 23, 1966, p. 4.
16. See, e.g., Senate, *NASA Authorization for Fiscal Year 1964*, report of the Committee on Aeronautics and Space Science, 88/1, Aug. 2, 1963, pp. 48–49, 113–16.
17. Ibid.
18. Though apparently never a formal commitment, this future role is implicit in numerous documents in the Biosatellite files and the Biomedical Experiments Working Group files, NASA HO.
19. This is referenced in many documents, e.g., "Administrator's Program Review," June 22, 1966, pp. 59–62, a transcript of presentations made by the life sciences directors to Administrator Webb. According to Walton Jones, former director of biotechnology and human research, this experiment was originally proposed for inclusion in the Biosatellite flights, but received no support from the Biosciences Division. The experiment was eventually flown in 1972.
20. The MSC position on animal research is recorded in numerous documents. See, e.g., testimonies of J. W. Humphreys and Charles A. Berry in House, *Future of the Bioscience Program of the NASA*, report of the Subcommittee on Space Science and Applications of the Committee on Science and Astronautics, 91/1, Dec. 24, 1969.
21. These concerns are expressed in memos and correspondence in the Life Science Working Group files (record group 255, accession 71A3309) and in "Report of the Life Sciences Study Task Group to Major Gen. Humphreys," Apr. 1968 (copy in NASA HO). They are also addressed by Reynolds and Jones in their respective interviews.
22. Reynolds interview.
23. Background on these individuals and representative samples of their writings are in Biography files, NASA HO.
24. Jones interview. Jones and others express these views in assorted memos in Life Sciences Working Group files and in "Report of the Life Sciences Study Task Group,"

For example, see Jones to J. W. Humphreys, "Life Sciences Working Group," Mar. 1, 1968.

25. This is evident in memos from the program office administrators to Seamans in response to Seamans's request for "thoughts" on the life sciences program, dated Feb. 3, 1966. Copies of these responses are in "Report of the Life Sciences Study Task Group."
26. Knauf interview; Roadman to Brainerd Holmes, "Redirection of NASA's Life Science Programs," Nov. 1961.
27. Knauf interview.
28. Responsibilities of the director of this office are summarized in "Administrator's Program Review: Life Sciences," June 22, 1966, a copy of which is in the Life Sciences Program files, NASA HO. Assorted documents are in the Center History Files, JSC history archives. The organization of this office is also discussed in the Berry interview.
29. Vinograd interview; assorted documents in personal files in possession of Vinograd.
30. Space Medicine Advisory Group, *Medical Aspects of an Orbiting Research Laboratory*, NASA SP-86, (Washington, 1966).
31. Vinograd interview; OMSF Management Instruction MM-7000-026A, "Establishment of the Medical Experiments Panel of the Manned Space Flight Experiments Board," Feb. 18, 1965.
32. Deitlein interviews.
33. "Minutes of the Life Science Directors Group Tenth Meeting," Feb. 7, 1966, in LSDG files, RG 255.
34. H. S. Brownstein to Life Sciences Directors, Mar. 10, 1966.
35. "Agreement for the Management of an Integrated Life Sciences In-Flight Experiments Program," draft copy, Mar. 9, 1966, copy in LSDG files, RG 255.
36. Copies of minutes of all meetings are in LSDG files, RG 255. Lovelace's frequent absences were discussed in a number of memos and are referenced in "Report of the Life Sciences Study Task Group."
37. For example, PSAC, "Report of the Bioastronautics Panel," 1962.
38. Jones and Reynolds interviews. Also cited by Col. Jack Bollerud, "Staff Study of the Structuring of Life Sciences Activities Within NASA," 1966, and "Report of the Life Sciences Study Task Group."
39. Seamans to program office associate administrators, "Life Sciences Directors Group," Feb. 3, 1966.
40. Homer Newell to Seamans, "Life Science Directors Group," July 11, 1966, with attached memo from Reynolds to Newell, "Life Sciences Directors Group," July 8, 1966, and "Life Sciences Coordination and Related Matters," Aug. 3, 1966.
41. George Mueller to Seamans, "Briefing Memo re LSDG," June 23, 1965; Mac Adams to William Rieke, "Life Sciences Directors Group," July 22, 1966; Raymond Romatowski, "Life Sciences Coordination and Related Matters," Aug. 5, 1966.
42. Mueller to Seamans, "Life Sciences Directors Group," July 6, 1966; Romatowski to Seamans, Aug. 5, 1966.
43. Rieke to Seamans, "Life Sciences Coordination and Related Matters," Aug. 3, 1966; Romatowski to Seamans, Aug. 5, 1966; Seamans to program office associate administrators, "Life Sciences Directors Group," Sept. 14, 1966; NASA Management Issuance 1152.18A, "NASA Life Sciences Directors Group," Aug. 1966.
44. Bollerud, "Staff Study of the Structuring of Life Sciences Activities within NASA," 1966.

## CHAPTER 9

1. PSAC, *The Space Program in the Post-Apollo Period,* report of the Joint Space Panels (Washington: Executive Office of the President, Feb. 1967), p. 13.
2. Ibid., p. 14.
3. Ibid., pp. 21–23, 65–69.
4. Ibid.
5. Ibid., pp. 24–25.
6. J. W. Humphreys to George Mueller, "Findings and Recommendations of the PSAC Space Science and Technology Panel," Sept. 18, 1967. This view was expressed in many different contexts throughout the 1960s.
7. The MSC position on animal research had the endorsement of NASA's top management and the OMSF associate administrator; however, some of NASA's life scientists held other views. Those in the Biosciences Division tended to favor animal research for purely scientific purposes; those in the Biotechnology-Human Research Division tended to support the position that animal research should be an adjunct to human research in support of advanced manned programs. A good summary of these three positions is in Robert Bell, "A Method for Distinguishing between Two Life Sciences Missions or Objectives," draft of an oral presentation given to the NASA Life Sciences Study Task Group, Feb. 13, 1968; a copy is in "Report of the Life Sciences Study Task Group to Maj. General J. W. Humphreys," unpublished report prepared for the NASA associate administrator and dated Apr. 17, 1968.
8. The documentary history of the Air Force Manned Orbiting Laboratory (MOL) is in the MOL files, NASA HO. Problems and deficiencies in the MOL are cited in many documents, e.g., "Fund Cuts Force 2-Year Stretch in MOL," *Aviat. Week and Space Technol.*, Nov. 27, 1967, p. 22; "Coming: A Lesson in Russian," *Journal of the Armed Forces,* Dec. 1967, p. 9; Robert F. Frietag, memo for general NASA distribution, "AAP Workshop/MOL Problem," Aug. 25, 1967.
9. PSAC, "Preliminary Report," draft of a report prepared by Ad Hoc Panel on Space Biology and Medicine, dated Sept. 12, 1967, p. 1; copy in PSAC files, NASA HO.
10. Ibid., pp. 2–3.
11. Ibid., p. 4.
12. W. H. Close to Homer Newell, "Dr. Seamans' October 9 Meeting with Dr. Bennett Relative to the Draft Biomedical Sub-Panel Report," Oct. 12, 1967.
13. Humphreys to Mueller, Sept. 18, 1967; Seamans to Mueller, "Informal Summary of Space Science and Technology Panel Meeting," Aug. 17, 1967.
14. Eugene Stead to Newell, Dec. 1, 1967.
15. Willis Shapley to William Lilly, "NASA Use of Medical Manpower," June 26, 1968.
16. Stead to Lewis Branscomb, Feb. 21, 1968, transmitting copy of report of Biomedical Working Group.
17. PSAC, "Informal Summary of the Space Science and Technology Panel Meeting," Mar. 7–8, 1968.
18. Milton Rosen to Stead, Mar. 1, 1968.
19. James V. Warren interview, June 12, 1979.
20. Humphreys to NASA associate administrator and program office associate administrators. "Life Sciences Management," Apr. 23, 1968, covering "Report of the Life Sciences Study Task Group," Apr. 17, 1968.
21. The exact circumstances and precise dates are not evident in extant documents. Several transcripts of the presentation exist, but none bears the exact date or cites authorities. None of the persons interviewed recalls the specific presentation. Hum-

phreys, in a memo to Mueller dated Sept. 18, 1967, refers to this study as being in process.

22. Bernard Maggin and Robert Bell, "The Management of the Life Sciences," transcript of an oral presentation to NASA management on an unspecified date in 1967, pp. 1, 8, 8a (note: p. 8a is marked "NOT TO BE REPRODUCED," and is deleted from all but one copy of transcript).
23. Ibid., pp. 8, 8a, 13.
24. Ibid., pp. 2, 8, 8a, 9–10.
25. Ibid., pp. 11–12.
26. Ibid., p. 14.
27. Bell to Raymond Romatowski, "Progress in Resolving Problems in the Management of the Life Sciences," Nov. 6, 1967. See also Maggin to Humphreys, Nov. 8, 1967, and Maggin and Humphreys interviews, Nov. 1979 and May 2, 1979.
28. Program office associate administrators to chairman, LSDG, "Life Sciences Responsibilities and Coordination," Nov. 30, 1967.
29. "Terms of Reference for the NASA Life Sciences Program Responsibilities and Coordination Study Task Group," Dec. 6, 1967, app. F, Enclosure 1 of the "Report of the Life Sciences Study Task Group to J. W. Humphreys."
30. "Report of the Life Sciences Study Task Group," p. 3.
31. Ibid., pp. 5–6.
32. Ibid., pp. 6–7.
33. Ibid., pp. 5–10.
34. Ibid., p. 11.
35. Ibid.
36. Humphreys, "Talking Notes for Presentation to the Management Council," Mar. 1, 1968.
37. Gilruth to Maggin, "Life Sciences Program," Jan. 22, 1968; Berry to Maggin, "Further Explanation of the MSC Proposal on NASA Life Sciences Organization," Feb. 15, 1968; Berry to Webb, "Life Sciences Program," Mar. 1, 1968; Maggin to Gilruth, Jan. 29, 1968; Webb to Gilruth, Mar. 16, 1968, in "Report of Life Sciences Study Task Group," app. G.
38. John Naugle to chairman, NASA Management Council, "Reorganization of Life Science Programs," June 18, 1968.
39. Reynolds interview. His opposition is also evident in the fact that he prepared a report opposing integration of life science programs on eve of first Life Sciences Study Task Group meeting. See Reynolds to Naugle, "NASA Life Science Programs," Nov. 21, 1967. See also Naugle to chairman, Management Council, Jan. 18, 1968; Reynolds to Naugle, "Organization and Management of NASA's Life Science Programs, Apr. 22, 1968; Reynolds to chairman, Planning Steering Group, "Life Sciences Program Memorandum," Aug. 30, 1968; Naugle to Walton Jones, "Establishment of a NASA Life Sciences Missions Advisory Board," Sept. 6, 1968.
40. H. S. Brownstein, unspecified memo, "Notes for the Record, Mar. 1, 1968 Meeting of NASA Management Council."
41. Naugle to Harry Hess, Dec. 18, 1968; Allen Brown to Naugle, Dec. 23, 1968; Brown to Newell, June 19, 1968.
42. Jones to Humphreys, "Life Sciences Working Group," Mar. 1, 1968; Humphreys to Newell, Sept. 4, 1968, and Reynolds, Sept. 6, 1968.
43. Newell to Humphreys, "Life Sciences Management," May 10, 1968. In this memo Newell notes his opposition to giving an office "responsible for technology and applied research" responsibility for "fundamental research." Newell was interviewed as part of this study; however, because the interview transcript was rife with transcription errors, he prefers that his views expressed in this interview not be cited in this study.

44. Humphreys to Newell, "Management of Space Biology and Aerospace Medicine Programs within the Agency," May 3, 1968; Newell to program office associate administrators (draft), "Life Sciences Management," May 8, 1968; Humphreys, memo for the record, "Aerospace Medicine and Space Biology Board," Aug. 9, 1968; Newell to Reynolds, Humphreys, and Jones, "Draft Memo and Proposed Directive on Space Biology and Aerospace Medicine Board," June 17, 1968.
45. The history of the biosatellite flights is in Biosatellite Project files, NASA HO; and J. W. Dyer, project manager, *Project Biosatellite: Historical Summary Report* (Moffet Field, Calif., NASA Ames Research Center, 1969).
46. Ibid. Scientists' concerns over the status of the project and NASA's support for the biosciences are contained in many letters and memos in the Biosatellite files, NASA HO.
47. House Committee on Science and Astronautics, *The Future of the Bioscience Program,* Hearings before the Subcommittee on Space Science and Applications, 91/1, Nov. 12-18, 1969, pp. 1-6. See also Naugle to Harry Hess, Dec. 18, 1968.
48. See, e.g., Brown to Naugle, Dec. 23, 1968. Similar sentiments are contained in many letters and reports, copies of which are in the Biosatellite files, NASA HO.
49. See testimony in *Future of Bioscience Program.* See also letters from Brown to Naugle, Dec. 23, 1968 and Brown to Newell, June 19, 1968.
50. See Karth's introductory comments in *Future of Bioscience Program,* pp. 1-2.
51. PSAC, *Biomedical Foundations of Manned Space Flight,* report of the Biomedical Working Group (Washington: Executive Office of the President, Nov. 1969), pp. 3-4.
52. Ibid., pp. 3, 20-25.
53. *Future of Bioscience Program,* p. 2.
54. Ibid.
55. See Adey's testimony in *Bioscience Hearings,* pp. 71-101, especially pp. 84-87. See also testimonies of Nello Pace, J. P. Meehan, Lamont C. Cole, Loren Carlson, and Donald W. Farner.
56. Refer to testimony of Adey and Pace.
57. Humphreys, testimony in *Bioscience Hearings,* pp. 132-34; Humphreys interview.
58. Humphreys and Charles. A. Berry, testimonies in *Bioscience Hearings,* pp. 148-51. In this, they were reaffirming a position originally articulated by Brainerd Holmes in a memo to Seamans, "OMSF Position on Animal-Biological Experiments in Space," Nov. 22, 1962.
59. These sentiments were implicit rather than explicit in the bioscience hearings. These views were expressed in many memos, letters, and reports issued between Dec. 1967 and Dec. 1969, many of which have been cited.
60. "Recommendations of the Committee," in *Future of Bioscience Program,* p. 39.
61. Karth to George Low, Feb. 2, 1960; Low to Karth, Jan. 28, 1970.
62. Senator Clinton B. Anderson to Thomas Paine, Nov. 14, 1969; Paine to Anderson, Jan. 8, 1970. Inquiries were also made by Congressmen Olin Teague and Overton Brooks.
63. This assessment is shared by Newell, Naugle, Reynolds, and Humphreys, as expressed in their interviews.

## CHAPTER 10

1. Testimony of George Low in House of Representatives, *1962 NASA Authorization,* Hearings before the Committee on Science and Astronautics, 87/1, Mar. 13-23, and Apr. 10-17, 1961, pt. 1, p. 344.
2. NAS-NRC, *Space Research: Directions for the Future,* report of a summer study by the Space Science Board, 3 vols. (Washington: NAS-NRC, 1965), vol. 3, and *A Review of*

*Space Research,* report of a summer study by the Space Science Board (Washington: NAS-NRC, 1962).

3. The evolution of NASA's plans for post-Apollo space programs is documented in the Manned Space Flight and Skylab files, NASA HO. Orbital laboratories and space stations had been viewed as logical objectives of manned flight programs since the mid-1950s in both the military services and NACA. Early studies include Emmanual Schnitzer (a Langley Research Center engineer), "Erectable Torus Manned Space Laboratory," 1960, and "A Report on the Research and Technological Problems of Manned Rotating Spacecraft," prepared by the staff of Langley Research Center and published as NASA Tech. Note D-1504, Aug. 1962. Among the earliest reports to propose a manned space station as the post-Apollo objective was "The Needs and Requirements for a Manned Space Station," prepared by the Space Station Requirements Steering Committee, Nov. 15, 1966.
4. For documentation see Manned Space Flight files, NASA HO. Particularly useful documents include *FY 1967 Advanced Mission Study Program Proposed by Program Offices,* published by NASA Office of Programs and Special Reports, Aug. 3, 1966; Marshall Space Flight Center, "Requirements for a Manned Space Station," Nov. 4, 1966; Manned Spacecraft Center (MSC), "Preliminary Technical Data for an Earth Orbiting Space Station," Nov. 7, 1966.
5. See, e.g., "Post-Apollo Earth Orbital Manned Space Flight Program Options to the Post-Apollo Advisory Group," prepared by the MSC staff, Feb. 15, 1968; "Earth Orbital Manned Space Flight," prepared for NASA Planning Steering Group, Mar. 21. 1969.
6. Office of Manned Space Flight, Advanced Missions Office, "Status Report on Integrated Manned Space Flight Program," undated; "Advanced Study—Five Year Program," Sept. 9, 1969.
7. "Status Report on Integrated Manned Space Flight Program," pp. 1–14; "Apollo Lunar Exploration Program," prepared for Apollo Lunar Explorations Office by MSC management, Sept. 9, 1969; "Position Paper on Manned Planetary Missions," prepared by the Manned Planetary Working Group of the Planetary Exploration Planning Panel, undated.
8. Charles A. Berry, "Perspectives on Apollo," in R. S. Johnston, et al., *Biomedical Results of Apollo,* NASA SP-368 (Washington, 1975), p. 591.
9. Ibid., pp. 591–92.
10. L. F. Dietlein, "Summary and Conclusions," and W. R. Hawkins and J. F. Zieglschmid, "Clinical Aspects of Crew Health," in *Biomedical Results of Apollo,* p. 579 and pp. 43–82, respectively.
11. Berry, "Perspectives on Apollo," p. 585.
12. Ibid.
13. Ibid., pp. 588–89; Hawkins and Zieglschmid, "Clinical Aspects of Crew Health," pp. 52–53; Bennie C. Wooley and Gary W. McCollum, "Flight Crew Health Stabilization Program," in *Biomedical Results of Apollo,* pp. 141–49.
14. J. L. Homick and E. F. Miller, II, "Apollo Flight Crew Vestibular Assessment," Dietlein, "Summary and Conclusions," and Berry, "Perspectives," in *Biomedical Results of Apollo*, pp. 329–31.
15. Berry, "Perspectives," p. 586.
16. Homick and Miller, "Apollo Flight Crew Vestibular Assessment," pp. 330–31, 339.
17. Ibid., pp. 332, 338–39.
18. Dietlein, "Summary and Conclusions," p. 576.
19. Ibid., p. 577; Berry, "Perspectives on Apollo," pp. 587–88; G. W. Hoffler and R. L. Johnson, "Apollo Flight Crew Cardiovascular Evaluations," in *Biomedical Results of Apollo,* pp. 262–63.

20. Horst Bucker, "Biostack—A Study of Biological Effects of HZE Galactic Cosmic Radiation," and Webb Haymaker, et al., "The Apollo 17 Pocket Mouse Experiment (BIOCORE)," *Biomedical Results of Apollo,* pp. 343-54 and 381-403, respectively.
21. G. R. Taylor, "The Apollo 16 Microbial Response to Space Environment Experiment," in *Biomedical Results of Apollo,* pp. 367-79.
22. W. Z. Osborne, et al., "Apollo Light Flash Investigations," in *Biomedical Results of Apollo,* pp. 355-65.
23. These changes are revealed in several articles and in "Life Sciences," in House, *1972 NASA Authorization,* Hearings before the Committee on Science and Astronautics, 92/1, Mar. 4 and Apr. 2-5, 1971, pt. 1, pp. 101-17.
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25. "Medicine and Physiology" and "Role of Man in Space," in *Space Research: Directions for the Future,* vol. 3, pp. 162-68.
26. Berry, "Introduction," p. 2, "A Biomedical Program for Extended Space Missions," prepared by the staff of the MSC Directorate of Medical Research and Operations, May 1969 (pages not numbered sequentially).
27. Ibid., p. 1.
28. "General Concepts," in "Biomedical Program for Extended Space Missions," pp. 1-2.
29. Ibid., pp. 3-5.
30. Ibid., p. 5; "Overall Positions and Objectives," in "Biomedical Program for Extended Space Missions," p. 1, ibid.
31. "Overall Positions and Objectives," pp. 1-8.
32. "Table of Contents" in *Biomedical Program*; see also "Status Report on Integrated Manned Space Flight Program."
33. "Integrated Medical and Behavioral Laboratory Measurements System," in *Biomedical Program,* pp. 1-3; see also Sherman Vinograd, "Medical/Behavioral Experiments Program," paper presented to the NAS, Sept. 11, 1969; Vinograd interview; N. Belasco and Sam L. Pool, "The NASA Program for an Integrated Medical and Behavioral Laboratory Measurements System," 1970; IMBLMS files, JSC history archives.
34. Vinograd, "Medical/Behavioral Experiments Program," pp. 10-11.
35. "Life Sciences," *1972 NASA Authorization,* pp. 101-102.
36. Ibid., pp. 102-03, 106.
37. Ibid., p. 103; "Human Factors Systems," House, *1971 NASA Authorization,* Hearings before Committee on Science and Astronautics, 91/2, Feb. 17-26, 1970, pt. III, p. 1404.
38. "Human Factors System," *1971 NASA Authorization,* p. 1404.
39. Interview, Walton Jones, 1979.
40. "Human Factors Systems," *1971 NASA Authorization,* p. 1404.
41. "Life Sciences," *1972 NASA Authorization,* pp. 108-09.
42. "Human Factors Systems," *1971 NASA Authorization,* pp. 1392-93.
43. Ibid.; McDonnell Douglas Astronautics Corp., "Test Results of Operational Ninety Day Manned Test of A Regenerative Life Support System," prepared for Langley Research Center under contract NAS1-8997 and published as NASA CR-111881, May 1971, pp. 1-4. The earliest study of this type of system identified during this historical analysis is Ames Research Center, *The Closed Life-Support System,* NASA SP-134 (Washington, 1967). See also J. F. Foster, ed., "Waste Management for Manned Space Operations," papers presented at a workshop sponsored by the Office of Manned Space Flight, Oct. 29-30, 1968.
44. McDonnell Douglas, "Test Results of Operational Ninety Day Manned Test of A Regenerative Life Support System," 501-02, 521-23, 631-32.
45. For a subsequent assessment, see Noel C. Willis, Jr., and John M. Neel, "The Space

Station Prototype Program: The Development of a Regenerative Life Support System for Extended-Duration Missions," MSC Tech. Document MSC-07290, Oct. 1972.

46. "AAP-Biomedical Experiments," *1971 NASA Authorization,* pp. 1302–07.
47. Ibid.

## CHAPTER 11

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2. Ibid.
3. Ibid.; Naugle interview.
4. Naugle interview.
5. Reynolds's arguments are detailed in Chap. 5
6. Naugle interview.
7. Humphreys's and Jones's views are discussed in detail in Chap. 9.
8. Documents related to the agency's decision to develop the Space Shuttle are in the Space Shuttle files, NASA HO, and in Senate and House reports of hearings on NASA authorizations for FY 1972, 1973, and 1974.
9. "Summary and Major Recommendations," Study Committee to Review NASA Life Science Programs, Sept. 1970; Milton W. Rosen to Newell, "Status Report on NASA Response to the National Academy of Sciences Study," Nov. 12, 1970.
10. George Low (Acting Administrator) to program office associate administrators, "Establishment of a NASA Director of Life Sciences in the Office of Manned Space Flight," Dec. 3, 1970.
11. Low, memo to program office associate administrators, "Biomedical and Bioscience Programs in NASA," July 20, 1970.
12. Newell to Low, "Organizational Alternatives," Nov. 9, 1970. For a dissenting view see Harold Klein, letter to Newell, Aug. 31, 1970.
13. Naugle interview; Newell interview.
14. Reynolds interview, Oct. 1979; Naugle interview.
15. NASA Management Issuance 1138.14, "Duties and Responsibilities of the Director of Life Sciences," May 28, 1971.
16. Ibid.
17. Shields Warren, chairman, Life Science Committee, to Newell, July 27, 1972; William Barry, "The Life Sciences Program of NASA," report for the Administrator, Feb. 1, 1974, pp. 2–3.
18. "Review of the Integrated Life Sciences Program," Feb. 12, 1973, contained in Administrator Fletcher's Correspondence and Files, NASA HO.
19. Warren to Newell, July 27, 1972 and Nov. 28, 1972; Barry, "Life Sciences Program of NASA," p. 3.
20. Barry, "Life Sciences Program of NASA," pp. 6–7.
21. Information derived from biographical files, NASA and JSC history archives.
22. Warren to Newell, July 27, 1972; Barry, "Life Sciences Program of NASA," p. 5.
23. Newell, memo to Low, Nov. 9, 1970.
24. Barry, "Life Sciences Program of NASA," p. 5. These comments should not be taken as a criticism of the performance of JSC Life Sciences Director Richard S. Johnston, whose many important contributions to the space program in various capacities during his 20 years with the agency are beyond question. Rather, Barry was questioning the wisdom of placing responsibility for biomedical research in the hands of one who was not a life scientist.

25. George Low to Administrator Fletcher, "NASA's Biomedical Activities," Nov. 2, 1972.
26. Barry, "Life Sciences Program of NASA," p. 1.
27. Ibid., p. 5.
28. Ibid.
29. Ibid., pp. 16–17.
30. Ibid., pp. 7–8.
31. Ibid.
32. Ibid., pp. 13–14.
33. Ibid.
34. Ibid., pp. 18–19.
35. Ibid., pp. 20–21.
36. Ibid., pp. 22–23.
37. For example, Warren to Newell, July 27, 1972 and Nov. 28, 1972.
38. For example, Low to Fletcher, "NASA's Biomedical Activities," Nov. 2, 1972.
39. Winter and Humphreys interviews.
40. "NASA Realigns Two Major Program Offices," NASA news release, Sept. 23, 1975.
41. Ibid.

## CHAPTER 12

1. R. S. Johnston, "Skylab Medical Program Overview," and L. F. Dietlein, "Skylab: A Beginning," in R. S. Johnston and L. F. Dietlein, *Biomedical Results from Skylab,* NASA SP-377 (Washington, 1977), pp. 4, 408.
2. These matters are detailed in the essays in Johnston and Dietlein, *Biomedical Results from Skylab.* Medical findings from Skylab are also discussed in W. David Compton and Charles D. Benson, *Living and Working in Space: A History of Skylab,* NASA SP-4208 (Washington: 1983), pp. 339–341.
3. J. K. Ferguson, et al., "Analysis of the Skylab Flight Crew Health Stabilization Program," in Johnston and Dietlein, *Biomedical Results from Skylab,* p. 45.
4. Ibid.
5. G. R. Taylor, et al., "Skylab Environmental and Crew Microbiology Studies," ibid., pp. 53–63.
6. Ashton Graybiel and others, "Experiment M131: Human Vestibular Function," and J. L. Homick, et al., "The Effects of Prolonged Weightlessness on Postural Equilibrium," ibid., pp. 74–113.
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8. G. D. Whedon, et al., "Mineral and Nitrogen Metabolic Studies, Experiment M071," in Johnston and Dietlein, *Biomedical Results from Skylab,* pp. 164, 166, 174.
9. W. E. Thornton, "Physiological Mass Measurements in Skylab," M. C. Smith, et al., "Bone Mineral Measurement—Experiment M078," W. E. Thornton, "Muscular Deconditioning and Its Prevention in Space Flight," in Johnston and Dietlein, *Biomedical Results from Skylab,* pp. 175–98.
10. Dietlein, "Skylab: A Beginning," p. 414.
11. C. S. Leach and P. C. Rambault, "Biochemical Responses of the Skylab Crewmen," and P. C. Johnson, et al., "Blood Volume Changes," ibid., pp. 204–15, 235–41.
12. Dietlein, ibid., p. 414.
13. C. E. Mengel, "Red Cell Metabolism Studies on Skylab," and S. L. Kimzey, "Hematology and Immunology Studies," ibid., pp. 242–82.
14. Dietlein, ibid., pp. 414–15.

15. R. L. Johnson, et al., "Lower Body Negative Pressure," G. W. Hoffler, et al., "Experimental M092: Lower Body Negative Pressure," W. E. Thornton, "Hemodynamic Studies of the Legs under Weightlessness," R. F. Smith, et al., "Vectorcardiographic Changes during Extended Space Flight (M093)," S. A. Bergman, et al., "Evaluation of the Electromechanical Properties of the Cardiovascular System after Prolonged Weightlessness," in Johnston and Dietlein, *Biomedical Results from Skylab,* pp. 284–366.
16. Dietlein, "Skylab: A Beginning," pp. 412–13.
17. L. E. Day, "The Space Shuttle: A New Approach to Space Transportation," paper presented at the 21st International Conference on Aeronautics, Oct. 9, 1970, p. 1. Copy in Shuttle documentation files, NASA HO.
18. Ibid., pp. 9–13; House Committee on Science and Astronautics, *Space Shuttle-Skylab,* status report for Subcommittee on NASA Oversight, 92/2, Jan. 2, 1972; Senate, *Space Shuttle Payloads,* Hearings before Committee on Aeronautical and Space Sciences, 93/1, Oct. 30–31, 1973; House, *Space Shuttle-Space Tug,* status report for Committee on Science and Astronautics, 93/2, Feb. 1974.
19. Space Science Board, *Scientific Uses of the Space Shuttle* (Washington: NAS, 1974), p. 154.
20. Ibid., pp. 154–55; "Final Report of the Space Shuttle Payload Planning Working Groups—Life Sciences," May 1973, pp. xi–xii.
21. Harold Sandler and David L. Winter, *Physiological Responses of Women to Simulated Weightlessness,* NASA SP-430 (Washington, 1978), pp. 1–2, 40–48; Winter interview.
22. "Final Report . . . Working Groups—Life Sciences," pp. C-1 to C-5.
23. Ibid., pp. A-1 to A-19, B-1 to B-3.
24. Ibid., p. xi and appendixes A, B, C, and D.
25. "Final Report . . . Working Groups—Life Sciences," p. xi; "Space Opportunities, 1973–1991: The NASA Payload Model," Oct. 1973, pp. 36–38. Copy in Shuttle documentation files, NASA HO.
26. Biography files, NASA HO; Winter interview; William Barry, "The Life Sciences Program of NASA," a report for the Administrator, Feb. 1, 1974.
27. The character of the office is described in Barry, "The Life Sciences Program of NASA."
28. At the time of his appointment, Noel Hinners was the space sciences program office administrator and John Naugle was the office's chief scientist. The sentiments mentioned in the text were expressed by Naugle and Newell in their respective interviews.
29. Winter interview.
30. Naugle interview.
31. This is the author's interpretation based on his background understanding of the two traditions. The view is implied in interviews with Reynolds, Naugle, and Winter.
32. Naugle and Soffen interviews.
33. Biography files, NASA HO and JSC history archives. The author's interpretation of the significance of backgrounds is supported by findings in Barry, "The Life Sciences in NASA." See also Soffen interview.
34. Winter interview.
35. Ibid., "Press Briefing with David Winter," Feb. 21, 1965, a transcript of which is in the Biography files, NASA HO.
36. Naugle interview.
37. "Future Directions for the Life Sciences in NASA," draft of a report prepared by Life Sciences Advisory Committee, Aug. 1978.
38. Naugle and Soffen interviews.
39. Biography files, NASA HO; Soffen interview.
40. Soffen interview.

# Appendix A

## SELECTED BIOMEDICAL TERMS OF AEROSPACE INTEREST

ABORT—an unscheduled interruption of a launch or a flight, enabling the safe release of an astronaut.

ABSOLUTE HUMIDITY—the amount of water vapor present in a unit quantity of a gas, generally expressed as a mass of water vapor per unit volume of gas plus water vapor, e.g., as grains per cubic foot.

ACCELERATION—the rate of change of velocity, expressed in feet (or centimeters) per second. See also PHYSIOLOGICAL ACCELERATION.

ACCEPTOR—changes produced by the organism's own behavior.

ACCLIMATIZATION—the habituation of an organism to a changed or different environmental condition.

ACOUSTICS—the science of sounds. The term includes propagation and conduction of all kinds of material vibration, their generation, perception, measurement, reproduction, and control. See also SOUND.

ACCUMSTOMIZATION—the process of learning the techniques of living with a minimum of discomfort in an extreme or new environment. See also ACCLIMATIZATION and ADAPTATION.

ADAPTATION—the response and adjustment of an organism to its total environment, or the process by which it becomes fit. See also ACCUMSTOMIZATION.

AEROEMBOLISM—the formation or liberation of gases in the blood vessels of the body brought on by a too rapid change from a high, or relatively high, atmospheric pressure to a lower one. See COMPRESSED AIR ILLNESS.

AERO-OTITIS MEDIA—an inflammatory reaction of the middle ear, resulting from a difference in pressure between the gas in the middle ear and the surrounding atmosphere. Also called otitic barotrauma. See also OTITIS MEDIA.

AEROSINUSITIS—an inflammatory reaction of one or more of the accessory nasal sinuses, resulting from a difference in pressure between the gas in the sinus and the surrounding atmosphere. Also called sinus barotrauma.

AEROSPACE MEDICINE—a speciality of medicine dealing with the treatment or prevention of unfavorable psycho-physiological functioning, resulting from flight or its related conditions.

AIR CONDITIONING—the process of cooling, cleaning, humidifying, or dehumidifying air in a room, hall, building, etc.

AIR SICKNESS—a condition of sickness frequently resulting from flight or acceleration. See MOTION SICKNESS.

ALTITUDE SICKNESS—in general, any sickness brought on by exposure to reduced oxygen tension resulting from reduction of barometric pressure.
ALVEOLAR OXYGEN PRESSURE—the oxygen pressure in the alveoli. The value is about 105 millimeters of mercury.
ALVEOLI—terminal air sacs deep within the lungs.
ANOXEMIA—See HYPOXEMIA.
ANOXIA—condition resulting from lack of sufficient oxygen for normal metabolic functions.
ANTHROPOMETRY—science of measurement of the human body itself, its parts and their relationships.
ANTIBIOTICS—chemical substances produced by microorganisms that alter the normal processes of other forms of life; may exhibit either cidal static or toxic effects.
ANTI-G SUIT—See G SUIT.
ASTRONAUT—person who rides in a space vehicle; test pilot or scientist. See COSMONAUT.
ASTRONAUTICS—the art, skill, or activity of operating spacecraft; in a broader sense, the science of spaceflight.
ATMOSPHERE—envelope of air surrounding the Earth; also the body of gases surrounding or comprising any planet or other celestial body (compare biosphere, geosphere, hydrosphere, lithosphere).
BAILOUT BOTTLE—personal supply of oxygen usually contained in a cylinder under pressure, utilized when the individual has left the central oxygen system, as in a parachute jump.
BAROTRAUMA—injury of a part or organ as a result of changes in barometric pressure (used as otitic barotrauma). See AERO-OTITIS MEDIA and AEROSINUSITIS.
BEHAVIOR—the way in which an organism, organ, body, or substance acts in an environment or responds to excitation, as the behavior of steel under stress, or the behavior of an animal in a test.
BENDS—popular term for COMPRESSED AIR ILLNESS.
BIOASTRONAUTICS—study of biological, behavioral, and medical problems pertaining to astronautics. This includes systems functioning in the environments expected to be found in space, vehicles designed to travel in space, and the conditions on celestial bodies other than Earth.
BIOCHEMISTRY—chemistry dealing with the chemical processes and compounds of living organisms.
BIODYNAMICS—study of the effects of dynamic processes (motion, acceleration, weightlessness, etc.) on organisms.
BIOENGINEERING—the art or science of designing the function or behavior of building, or equipping mechanical devices or artificial environments to the anthropometric, physiological, or psychological requirements of the organisms that will use them. The application of engineering techniques to biological problems.
BIOINSTRUMENTATION—use of instruments for the purpose of detecting, measuring, recording, telemetering, processing, or analyzing different biological values or quantities as encountered in spaceflight.
BIOLOGICAL RHYTHM—change in a variable biological process as influenced by environmental conditions. See also CIRCADIAN RHYTHM and DIURNAL RHYTHM.
BIOLOGY—the science of life and the living.
BIOMETRY—the application of mathematical and statistical principles to the biological sciences.
BIONICS—the study of systems, particularly electronic systems, which function after the manner of, or in a manner characteristic of, or resembling, living systems.

BIOPAK—container for housing a living organism in a habitable environment and for recording biological functions during spaceflight.

BIOPHYSICS—the physics of vital processes.

BIOSATELLITE—an artificial satellite specifically designed to contain and support humans, animals, or other living material in a reasonably normal manner for an adequate period of time and which, particularly for humans and animals, possesses the proper means for safe return to the Earth. See ECOLOGICAL SYSTEM.

BIOSENSOR—a sensor comprising a living system used to provide information about interaction of physical conditions and biological response in a particular environment.

BIOSPHERE—transition zone between Earth and the atmosphere within which most forms of terrestrial life are commonly found; the outer portion of the geosphere, the inner or lower portion of the atmosphere, and the hydrosphere.

BIOTELEMETRY—the remote measuring and evaluation of life functions, as in spacecraft and artificial satellites.

BIOTRON—test chamber used for biological research within which the environmental conditions can be completely controlled, thus allowing observations of the effect of variations in environment on living organisms or providing particular environments whenever needed.

BRADYCARDIA—abnormal slowness of the heartbeat.

CARDIOVASCULAR—pertaining to the heart and blood vessels.

CHEMICAL STERILIZATION—complete destruction of microorganisms by chemical substances.

CHLOROPLAST—a plastid containing chlorophyll, with or without other pigments, embedded singly or in considerable numbers in the cytoplasm of a plant cell.

CHOKES—pain and irritation in chest and difficulty in breathing, due to release of gas bubbles in the pulmonary circulation as a result of reduced ambient pressure.

CHROMOSOMES—basophilic granules consisting of deoxyribonucleic acid containing the hereditary factors. They are usually constant in number for a biological species. The chromatin of the cell nucleus resolves into the chromosome prior to mitotic division of the cell.

CIRCADIAN RHYTHM—a regular change in physiological function occurring in approximately 24-hour cycles, or other well-defined time intervals.

CLEAN ROOM—an area where viable and nonviable particles are controlled according to established standards.

CLOSED ECOLOGICAL SYSTEM—system that provides for the maintenance of life in an isolated living chamber through complete reutilization of the material available, in particular, by means of a cycle wherein exhaled carbon dioxide, urine, and other waste matter are converted chemically or by photosynthesis into oxygen, water, and food.

CLOSED RESPIRATORY GAS SYSTEM—completely self-contained system within a sealed cabin, capsule, or spacecraft that will provide adequate oxygen for breathing, maintain adequate cabin pressure, and absorb the exhaled carbon dioxide and water vapor.

COMPONENTS—an integral part of a complete unit that is essential to perform a particular function required of the unit.

COMPRESSED AIR ILLNESS—a disease or condition characterized principally by neuralgic pains, cramps, and swelling, and which includes collapse and sometimes results in death. This condition is caused by the formation of the gas bubbles (mostly nitrogen) in the body fluids, the tissues, and in the circulating blood. It is the result of lowered gas tension associated with the relatively rapid reduction of ambient pressure, i.e., a too rapid change from a high or relatively high atmospheric pressure to a lower one.

CONDITIONED REFLEX—a reflex not normally present that has been developed by regular association of some physiological function with an unrelated outside event or stimulus.

CONTAMINANT—a viable or nonviable particle, the presence of which may or may not interfere with the results of a planned experimental program.

CONTROL—to regulate, check, or keep within limits.

COORDINATION—to bring into a common action, movement, or condition; to act together in a smooth, concerted way.

CORIOLIS EFFECTS—physiological effects (nausea, vertigo, dizziness, etc.) felt by a person moving radially in a rotating system, as a rotating space station.

CORIOLIS FORCE—a deflecting force acting on a body in motion (as an airplane or projectile) due to the Earth's rotation. Any object moving above the Earth with constant space velocity is deflected relative to the surface of the rotating Earth. Deflection is to the right in the northern hemisphere and to the left in the southern hemisphere.

COSMIC RADIATION—highly penetrating radiation from extraterrestrial sources reaching the entire surface of the Earth. The hard (primary) component consists of high-energy particles, mainly mesons, a small number of protons, and a few nuclei of heavier atoms like carbon, nitrogen, oxygen, and iron. The soft (secondary) component, largely formed as the result of interaction with the atmosphere, is made up of about equal proportions of positrons, negative electrons (negatrons), and photons with energy less than 200 MeV.

CREPUSCULAR—pertaining to twilight as opposed to day or night. Animals, birds, and insects that are active at dawn or dusk are said to be crepuscular.

CULTURE—the propagation of microorganisms or of living tissue cells in special media conducive to their growth; the process by which microorganisms are grown as a means of isolation and identification; or the growth of microorganisms.

CYBERNETICS—comparative study of the automatic control system formed by the nervous system and brain, and by mechanical-electrical communication systems; the science of control mechanisms and of the transmission and processing of information that they entail; mathematical modeling, biostatistics, biophysics, computer simulation of physiological processes and computerization of data reduction; man-machine interrelationships. See also MAN-MACHINE INTEGRATION.

DECELERATION—rate of diminution in the speed of a vehicle or moving part; measured in feet per second per second.

DECOMPRESSION—systematic reduction of atmospheric pressure; particularly, various techniques for preventing CAISSON DISEASE or the CHOKES.

DECONTAMINATION—process of removing chemical, biological, or radiobiological contamination from, or neutralizing it on, a person, item, or area.

DEHYDRATION—removal of water from the body or a tissue; or the condition which results from undue loss of water.

DEMAND OXYGEN SYSTEM—see DEMAND SYSTEM.

DEMAND SYSTEM—an oxygen system in which oxygen flows to the user during inspiration only.

DENITROGENATION—removal of nitrogen dissolved in the blood and body tissues, usually by breathing pure oxygen for an extended period of time, in order to prevent aeroembolism at high altitudes.

DESICCATION—dehydration; the removal of water.

DIASTOLIC BLOOD PRESSURE—pressure exerted by the blood during periods between cardiac contraction.

DISORIENTATION—loss of proper bearings or a state of mental confusion, especially as to time, place, or identity.

DIURESIS—increased secretion of urine.

DIURNAL—related to daytime. Animals active mainly during daylight hours are said to be diurnal; the opposite of nocturnal.

DIRUNAL RHYTHM—regular change in physiological function occurring in approximately 24-hour cycles.

DOSE—also referred to as dosage. The accumulated or total quantity of radiation. According to current usage, the radiation delivered to a specific area of the body or to the whole body. Units used in specifying the dose are roentgens for x rays or gamma rays, and reps or rems for beta rays.

DOSIMETRY—accurate and systematic determination of the amount given up by ionizing radiation in tissues and other substances. See also PERMISSIBLE DOSE and DOSE.

DRUG—substance used as a medicine.

DRYHEAT STERILIZATION—destruction of all living forms through use of high temperature applied in the absence of appreciable moisture.

DYNAMIC STEREOTYPE—system of conditioned reflexes reinforced numerous times in the same sequence or combination so that they come to be performed smoothly.

DYSBARISM—pathological condition of the body resulting from the existence of a pressure differential between the total ambient pressure and the total pressure of dissolved and free gases within the body tissues, fluids, and cavities. See also COMPRESSED AIR ILLNESS.

DYSPNEA—difficult or labored breathing.

EBULLISM—formation of bubbles, with particular reference to water vapor bubbles in biological fluids caused by reduction of ambient pressure; the boiling of body fluids.

ECOLOGY—study of the environmental relation and interaction of organisms, both flora and fauna.

ENDOGENOUS RHYTHM—rhythm generated from within the animal (i.e., an internally driven rhythm).

ENERGY BALANCE—conserved quantity involving the maximum amount of work that a system does in coming to a state of equilibrium.

ENVIRONMENT—external condition, or the sum of such conditions, in which a piece of equipment, a living organism, or a system operates.

ENZYME—an organic compound, frequently a protein, capable of accelerating or producing by catalytic action some change in its substrate for which it is often specific.

ESCAPE—safe ejection of an astronaut.

EXPIRATORY RESERVE—volume of air that can be expelled from the lungs after a normal expiration.

EXPOSURE SUIT—suit designed to protect a person from harmful effects of extreme environment, such as cold or heat.

EXTRAPOLATION REFLEXES—perception of a changing situation whereby an organism is able to foresee further development of an ongoing process and behave accordingly.

EXTRATERRESTRIAL LIFE—life forms evolved and existing outside the terrestrial biosphere.

EXTRAVEHICULAR ACTIVITY (EVA)—activity of an astronaut in space outside the space vehicle.

EXOBIOLOGY—branch of biology that deals with the search for life beyond the regions of the Earth.

FATIGUE—a state of increased discomfort and decreased efficiency resulting from prolonged or excessive exertion, with resulting loss of powers or capacity to respond to stimulation.

FEEL—the sensation or impression that a pilot has or receives as to his or the aircraft's altitude, orientation, speed, direction of movement, or acceleration, or proximity to nearby objects, or, as most often used, as to the aircraft's stability and responsiveness to control.

FILTER—a medium such as spun glass, paper, or wire mesh used to remove matter from a volume of air or liquid.

FIRST SIGNAL SYSTEM—system of conditioned reflexes to nonlanguage stimuli; includes both somatic and visceral reflexes; is common to animals and man; in man it is very intimately related to the second signal system.

FLOTATION GEAR—gear or apparatus, such as commonly inflatable bags, vests, and rafts, carried aboard a vehicle to support the vehicle or persons downed in water.

FRUSTRATION THRESHOLD—level of emotional trauma at which an individual feels or shows frustration over inability to achieve an objective.

FULL PRESSURE SUIT—suit which completely encloses the body and in which a gas pressure sufficiently above ambient pressure for maintenance of normal function may be sustained.

FUNCTIONAL RESERVES—ability of the body to accomplish additional muscular or other activity and useful work beyond the normal level of activity of an individual.

GAMMA RAY—a quantum of electromagnetic radiation emitted by a radioactive nucleus, each such photon being emitted as a result of a quantum transition between two energy levels of the nucleus.

GAS EXCHANGER—biological system used to provide oxygen and remove carbon dioxide as a means of life support during spaceflight.

G-FORCE—inertial force usually expressed in mutiples of Earth gravity.

GNOTOBIOTICS—aspect of biology concerned with animals whose microbial populations are totally known and rigidly controlled.

GRAVIRECEPTORS—highly specialized nerve endings and receptor organs located in skeletal muscles, tendons, joints, and the inner ear, which furnish information to the brain about body position, equilibrium, and the direction of gravitational forces.

GRAVITATIONAL BIOLOGY—study of the force of gravitation and its effect on life forms.

GRAVITY—a property of matter which gives rise to an attractive force between masses. See SUBGRAVITY.

G-SUIT—suit that exerts pressure on the abdomen and lower parts of the body to prevent or retard the collection of blood below the chest under positive acceleration. See PRESSURIZED SUIT.

G-TOLERANCE—a limiting value in a person or other animal, or in a piece of equipment, to an acceleration.

HEAT TOLERANCE—a limit to withstand higher than normal temperatures without loss of efficiency or impairment of function.

HIGHER NERVOUS ACTIVITY—activity of the cortex and higher parts of the subcortex, i.e., activity which maintains the complex relations of the whole organism to the external world; may rightly be called (in place of the earlier term "psychological") higher nervous activity.

HIBERNATION—the dormant, torpid, resting, reduced metabolic state in which certain animals pass the winter.

HUMAN ENGINEERING—science of designing, building, or equipping mechanical devices or artificial environments to the anthropometric, physiological, or psychological requirements of the people who will use them.

HUMAN FACTOR—study of psychological and physiological variables that affect man's performance in an operational system.

HYDROSTATIC EQUILIBRIUM—state of a fluid whose surfaces of constant pressure and constant mass or density coincide and are homeostatic throughout.

HYPEROXIA—condition in which the total oxygen content of the body is increased above that normally existing at sea level.

HYPERVENTILATION—overbreathing; a respiratory-minute volume, or pulmonary ventilation, that is greater than normal.

HYPERVENTILATION SYNDROME—syndrome of blurring of vision, sensation, tingling of the extremities, faintness, and dizziness, which may progress to unconsciousness and convulsions, caused by reduction of the normal carbon dioxide tension of the human body, due to increased pulmonary ventilation.

HYPOBARIC—pertaining to low atmospheric pressure, particularly the low atmospheric pressure of high altitudes.

HYPOBARISM—disturbances resulting from a decrease of ambient pressure to less than that within the body fluids, tissues, and cavities.

HYPOCAPNIA—deficiency of carbon dioxide in the blood and body tissues, which may result in dizziness, confusion, and muscular cramps.

HYPODYNAMIA—diminished power; a reduction of normal or vital powers.

HYPOVENTILATION—a respiratory-minute volume or pulmonary ventilation that is less than normal.

HYPOXEMIA—condition or reduction of the normal oxygen tension in the blood.

HYPOXIA—deficiency of oxygen; any state wherein a physiologically inadequate amount of oxygen is available to, or utilized by, tissue without respect to cause or degree.

IMMOBILIZATION—usually considered to be physical or mechanical, but could be biochemical. See also RESTRAINT SYSTEM.

INSTABILITY—condition of a body if, when displaced from a state of equilibrium, it continues, or tends to continue, to depart from the original condition. Compare stability.

INTERMITTENT PRESSURE BREATHING—pressure breathing in which different pressures are used at different points in the respiratory cycle, usually with a high pressure during inspiration and lower pressure during expiration.

INTEROCEPTIVE-EXTEROCEPTIVE AFFERENTATION—refers to neural impulses reaching the cortex from the sensory receptors of internal organs (interoceptive) or from the external environment (exteroceptive).

IONIZATION—process by which neutral atoms or groups of atoms become electrically charged, either positively or negatively, by the loss or gain of electrons; or the state of a substance whose atoms or groups of atoms have become thus charged.

IONIZING RADIATIONS—any particulate or electromagnetic radiation capable of producing ions, directly or indirectly, in its passage through matter. Alpha and beta particles produce ion pairs directly, while gamma rays and x-rays liberate electrons as they traverse matter, which in turn produce ionization in their paths.

IRRADIATION—exposure to radiation. One speaks of radiation therapy, but of irradiation of the patient. The exposure of material to x-ray, gamma-ray, or slow neutron radiation. The exposure of material in a nuclear reactor. Bombardment of material with particle radiation.

ISOLATION—use of culture medium or other appropriate environmental conditions for the purpose of further study. In medicine, to separate from other persons, materials, or objects.

LABYRINTHINE—referring to the labyrinth of the inner ear, which acts as an acceleration sensor.

LAG—delay between change of conditions and the indication of the change on an instrument. Delay in human reaction. The amount one cyclic motion is behind another, expressed in degrees. The opposite is "lead."

LAP BELT—safety belt that fastens across the lap. This is the usual kind of safety belt. Also called a seat belt.

LEANS—illusion of a craft being tilted, with corresponding leaning of the crew in the opposite direction, caused by a false labyrinthine reaction uncorrected by visual cues.

LENS—medium-crystalline lens of the eye.

LIFE SCIENCES—field of scientific disciplines encompassing biology, physiology, psychology, medicine, sociology, and other related areas.

LIFE SUPPORT SYSTEM—system of instrumentation used in a spacecraft to facilitate the maintenance of normal life processes in living organisms. See also NITROGEN CYCLE.

MAGNETIC FIELD—region in the neighborhood of a permanent magnet or a current-carrying conductor in which magnetic forces can be detected.

MAN-MACHINE SYSTEM—system in which the functions of the man and the machine are interrelated and necessary for the operation of the system.

MAN-MACHINE INTEGRATION—matching of the characteristics and capabilities of man and machine to obtain optimum conditions and maximum efficiency of the combined system.

MANNED—refers to a vehicle occupied by one or more persons who normally have control over the movements of the vehicle, as in a manned aircraft or spacecraft, or who perform some useful function while in the vehicle.

MECHANORECEPTOR—a nerve ending that reacts to mechanical stimuli, as touch, tension, and acceleration. See also SENSOR.

METABOLISM—sum of the physical and chemical processes by which living organized substances are produced and maintained; also, the transformation by which energy is made available for the uses of the organism.

MICROORGANISM—minute, living organism, usually microscopic. Those of medical interest are bacteria, spiral organisms, rickettsia, viruses, molds, and yeasts.

MOTILITY—ability to move spontaneously.

MOTION SICKNESS—syndrome of pallor, sweating, nausea, and/or vomiting, which is induced by unusual accelerations. See also AIR SICKNESS.

NITROGEN CYCLE—exchange of nitrogen between animals and plants, in which plants convert urea or nitrates to protein; animals digest protein and excrete its nitrogen content as urea, which is taken up again by plants. See LIFE SUPPORT SYSTEM.

NITROGEN DESATURATION—reduction of the nitrogen content of the tissues of the body by breathing gases not containing nitrogen (e.g., breathing a helium nitrogen mixture to eliminate nitrogen in the body).

NOCTURNAL—moving about at night, as nocturnal animals, birds, or insects. Occurring during nighttime hours, as opposed to diurnal.

NUTRITION—the sum of the processes by which an animal or plant concentrates and assimilates food substances.

NYCTOTHERMAL—pertaining to both day and night. It is used to describe rhythms (e.g., nyctothermal rhythms of man).

NYSTAGMUS—involuntary rapid movement of the eyeball, which may be horizontal, vertical, rotatory, or any combination of these, especially occurring as a result of eye fixations and stimulations of the inner ear during rotation of the body.

OPEN SYSTEM—system that provides for the body's metabolism in an aircraft or spacecraft cabin by removal of respiratory products and of waste from the cabin and by use of stored food and oxygen.

OPERATIVE TEMPERATURE—an equivalent or effective temperature parameter used in the study of human bioclimatology, one of several factors designed to measure the cooling effect of air on a human body under specific hypothetical conditions and apparel.

OPTICAL ACTIVITY—property possessed by many substances whereby plane-polarized light, in passing through them, undergoes a rotation of its plane of polarization, the angle of rotation being proportional to the thickness of the substance traversed by the light. See also POLARIMETRY.

ORIENTING-INVESTIGATORY REFLEX—response of an organism to any change in the environment.

ORTHOSTATIC TOLERANCE—ability to withstand immobilization in an erect position for a long period of time.

OTITIS—inflammation of the ear, which may be marked by pain, fever, abnormalities of hearing, deafness, tinnitus, and vertigo. See also OTITIS MEDIA.

OTITIS MEDIA—inflammation of the middle ear. See also OTITIS.

OTOLITH—dustlike substance made up of minute six-sided prisms of calcium otoconia carbonate arranged in a single layer in the gelatinous film which covers the maculae acustacae of the membranous labyrinth of the inner ear.

OXYGEN RECOVERY—the regaining of utilized oxygen from carbon dioxide and other metabolic compounds.

PARAFOVEAL VISION—vision in which the eye is so oriented toward the pertinent light source as to have the light fall on some portion of the retina surrounding the fovea. See also FOVEA.

PARTIAL PRESSURE SUIT—skintight suit which does not completely enclose the body, but which is capable of exerting pressure on the major portion of the body to counteract an increased oxygen pressure in the lungs. See also PRESSURE SUIT.

PATHOLOGY—branch of medicine concerned with the essential nature of disease, especially of the structural and functional changes in tissues and organs of the body which cause or are caused by disease.

PATHOMORPHOLOGY—perverted or abnormal morphology.

PATHOPHYSIOLOGY—physiology of disordered functions.

PAYLOAD—amount or character of the load carried by an aircraft, rocket, or spacecraft over and above that which is necessary for the operation of the vehicle for its flight.

PERMISSIBLE DOSE—dose of ionizing radiation which, in the light of present knowledge, is not expected to cause appreciable bodily injury to a person during his lifetime. See also DOSIMETRY and DOSE and RADIATION DOSE.

PHOTORECEPTOR—sensory organ that responds to the stimulus of light waves. The eye is the most familiar organ of this kind, but there are great varieties of visual systems among lower forms of living organisms. The skin is a photoreceptor, although its response is evident only in the degree of pigmentation.

PHYSIOLOGICAL ACCELERATION—acceleration experienced by a human or an animal test subject in an accelerating vehicle. See also ACCELERATION and PHYSIOLOGY.

PHYSIOLOGY—science concerned with functions of living organisms or their parts, as distinguished from morphology, anatomy, etc.

PLANETARY QUARANTINE—sterilization and decontamination studies directed to the prevention of contamination of planets by terrestrial organisms so that the search for extraterrestrial life may have validity.

POSITIVE ACCELERATION—acceleration such that speed increases; accelerating force in an upward sense or direction, e.g., from bottom to top, or seat to head; acceleration in the direction in which this force is applied. See also ACCELERATION.

POSTHYPOXIA PARADOX—abrupt convulsive incident that may occur when a marked oxygen deficiency is relieved by sufficient oxygen; this contrasts with the normal rapid recovery from lack of oxygen. See also HYPOXIA and HYPEROXIA and ANOXIA.

PRESSURIZED—containing air or other gas, at a pressure higher than ambient. See also PRESSURIZED SUIT.

PRESSURIZED SUIT—suit designed to provide pressure directly on the body so that respiratory, circulatory, and other functions may continue as near normally as possible, under low-pressure conditions occurring at high altitudes or in spaceflight without the use of a pressurized cabin. See also PRESSURIZED and G-SUIT.

PROPHYLACTIC—tending to ward off disease; a remedy that tends to ward off disease.

PROPHYLAXIS—prevention of disease; preventive treatment.

PSYCHOLOGY—science of the functions of the mind, such as sensation, perception, memory, and thought; and more broadly, the behavior of an organism in relation to its environment.

PSYCHOMOTOR ABILITY—of or pertaining to muscular action ensuing directly from a mental process, as in the coordinated manipulation of aircraft or spacecraft controls.

PSYCHONEURAL ACTIVITY—behavior of animals trained in what is termed an instrumental, place-learning situation.

PSYCHOPHYSICAL QUANTITY—a physical measurement, as a threshold, dependent on human attributes or perception.

PSYCHROPHILE—an organism whose optimum temperature for growth and reproduction is low (approximately 10–15°C for most cold-loving microorganisms).

RADIAL—general: issuing in rays, related to rays of light; medical: pertaining to the radius bone.

RADIATION—emission and propagation of energy through space or through a material medium in the form of waves (e.g., electromagnetic radiation, sound waves, and elastic waves). The term radiation, or radiant energy, usually refers to electromagnetic radiation, which is classified, according to frequency, as Hertzian or radio-frequency and microwave, infrared or heat, visible or light, ultraviolet, x-ray, and gamma ($\gamma$) ray. See also CHEMICAL, DRY HEAT, INDICATOR (STERILITY), and STERILIZATION.

RADIATION DOSE—amount of radiation absorbed by a material, system, or tissue in a given amount of time; usually measured in one of the commonly accepted units such as roentgen, roentgen-equivalent-man, or roentgen-equivalent-physical, etc. See also PERMISSIBLE DOSE and DOSE.

RADIATION SICKNESS (illness)—acute, self-limiting organic disorder following radiation and characterized by a group of signs and symptoms called the acute radiation syndrome, varying with the level or dose of whole-body irradiation received. Usual agents producing injury are gamma rays, x-rays, and fast and slow neutrons.

RADIOBIOLOGY—term used interchangeably with radiation biology; the science dealing with every step in the action of radiation on living matter, from the absorption of energy to injury and repair or death of the cell of the organism. Radiobiology has many facets: energy absorption; ionized and excited molecules; cell changes, biochemical lesions, sub-microscopial lesions, visible lesions, and cell death; early physiological response to radiation; acute somatic response to radiation; delayed somatic effects; and mutations leading to genetic damage.

RADIO FREQUENCY—an electromagnetic wave frequency intermediate between audio-frequencies and infrared frequencies, used in radio and TV transmission.

REFLEX—response; the organism's total response to a stimulus; responses are referred to as reflexes whether they are produced by classical conditioning or instrumental conditioning; involuntary reflexes versus voluntary reflexes.

RELIABILITY—suitable or fit to be relied on; trustworthy. Unlikely to break down or cause trouble.

REM—acronym for roentgen-equivalent-man.

RESPIRATION—act or function of breathing; the act by which air is drawn into and expelled from the lungs, including inspiration and expiration.

RESTRAINT SYSTEM—physical device used to limit mobility. See also IMMOBILIZATION.

RETINA—innermost tunic and perceptive structure of the eye, formed by the expansion of the optic nerve, and covering the back part of the eye.

REVERSE AFFERENTATION—feedback; the development of coordinated responses where afferent impulses from the muscles play a role in the regulation of the extent of muscular activity.

RHYTHM—movement marked by regular recurrence of or regular alternation in phenomena; hence, periodicity. There are many different types of rhythm, including daily rhythm, diurnal rhythm, circadian rhythm, endogenous rhythm, nocturnal rhythm, physiological rhythm, temperature rhythms, activity rhythm, and hormone-production rhythm.

SANITARY ENGINEERING—application of engineering principles to matters concerning health and the prevention of infection and disease.

SECOND SIGNAL SYSTEM—system of conditioned reflexes to verbal stimuli.

SELECTION—choosing for survival or elimination. Theory under which organisms tend to produce progeny far above the means of subsistence; a struggle for existence ensues which results in the survival of those with favorable variations. Since the favorable variations accumulate as the generations pass, the descendants tend to diverge markedly from their ancestors and to remain adapted to the conditions under which they live.

SENSATION—an impression conveyed by an afferent nerve to the sensorium commune.

SENSATION LEVEL—the level of psychophysiological stimulation above the threshold.

SENSE—a faculty by which the conditions or properties of things are perceived. Hunger, thirst, malaise, and pain are varieties of sense; a sense of equilibrium, of well-being (euphoria), and other senses also are distinguished.

SENSOR—component of an instrument that converts an input signal into a quantity, which is measured by another part of the instrument. See also MECHANORECEPTOR.

SIMULATOR, FLIGHT—training device to familiarize personnel with situations that are likely to be encountered in flight.

SLEEP-WAKEFULNESS—behavioral parameter related to performance with regard to varying amounts of sleep of an organism.

SOLAR FLARE—a bright eruption of the sun's chromosphere, ejecting high-energy protons which present a serious hazard to man in space.

SOLAR RADIATION—radiations from the Sun comprise a wide range of wavelengths in the electromagnetic spectrum, ranging from the short ultraviolet radiation at one end to the long infrared radiation at the other. Fortunately for man, much of the energy toward either end of the spectrum is absorbed by the atmosphere, with the solar radiation on Earth being confined largely to the visible and near infrared.

SPACE BIOLOGY—see BIOASTRONAUTICS.

SPACE CAPSULE—container for conducting experiments during spaceflight.

SPACE MEDICINE—see AEROSPACE MEDICINE.

SPACE STATION—a manned space platform in Earth's orbit, designed as a supply station for spacecraft.

SPACE SUIT—a pressure suit for wear in space or at very low ambient pressures within the atmosphere, designed to permit the wearer to leave the protection of a pressurized cabin. See also PRESSURIZED SUIT and G-SUIT.

SPACECRAFT—devices, manned or unmanned, designed to be placed in orbit about the Earth or into a trajectory toward another celestial body.

STERILIZATION—complete destruction of all living organisms by application of heat, chemicals, or radiation. See also CHEMICAL, DRYHEAT, and RADIATION.

STIMULUS—any agent, act, or influence that produces functional or trophic reaction in a receptor or in an irritable tissue; any event that initiates behavior; more specifically, any energy change that activates a sense organ.

STRESS—effect of a physiological, psychological, or mental load on a biological organism, which causes fatigue and tends to degrade proficiency.

SUBGRAVITY—condition in which the acceleration acting on a body is less than normal, between zero and one g. See also GRAVITY.

TACHYCARDIA—very rapid beating of the heart; term is usually applied to a pulse rate above 100 per minute.

TELEMETRY—science of measuring and transmitting quantities (pulse rate, respiratory rate, etc.) to a distant station where they are interpreted and recorded.

TEMPERAMENT—a determinant of personality. Other determinants of the same order include demands, interests, and capacities.

TEMPERATURE—intensity of heat as measured on a scale (Fahrenheit, Celsius) by means of various instruments.

TOLERANCE—ability to endure without ill effect, such as ability to endure the continued or increasing use of a drug.

TOXICOLOGY—sum of what is known regarding poisons; the scientific study of poisons, their actions, their detection, and treatment of the conditions produced by them.

TRACKING TASK—a sight experiment conducted during spaceflight or simulated spaceflight.

TYPOLOGY—study and especially analysis of division of humanity in terms of social types; of higher nervous activity—strength, balance, and mobility.

VELOCITY—rate of change of position or rate of displacement, expressed in feet (or centimeters) per second. Velocity is a vector quantity; i.e., for its complete specification, its direction as well as its magnitude must be stated.

VENTILATION—biologically, the aeration of the lungs and blood by breathing; the inhalation and exhalation of air in the process of respiration.

VIABILITY—the state of being alive, capable of growth and reproduction, following exposure to an unfavorable environment.

VIBRATION—motion due to a continuous change in the magnitude of a given force, which reverses its direction with time.

WASTE CYCLING—conversion of metabolic waste products within a space cabin for the purpose of recovering potable water.

WATER IMMERSION—submersion in water for the purpose of studying some simulated effects of weightlessness, especially on the cardiovascular system.

WEIGHTLESSNESS—condition in which no acceleration within the system in question can be detected by an observer.

WORK-REST CYCLE—activity alternated with periods of respite, studied to measure psychophysiological performance under varying conditions.

X-RAY—non-nuclear electromagnetic radiation of very short wavelength, lying within the interval of 0.1 to 100 angstroms (between gamma rays and ultraviolet radiation).

ZERO-G—see WEIGHTLESSNESS.

# Appendix B

## ORGANIZATIONAL ARRANGEMENTS FOR THE ADMINISTRATION OF LIFE SCIENCES PROGRAMS AT HEADQUARTERS AND CENTERS, 1958-1980

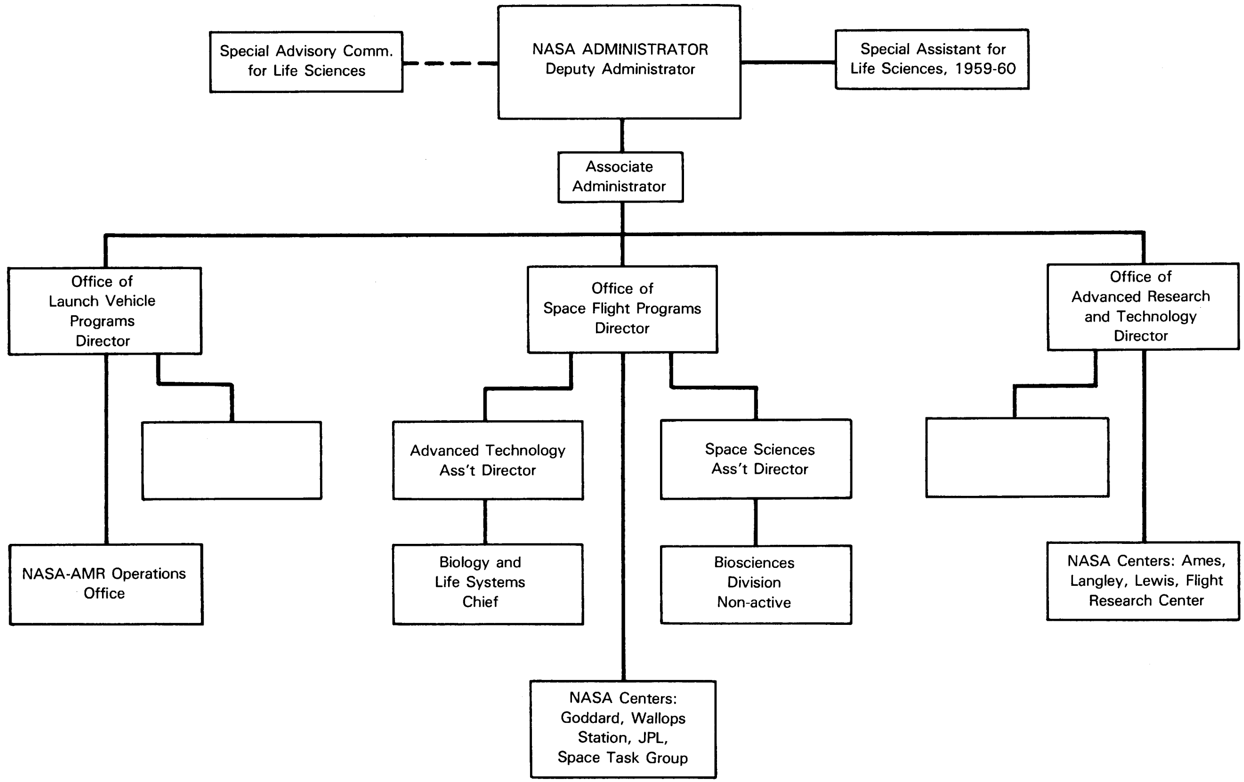
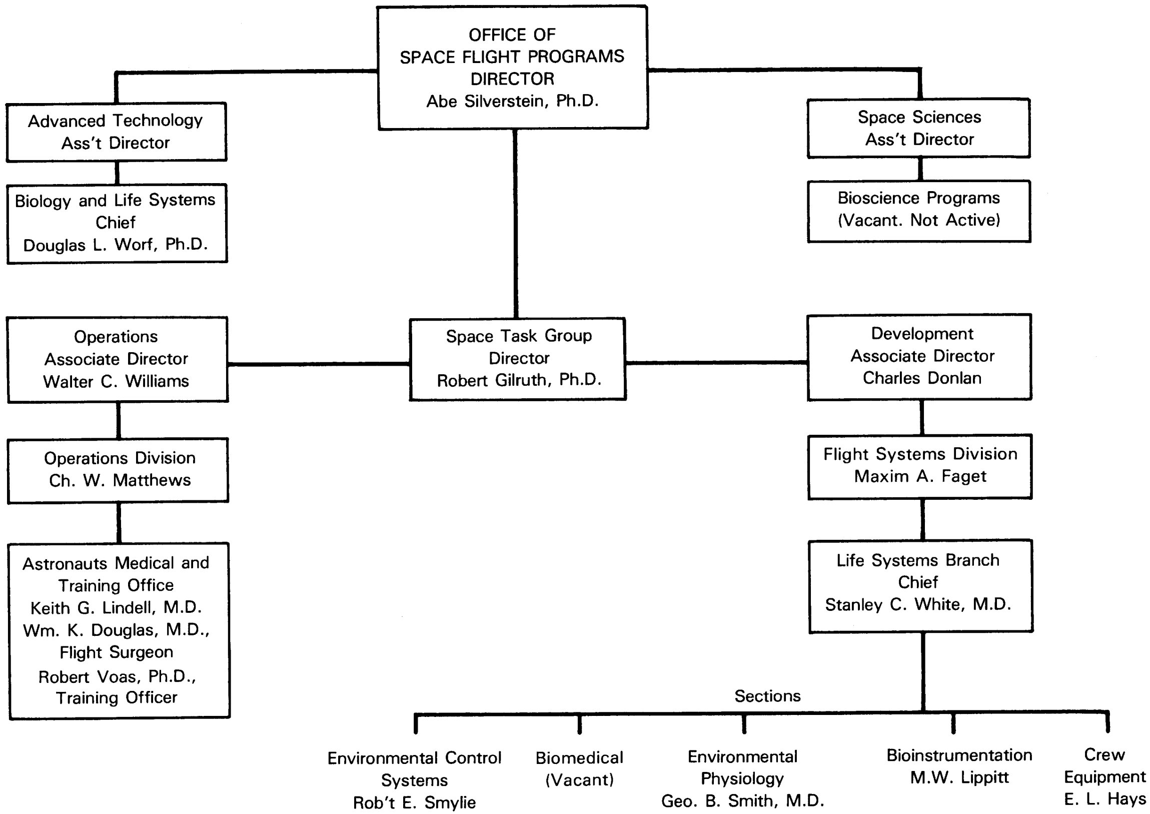


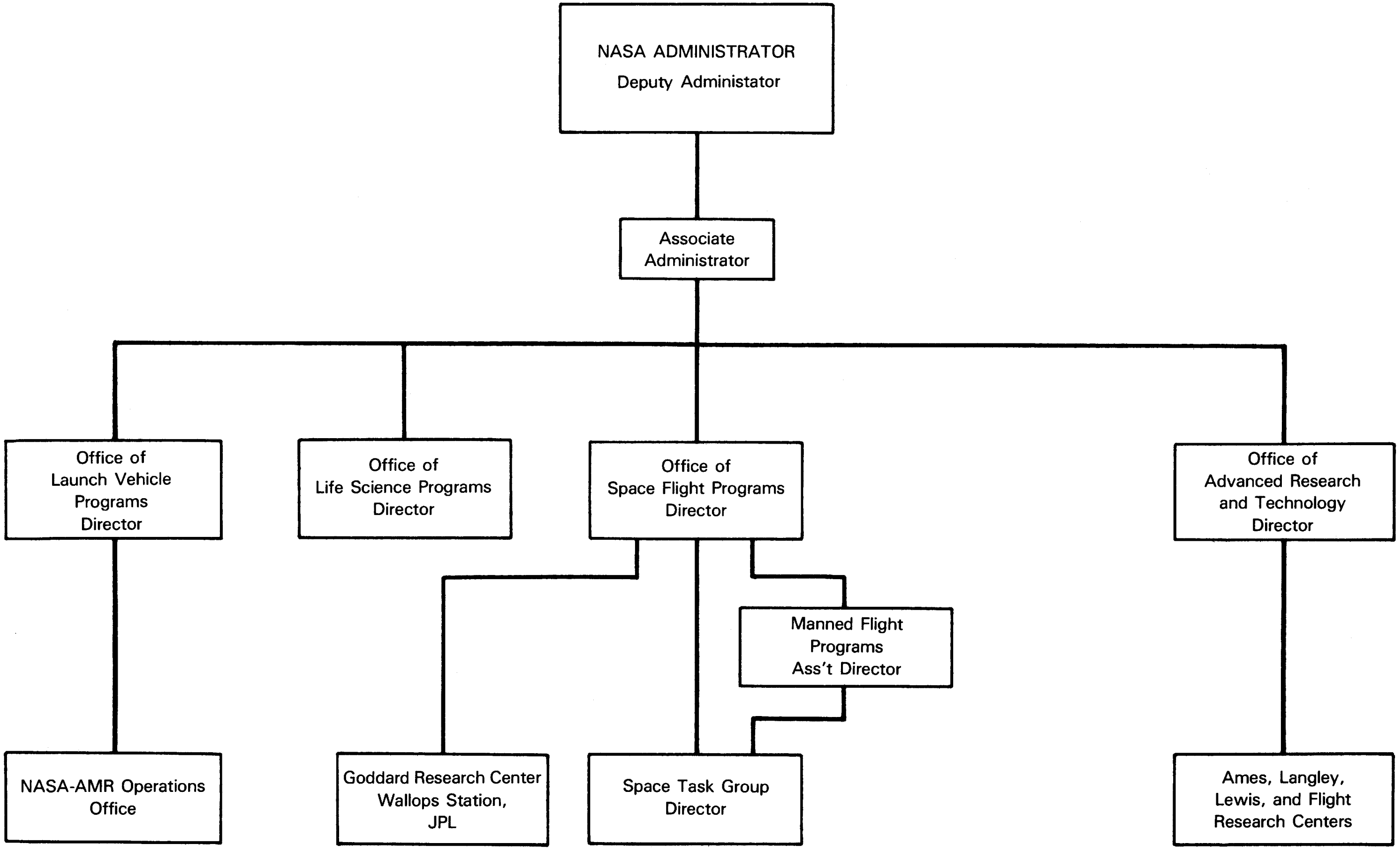

**Chart 1. NASA Headquarters, 1958-1960**

## Chart 2. Office of Space Flight Programs, 1958-1961[1]




[1] The organizational arrangements at Space Task Group remained essentially unchanged until 1962, when it became the Manned Spacecraft Center.

Chart 3. NASA Headquarters, 1960-1961



## Chart 4. Office of Life Sciences Programs, 1960-1961

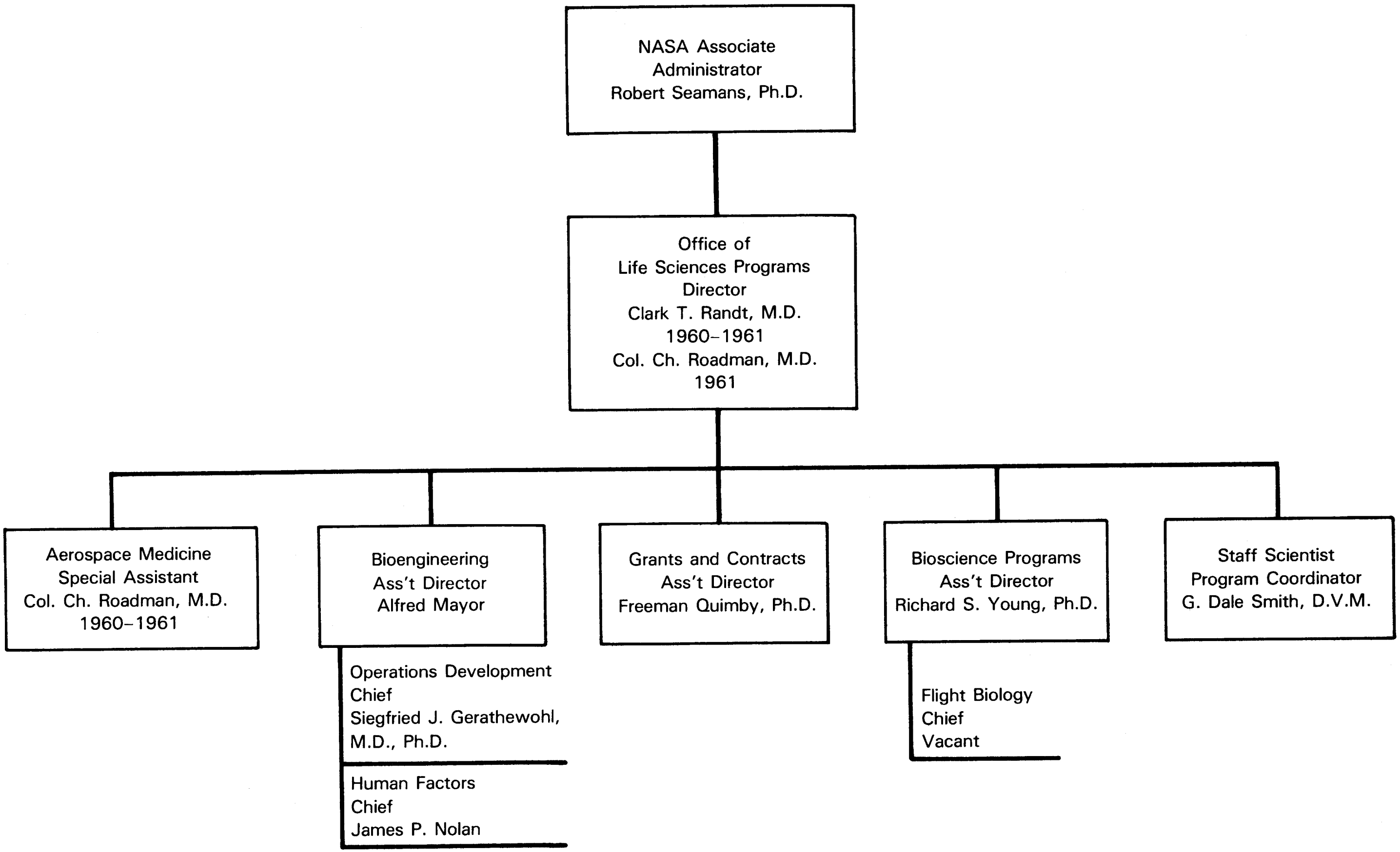
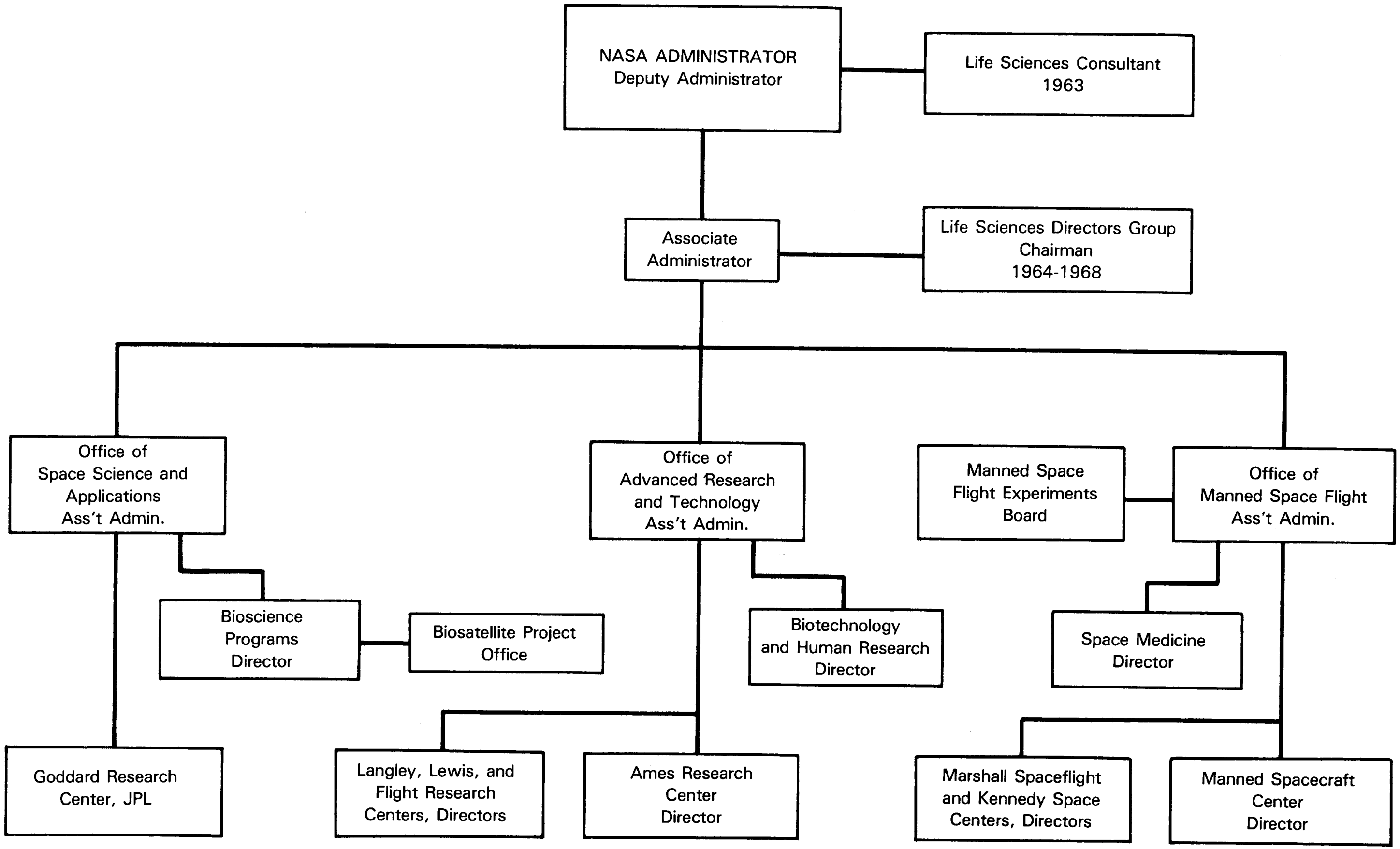


**Chart 5. NASA Headquarters, 1962-1970**



## Chart 6. Office of Space Science and Applications, 1962-1970

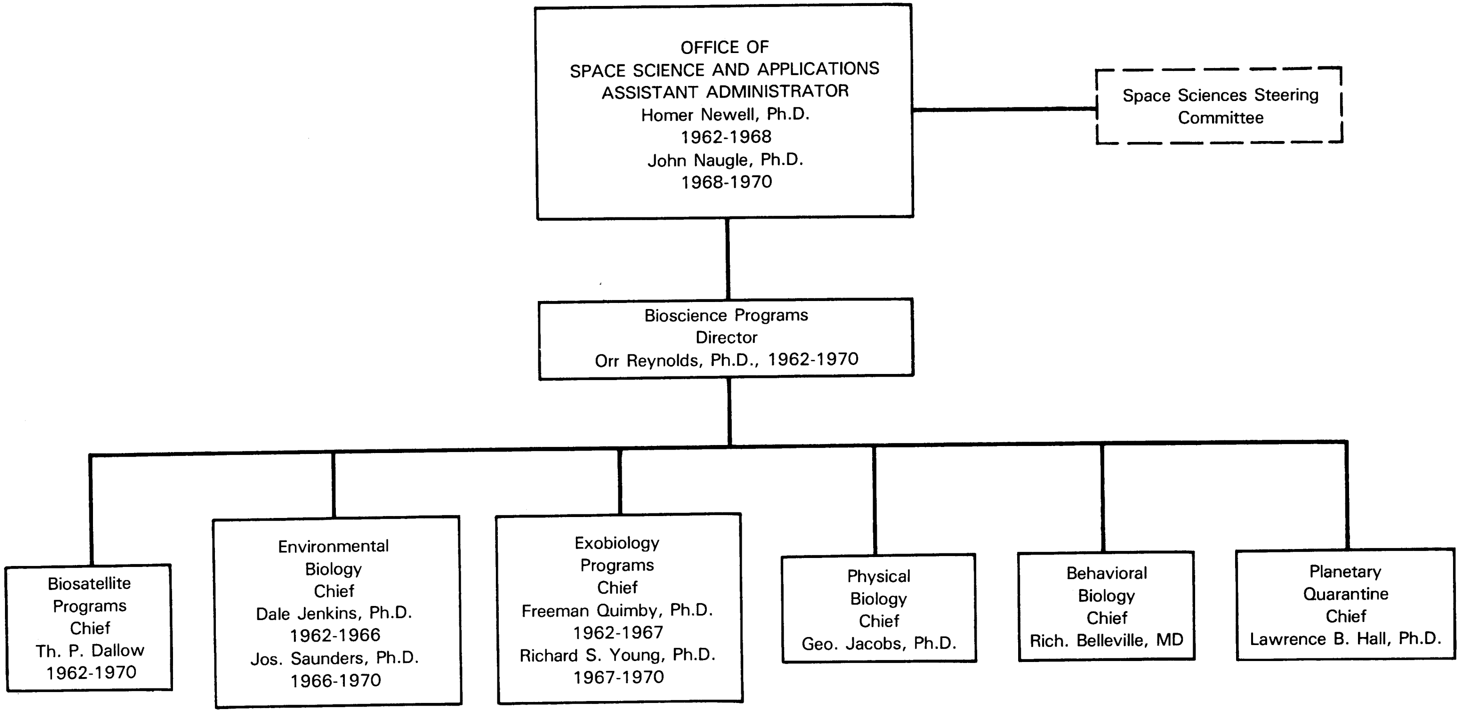


**Chart 7. Office of Advanced Research and Technology and Ames Research Center, 1962-1970**

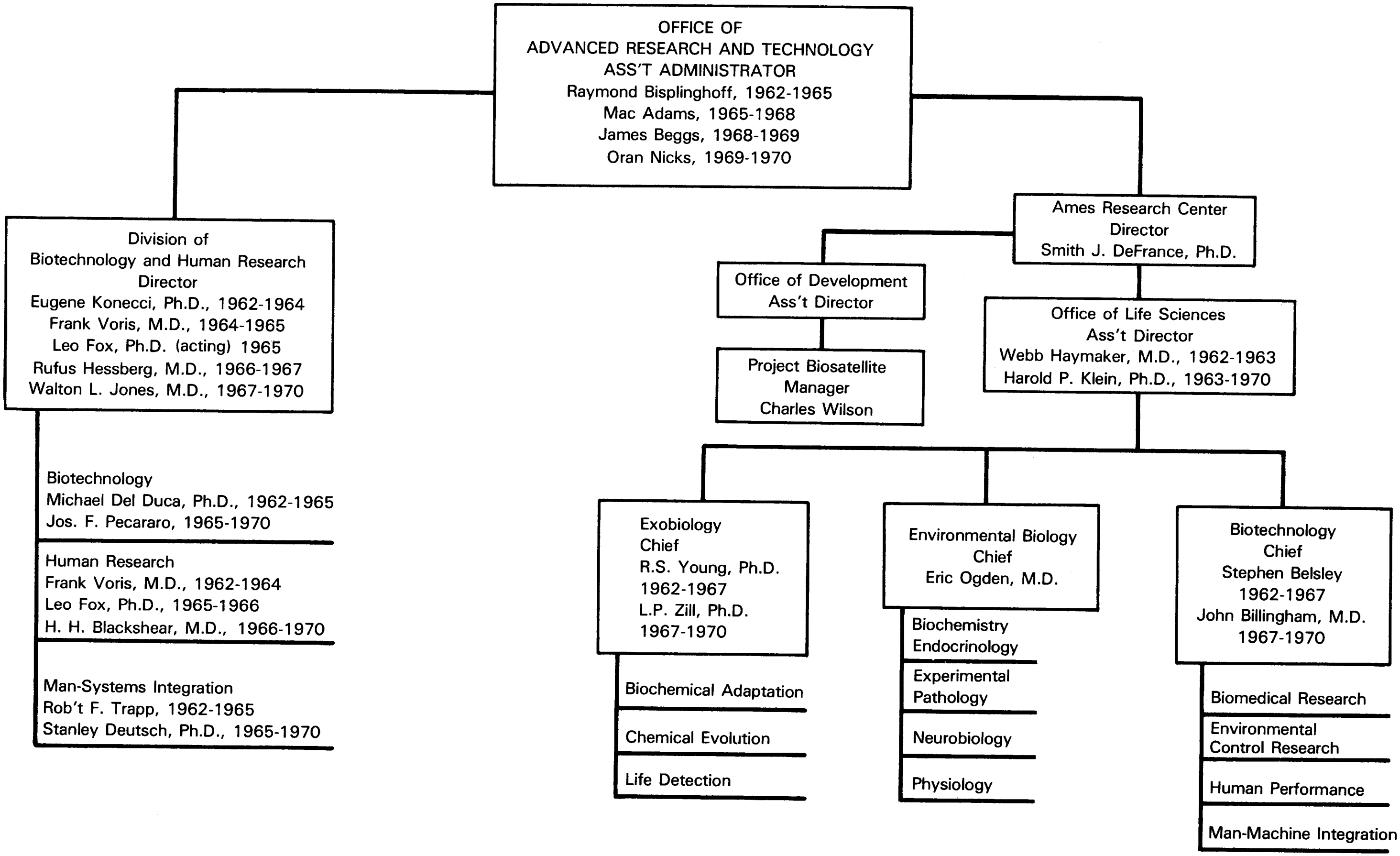


**Chart 8. Office of Manned Space Flight, 1962-1970, and Manned Spacecraft Center, 1962-1966**

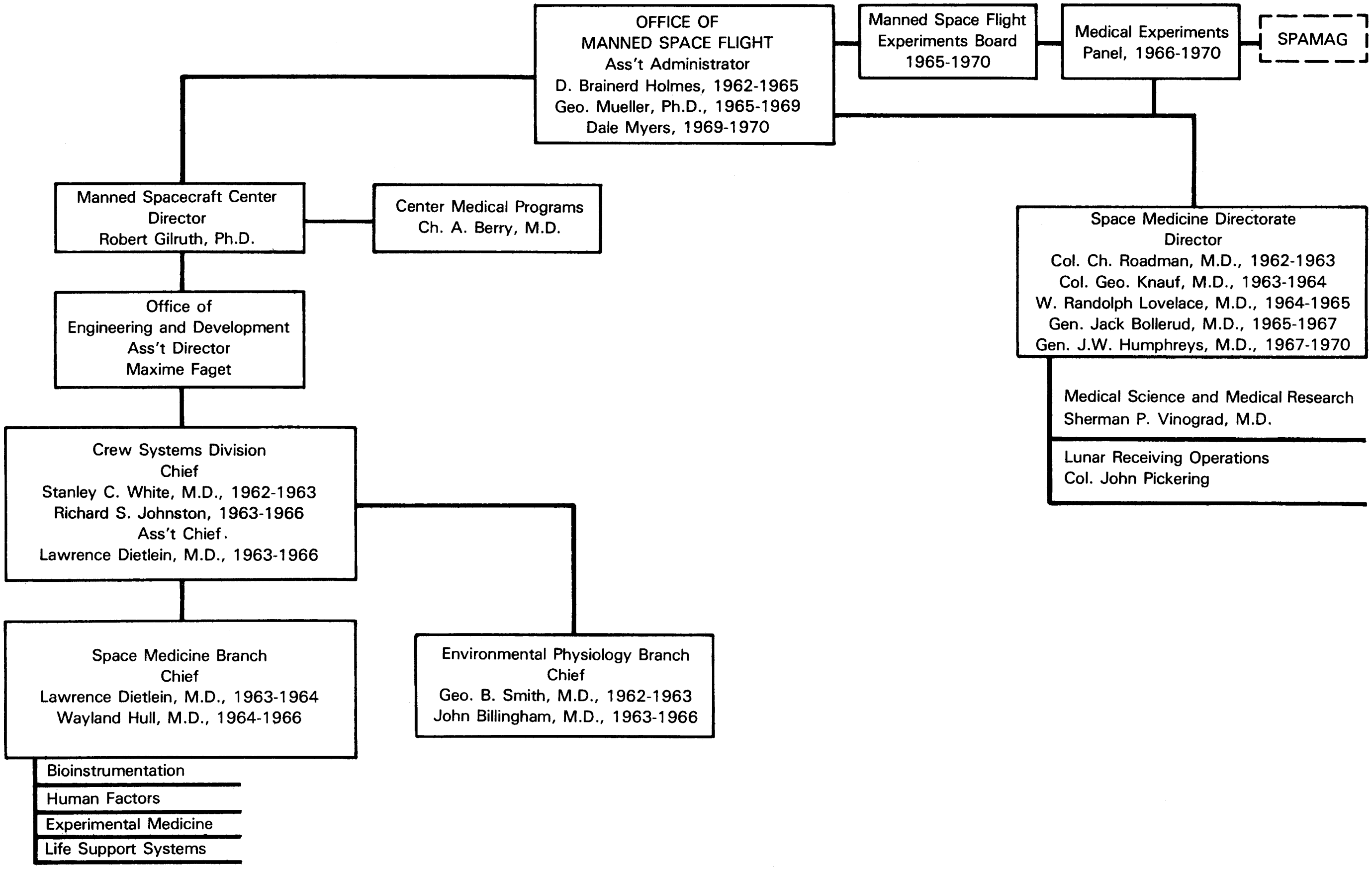
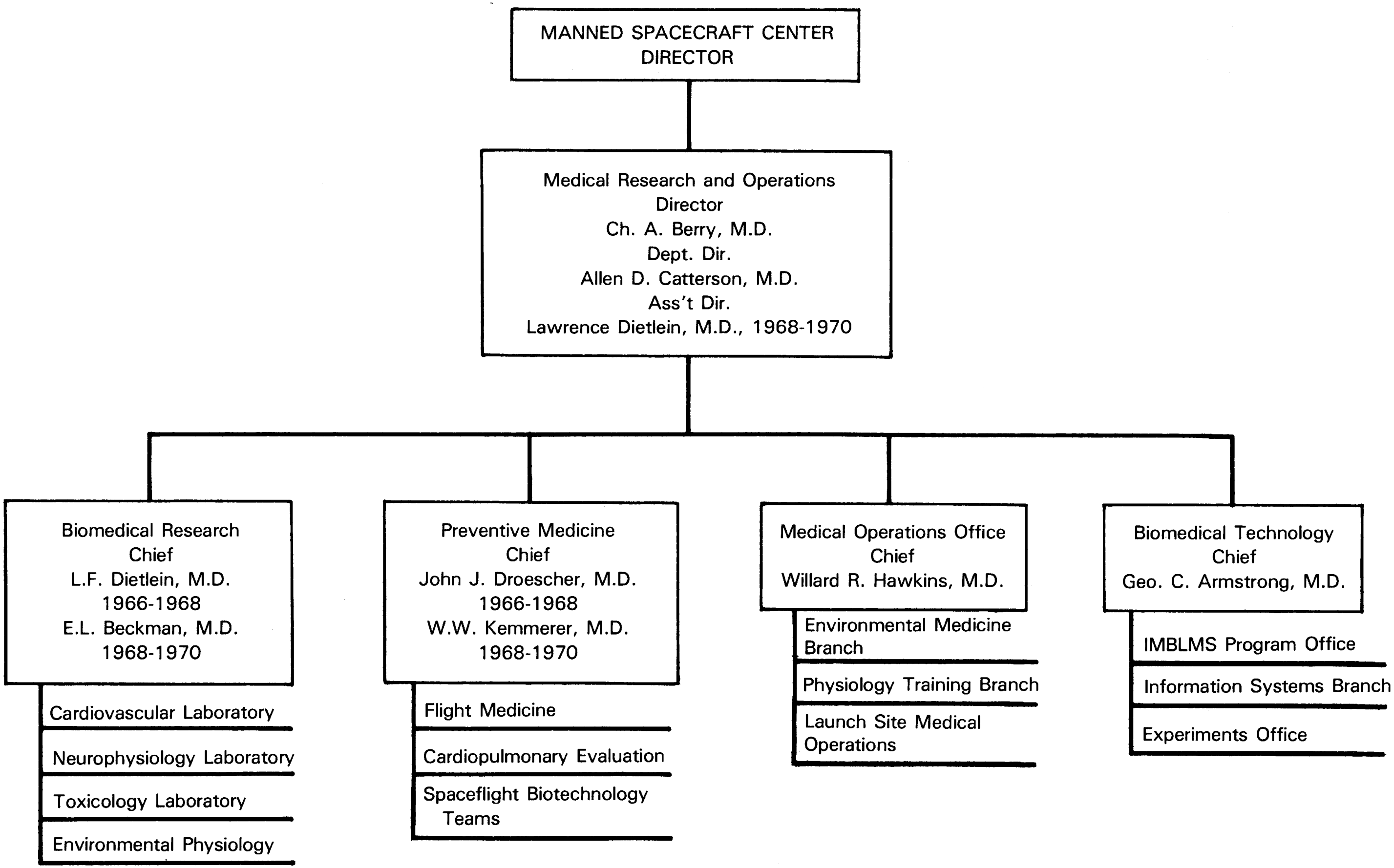


**Chart 9. Manned Spacecraft Center, Directorate of Medical Research and Operations, 1966-1970**



## Chart 10. NASA Headquarters, 1971-1975

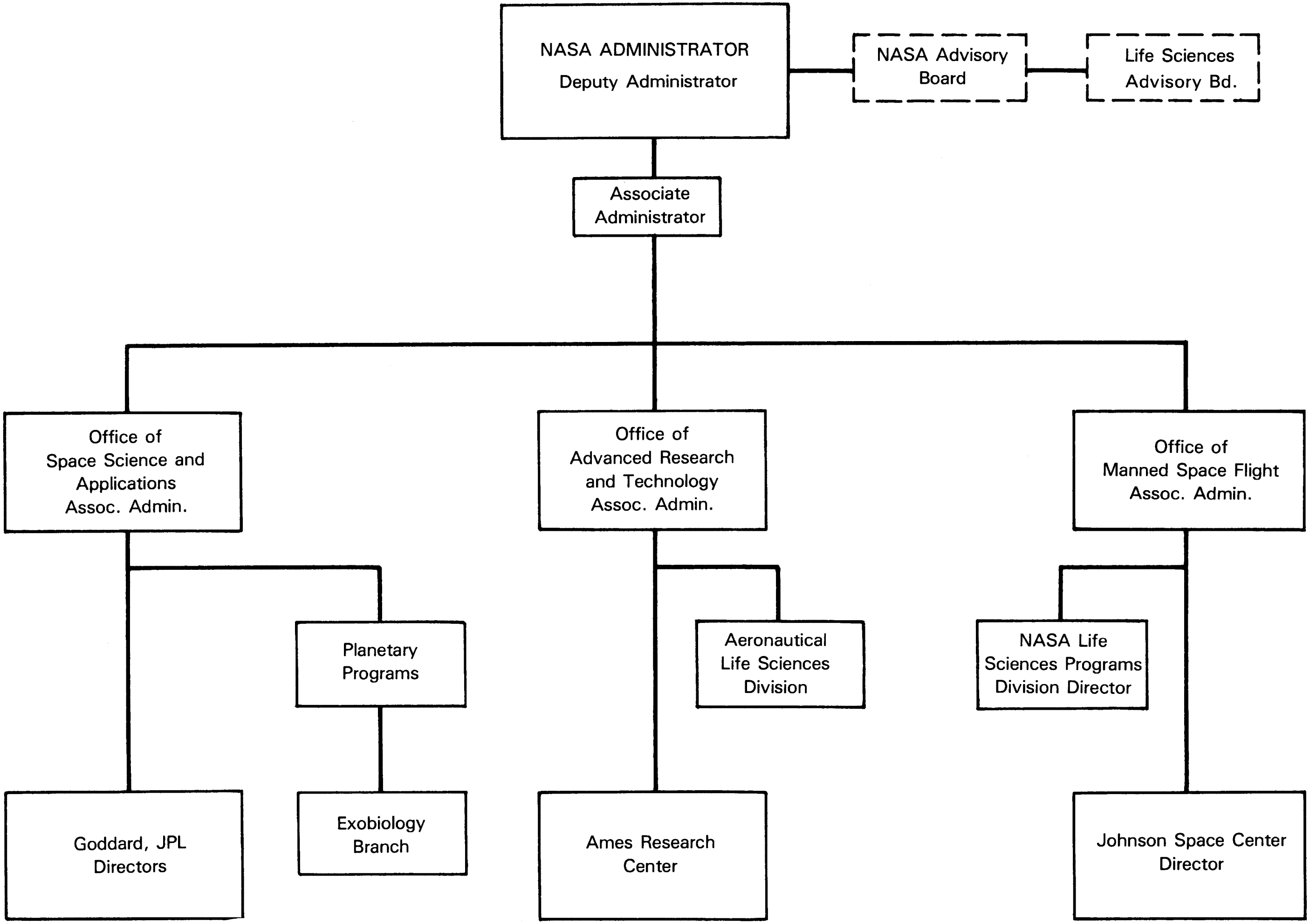


**Chart 11. NASA Headquarters, 1975-1980**

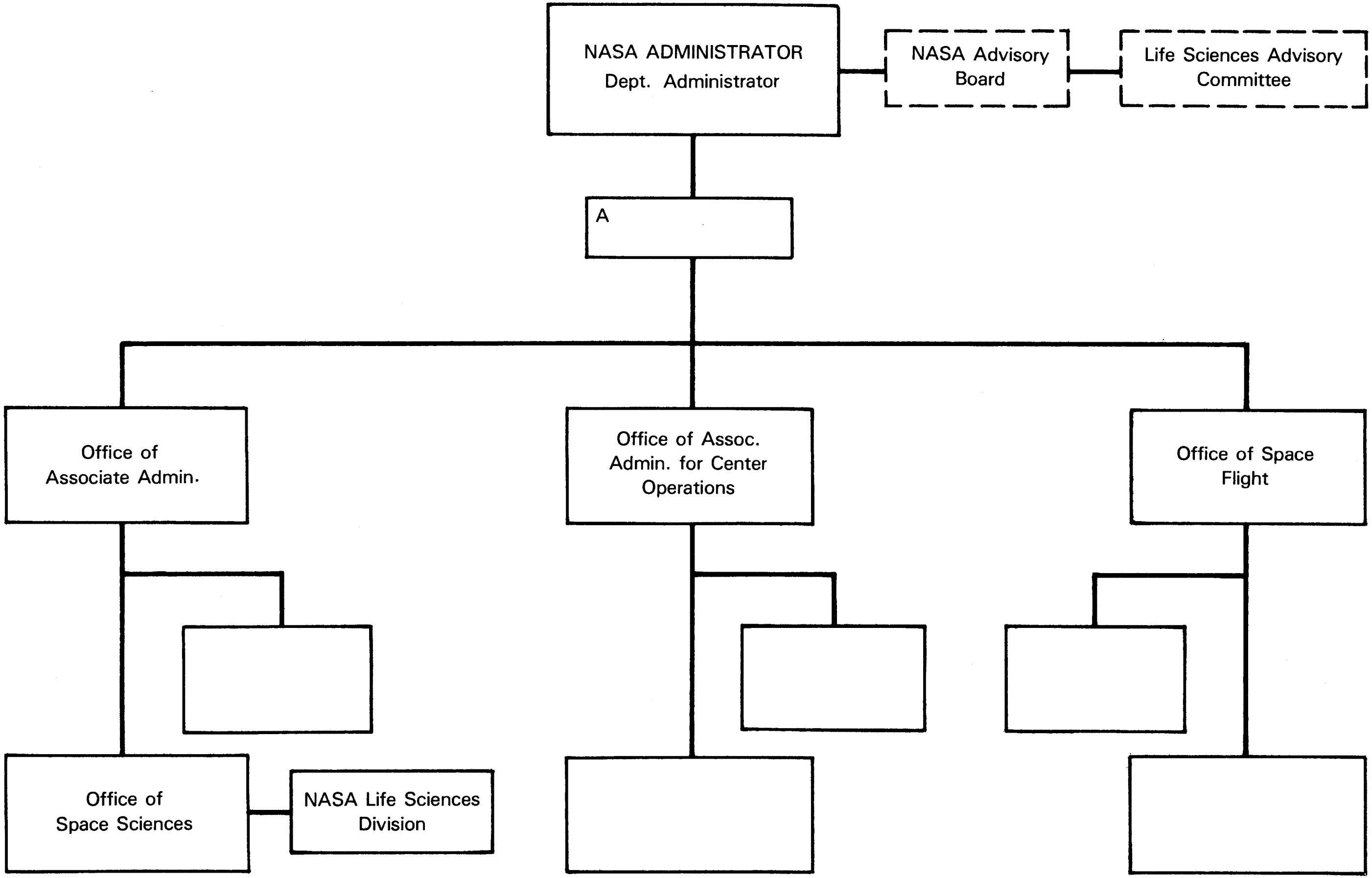
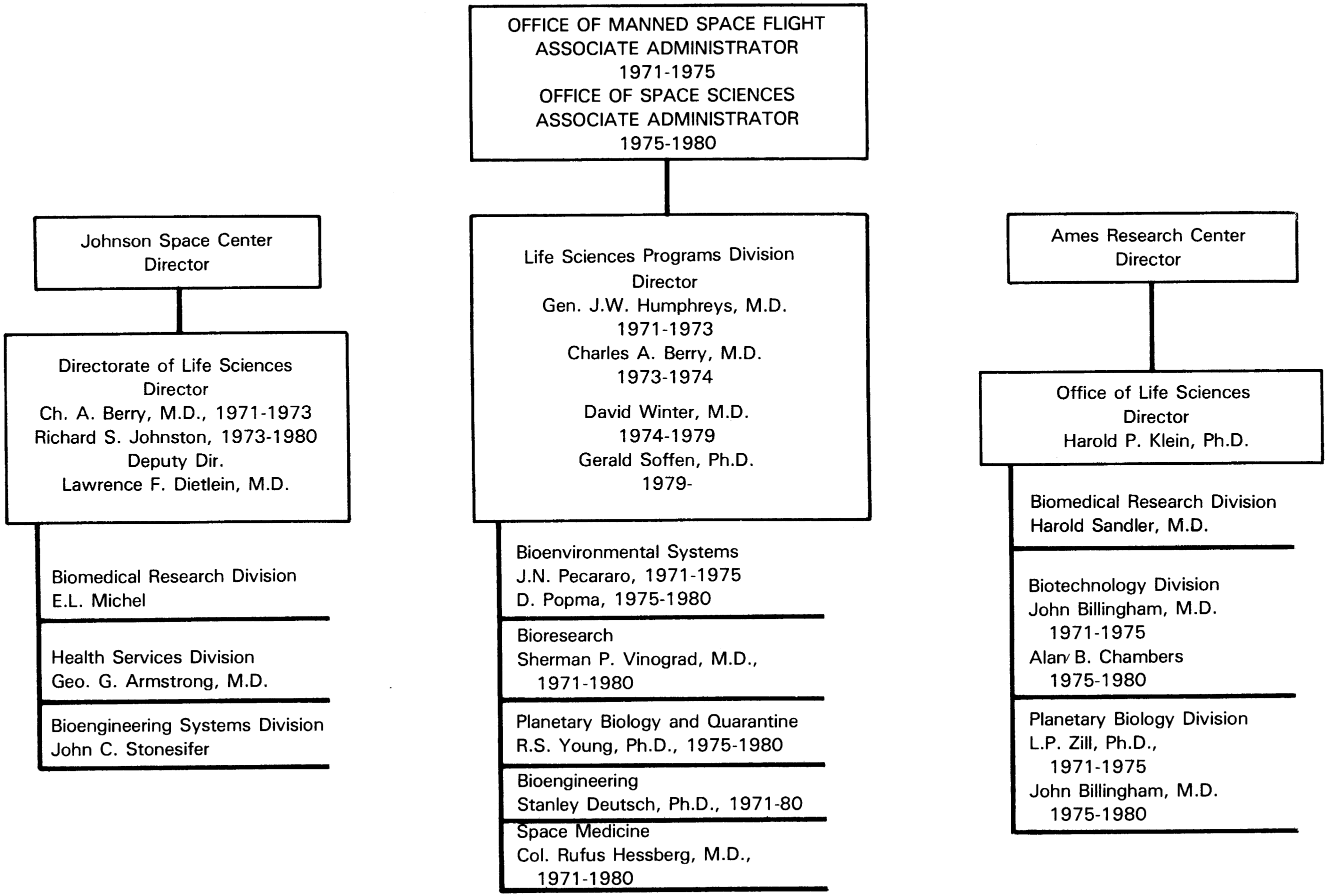


Chart 12. NASA Life Sciences Programs Division, 1971-1980



# Appendix C

## FORMAL REVIEWS OF ORGANIZATION AND MANAGEMENT OF NASA'S LIFE SCIENCES PROGRAMS, 1960–1978

| Year | Review by | Sponsor | Chairman | Major recommendations |
|---|---|---|---|---|
| 1960 | Biosciences Advisory Committee | NASA | Seymour Kety, M.D. | Establish life sciences program office. Give life sciences director authority equal to other program office directors. |
| 1962 | Working Group on Life Sciences | NASA | Bernard Maggin, NASA | Establish separate program offices for space biology, space medicine, and biotechnology. |
| | Bioastronautics Panel | PSAC | Paul Beeson, M.D. | Establish unified life sciences program with emphasis on biomedical research. Appoint a prominent life scientist to a top management position. |
| | Working Group on Biology, Space Research Summer Study | NAS-Space Science Board and NASA | Norton Nelson, M.D. | Appoint a prominent life scientist to a top management position. Place greater emphasis on basic research in biology and medicine. |
| 1963 | Consultant Study | NASA | Nello Pace, Ph.D. | Appoint a director of biospace missions with level of authority equal to program office administrators and with authority to coordinate biomedical programs. |
| 1966 | Staff study of structuring of life sciences programs | NASA | Gen. Jack Bollerud, NASA Dir. Space Medicine | Establish a unified life sciences program office. Make life sciences director equal in authority to program directors. |

| | | | | |
|---|---|---|---|---|
| 1967 | Biomedical Working Group, Science and Technology Committee | PSAC | Eugene Stead, M.D. | Unify life sciences program to place greater emphasis on basic research in medical science. |
| | No title—oral presentation for Assoc. Admin. Seamans | NASA | Bernard Maggin and Robert Bell, both NASA | No recommendations—Note ineffectiveness of Life Sciences Directors Group, jurisdictional conflicts among life sciences offices, and conflicts between headquarters space medicine and MSC space medicine. |
| 1968 | Life Sciences Study Task Group | NASA | J.W. Humphreys, NASA Dir. Space Medicine | Establish single integrated life sciences office within Office of Advanced Research and Technology. Give director of life sciences authority equal to program office administrators for life sciences matters. Abolish Life Sciences Directors Group. |
| 1969 | Biomedical Working Group, Science and Technology Committee | PSAC | Eugene Stead, M.D. | Integrate biomedical programs into single office. Appoint prominent biomedical scientist to top management position. Make fundamental research in biology and medicine primary program objective. |
| 1970 | Committee to review NASA life sciences programs | NAS-Space Science Board and NASA | H. Bentley Glass, Ph.D. | Establish a life sciences advisory board composed of prominent life scientists, and with direct access to NASA Administrator. Establish a unified office of space biology and medicine headed by an associate administrator. Make basic research in biology and medicine the |

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| | | | | primary focus of the integrated program. |
| 1974 | Staff study of life sciences program | NASA | William Barry, M.D. | Integrate biological and man-oriented life sciences into a single program. Appoint a life scientist to a top management position. Consolidate life sciences programs at Ames and JSC into a single program located at JSC. Place integrated center program under leadership of a proven life sciences researcher. |

# Appendix D

## NASA'S LIFE SCIENCES PROGRAMS, 1958–1980: RESEARCH, DEVELOPMENT, INFLIGHT EXPERIMENTS

This appendix consists of three charts. Chart 1 surveys the committees whose recommendations have influenced NASA's long-range planning in biomedical research and development. Chart 2 outlines the experiment protocols for extended manned flights as embodied in the Integrated Medical and Behavioral Laboratory Measurement System.

**Chart 1. Long-Range Planning for Biomedical Investigations in Space: Technical Review Committees and Their Recommendations**

| Year | Committee | Sponsor | Members | Recommendations |
|---|---|---|---|---|
| 1958 | Working Group on Human Factors and Training of the Special Committee on Space Technology | NACA/ NASA | W. Randolph Lovelace, II, M.D.,* Lovelace Foundation for Medical Research<br>A. Scott Crossfield, North American Aviation<br>Hubert M. Drake, NASA High-Speed Flight Station<br>Gen. Donald D. Flickinger, M.D., USAF<br>Col. Edward B. Giller, USAF<br>James B. Hardy, Ph.D., Naval Air Development Center<br>Wright H. Langham, Los | 1. Determine "fine" and "gross" degradations resulting from acceleration forces in terms of performance, reversible tissue damage, and short- and long-term irreversible tissue damage.<br>2. Determine physiological effects of and countermeasures against high-intensity radiation, cosmic radiation, and solar flares.<br>3. Determine physiological effects of "artificial" factors such as leakage from nuclear propulsive systems and ionization resulting from flight.<br>4. Study requirements for human information processing, displays and controls, and "closed cycle living."<br>5. Conduct research and development for en- |

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| | | Alamos Scientific Laboratory<br>Ulrich C. Luft, M.D., Ph.D., Lovelace Foundation<br>Boyd C. Myers, NASA, Secretary | vironmental control systems to support men for flights up to six months in duration.<br>6. Refine procedures for selecting space crews and develop flight systems and simulators for continuing evaluation of selection and training criteria. |
| 1958–1960 Special Committee on Life Sciences | NASA Administrator | Lovelace*<br>Capt. Norman Barr, M.D., Naval Bureau of Medicine<br>Lt. Cmdr. John Ebersole, M.D., Naval Fleet Medical Officer<br>Gen. Donald Flickinger, M.D., USAF Director of Bioastronautics<br>Lt. Col. Robert Holmes, M.D., Army Medical Research and Development Command<br>Wright Langham, Ph.D., Los Alamos Scientific Laboratory<br>Robert Livingston, M.D., NIMH<br>Orr Reynolds, Ph.D., DoD Office of Research and Engineering<br>Boyd C. Myers, NASA, Secretary | No specific report or recommendations. Served as advisory body for selection and training of Mercury astronauts, development, testing, and evaluation of Mercury life-support systems, and formation of Mercury inflight medical monitoring. |

| | | | | |
|---|---|---|---|---|
| 1960 | Biosciences Advisory Committee | NASA Administrator | Seymour Kety, M.D.,* NIH<br>David Goddard, Ph.D., Dept. of Botany, Univ. of Pennsylvania<br>Donal G. Marquis, Ph.D., MIT<br>Wallace Fenn, Ph.D., School of Medicine and Surgery, Univ. of Rochester<br>Robert S. Morrison, M.D., Rockefeller Foundation<br>Cornelius Tobias, Ph.D., Univ. of California | Development of broad research program to encompass "basic biology" (search for extraterrestrial life and data related to biogenesis); "applied medicine and biology" (physiological effects on man in flight of weightlessness, acceleration forces, radiation, closed environments, changes in circadian rhythm, and toxicity and contamination); and "basic medical and behavioral sciences" (respiratory physiology, circulatory physiology, metabolism, neurophysiology, and behavior). |
| 1962 | Working Group on Biology, Space Science Board Summer Study to Review Space Research | NASA and NAS Space Science Board | Allan H. Brown, Ph.D., Dept. of Botany, Univ. of Pennsylvania*<br>Colin Pittendrigh, Dept. of Biology, Princeton Univ.<br>Nine academic biologists<br>Three government agency biologists<br>One research foundation biologist<br>One academic biophysicist<br>One academic M.D.<br>One government agency physician | Develop techniques for identifying evidence of extraterrestrial life, sterilizing spacecraft, and preventing back-contamination. Conduct research and development on bioregenerative life-support systems for manned spaceflights. Conduct inflight and ground-based research to study effects of gravity and null-gravity, alterations in biological rhythms, and radiation on biological systems. |

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|---|---|---|---|
| Working Group on NASA and NAS Space Science Board Space Probe Sterilization of Ibid. | | Allan H. Brown*<br>Six academic biologists<br>Three research group bio-scientists<br>One government agency biologist<br>One military biologist | Conduct research and development to identify best technique or combination of techniques (heat, radiation, chemicals) to sterilize space probes and prevent biological contamination of moon and planets and back-contamination of Earth. |
| Working Group on Man as Scientist in Space Exploration, Ibid. | NASA and NAS Space Science Board | Norton Nelson, M.D., New York University<br>Five academic biologists<br>Two academic biophysicists<br>Two academic bioengineers<br>Two academic geologists<br>Two academic astronomers<br>One academic psychologist<br>One government agency biologist<br>Two government agency physicians<br>One government agency geologist<br>Three government agency (NASA) bioengineers<br>One research foundation biologist<br>One research foundation biophysicist<br>Two industry engineers<br>One industry | 1. Train astronauts to conduct scientific investigations (particularly in biology, geology, and astronomy). 2. Plan to establish permanent science laboratory on Moon. 3. Plan manned orbital research laboratory with primary emphasis on biomedical experiments. 4. Conduct research and development to support manned flight to Mars with primary objective to conduct biological investigations. 5. Develop programs for training space scientists and for selecting scientist-astronauts. |

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| | | | physician<br>One military psychologist | |
| 1963 | Life Sciences Consultant Report 7 | NASA Administrator | Nello Pace, Ph.D., Univ. of California | Conduct research and development to support a program in inflight biological investigations using automated systems, small biological packages, and primates. |
| | Biomedical Experiments Working Group | NASA Office of Manned Space Flight | Unidentified | Detailed in Chap. 4. |
| 1964 | Space Medicine Advisory Group | NASA Office of Manned Space Flight | Sherman P. Vinograd, M.D., NASA*<br>Andres I. Karsten, M.D., USAF Aerospace Medical Division, cochairmen<br>Six academic physicians<br>Two government agency physicians<br>Two military physicians<br>Four academic biologists<br>One government agency biologist<br>One academic pharmacologist<br>One academic biochemist<br>Three academic psychologists | Detailed in Chap 4. |
| 1965 | Working Group on Fundamental Biology for Summer Study, Space Research—Directions for Future | NASA and NAS Space Science Board | Allan H. Brown, Ph.D., Dept. of Botany, Univ. of Pennsylvania | Emphasize research in environmental biology (biological effects of radiation, alterations in biorhythms, variations in |

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|---|---|---|---|---|
| | | | Six academic biologists | gravity) and in human tolerance to variables of space environment. Develop exobiology program with emphasis on search for life on Mars. Conduct research and development to improve Biosatellite, refine techniques for spacecraft sterilization, and develop an automated biological laboratory for use in planetary exploration. |
| | Working Group on Medicine and Physiology | NASA and NAS Space Science Board | Loren D. Carlson, Ph.D., Dept. of Physiology, Univ. of Kentucky<br>Three academic physicians<br>One industry physician<br>One research foundation physician<br>Two academic biologists | Emphasis on development of an orbital research laboratory for medical, physiological, and behavioral investigations in extended-duration flight. Enhanced program of ground-based research in fundamental medicine, physiology, and behavior. |
| 1966 | American Institute of Biological Sciences (AIBS) | NASA Office of Space Sciences | Robert Lindberg, Ph.D., Northrop Corp. Laboratories<br>Elie A. Schneour, Ph.D., Dept. of Molecular and Genetic Biology, Univ. of Utah<br>Ralph Baker, Ph.D., Dept of Botany, Colorado State Univ.<br>Theodore Sudia, Ph.D., AIBS<br>Gilbert Levin, | Support research and development for a manned orbiting research laboratory having primary objective of conducting research into effects of space environment on Earth organisms, the value of bioregenerative life-support systems, the search for extraterrestrial life, and the assessment of techniques and technologies for remote sensing life detection. |

| | | | | |
|---|---|---|---|---|
| | | | Ph.D., Bio-spherics Research, Inc. George K. Davis, Ph.D., Dept. of Biological Sciences, Univ. of Florida | |
| | Study Group on Biology and the Exploration of Mars | NASA and NAS Space Science Board | Colin Pittendrigh, Ph.D., Dept. of Biology, Univ. of Pittsburgh Joshua Lederberg, Ph.D. Thirty-six biological scientists drawn primarily from academia | "Biological exploration" of Mars should be a major program objective of the 1970s, with primary emphasis on automated systems and remote observation and investigation. |
| 1970 | Study to Review NASA Life Science Programs | NASA and NAS Space Science Board | H. Bentley Glass, Ph.D., Dept. of Biology, State Univ. of New York* One academic physician One government agency physician Three research hospital physicians Three academic biologists | 1. Make unmanned investigations of exobiology and planetary biology prime objectives of 1970s. 2. Development programs for biological experimentation in Skylab and Shuttle programs. 3. Establish strong program of research in clinical medicine, man-oriented biomedicine and animal bioscience to establish baselines and predictive values for extended-duration manned flights. 4. Establish a special research group to study requirements in biotechnology and bioinstrumentation for extended-duration manned flights. |
| | Working Group on In- | NASA and | John Spizizen, | 1. Development of a pro- |

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|---|---|---|---|---|
| | fectious Disease in Manned Spaceflight | NAS Space Science Board | M.D., Scripps Clinic and Research Foundation<br>Three academic physicians<br>One military physician<br>One academic biologist | gram of preflight quarantine and isolation as "highest priority." 2. Use of immunological and microbiological screening and surveillance techniques in selection of flight crews. 3. Research program to identify critical microorganisms and to evaluate viability, replicability, and mutability in space environment. 4. Active research and development program to identify effective countermeasures. |
| 1978 | Life Sciences Advisory Committee | NASA Advisory Council | G. Donald Whedon, M.D., NIH*<br>Two academic physicians<br>Two research foundation physicians<br>One government agency physician<br>One military physician<br>One academic biochemist<br>Two academic geologists<br>One academic biologist<br>Three academic engineers<br>One government agency agronomist | Detailed in Chap. 12. |

*Denotes committee chairman.

**Chart 2. Biomedical Investigations for Extended-Duration (Post-Skylab) Manned Spaceflight Programs**

Medical/Behavioral Measurement Capability of Integrated Medical and Behavioral Laboratory Measurement System

I. *NEUROLOGICAL*

Clinical evaluation (to include reflexes and sensory and motor pathways)

Agravic perception of personal and extrapersonal space (minimum restraint device)

Ocular counterrolling

Oculogyral illusion

Visual task with head rotation

Electronystagmogram

Angular acceleration threshold

To be done with litter-chair

EEG

II. *CARDIOVASCULAR*

Clinical evaluation

ECG (Frank lead system)

Phonocardiogram

Cardiac output—(by impedance if technique verified; by indicator-dilution if necessary)

Arterial blood pressure

Venous pressure—peripheral

Blood volume and fluid compartments—see hematology and metabolism

Regional blood flow—limb (or digit) (distribution of blood volume) (Limb plethysmography)

Venous compliance

Anteriolar reactivity

Arterial pulse contour

Inflight exercise

LBNP

Elastic leotards

*PROVIDE FOR INSTALLATION IF REQUIRED:*

Ballistocardiogram
Carotid body stimulation
Thoracic blood flow
Venous pressure—central
(by catheter if necessary)

III. *RESPIRATORY*

Clinical evaluation

Respiratory rate

Lung volumes including residual volume (for total lung capacity, and mixing efficiency)

Pressure, flow, and volume (simultaneously) (airway resistance)

Compliance—lung or total (lung if can)

Distribution of blood flow and gas in lungs

Includes: Capillary blood $O_2$, $CO_2$, and pH

Breath-by-breath $O_2$ consumption and $CO_2$ production

$O_2$ consumption—with measured exercise

Alveolar-to-arterial gradient breathing air and 100 percent oxygen

Diffusion capacity (if suitable technique) (look into $O_2{}^{18}$ method—Dr. Richard W. Hyde, Univ. of Pennsylvania, Dept. of Physiology)

IV. *METABOLISM AND NUTRITION*

Clinical evaluation

Energy metabolism (continuous $O_2$ and $CO_2$ analysis with breath-by-breath sensitivity) with various levels of activity

Oral temperature

Skin temperature

Caloric intake

Body mass in flight (Thornton technique—GFE)†

[Lean body mass pre- and post flight]—(Not a part of IMBLMS)

Muscle size and strength

Balance studies

—Fluid, including sweat

—Nitrogen (see area IX)

—Mineral (see area IX)

—Electrolyte (see area IX)

Provide for: Accurate urine volume measurement

Accurate wet weight of feces

Return of total dry stool

Accurate fluid intake measurement

Return of all food packages marked by date, time, and individual

Sweat measurement and sample return

Total body water (Breatholater or deuterium)

†Clinical laboratory evaluations—see list under area IX

*PROVIDE FOR INSTALLATION IF REQUIRED:*

EMG

Bone densitometry-isotope technique

IV. *METABOLISM AND NUTRITION (continued)*

Gastric pressure and pH (endoradiosonde)

Plasma volume onboard

Mineral metabolism by isotopic techniques

V. *ENDOCRINOLOGY*

Clinical evaluation

†Clinical laboratory evaluations—see list

VI. *HEMATOLOGY*

Clinical evaluation

Rumple leede

Blood volume and fluid compartment

Plasma volume—RHISA
RBC mass—$DFP^{32}$ or $Cr^{51}$
Total body water

RBC survival—$DFP^{32}$

Clinical laboratory evaluations—see list

VII. *MICROBIOLOGY AND IMMUNOLOGY*

Clinical evaluation

Body microflora (bacterial, viral, and fungal)

Environmental culturing (bacterial, viral, and fungal)

Clinical laboratory evaluations—see list

VIII. *BEHAVIORAL EFFECTS*

Clinical evaluation

Sensory test battery (see also neurology)

Perceptual evaluation (if validity of tests established)

Higher thought processes

Memory—short- and long-term

Vigilance (by measurement of operational tasks)

Learned activity (tracking and reaction time)

Recording of crew intercommunication with automatic erase in 15 minutes if not sampled

Time and motion study

IX. *CLINICAL LABORATORY EVALUATIONS*

Creatine and creatinine—urinary

Urinary and fecal: N, Ca, P, Na, K, Cl, and Mg

Mucoproteins—urinary (Pi)*

Pyrophosphates—urinary (Pi)*

Hydroxyprolines—urinary (probably Pi)

Total amino acids—urinary (Pi)

Urinary: Osmolality, color, specific gravity, pH, glucose, protein, bile, blood, and microscopic (i.e., routine urinalysis—in flight)
Plasma volume (probably P&P)**
Electrolytes—serum

IX. *CLINICAL LABORATORY EVALUATIONS (continued)*

Total protein—plasma
Glucose—blood (in flight)
Ca and $PO_4$—serum (probably Pi)
Bilirubin—serum
Cholesterol—serum (probably Pi)
BUN (probably Pi)
Uric acid—blood (Pi)
Alkaline phosphatase—serum (probably Pi)
pH, $pO_2$, and $pCO_2$—blood
Bicarbonate—blood
CPK (creatine phosphokinase—serum) (Pi)
LDH and LDH isoenzymes—serum (onboard if have electrophoresis)
SGOT—serum
SGPT—serum
Aldosterone—urine (Pi)
ADH—urinary and serum (Pi)
ACTH—blood (Pi)
Serum free thyroxin ($T_4$—serum) (if in flight, will require thin-layer chromatography)
TBPÅ (probably Pi)
17-Hydroxycorticosteroids—urine and blood (Pi)
17-Ketosteroids—urine (Pi)
VMA-urine (probably Pi)
Metanephrines—urine (Pi)
Catechols—urine (Pi)
Histamine—blood and urine (Pi)
5-Hydroxyindolacetic acid—urinary (probably Pi)
Blood cell morphology (RBC, WBC, and differential—smear will suffice for platelets)
Reticulocyte count
Hematocrit
Hemoglobin
RBC fragility (osmotic)
RBC mass and survival
Bleeding time
Clotting time
Prothrombin consumption
Clot retraction
Lymphocyte karotyping (probably Pi)
WBC mobilization (Rebuck technique)

IX. *CLINICAL LABORATORY EVALUATIONS (continued)*

| | |
|---|---|
| Immunoglobulins and fibrinogen<br>Transferrins<br>Hemoglobin<br>Methemoglobin | On board if have electrophoresis |

RBC enzyme studies (Pi) (ref. Governing Protocol M110)

Complement titration

Antibody titration

*PROVIDE FOR INCLUSIONS IF REQUIRED:*

Sulfate—urinary
TSH (Pi)
Growth hormone (Pi)
Thyroid-bound globulin ($T_3$) (Pi)
Parathyroid hormone (radioimmune technique—serum) (Pi)
Parathyroid hormone—urinary (Nelson technique) (Pi)
Calcitonin—serum (Pi)
Insulin assay (Pi)
Glucagon assay (Pi)
Serotonin (5-HIAA)—blood (Pi)
Platelet adhesiveness
Fibrinolytic activity
Blood rheology
Blood lipids

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+Government-furnished equipment.
*Pi—postflight evaluation of inflight samples.
**p&p—pre- and postflight.

# Appendix E

## MEDICAL SUPPORT FOR MANNED SPACEFLIGHT OPERATIONS

### Item 1

### Medical and Behavioral Evaluation of Astronaut Candidates

The following are extracts from U.S. Senate, *Project Mercury: Man-in-Space Program of the NASA*, Report of the Committee on Aeronautical and Space Sciences, 86th Cong., 1st sess., Dec. 1, 1959, pp. 42–46, 62–68. The evaluation of subsequent astronaut candidates remained fundamentally unchanged.

*Medical factors involved in Mercury astronaut selection*

1. *Physical fitness.*—Immediately following their Washington interviews the candidates were assigned to groups, five of six men each and one of two. One group at a time reported to the Lovelace Clinic in Albuquerque, N. Mex., for an exhaustive series of examinations. The other men returned to their home stations to await the call for their groups. The first contingent entered Lovelace February 7, and the others on succeeding Saturdays. Each candidate spent 7½ days and 3 evenings at the Lovelace facility.

General physical requirements were established by the NASA Life Sciences Committee; since all those examined were active test pilots it was not anticipated that any would be disqualified as physically unfit. Rather, degrees of physical soundness were obtained and evaluation was dependent upon a comparison of each man to his fellow candidates.

To establish a comparative yardstick, the Lovelace program began with a complete aviation and medical history extending to the following areas:

Hematology and pathology (blood and study of tissues).
Roentgenology (X-ray consultations).
Ophthalmology (eyes).
Otolaryngology (ears, nose and throat).
Cardiology (heart and circulation).
Neurology and myology (nerves and muscles).
General internal medicine.
Related laboratory studies.

Special consultations were provided if indicated by the candidate's medical history or any of the general examinations. These examinations were given under normal clinical procedures, while the subject was in a resting condition.

Results were recorded on special computing cards developed by the Lovelace Clinic for the astronaut program. These cards are mark-sensed so they may be read directly by the examining physician and contain the candidate's complete aviation and medical histories and examination findings.

2. *Psycho-physiological stress testing procedures.*—A determination of the candidate's psychological makeup and an estimate of his ability to cope with stresses was made.

The Air Force, with the assistance of Army and Navy specialists, conducted psychological and stress measurements at the Wright Air Development Center Aeromedical Laboratories. The examinations were in these general areas:

*(a)* Psychiatric evaluation, psychological testing, anthropometric studies.

*(b)* Stress tolerance determinations to: Thermal flux, accelerative forces, low barometric pressures, pressure suit protection, isolation and confinement.

*(c)* Final clinical appraisal of suitability.

Testing at WADC was conducted with candidates in six groups of five men each and one group of two. The first group entered February 15; each man was evaluated 6 days and 3 evenings. A complex appraisal of both clinical and statistical test results went into the WADC evaluation of candidates. As in the case of the Lovelace examinations, results were not a matter of passing or failing, but instead were measures of how one candidate compared with all others.

3. *Final selection.*—Data from the Lovelace and WADC examinations were compiled and forwarded to the NASA Langley space flight activity, for the fourth and final step in the selection process. At Langley, a group representing both the medical and technical fields evaluated the previous examinations. The seven ultimately selected were chosen as a result of physical, psychological and stress tolerance abilities and because of the technical experience each represents.

*Clinical examinations given by the Lovelace Clinic*

Medical history and physical examination, with internal examinations and orthopedic or other specialty consultations, included:

1. Laboratory tests: hemoglobin (measure of oxygen carrying red pigment); hematocrit (examination of blood by use of a centrifuge); grouping; Rh factor; serology (examination of blood serums); sedimentation rate (analysis of urine deposits); stool examinations; urinalysis; gastric analysis; cholesterol (substance present in gallstones, heart ailments, etc.); liver function test; urinary steroid excretion (measures of the hormones, acids and poisons); blood nitrogen; blood protein; protein-bound iodine; special serum studies; throat culture, and chemical examination of body outputs, and blood counts.
2. X-rays: chest, large intestine, sinuses, spine, stomach, esophagus, teeth and heart. Moving pictures were taken of the heart to determine any artery calcification.
3. Eyes: history, dilation, visual fields, tonometry (measure of inner pressure on the eyes), slit lamp, dynamic visual acuity, depth perception, night vision, and photography of conjunctival vessel (eye membrane) and retina.
4. Ears, nose, and throat: examination of throat and nasal passages; audiogram with and without background noises; speech discrimination and voice tape recording.
5. Heart: cardiograms of heart muscle contraction, heart stroke volume and heart sounds; measure of the chest which overlies the heart.
6. Nerves and muscles: general neurologic examination with muscle testing; electric stimulation of the nerves to determine response; measure of any nerve abnormality; tracing of electric currents produced by the brain.

*Special dynamic examinations given by the Lovelace Clinic to measure body efficiency*

1. Physical competence: measured by an ergometer, a device similar to a bicycle. Subject pedals increasing amount of weight while wearing an oxygen mask. Heartbeat and oxygen consumption determined. Evaluation is made by the amount subject can pedal by the time his heart reaches 180 beats per minute.
2. Pulmonary function: lung capacity and breathing efficiency determined by measuring the amount of oxygen subject breathes normally and during exercise.
3. Lean body mass: a correlation of the following:

   Total body radiation count, conducted by the Atomic Energy Commission's Los Alamos Laboratories to determine the amount of potassium in the body.

   Specific gravity, weighing the subject in air and while he is totally immersed in water.

   Blood volume, measured by inhaling a small amount of carbon monoxide and observing the amount absorbed by the blood after a specified time.

   Water volume, determined by swallowing a small amount of tritium and observing its rate of dilution.
4. Presence of heart-chamber openings: amount of blood oxygen is measured during and after a Valsalva maneuver. The Valsalva exercise is accomplished by blocking the nose and blowing into a tube.

*Stress test conducted at the Wright Air Development Center*

1. Harvard step: subject steps up 20 inches to a platform and down once every 2 seconds for 5 minutes to measure his physical fitness.
2. Treadmill maximum workload: Subject walks at a constant rate on a moving platform which is elevated 1 degree each minute. Test continues until heart reaches 180 beats per minute. Test of physical fitness.
3. Cold pressor: Subject plunges his feet into a tub of ice water. Pulse and blood pressure measured before and during test.
4. Complex behavior simulator: A panel with 12 signals, each requiring a different response. Measure of ability to react reliably under confusing situations.

5. Tilt table: Subject lays on steeply inclined table for 25 minutes to measure ability of the heart to compensate for body in an unusual position for an extended time.

6. Partial pressure suit: Subject is taken in pressure chamber to a simulated altitude of 65,000 feet in an MC1 partial pressure suit. Test lasts 1 hour. Measure of efficiency of heart system and breathing at low ambient pressures.

7. Isolation: Subject goes into a dark, soundproof room for 3 hours to determine his ability to adapt to unusual circumstances and to cope with the absence of external stimuli.

8. Acceleration: Subject is placed in a centrifuge with his seat inclined at various angles to measure his ability to withstand multiple gravity forces.

9. Heat: Subject spends 2 hours in a chamber with the temperature at 130° F to measure reaction of heart and body functions while under this stress.

10. Equilibrium and vibration: Subject is seated on a chair which rotates simultaneously on two axes. He is required to maintain the chair on an even keel by means of a control stick with and without vibration, normally and while blindfolded.

11. Noise: Subject is exposed to a variety of sound frequencies to determine his susceptibility to tones of high frequency.

*Psychological tests administered at the Wright Air Development Center*

1. To determine personality and motivation: Interviews; Rorschach (ink blot); apperception (tell stories suggested by pictures); draw-a-person; sentence completion; self-inventory based on 566-item questionnaire; officer effectiveness inventory; personal preference schedule based on 225 pairs of self-descriptive statements; personal inventory based on 20 pairs of self-descriptive statements; preference evaluation based on 52 statements; determination of authoritarian attitudes, and interpretation of the question, Who am I?

2. To determine intelligence and special aptitudes: Wechsler adult scale; Miller analogies; Raven matrices; Doppelt mathematical reasoning test; engineering analogies; mechanical comprehension; officer qualification test; aviation qualification test; space memory; spatial orientation; hidden figures perception; spatial visualization, and peer ratings.

## 2. Psychiatric Evaluation of Candidates for Space Flight[1]

(A paper by George E. Ruff, Captain, USAF (MC) and Edwin Z. Levy, Captain, USAF (MC), Stress and Fatigue Section, Biophysics Branch, Aero Medical Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio)

The high levels of stress expected in space flight require careful screening of potential pilots by psychological and physiological techniques. Since emotional demands may be severe, special emphasis must be placed on psychiatric evaluation of each candidate for a space mission.

The selection process begins with a detailed analysis of both the pilot's duties and the conditions under which he will carry them out. As long as we have had no direct experience with space flight, some aspects of this analysis will necessarily be speculative. We must thus rely heavily on knowledge of behavior during stress situations in the past. As a result, data from military operations, survival experiences, and laboratory experiments have guided the choice of men for space missions now being planned.

Although striking exceptions are seen, the individuals who have done best under difficult circumstances in the past have been mature and emotionally stable. They have usually been able to harmonize internal needs with external reality in an effective manner. When subjected to stress, anxiety has not reached high enough levels to paralyze their activity.

After the requirements of the mission and the qualifications of the individual best suited to accomplish it have been decided, it is necessary to select measures for determining who has the most of each desirable characteristic and the least of each undesirable characteristic. This can be done by using interviews and projective tests to give an intensive picture of each individual. Objective tests supplement the personality evaluation and measure intellectual functions, aptitudes, and achievements. After examination of the background data, interview material, and test results, clinical judgment is used to decide which men are psychologically best qualified for the assignment.

As firsthand knowledge of space flight increases, these procedures must be reexamined. When enough data have accumulated, predictions can be checked against performance criteria. Methods

[1]For presentation to 115th annual meeting, the American Psychiatric Association, Philadelphia, Pa., Apr. 29, 1959.

which predicted accurately will be retained and improved. Those with little value will be discarded. New measures can be added on the basis of increasing experience. Once correlation between psychological variables and the quality of performance have been determined, the accuracy of future selection programs should be raised.

A clinical approach of this type was used in selecting pilots for the first U.S. manned satellite experiment—NASA's Project Mercury. The objective was to choose men for a 2-year training program, followed by a series of ballistic and orbital flights. The pilot's duties will consist largely of reading instruments and recording observations. However, he will retain certain decision-making functions, and will be required to adapt to changing conditions as circumstances may demand.

By combining data on the nature of this mission with information on behavior during other stressful operations, the following general requirements were established:

(1) Candidates should have a high level of general intelligence, with abilities to interpret instruments, perceive mathematical relationships, and maintain spatial orientation.

(2) There should be sufficient evidence of drive and creativity to insure positive contributions to the development of the vehicle and other aspects of the project as a whole.

(3) Relative freedom from conflict and anxiety is desirable. Exaggerated and stereotyped defenses should be avoided.

(4) Candidates should not be overly dependent on others for the satisfaction of their needs. At the same time, they must be able to accept dependence on others when required for success of the mission. They must be able to tolerate either close associations or extreme isolation.

(5) The pilot should be able to function when out of familiar surroundings and when usual patterns of behavior are impossible.

(6) Candidates must show evidence of ability to respond predictably to foreseeable situations, without losing the capacity to adapt flexibly to circumstances which cannot be foreseen.

(7) Motivation should depend primarily on interest in the mission rather than on exaggerated needs for personal accomplishment. Self-destructive wishes and attempts to compensate for identity problems or feelings of inadequacy are undesirable.

(8) There should be no evidence of impulsivity. The pilot must act when action is appropriate, but refrain from action when inactivity is appropriate. He must be able to tolerate stress situations positively, without requiring motor activity to dissipate anxiety.

The chances of finding men to meet these requirements were increased by the preselection process. Eligibility for the mission was restricted to test pilots who had repeatedly demonstrated their ability to perform functions essential for the Mercury project. Records of men in this category were reviewed to find those best suited for the specific demands of the mission. A group of 69 were then invited to volunteer. The 55 who accepted were given a series of interviews and psychological tests. On the basis of these data, 32 were chosen for the final phase of the selection program. This phase was designed to evaluate each candidate's medical and psychological status, as well as to determine his capacity for tolerating stress conditions expected in space flight.

The psychological evaluation included 30 hours of psychiatric interviews, psychological tests, and observations of stress experiments. The information obtained was used to rate candidates on a 10-point scale for each of 17 categories. Ratings were made on the basis of specific features of behavior—both as indicated by the past history and as observed during the interviews. Even though the general population was used as a reference group, the scales are normative only in an arbitrary sense. The 10 levels represent subjective decisions on which characteristics are ideal, which are average and which are undesirable. Although the reliability among raters is excellent, validation studies have not yet been done.

The categories are:

(1) Drive: An estimate of the total quality of instinctual energy.

(2) Freedom from conflict and anxiety: A clinical evaluation of the number and severity of unresolved problem areas and of the extent to which they interfere with the candidate's functioning.

(3) Effectiveness of defenses: How efficient are the ego defenses? Are they flexible and adaptive or rigid and inappropriate? Will the mission deprive the candidate of elements necessary for the integrity of his defensive system?

(4) Free energy: What is the quantity of neutral energy? Are defenses so expensive to maintain that nothing is left for creative activity? How large is the "conflict-free sphere of the ego"?

(5) Identity: How well has the candidate established a concept of himself and his relationship to the rest of the world?

(6) Object relationships: Does he have the capacity to form genuine object relationships? Can he withdraw object cathexes when necessary? To what extent is he involved in his relationships with others?

(7) Reality testing: Does the subject have a relatively undistorted view of his environment? Have his life experiences been broad enough to allow a sophisticated appraisal of the world? Does his view of the mission represent fantasy or reality?

(8) Dependency: How much must the candidate rely on others? How well does he accept dependency needs? Is separation anxiety likely to interfere with his conduct of the mission?

(9) Adaptability: How well does he adapt to changing circumstances? What is the range of conditions under which he can function? What are the adjustments he can make? Can he compromise flexibly?

(10) Freedom from impulsivity: How well can the candidate delay gratification of his needs? Has his behavior in the past been consistent and predictable?

(11) Need for activity: What is the minimum degree of motor activity required? Can he tolerate enforced passivity?

(12) Somatization: Can the candidate be expected to develop physical symptoms while under stress? How aware is he of his own body?

(13) Quantity of motivation: How strongly does he want to participate in the mission? Are there conflicts between motives—whether conscious or unconscious? Will his motivation remain at a high level?

(14) Quality of motivation: Is the subject motivated by a desire for narcissistic gratification? Does he show evidence of self-destructive wishes? Is he attempting to test adolescent fantasies of invulnerability?

(15) Frustration tolerance: What will be the result of the failure to reach established goals? What behavior can be expected in the face of annoyances, delays, or disappointments?

(16) Social relationships: How well does the subject work with a group? Does he have significant authority problems? Will he contribute to the success of missions for which he is not chosen as pilot? How well do other candidates like him?

(17) Overall rating: An estimate of the subject's suitability for the mission. This is based upon interviews, test results, and other information considered relevant.

It can be seen that catetories 1, 2, 4, and 10 are largely economic constructs: 3, 5, 6, and 7 are ego functions; while the rest are specific characteristics considered important for space flight. The categories represent many different levels of abstraction and are not independent dimensions. In the final analysis, they are less a means of quantifying data than of organizing their interpretation. Not only do they provide a method to compare one subject with another, but also tend to focus attention on the material most closely related to the mission requirements.

An initial evaluation of each man was made by two psychiatrists, through separate interviews during the preliminary screening period. One interview was devoted primarily to a review of the history and current life adjustment, while the other was relatively unstructured. Finally, ratings were compared, information pooled, and a combined rating made. Areas of doubt and disagreement were recorded for subsequent investigation.

The men accepted for the final screening procedure were seen again several weeks later, after an intensive evaluation of their physical status had been completed. Each candidate was reinterviewed and the following psychological tests were administered:

*Measures of motivation and personality*

(1) Rorschach.

(2) Thematic apperception test.

(3) Draw-a-person.

(4) Sentence completion test.

(5) Minnesota multiphasic personality inventory.

(6) Who am I?: The subject is asked to write 20 answers to the question "Who am I?" This is interpreted projectively to give information on identify and perception of social roles.

(7) Gordon personal profile: An objective personality test yielding scores for "ascendency," "responsibility," "emotional stability," and "sociability."

(8) Edwards personal preference schedule: A forced-choice questionnaire measuring the strengths of Murray's needs.

(9) Shipley personal inventory: Choices are made from 20 pairs of self-descriptive statements concerning psychosomatic problems.

(10) Outer-inner preferences: A measure of interest in and dependence on social groups.

(11) Pensacola Z-scale: A test of the strength of "authoritarian" attitudes.

(12) Officer effectiveness inventory: A measure of personality characteristics found in successful Air Force officers.

(13) Peer ratings: Each candidate was asked to indicate which of the other members of the group

who accompanied him through the program he liked best, which one he would like to accompany him on a two-man mission, and which one he would assign to the mission if he could not go himself.

*Measures of intellectual functions and special aptitudes*

(1) Wechsler adult intelligence scale.

(2) Miller analogies test.

(3) Raven progressive matrices: A test of nonverbal concept formation.

(4) Doppelt mathematical reasoning test: A test of mathematical aptitudes.

(5) Engineering analogies: A measure of engineering achievement and aptitudes.

(6) Mechanical comprehension: A measure of mechanical aptitudes and ability to apply mechanical principles.

(7) Air Force officer qualification test: The portions used are measures of verbal and quantitative aptitudes.

(8) Aviation qualification test (USN): A measure of academic achievement.

(9) Space memory test: A test of memory for location of objects in space.

(10) Spatial orientation: A measure of spatial visualization and orientation.

(11) Gottschaldt hidden figures: A measure of ability to locate a specified form imbedded in a mass of irrelevant details.

(12) Guilford-Zimmerman spatial visualization test: A test of ability to visualize movement in space.

In addition to the interviews and tests, important information was obtained from the reactions of each candidate to a series of stress experiments simulating conditions expected during the mission. Neither the design of these tests nor the physiological variables measured will be discussed. Psychological data were derived from direct observation of behavior, postexperimental interviews, and administration before and after each run of alternative forms of six tests of perceptual and psychomotor functions. These procedures were:

(1) Pressure suit test: After dressing in a tightly fitting garment designed to apply pressure to the body during high altitude flight, each candidate entered a chamber from which air was evacuated to simulate an altitude of 65,000 feet. This produces severe physical discomfort and confinement.

(2) Isolation: Each man was confined to a dark, soundproof room for 3 hours. While this brief period is not stressful for most people, data are obtained on the style of adaption to isolation. This procedure aids in identifying subjects who cannot tolerate enforced inactivity, enclosure in small spaces or absence of external stimuli.

(3) Complex behavior simulator: The candidate was required to make different responses to each of 14 signals which appeared in random order at increasing rates of speed. Since the test produces a maximum of confusion and frustration, it measures ability to organize behavior and to maintain emotional equilibrium under stress.

(4) Acceleration: The candidates were placed on the human centrifuge in various positions and subjected to different G loads. This procedure leads to anxiety, disorientation, and blackout in susceptible subjects.

(5) Noise and vibration: Candidates were vibrated at varying frequencies and amplitudes and subjected to high energy sound. Efficiency is often impaired under these conditions.

(6) Heat: Each candidate spent 2 hours in a chamber maintained at 130°. Once again, this is an uncomfortable experience during which efficiency may be impaired.

After all tests were completed, an evaluation of each man was made by a conference of those who had gathered the psychological data. Final ratings were made in each category described previously, special aptitudes were considered, and a ranking within the group was derived. By combining the psychiatric evaluations, results of the physical examinations and physiological data from the stress test procedures, the group was subdivided under the headings "Outstanding," "Recommended," and "Not Recommended." Finally, seven men were chosen from the list according to the specific needs of the Mercury project.

## IMPRESSIONS OF CANDIDATES FOR SPACE FLIGHT

Although the results of the selection program can't be assessed for several years, impressions derived from psychiatric evaluations of these candidates are of interest. In answer to the question, "What kind of people volunteer to be fired into orbit?" one might expect strong intimations of psychopathology. The high incidence of emotional disorders in volunteers for laboratory experiments had much to do with the decision to consider only candidates with records of effective performance under difficult circumstances in the past. It was hoped that avoiding an open call for volunteers would reduce the number of unstable candidates.

In spite of the preselection process, we were surprised by the low incidence of such disorders in the 55 candidates who were interviewed. For the 31 candidates who survived the initial screening and physical examination, repeat interviews and psychological tests confirmed the original impressions. There was no evidence for a diagnosis of psychosis, clinically significant neurosis, or personality disorder in any member of this group.

Certain general comments can be made concerning the 31 men who received the complete series of selection procedures. The mean age was 33, with a range from 27 to 38. All but one were married. Twenty were from the Midwest, Far West, or Southwest. Only two had lived in large cities before entering college. Twenty-seven were from intact families. Twenty were only or eldest children. (In this connection, it is perhaps worth noting that four of the seven men chosen are named "junior.") Pronounced identifications with one parent were about equally divided between fathers and mothers, although mothers with whom such identifications were present were strong, not infrequently masculine figures.

Impressions from the interviews were that these were comfortable, mature, well-integrated individuals. Ratings in all categories of the system used consistently fell in the top third of the scale. Reality testing, adaptability, and drive were particularly high. Little evidence was found of unresolved conflict sufficiently serious to interfere with functioning. Suggestions of overt anxiety were rare. Defenses were effective, tending to be obsessive-compulsive, but not to an exaggerated degree. Most were direct, action-oriented individuals, who spend little time introspecting.

Although dependency needs were not overly strong, most showed the capacity to relate effectively to others. Interpersonal activities were characterized by knowledge of techniques for dealing with many kinds of people. They do not become overly involved with others, although relationships with their families are warm and stable.

Because of the possibility that extreme interest in high performance aircraft might be related to feelings of inadequacy in sexual or other areas, particular emphasis was placed on a review of each candidate's adolescence. Little information could be uncovered to justify the conclusion that unconscious problems of this kind were either more or less common than in other occupational groups.

A high proportion of these men apparently passed through adolescence in comfortable fashion. Most made excellent school and social adjustments. Many had been class presidents or showed other evidence of leadership.

Most candidates entered military life during World War II. Some demonstrated an unusual interest in flying from an early age, but most had about the same attitudes toward airplanes as other American boys. Many volunteered for flight training because it provided career advantages or appeared to be an interesting assignment.

Candidates described their feelings about flying in a variety of terms: "something out of the ordinary," "a challenge," "a chance to get above the hubbub," "a sense of freedom," "an opportunity to take responsibility." A few look upon flying as a means of proving themselves or to build confidence. Others consider it a "way for good men to show what they can do."

Although half the candidates volunteered for training as test pilots, the others were selected because of achievements in other assignments. Most view test flying as a chance to participate in the development of new aircraft. It enables them to combine their experience as pilots and engineers. Their profession is aviation and they want to be in the forefront of its progress. Danger is admitted, but deemphasized—most feel nothing will happen to them. But this seems to be less a wishful fantasy than a conviction that accidents can be avoided by knowledge and caution. They believe that risks are minimized by thorough planning and conservatism. Very few fit the popular concept of the daredevil test pilot.

Although attempts have been made to formulate the dynamics underlying the pursuit of this unusual occupation, generalizations are difficult to make. Motives vary widely. While it is clear that conscious reasons may be unrelated to unconscious determinants, the variation in conscious attitudes illustrates the impossibility of a single explanation for a career which has different meanings for different individuals. One man, for example, stated that he enjoys flight testing because it allows him to do things which are new and different. He enjoys flying the newest aircraft available—vehicles that most pilots will not see for several years. Another is an aeronautical engineer who is primarily interested in aircraft design. He looks upon a flight test much as the researcher views a laboratory experiment.

Reasons for volunteering for Project Mercury show a mixture of professionalism and love of adventure. Candidates are uniformly eager to be part of an undertaking of vast importance. On one hand, space flight is viewed as the next logical step in the progress of aviation; on the other, it represents a challenge. One man expressed the sentiments of the group by saying, "There aren't many new frontiers. This is a chance to be in on one of them." Other expressions included: "a new dimension of flight," "a further stage in the flight envelope of the manned vehicle," "a chance to get your teeth into something big," "the sequel to the aviation age," a "contribution to human knowledge," "an opportunity for accomplishment," "the program of the future," "an interesting, exciting field," "a chance to be on the ground floor of the biggest thing man has ever done."

At the same time, most candidates were practical. They recognized that this project will benefit their careers. To some it is a chance to insure an interesting assignment. Most recognize the trend away from conventional manned aircraft and look upon the Mercury project as a means for getting into the midst of future developments. One said: "We're the last of the horse cavalry. There aren't going to be many more new fighters. This is the next big step in aviation. I want to be part of it." Most are aware of the potential personal publicity and feel this would be pleasant, but "not an important reason for volunteering."

Although all candidates are eager to make the flight, it is not their only concern. Most want to participate in development of the vehicle and have an opportunity to advance their technical training. The orbital ride is partly looked upon as a chance to test an item of hardware they have helped develop. Risks are appreciated, but accepted. Most insist they will go only when the odds favor their return. No one is going up to die. They are attracted by the constructive rather than the destructive aspects of the mission.

Psychological tests of these 31 men indicate a high level of intellectual functioning. For example, the mean full-scale scores for the seven who have been selected range from 130 to 141, with a mean of 135. The pattern is balanced, with consistently high scores on both verbal and performance subtests.

Projective measures suggest the same healthy adaptations seen in the interviews. Responses to the Rorschach, for example, were well organized. Although not overly rigid, they did not suggest much imagination and creativity. Aggressive impulses tended to be expressed in action rather than fantasy.

Behavior during the isolation and complex behavior simulator tests—which might be considered input-underload and input-overload situations—showed evidence of great adaptability. No candidate terminated isolation prematurely and none viewed it as a difficult experience. As might be expected for this brief exposure, no perceptual changes were reported. Fifteen subjects "programmed" their thinking in isolation. In five of these men, the attempt to organize thoughts was considered evidence of an overly strong need for structuring. Sixteen permitted random thought, relaxed and enjoyed the experience. Most slept at least part of the time.

When placed under opposite conditions—with too much to do instead of too little—the candidates were usually able to keep from falling hopelessly behind the machine. Only a few were troubled by the impossibility of making all responses promptly. The majority became content to do as well as possible, showing a gradually increasing level of skin resistance, even though working at a frantic pace.

Reactions to physiological stressors correlated positively with the psychiatric evaluations. Candidates who had been ranked highest on psychological variables tended to do best in acceleration, noise and vibration, heat, and pressure chamber runs. Their stress tolerance levels were among the highest of the hundreds of men subjected to these procedures in the past. Uncomplaining acceptance of the discomforts and inconveniences of this phase of the program appeared to reflect not only their strong motivation, but also their general maturity and capacity to withstand frustration.

In summary, it is suggested that the most reasonable approach to selecting men for doing something no one has done before is to choose those who have been successful in demanding missions in the past. To decrease the probability of error, a broad sample of behavior must be observed. Every effort should be made to make these observations as relevant to the expected demands of the mission as possible.

By selecting only those candidates who were able to adapt to whatever conditions confronted them, we hope we have found those who are best qualified for space flight. Our confidence is further strengthened by the attitudes of the men who were chosen. Most reflected the opinion of the candidate who, when asked why he had volunteered, explained: "In the first 50 years since the Wright brothers, we learned to fly faster than sound and higher than 50,000 feet. In another 5 years, we doubled that. Now we're ready to go out 100 miles. How could anyone turn down a chance to be part of something like this?"

## Item 2

### Astronaut Training Programs for Mercury, Gemini, and Apollo

The following are extracts from U.S. Senate, *Project Mercury: Manned Space Program of the NASA,* and "Flight Crew Training Program," NASA General Working Paper 10 022, prepared at Manned Spacecraft Center, Houston, and dated Jan. 17, 1964. Other items describing the medical and training programs are in publications cited in the "Technical Reports" section of the bibliography.

2. MERCURY ASTRONAUT TRAINING PROGRAM

The initial phase of the astronaut training program is broken down into six areas of activity:

1. *Education in the basic sciences.* —Essentially an academic educational program, this area includes instruction in astronautics, particularly ballistics, trajectories, fuels, guidance, and other aspects of missile operations, basic aviation medicine and orbital flight hygiene, the space environment, astronomy, meteorology, astrophysics, and geography, including the techniques for making scientific observations in these areas.

2. *Familiarization with the conditions of space flight.* —This phase of training is designed to familiarize the astronauts with the heat, pressure, G force levels and other special conditions of space flight. It includes periodic simulated flights in centrifuges and pressure chambers, weightless flying, training in human disorientation devices, the development of techniques to minimize the effects of vertigo, and experiments with high heat environments.

This part of the training program will provide data on the ability of the astronaut to contribute to system reliability under the conditions to be encountered during flight, the psychological and physiological effects of the normal and various emergency conditions which may be encountered during flight, and the requirements for the support and restraint systems, the environmental control system, and the crew space layout.

3. *Training in the operation of the Mercury space vehicle.* —The objective of this segment of the program is to provide a thorough knowledge in the operation and maintenance of the Mercury vehicle and its component subsystems, with particular emphasis being placed on the use and maintenance of the scientific instruments and life-support equipment.

4. *Participation in the vehicle development program.* —Each of the astronauts is assigned to a system or subsystem of the Mercury vehicle. In this work, he will acquire specialized knowledge of value to the entire group. This information is exchanged in a series of informal seminars.

Actual work on the vehicle development program by the astronauts will provide limited augmentation of the Space Task Group staff as well as providing them with an intimate knowledge of all aspects of the Mercury vehicle itself.

5. *Aviation flight training.* —The Mercury astronauts will continue to maintain their proficiency in high performance aircraft in an aviation flight training program. Continued operation of high performance aircraft will give them additional altitude acclimatization, instrument flight training and the physiology of high altitude, high speed flight.

6. *Integration of astronaut and ground support and launch crew operation.* —Familiarization with the operation of ground support equipment and launch crew operations will be accomplished in coordination with the agencies providing boosters and launch facilities. Training in the operation and use of ground support equipment and observation of launch operations will provide the astronauts with complete knowledge of the launch phase of Mercury flights.

Existing research, development, training and test facilities of the armed services, industry and educational institutions throughout the country will be utilized for maximum effectiveness at minimum cost. A number of experts in many of the scientific and technical subject areas will give lectures to the astronauts during their educational program.

The concentrated astronaut education program began with overall program orientation briefings by members of the Space Task Group staff. While assigned to the Langley facility, the Mercury astronauts will work as integrated members of the NASA Space Task Group.

Each of the Mercury astronauts had been detailed to the NASA by his respective military service but is still considered to be on active duty and is receiving military service pay. The astronauts will remain on duty with NASA on a full-time basis.

*Completed training activities*

1. Visit to McDonnell Aircraft Corp., St. Louis, for capsule familiarization.
2. Wright Air Development Center:
   *(a)* General pressure suit indoctrination:
      (1) Centrifuge ride using Redstone and Atlas launch profiles.
      (2) Reentry heat profile with suits unpressurized but vented.
      (3) Pressure chamber run to 100,000 feet with suit pressurized.
   *(b)* Check of low residue diets for 3 days.
3. Naval Medical Research Institute of Bethesda, Md.:
   *(a)* Determination of basal metabolic rate, cutaneous blood flow rate, and sweat rate at environmental temperatures of 95° F and 114° F.
   *(b)* Familiarization with the effects of excessive carbon dioxide.
4. Visit to Cape Canaveral:
   *(a)* Familiarization with the organization of the Ballistic Missile Division and the Atlantic Missile Range.
   *(b)* Study of launching procedures and missiles under development at Cape Canaveral.
5. Witness of capsule recovery operation on board a naval destroyer.
   *(a)* This recovery took place at sea when the capsule was dropped from a C-130 airplane from an altitude of 20,000 feet.
6. Skin diving training at Navy Little Creek Amphibious Base.
   *(a)* To simulate the effects of the weightless state and maintain physical fitness of the astronauts.
7. Visit to Army Ballistic Missile Agency.
   *(a)* This trip was to familiarize the astronauts with the Redstone Missile.
8. Acceleration studies with centrifuge at Johnsville.
9. Trip to Convair, San Diego, for familiarization with the Atlas booster.
   *(a)* Tour of plant facilities.
   *(b)* Study of Atlas construction and operational procedures.
   *(c)* Discussions with Convair engineers.
10. Trip to Edwards Air Force Base for briefing on the X-15 research airplane.
11. Fittings for pressure suits at contractor's (Goodrich) plant.

*Future and continuing training activities*

1. Study of space mechanics and sciences: This study consists of discussion-type training sessions led by NASA engineers and scientists. Six to ten hours of almost every week have been spent on these subjects.
2. Pressure suit checks in the McDonnell capsule at St. Louis.
3. Specialty work area assignments.
4. Training on NASA space flight simulator to develop physical skills in retrofiring and reentry.
5. Continuation of studies in space mechanics and sciences.
6. Continual participation in the vehicle development program.
7. Continuation of flight and simulator training.
8. Participation in research and development launch and recovery activities.
9. Periodic visits to McDonnell for checkout procedures and training.
10. Survival, disorientation, and communications training at Pensacola, Fla.
11. Flights for practice in eating and drinking in the weightless state.

*Astronaut specialty area assignments*

1. Malcolm S. Carpenter: Communications and navigational aids.
2. Leroy G. Cooper: Redstone booster.
3. John H. Glenn: Crew space layout.
4. Virgil I. Grissom: Automatic and manual attitude control system.
5. Walter M. Schirra: Life support system.
6. Alan B. Shepard: Range, tracking, and recovery operations.
7. Donald K. Slayton: The Atlas booster.

# GEMINI AND APOLLO TRAINING

## 3.0 Training Program

The Training Phasing Chart (chart 1, section 4.0) is provided to indicate the overall chronological phasing of the training for the preparation of the flight crews for crew assignment to the first manned flights of the projects. The Gemini training for the command and senior astronauts and the astronauts is staggered due to the required time to train the new group. This staggering of the Gemini mission training eliminates the unrealistic trainer time utilization required for preparing the total group simultaneously for the first flights.

The training program is discussed in detail in this section under three major headings: General, Gemini and Apollo training.

3.1 **General Training:** The training areas that fall under the general heading are those that apply to both projects. These areas are Science and Technology Summary Courses, Operations Familiarization, Environmental Familiarization, Contingency Training, Spacecraft and Launch Vehicle Design and Development and Aircraft Flight Program.

3.1.1 **Science and Technology Summary Courses:** The Space Science and Technology courses were chosen to fulfill the specific requirements as designated in section 2.0. They are oriented to bring the flight crews to a common level of understanding on the subjects. The majority of these courses are basic in nature with two of them dealing directly with spacecraft systems—Gemini Onboard Computer and Apollo Guidance and Navigation. However, a basic digital computer course is given prior to the specific Gemini computer course and the basic material of inertial guidance systems is covered in conjunction with the Apollo Guidance and Navigation. With a limited amount of training time available, all of the courses are aligned to presenting that portion of the material under the subject title that is pertinent to the work of the flight crews within the projects and missions. Each course is defined in outline form in the Appendix.

A detailed schedule for the academic program is given in section 4.0. On a weekly basis the courses are scheduled on Monday, Tuesday, and Wednesday for sixteen hours of instruction. The remainder of the week, during this period of academic training, is devoted to project briefings, systems training, operations familiarization, course field trips, physical fitness, and aircraft flying.

The Science and Space Technology courses are listed below with the number of hours of instruction:

| Course | Hours Instruction |
|---|---|
| * Geology | 58 |
| ** Flight Mechanics | 40 |
| ** Digital Computers | 12 |
| * Gemini Onboard Computer | 24 |
| Rocket Propulsion Systems | 12 |
| Aerodynamics | 8 |
| Astronomy | 15 |
| * Guidance & Navigation | 34 |
| Communications | 8 |
| Physics of the Upper Atmosphere and Space | 12 |
| Medical Aspects of Space Flight | 12 |
| Meteorology | 4 |
| Total | 239 |

*All flight crews will participate.
**Refresher courses for command and senior flight crews—participate when possible.

Further instruction in geology after the designated 58 hour course will be scheduled on a frequent basis to prepare the flight crews for exploration of the lunar surface. The general content of the follow-on program in geology is also indicated in the Appendix.

3.1.2 **Operations Familiarization:** The flight crews will be familiarized with the operational support required for spaceflight. The following briefings and tours of facilities will be conducted:

1. Gemini Prelaunch Activities (Cape Kennedy)—

   Overall prelaunch activities briefing

   Tour and briefing on spacecraft and astronaut prelaunch activities (hangar S)

Tour of complex 19 and briefings on launch operation

Briefing at Gemini Control Center on operations and equipment including launch vehicle guidance

Briefing at central control on operation and equipment

2. Apollo Prelaunch Activities (Cape)—Tour and briefing at Saturn launch complex on launch operation

3. Integrated Mission Control Center—Briefing on Equipment and Operation

4. Recovery Operations Briefing

3.1.3 **Environmental Familiarization:** The areas of the mission environment in which the flight crews will be familiarized are acceleration, weightlessness, lunar gravity, vibration and noise, and pressure suit environment.

1. Acceleration—The acceleration familiarization is one of the objectives of the centrifuge programs. The purpose of this training is to minimize possible pilot performance degradation because of accelerations. The second Gemini centrifuge training program is planned to be conducted shortly before the first manned Gemini flights. This program will familiarize the flight crews with launch, selected launch aborts and reentry acceleration profiles. A similar centrifuge training program is planned for the Apollo program. The centrifuge programs are discussed in detail in the Gemini and Apollo training portions of this paper.
2. Weightlessness and Lunar Gravity—By means of a modified KC-135 to fly at zero gravity for approximately 30 seconds per parabolic trajectory the flight crews will be exposed to weightlessness. In the same manner the crews will be exposed to lunar gravity (1/6 "g"). Each pilot will receive two flights in the KC-135 with each flight containing 18–20 parabolas. Three pilots can be accommodated on a flight. Therefore, the training will require ten flights (two flights per day for five days) to complete the training for the fourteen astronauts. The 6570th Aerospace Medical Research Laboratories, Wright Patterson Air Force Base, will support and conduct this training.

   Within the two KC-135 flights the flight crews will accomplish the following activities:

a. Torque board (small plywood panel with handles on both sides)
b. Soaring and tumbling
c. Self-rotation
d. Free-float sensations
e. Eating and drinking
f. Hand tool maintenance (untethered)
g. Hand tool maintenance (tethered)
h. Single-impulse mass ejection
i. Tumble and spin recovery
j. Self maneuvering unit flight
k. Fluid dynamics demonstration
l. Coriolis effect demonstration
m. Walking behavior under lunar gravity

The flight crews will practice moving about under lunar traction with the Apollo pressure suit and personal life support system prior to the lunar landing mission. A device consisting of a platform inclined at the correct angle to produce 1/6 gravity for the man suspended perpendicular to the platform by a guywire system will be used. This device is limited to only one direction of motion and will be supplemented by aircraft flights.

3. Vibration and Noise—No special training will be provided in this area. However, exposure to the vibrational modes and noise environment of the launch vehicle is included in the part-task launch abort training to be received on the Ling-Temco-Vought simulator. The noise environment will also be simulated through the headsets in the mission simulators.

4. Pressure Suit—Upon receipt of the training pressure suits the flight crews will be given an indoctrination to the capabilities of the suit. The Space Suit Section of Crew Systems Division will conduct this training in conjunction with and post-suit fitting sessions. The content of the indoctrination is listed below:

a. Briefing on suit design and construction

b. Practice donning and doffing suit

c . Experience walking at 3.5 psi differential pressure

d. Experience mobility of suit in spacecraft mock-up at 0, 3.5, and 5.0 psi differential pressures

e. Experience altitude chamber ride for operation of the suit under design conditions

Throughout the different training programs, the pilots will use their pressure suits to become familiar with its operation in the different phases of the mission.

3.1.4 **Contingency Training:** Those contingency situations that can occur during or after a space flight for which training can reduce the hazards involved are survival after landing in hostile terrain until recovery, ejection and use of the personal parachute.

1. The three basic survival conditions for which training will be accomplished are tropic, desert and water. The purpose of the training is to provide the pilots with the confidence and ability to survive in an emergency landing environment until rescue can be effected. In each case the training is divided into three phases: lectures and briefings on survival concepts, techniques and skills; demonstrations of the survival methods; and field experience to apply the knowledge gained from the first two phases.

   a. Tropic Survival—The five day course in tropical survival will be supported by the USAF Tropic Survival School, Albrook Air Force Base, Panama Canal Zone. The first two days will be lectures and demonstrations and the next three days will be field training. The academics will include lectures on the major types of tropical rain forests, tropic plants and animals as applicable to survival, terrain, travel, self first-aid, use of kit equipment, and contacting indigenous people.

      The demonstrations include shelter construction, improvising equipment, building animal snares and traps, and signaling.

      Two days will be spent at field sites with one day required to travel to and from the field area. In the field the crews will be split into teams of two men each, as the case would be in Gemini, and assigned an area for their campsite out of sight and hearing of the other teams. One instructor is assigned to two teams to monitor their activities and give advice when necessary. Each man will have the same equipment as he would have in an actual survival situation. In the field training the flight crews will receive first-hand experience in procuring food, establishing a camp, improvising equipment and clothing and signaling rescue aircraft in the tropical environment.

b. Desert Survival—The desert survival course will be a five day course implemented in the same manner as the tropic survival. The Air Force Survival School, 3635th Flying Training Wing, Stead Air Force Base, Nevada, will provide the instruction formulated around space flight mission requirements. One and one-half days of academics will be received on the characteristics of world desert areas and survival techniques. One day of demonstrations will be given at the field site on the proper use and care of the survival equipment, and the use of the parachute in the construction of clothing, shelters and signals. The field training will be conducted in an area considered representative of many of the world's desert regions. As in the tropic survival field training the teams of two pilots each will spend two days at remote sites practicing desert survival techniques in practical training.

c. Water Survival—The one-half day academic portion of the water survival training will be given by Dr. D. Stullken of the Recovery Operations Division. Dr. Stullken's lecture will cover the following topics: requirements for human survival; food and water requirements and sources at sea; progressive aspects of survival; effects of drinking sea water.

   For the practical experience in water survival one day of activities is scheduled at the Water Safety and Survival School, Naval School of Preflight, Pensacola, Florida. They will conduct the following training in their enclosed tank without and with the pressure suits: basic swimming strokes; underwater escape from a cockpit; life raft boarding; parachute water landing; helicopter rescue by sling and seat; parachute drag escape; parachute engulfment and shroudline entanglement.

   The survival equipment will also be exercised during the water egress training.

2. Ejection Seat Training—Each pilot will receive two rides on the Gemini ejection seat tower at the Air Crew Equipment Laboratory, Philadelphia Naval Base, Pennsylvania. The purpose of this training is to familiarize the crew with the seat operation, build their confidence in using the seat and obtain ejection slump measurements for each pilot for adjusting the C.G. of the

Gemini seat for the actual flights. The two rides, one at 8 "g's" and 1 at 12 "g's" at approximately 250 "g's" per second onset rate, will be completed for three pilots each day of operation.

The slump data is recorded by cameras and the seat acceleration data is telemetered from the seat and presented on an oscillograph recorder. The data obtained will be extrapolated to the design limits of the Gemini ejection seat of 22 "g's" per second onset rate by correlating this data with the data received from the test program completed in July 1963.

3. Parachute Training—To prepare the flight crews for the contingency situation of using the personal parachute during a space flight mission, instruction in parachuting will be given the pilots. The course has been designed to train the flight crews in the areas of parachute landing, parachute maneuvering to avoid ground obstacles and parachute drag after landing. By far the majority of non-fatal injuries that occur in parachuting are attributed to these three areas. An area of concern on high altitude ejection is free fall, which will be covered by a comprehensive briefing. Since the use of the personal parachute could occur over land or water, the training considers both contingencies.

   The parachute training will be conducted on a very low risk basis by the use of the Para-Commander parachute built by the Pioneer Parachute Company. The safety of this parachute is inherent in its method of operation which also makes it particularly suited for training. This parachute is an ascending parachute when towed behind a vehicle with a long tow line. The distinct advantages of this canopy are: the jumper has a fully inflated and stable canopy before leaving the ground; and, the rate of descent can be controlled by the towing velocity to increase the landing velocity in increments from a light to a free descent landing.

   The following paragraphs outline each phase of the training as they will be accomplished:

   a. Parachute Landing Fall—Ground School—Four Hours—This training will consist of demonstrations, instruction, and supervised practice in "prepare-to-land" position, touchdown, roll procedures and canopy securing. Initial training will be on the ground, the second phase from a raised platform.

b. Launch Procedure—15 minutes—This training is particular to the ascension canopy and is conducted at the time of the first flight on the parachute. This training will consist of equipment checkout and launch procedure.

c. Parachute Landing Fall—Towed Flight and Landing—One and one-half per man—This phase is supervised training in actual parachute landings. Each pilot will make five towed parachute landings ranging from light to normal parachute impact.

d. Canopy Manipulation—Ground School—One-half hour—Ground training will be conducted in parachute slip and turn control by riser manipulation.

e. Canopy Manipulation—Free Descent—One hour per man—This phase consists of supervised training in actual canopy manipulation. Each pilot will make three free descents in which programmed turns and slips will be executed. The training will be accomplished by towing the trainee to altitude and releasing the tow line to provide free descent.

f. Parachute Water Landing—(Ground School)—Four hours—This phase consists of demonstration, instruction and supervised practice in water impact and harness and equipment release.

g. Parachute Water Landing—Towed Flight and Landing—One hour per man—Supervised training in actual water landings will be conducted with each pilot making three descents into the water and completing water landing procedures.

h. Free Fall Technique—Four Hour briefing—A briefing on the techniques of free fall stabilization and maneuvering will conclude the parachute training program.

3.1.5 **Spacecraft and Launch Vehicle Design and Development:** The pilots will participate in and contribute to spacecraft and launch vehicle design and development, by means of the activities listed below:

1. Participate in spacecraft and launch vehicle engineering and mock-up reviews.

2. Participate in specific contractor and MSC design and development studies and simulations.

3. Attend the various internal and contractor meetings which are of concern to the pilots.

4. Participate in pressure suit and personal equipment development.

5. Follow project ground test programs.

6. Follow the development of preflight test program of spacecraft.

3.1.6 **Aircraft Flight Program:** Spacecraft flight readiness will be maintained through the use of T-33, F-102, and T-38 type aircraft assigned to MSC and based at Ellington Air Force Base.

A two-week course in flying helicopters will be provided the pilots by the Naval School of Preflight, Pensacola, Florida, with a continuing program conducted at Ellington Air Force Base. The helicopter flying will prepare the flight crews for further simulations of the lunar landing.

3.2 **Gemini Training**

3.2.1 **Project Briefings and Systems Training:** This training will familiarize the flight crews with the total Gemini Project starting with a description of the mission to be performed and progressing to the launch vehicle systems, the spacecraft systems and crew station.

1. Mission Profiles—The following Gemini mission considerations will be presented to the pilots over a two day period:

   Movie— "Gemini Project"

   Mission Objectives

   Launch Schedule

   Spacecraft Description—Configuration and Modular Design

   Gemini; Agena Mission Phases

Launch Window Constraints
Rendezvous Trajectories and Techniques
Entry—primary and backup procedures

2. Launch Vehicle Briefing—The launch vehicle briefing will be conducted by the Martin Marietta Corporation over a two day period at the Manned Spacecraft Center. The briefing is of sixteen hours duration and is presented in two phases. Phase I is devoted to discussion of all airborne systems to a functional block diagram analysis level including systems interface. Phase II consists of discussions of vehicle and subsystems flight characteristics directly affecting manned flight.

   Phase I—Airborne Systems (Day 1)—

   LV Familiarization—The basic structure, weights, and other physical characteristics of the launch vehicle. Also, major modifications made to the Titan II in conversion to the Gemini launch vehicle.

   LV Electrical System—Power sources, distribution and the flight sequencing functions of the electrical system.

   Propulsion and Propellant Systems—A functional analysis of engine operation, of the major engine components, characteristics of the propulsion system, the propellants, their fees, monitoring, temperature conditioning, and physical characteristics.

   Guidance and Controls—Functional loop analysis of the flight controls and the MOD III G Radio Guidance Systems, block diagram discussions of the primary and secondary flight control system, a flow and component analysis of the hydraulic system, the guidance/control interface and basic flight sequencing.

   Malfunction Detection System—Detection philosophy and basic system operation.

   Range Safety and Ordnance Systems—The philosophy of and components used by the range safety and ordnance systems.

   Instrumentation System—Airborne telemetry system, major vehicle parameters to be monitored, block diagram analysis of the monitoring equipment.

AGE Philosophy and Countdown Techniques—Type of equipment used in checkout and launch of the vehicle and analysis of the countdown activities.

Phase II—Vehicle Parameters and Performance (Day 2)—

Flight Dynamics—Analysis of launch vehicle parameters.

Guidance and Controls—The parameters of control and guidance—both open and closed loop.

Propulsion System—System performance characteristics; effects of attitudes, propellant conditioning, effect of vibration on vehicle performance and changes being made to eliminate these vibrations.

Failure Modes and Abort Studies—Malfunction events and their resulting effect upon vehicle behavior and pilot escape, the relative probability of malfunctions by subsystem and steps taken to assure maximum astronaut survival.

3. Spacecraft Systems Briefings and System Trainer Operation—A 30-hour set of briefings extending over one week on the Gemini spacecraft systems will be presented to the flight crews. These lectures are operationally and sequentially oriented and will utilize the Gemini Systems Trainers extensively. In order to provide the class with a background in cockpit layout, an introduction to controls and displays will be given by Crew Station Branch before the systems lectures. Courses will be presented by qualified MAC instructors who will detail the normal modes of system operation, the alternate modes, and the functional relationships of components and subsystems. The instructors will be assisted by systems experts from the various engineering departments of MAC who will supply the design philosophies and backgrounds of each system. The schedule for the Gemini spacecraft systems briefings is:

   Monday—Controls and Displays, Attitude and Maneuver Control System

Tuesday—Attitude and Maneuver Control System

Wednesday—Electrical Power Generation and Distribution, Sequential System

Thursday—Environmental Control System, Propulsion Systems

Friday—Instrumentation, Communications

4. Crew Station—In the systems briefings the systems controls and displays will be discussed system by system without the total crew station being available. Therefore, the pilots will spend some time in the Gemini Mission Simulator to become familiar with the total crew station geometry. At this time engineers from the Flight Crew Support Division will be on hand to discuss the crew station with the individual pilots and answer their respective questions.

3.2.2 **Part Task Training:** The Gemini Part Task Training will prepare the crews for and supplement the mission simulator training in the retrofire reentry control tasks. The trainer has the capability of providing the retrofire and reentry control tasks in the rate command and direct control modes. Retrofire capabilities consist of variable thrust alinement, variable firing sequence, and failure of one or more retrorockets to fire. Four reentry profiles have been preprogramed: a constant lift trajectory, two roll modulated trajectories for correcting down range and cross range errors, and a zero lift trajectory. Approximately ten hours training per pilot will be completed, which will be dependent on the individual's needs.

The Farrand Visual Display System is being modified to provide a visual docking simulation of the Agena target in conjunction with a star background with a range capability of 50 nautical miles to docking. Although it is basically a research tool, it will also be a valuable supplement to the docking and Gemini mission trainers for night rendezvous at an earlier date than the GMS external display system. Each pilot will be scheduled for several sessions of this simulator.

3.2.3 **Launch Vehicle Abort Training:** The launch abort training will be accomplished on the Ling-Temco-Vought moving base simulator to provide a high fidelity simulation including the kinesthetic cues of a wide variety of Gemini normal and malfunction launch trajectories.

In the simulation the launch abort instrumentation of the left hand portion of the Gemini panel will duplicate the spacecraft panel with the indicator lights, accelerometer, flight director attitude indicator, analog tank pressure gauges, and the event timer. The launch vehicle controls will also be duplicated from the spacecraft.

The categories of training runs to be simulated are:

1. Normal launch or variation of limits of normal launch
2. Engine failures—partial or total loss of thrust
3. Sequential failure
4. Pressurization and propellant failures
5. Guidance failures
6. Spacecraft and instrument failures
7. Ordnance and electrical failures
8. Double failures

One week prior to the start of the simulation all the flight crews participating will receive a thorough briefing at MSC on the abort situations to be simulated, the cockpit indications of the impending failure and interpretation of these indications, the action to be taken and the ground rules for the launch abort simulation. At that time a briefing package of the launch vehicle characteristics and their mechanization in the simulator will be distributed.

The training on the simulator will consist of six two-hour sessions which will result in approximately 150 runs. Two pilots will alternate between sessions to receive two sessions a day for three consecutive days. Before the first session a short review briefing will be held at the contractor's plant to review the ground rules, simulator limitations and answer questions. The first day of running will be familiarization runs which will familiarize the pilots to the different types of failure situations. Approximately 50 familiarization runs will be completed. These runs will be quickened where possible by starting the run just prior to the initiation of the effect of the malfunction. During the familiarization runs the malfunction to be simulated will be discussed before and after each run. For the four remaining sessions the malfunctions will be programed at random to include variations of the normal launch.

The number of runs of a particular type will be determined by its difficulty to successfully abort and the probability of the malfunction.

3.2.4 **Egress Training:** The Gemini Egress Training Program consists of four training sessions plus full scale recovery training for the specific mission crew and backup crew thirty days prior to flight date.

Session One will be held at the Spacecraft Flotation Tank, Ellington Air Force Base. Training will consist of briefing on sink rate, sink attitude, underwater egress techniques, and a film on underwater escapes from boilerplate spacecraft. Two astronauts will be scheduled per session.

Session Two will also be conducted at the Flotation Tank. Training will consist of E.C.S. operation, personal equipment operation, and familiarization with flotation characteristics, and surface egress techniques and practice.

Session Three will be aboard the spacecraft handling ship "Retriever" in Galveston Bay or the Gulf of Mexico. Training will consist of demonstration of flotation characteristics on the open water, possible flooding effects, surface egress practice, and use of Gemini survival gear.

Session Four will also be aboard the spacecraft handling ship "Retriever" in the Gulf or Bay. Training will consist of practicing preimpact and impact procedures, operation of radios and E.C.S. equipment, snorkel and cabin vent valve operation, flotation collar, and shipboard egress.

Refresher training for each specific mission crew and backup crew will be held in open water near Cape Kennedy, Florida, during the full scale recovery exercises approximately 30 days prior to each flight.

Portions of the Egress Training Program may be modified at a later date as a result of the test/evaluation/development program managed by Recovery Operations Division. Participation of the Flight Crew Support Division and Flight Crews is required during the test evaluation phase to assure proper continuity and development of preliminary operating procedures to be further developed and perfected by all flight personnel during the egress training program.

## EGRESS TRAINING OUTLINE

**Session 1**

Three hours (Boilerplate 201)
Flotation Tank, EAFB

1. Review test film
2. Four underwater egresses
3. Briefing

**Session 2**

Two hours (Static Article 5)
Flotation Tank, EAFB

1. Egress checklist
2. Personal equipment operation
3. E.C.S. operation
4. Surface egress practice

**Session 3**

Two hours (Boilerplate 201)
Galveston Bay

1. Flotation characteristics
2. Flooding effects
3. Surface egress
4. Life raft

**Session 4**

Three hours (Static Article 5)
Galveston Bay

1. Preimpact checklist
2. Impact
3. Radio, E.C.S., snorkel operation
4. Flotation collar
5. Shipboard egress

**Refresher Training**

Six hours (Static Article 5)
Open water Florida

1. Recovery briefing
2. Review egress films
3. Preimpact checklist
4. Impact
5. E.C.S. operation
6. Radio operation
7. Personal equipment operation
8. Flotation characteristics
9. Surface egress
10. Life rafts
11. Helicopter pick-up
12. Flotation collar
13. Shipboard egress

3.2.5 **Centrifuge Training:** A second Gemini centrifuge program will be accomplished at the Aviation Medical Acceleration Laboratory, NADC, Johnsville, Pennsylvania, (See chart IV, section 4.0). The objectives of the program are: familiarization with Gemini accelerations profiles and control task training during reentry accelerations for the new crew personnel and refresher training in the Gemini acceleration profiles for the assigned Gemini crews.

The Gemini I centrifuge fixture (updated) will be used for the program. The simulation will be similar to the Gemini I program, that is, launch is open loop and reentry profiles generated from modified six degree-of-freedom equations of motion with altitude time rate of change preprogramed. Each pilot will accomplish the following runs:

1. Normal launch and reentry with half down range reentry profile.
2. Normal launch and reentry with zero lift reentry profile.
3. Normal launch and reentry with intermediate down range reentry profile.
4. Launch abort and associated reentry. Abort prior to staging due to engine failure.
5. Launch abort and associate reentry. Abort at T + 150 seconds simulating second stage ignition failure.

3.2.6 **General Mission Training:** The mission training phase of the Gemini training will provide the crews with training in both normal and abnormal spacecraft and spacecraft systems operation. The Gemini mission simulator supplemented by the systems trainers, briefings and the docking trainer will be used to provide this training.

The mission training is divided into four phases: familiarization, system failure training, general mission training with random malfunctions and docking training. A brief description of each phase is as follows:

1. Familiarization—The purpose of this phase of the mission training program is to thoroughly indoctrinate crew members with Gemini spacecraft systems and their normal operation throughout an entire "normal" mission profile. Since the visual display system will not be available until later, all control will be done on instruments. Implementation of this phase is as follows:

   Systems Trainers—A thorough review of the systems and their normal operation will be conducted prior to the crew's participation on the GMS. This review will emphasize system operation during typical orbital and rendezvous missions. These briefings will be operationally oriented and as detailed as possible.

Gemini Mission Simulator (14 hours)—Each pilot will complete seven familiarization sessions of approximately two hours each on the Gemini Mission Simulator, five of which will be in the left seat and two in the right seat.

Familiarization Sessions:

Session No. 1—Left Seat—Attitude and maneuvering control practice using the various control modes. Included in this session will be retrofire attitude control and platform alignment procedures.

Session No. 2—Left Seat and Session No. 3—Right Seat, Typical launch (through insertion and initial platform alignment) and reentries (from final platform alignment to impact). Insertion parameters such as velocity correction required by pilot to obtain nominal orbit and impact points of the reentry footprint will be varied.

Session No. 4—Left Seat—Three orbit mission.

Session No. 5—Left Seat, and Session No. 6—Right Seat, Typical rendezvous and catch-up maneuvers.

Session No. 7—Left Seat—Normal mission with rendezvous at first apogee.

2. System Failure Training—The purpose of this phase of the mission training is to thoroughly prepare the flight crews in system failure detection analysis, correction, and/or alternate procedures. Failures primarily dependent upon criticality of mission success and secondarily upon probability of occurrence will be emphasized. This phase of the program will require approximately ten weeks. Generally, the first day of each week will be utilized to cover a particular system on the system trainers or by briefings attended by all crew members. The remaining four days of each week will consist of the application of this information by individual crew members on the mission simulator.

   A brief outline of this phase of training is provided on the next page.

**Systems Failure Training**

| Systems | Sessions: Systems Trainers | GMS: Left Seat | GMS: Right Seat |
|---|---|---|---|
| Electrical Sequential* | 1 | 2(No. 8, 9) | |
| Electrical Power | 1 | | 1 (No. 10) |
| ACME | 1 | 1 (No. 11) | |
| OAMS | 1 | 1 (No. 12) | |
| RCS | 1 | 1 (No. 13) | |
| Combined ACME, OAMS & RCS | | 1 (No. 14)<br>1 (No. 15) | |
| Navigation and Control (IMU, Radar, FDI, Time Reference System, Computer, Horizon Sensors) | Briefing | | 1 (No. 16) |
| ECS | 1 | | 1 (No. 17)** |
| Comm. and Instrumentation (DCS, Telemetry, Voice, Beacons) | Briefing | | 1 (No. 18) |
| Total Sessions | 8 | 7 | 4 |
| Approximate Hours | 20 | 14 | 8 |

*During the second session on the GMS on Electrical Sequential (left seat) the Electrical Power is covered in the right seat.
**In Pressure Suit.

3. Mission Training with Random Malfunctions (24 Hours)—This phase consists of 12 sessions per pilot on the GMS of which 8 sessions/pilot will be in left seat and 4 sessions/pilot in the right seat. A preselected list of random malfunctions will be programed for each session. Usually these malfunctions will not require an aborted or early termination of the mission, however, one session will concentrate on launch abort problems. The sessions will be divided as follows:

   Session 19—Left Seat, and Session 20—Right Seat—Three orbit mission.

Session 21—Left Seat—Three orbit mission.

Session 22—Left Seat, and Session 23—Right Seat—Launch Abort problems.

Session 24—Left Seat—Three orbit mission (in pressure suit).

Session 25—Left Seat, and Session 26—Right Seat—Rendezvous mission with rendezvous at first apogee.

Session 27—Left Seat, and Session 28—Right Seat—Rendezvous mission utilizing slow catch-up procedure.

Session 29—Left Seat—Same as Session 25.

Session 30—Left Seat—Same as Session 26.

4. Translation and Docking Training—The program utilizing the MSC docking trainer, consists of eight sessions of approximately two and one-half hours each. In addition each pilot will occupy the right seat during Session No. 1. Normally twelve runs will be made per session half of which will be made with no scheduled failures. A typical docking maneuver includes the following operations, (starting from various initial conditions and closure rates); alignment of spacecraft with the Agena, maneuver into docking cone, engagement, latch-on, rigidize, docking tasks, unlatch, maneuver out of docking cone.

   Session 1 will be a familiarization session with six nominal runs and six non-nominal runs. The non-nominal runs are for demonstration purposes. Four runs will be made in each mode of operation. Failures will be demonstrated and corrective action taken by the pilot. One pilot will ride as observer in the right seat while the pilot in the left seat controls attitude translation.

   Session 2 will consist of practice in Rate Command Mode with six nominal and six non-nominal runs scheduled. All control is from left seat with one pilot onboard.

   Session 3 will consist of practice in Pulse Mode with six nominal and six non-nominal runs scheduled with one pilot onboard. All control is from the left seat.

Session 4 will consist of practice in Direct Mode with six nominal and six non-nominal runs. One pilot onboard. Control is from the left seat.

Session 5 will consist of task sharing between the left and right seat positions. The pilot in the left seat will control translation and the pilot in the right seat will control attitude. Two runs will be made in each of the three modes of operation. Each pilot will make six runs in each seat. No malfunctions are scheduled.

Session 6 consists of task sharing utilizing the Rate Command Control Mode. Six runs will be nominal and six runs will include non-nominal run conditions. Each pilot will make six runs in each seat.

Session 7 is a task sharing utilizing the Rate Command Control Mode. Six runs will be nominal and six runs will be non-nominal. Each pilot will make six runs in each seat.

Session 8 consists of task sharing utilizing the "direct" control mode during six nominal and six non-nominal runs. Each pilot will make six runs in each seat.

Approximately sixteen failures may be simulated on the trainer with up to four failures occurring at any one time. Only thirteen failures can be simulated for which the pilot may take corrective action and continue the rendezvous. Three failures can be simulated which would probably require abort of the rendezvous, namely—OR LOGIC roll, OR LOGIC yaw, and maneuver malfunctions. Corrective action which may be accomplished by the pilots consists of switching ACME Logic from PRImary and SECondary, switching gyros from PRImary to SECondary, switching ATTITUDE CONTROL MODE, switching ATTITUDE DRIVERS or MANEUVER DRIVERS to SECondary. A failure analysis for the translation and docking trainer is included in the appendix.

Failures to be simulated are as follows:

1. OAMS ATTITUDE DRIVERS
2. OAMS MANEUVER DRIVERS
3. OR LOGIC ROLL
4. OR LOGIC YAW

5. COMMUNICATIONS L. SEAT TO R. SEAT
6. COMMUNICATIONS R. SEAT TO L. SEAT
7. DIRECT MODE
8. PULSE MODE
9. RATE COMMAND MODE
10. RATE GYRO—ROLL
11. RATE GYRO—PITCH
12. RATE GYRO—YAW
13. ACME LOGIC—ROLL
14. ACME LOGIC—PITCH
15. ACME LOGIC—YAW
16. MANEUVER MALFUNCTIONS

Outlines of the sessions as well as possible failures are shown below. Specific failures on a run to run basis will be detailed shortly prior to commencement of this training and at a time when simulation requirements can be better assessed.

TRANSLATION AND DOCKING TRAINING OUTLINE

| Session | Mode | Pilotage | Runs |
|---|---|---|---|
| 1 | ALL | Left seat (right seat occupied) | 12 |
| 2 | RATE COMMAND | Left seat | 12 |
| 3 | PULSE | Left seat | 12 |
| 4 | DIRECT | Left seat | 12 |
| 5 | ALL | Both seats | 12 |
| 6 | RATE COMMAND | Both seats | 12 |
| 7 | PULSE | Both seats | 12 |
| 8 | DIRECT | Both seats | 12 |

### 3.3 Apollo Training

3.3.1 **Project Briefings:** This training will familiarize the flight crews with the Apollo mission and the present state of development of the spacecraft and launch vehicle.

1. Mission Profiles—The following Apollo mission considerations will be presented to the pilots over a two day period:

Movie—"Apollo Project"

Launch Schedules

General Launch Vehicle Description—S-1B, S-V

General Spacecraft Description (Command, Service and Lunar Excursion Modules)

Lunar Landing Mission Profile

Earth Orbit
Translunar
Lunar
Transearth
Entry and Landing
Abort Considerations

3.3.2 **Launch Vehicle Briefing:** The Marshall Space Flight Center, Huntsville, Alabama, will give the flight crews a briefing on the S-1B and S-V launch vehicles and their systems and a tour of MSFC's facilities.

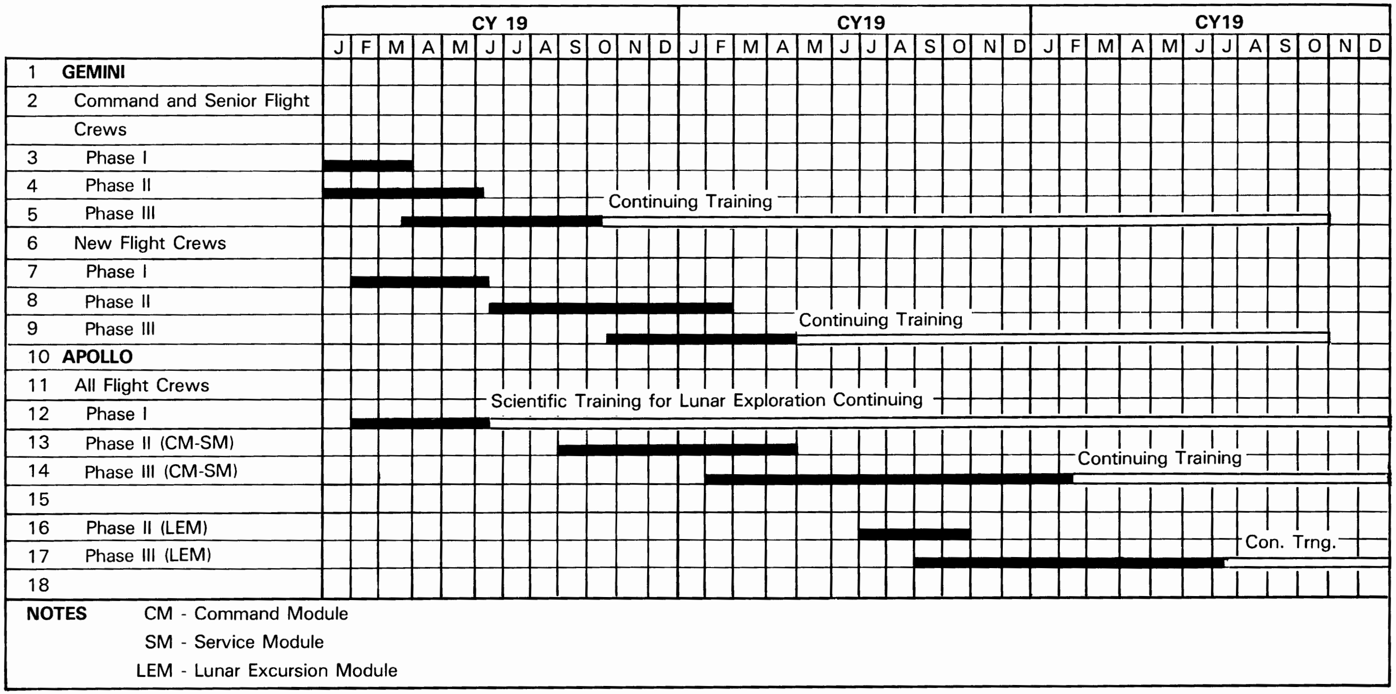
3.3.3 **Systems Familiarization Briefings:** A series of familiarization briefings on Apollo CM/SM and LEM spacecraft systems will be given the flight crews. These briefings are intended to provide background knowledge in systems operation to facilitate the overall mission study. The various systems to be covered include: Guidance and Navigation, Stabilization and Control, Reaction Control, Spacecraft Propulsion, Power Generation and Distribution, Sequential Circuits, Environmental Control, Communication and Instrumentation.

## Chart I. Training Phasing

Phase I - Scientific and Space Technology Courses, Project Familiarization and Flight Operations Briefings

Phase II - Environmental Familiarization, Control Task, Spacecraft Egress, LEM Ingress and Contingency Training

Phase III - Mission Training: Systems Launch Vehicle Abort and Full Mission Training



## Chart II. Crew Training Equipment Schedule

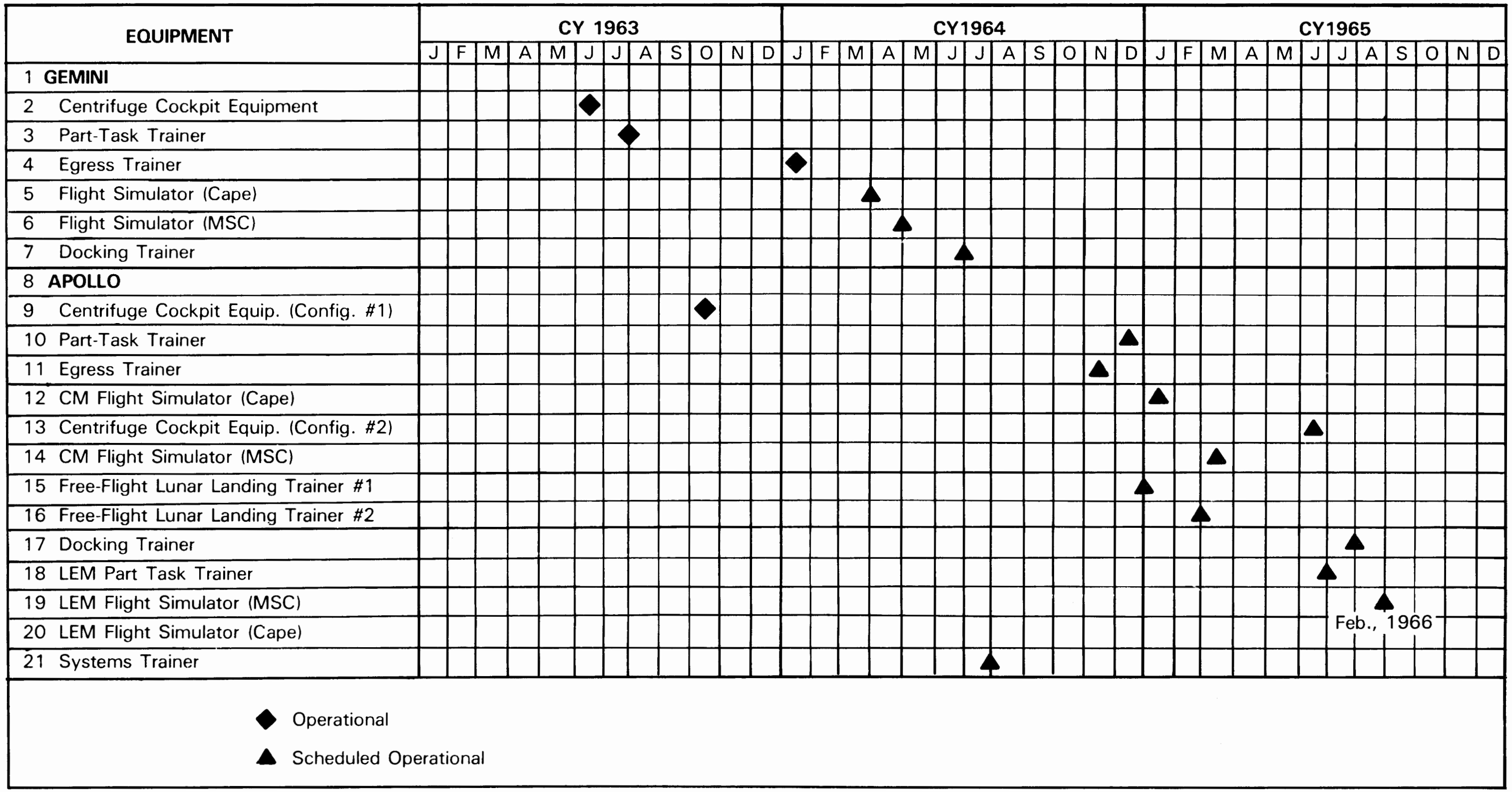


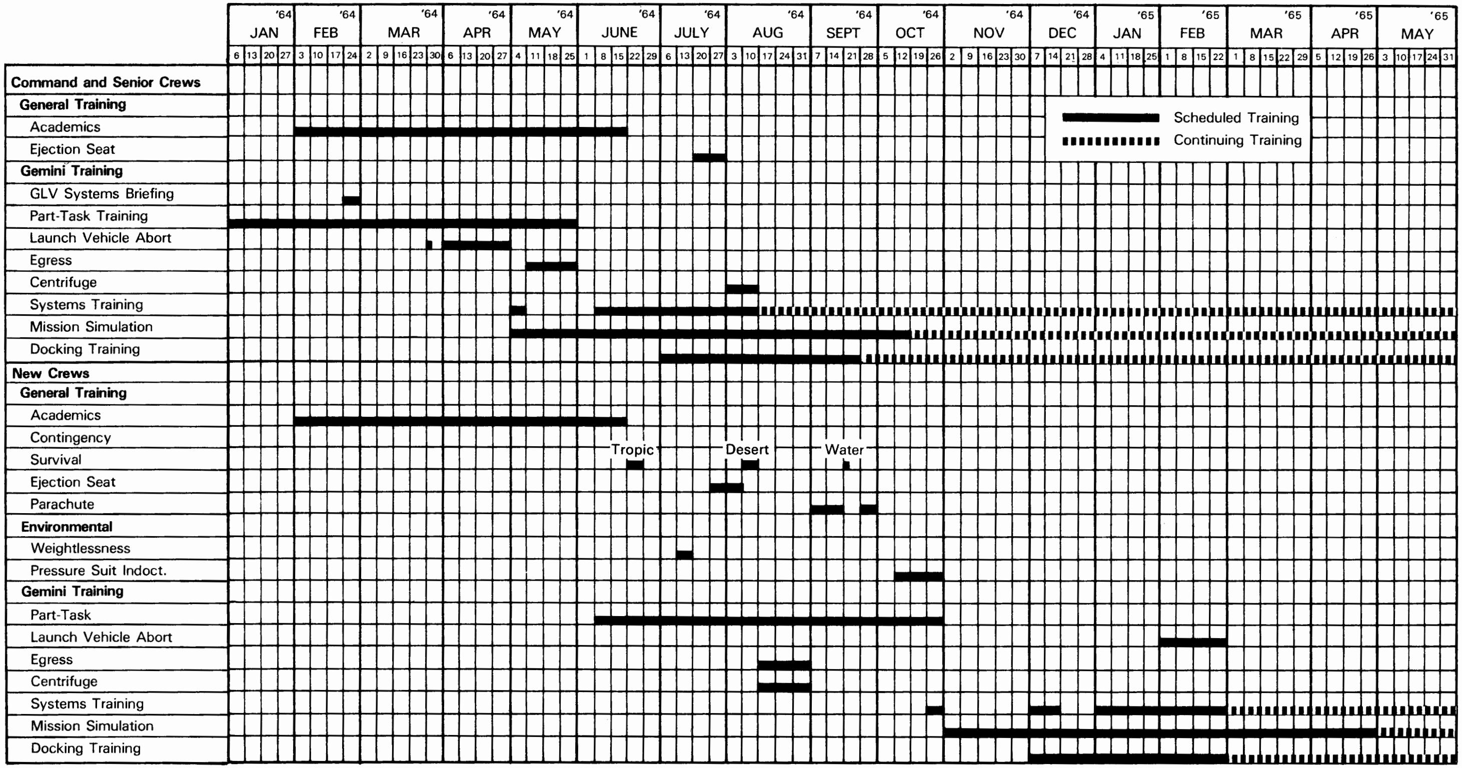
**Chart III. Academic Training Schedule**

| | Total Hours | Hrs/Week | FEB | | | | MARCH | | | | | APRIL | | | | MAY | | | | JUNE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 3 | 10 | 17 | 24 | 2 | 9 | 16 | 23 | 30 | 6 | 13 | 20 | 27 | 4 | 11 | 18 | 25 | 1 | 8 | 15 | 22 | 29 |
| **GEMINI PROJECT BRIEFINGS AND SYST. TNG.** | | | | | | | | | | | | | | | | | | | | | | | | |
| Mission Profiles | | | | | ■ | | | | | | | | | | | | | | | | | | | |
| L.V. Briefing (Eng. Detail)* | | | | | | ■ | | | | | | | | | | | | | | | | | | |
| S/C System Trainer Briefings | | | | | | | | ■ | | | | | | | | | | | | | | | | |
| Static Simulator-Controls & Displays | | | | | | | | | ■ | | | | | | | | | | | | | | | |
| **OPERATIONS FAMILIARIZATION** | | | | | | | | | | | | | | | | | | | | | | | | |
| Cape Kennedy (Launch) | | | | | | | | | | | | ■ | | | | | | | | | | | | |
| IMCC Briefing** | | | | | | | | | | | | | ■ | | | | | | | | | | | |
| Recovery Operations Briefings** | | | | | | | | | | | | | | ■ | | | | | | | | | | |
| **APOLLO PROJECT BRIEFINGS AND SYST. TNG.** | | | | | | | | | | | | | | | | | | | | | | | | |
| Mission Profiles | | | | | | | | | | | | | | | | ■ | | | | | | | | |
| L.V. Familiarization Briefing-MSFC | | | | | | | | | | | | | | | | | ■ | | | | | | | |
| S/C Familiarization Briefing | | | | | | | | | | | | | | | | | | ■ | ■ | | | | | |
| **BASIC SCIENCE AND TECHNOLOGY COURSES** | | | | | | | | | | | | | | | | | | | | | | | | |
| Geology* | 58 | 4 | ■ | ■ | ■ | ■ | ■ | | ■ 2 | ■ 2 | ■ 2 | ■ 2 | ■ | ■ | ■ | ■ | ■ 2 | ■ 2 | ■ 2 | | ■ | ■ | | |
| Field Trips | | | | | | | ■ | | | | ■ | | | | ■ | | | | | ■ | | | | |
| Flight Mechanics** | 40 | 4 | | | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | |
| Astronomy | 15 | 3 | | | ■ | ■ | ■ | | ■ | ■ | | | | | | | | | | | | | | |
| Planetarium | | | | | | | | | | ■ | | | | | | | | | | | | | | |
| Digital Computers** | 12 | 4 | | | ■ | ■ | ■ | | | | | | | | | | | | | | | | | |
| Gemini Onboard Computer* | 24 | 6 | | | | | | | ■ | ■ | ■ | ■ | | | | | | | | | | | | |
| Rocket Propulsion | 12 | 2 | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | |
| Aerodynamics | 8 | 2 | | | | | | | | | | | ■ | ■ | ■ | ■ | | | | | | | | |
| Physics of Upper Atmos. and Space | 12 | 4 | | | | | | | | | | | ■ | ■ | ■ | | | | | | | | | |
| Guidance and Navigation* | 34 | 8 | | | | | | | | | | | | | | ■ 2 | ■ | ■ | ■ | ■ | | | | |
| Communications | 8 | 2 | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | | | | | |
| Medical Aspects of Space Flight | 12 | 2 | | | | | | | | | | | | | | ■ 4 | ■ | ■ | ■ | ■ | | | | |
| Meteorology | 4 | 4 | | | | | | | | | | | | | | | | | | | ■ | | | |

*All astronauts participate

**Present crews participate when possible for

## Chart IV. Overall Training Schedule



## Item 3

## Survey of Medical Investigations Conducted during Mercury, Gemini, and Apollo Programs

The tables, charts, and figures presented here are extracted directly from relevant technical reports that are identified in the bibliography. These extracts are not intended to provide a complete overview of all medical investigations conducted during these series. Rather, they are intended (1) to show the range of medical investigations conducted, (2) to show the growth and sophistication of medical investigations, and (3) to allow easy comparison of the separate missions along specific medical parameters. For a complete review of all biomedical investigations and findings, refer to relevant technical reports.

### A. General Clinical Evaluations and Findings

**Vital Signs (MR-3 Flight)**

| | Preflight | Postflight | |
|---|---|---|---|
| | −8 hr | Shipboard | +3 hr |
| Body weight nude (post voiding) | 169 lb 4 oz | 167 lb 4 oz | 166 lb 4 oz |
| Temperature, °F | 99.0 (rectal) | 100.2 (rectal) | 98 (oral) |
| Pulse per min | 68 | 100 | 76 |
| Respiration per min | 16 | | 20 |
| Blood pressure, mm Hg: | | | |
| Standing | | | 102/74 |
| Sitting | 120/78 | 130/84 | |
| Supine | | | 100/76 |
| Pulse per min: | | | |
| Before exercise | 68 | | 76 |
| After exercise | 100 | | 112 |
| | (2¾ min)[a] | | (3 min.)[a] |

[a]Time for return to normal.

## General Clinical Evaluations and Findings (continued)

### Clinical Evaluation (MA-6 Flight)

[All times are eastern standard]

| | Preflight (launch morning) | | Postflight | |
|---|---|---|---|---|
| General status | Eager for flight | | Alert, but not talkative; sweating profusely; appeared fatigued; not hungry. | |
| Weight, lb | 171-7/16 at 3:15 a.m. | | 166-2/16 at 6:50 p.m. (5-5/16 lb loss).[a] | |
| Temperature, °F | 98.2 (oral) | | 99.2 (rectal at 4:00 p.m.); 98.0 (oral at 12:00 p.m.). | |
| Respiration, breaths/min | 14 | | 14. | |
| Pulse, beats/min | 68 | | 76 on shipboard, 72 at Grand Turk. | |
| Blood pressure, (left arm), mm Hg | 118/80 (sitting) | | 105/60 (standing); 120/60 (supine) at 3:45 p.m.; 128/78 (sitting) at 9:30 p.m. | |
| Heart and lungs | Normal | | Normal—no change. | |
| Skin | No erythema or abrasions. | | Erythema of biosensor sites; superficial abrasions second and third fingers of right hand. | |
| Extremity measurements: | Left | Right | Left | Right |
| Wrist, in | 6-7/8 | 7 | 6-3/4 | 7 |
| Calf (maximum), in | 16-7/8 | 16-1/2 | 10-5/8 | 16-1/8 |
| Ankle (minimum), in | 9-3/8 | 9-1/8 | 9 | 9-1/4 |

[a]Not true inflight weight loss, since the scales were neither the same nor compared and postflight weight was 4 hours 8 minutes after landing.

**Table 16—VI. Peak Heart Rates During Launch and Reentry**

| Gemini mission | Crewman[a] | Peak rates during launch, beats/min | Peak rates during reentry, beats/min |
|---|---|---|---|
| III | CP | 152 | 165 |
| | P | 120 | 130 |
| IV | CP | 148 | 140 |
| | P | 128 | 125 |
| V | CP | 148 | 170 |
| | P | 155 | 178 |
| VI-A | CP | 125 | 125 |
| | P | 150 | 140 |
| VII | CP | 152 | 180 |
| | P | 125 | 134 |
| VIII | CP | 138 | 130 |
| | P | 120 | 90 |
| IX-A | CP | 142 | 160 |
| | P | 120 | 126 |
| X | CP | 120 | 110 |
| | P | 125 | 90 |
| XI | CP | 166 | 120 |
| | P | 154 | 117 |
| XII | CP | 136 | 142 |
| | P | 110 | 137 |

[a] CP indicates command pilot; P indicates pilot.

## Apollo Group Mean Values for Preflight Summary and Postflight Orthostatic Evaluations

| Measurement | Protocol Condition | Preflight Summary Response N | $\bar{X}$ | $SD_i$ | $SD_t$ | Postflight First N | $\bar{X}$ | p | Second N | $\bar{X}$ | p | Third N | $\bar{X}$ | p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heart rate (bpm) | Control | 24 | 61.6 | 8.60 | 1.06 | 24 | 69.7 | 0.02 | 24 | 67.2 | n.s. | 15 | 63.5 | n.s. |
| | −30 mm Hg* LBNP | 18 | 65.7 | 11.11 | 1.42 | 18 | 84.3 | 0.005 | 18 | 72.7 | n.s. | 15 | 68.5 | n.s. |
| | −40 | 18 | 70.7 | 11.20 | 1.40 | 18 | 96.7 | 0.001 | 18 | 79.8 | 0.05 | 15 | 74.5 | n.s. |
| | −50 | 18 | 76.5 | 13.27 | 1.55 | 17 | 108.5 | 0.001 | 17 | 92.2 | 0.02 | 15 | 82.7 | n.s. |
| | Recovery | 18 | 59.1 | 8.66 | 1.08 | 18 | 67.4 | n.s. | 18 | 64.1 | n.s. | 15 | 60.5 | n.s. |
| | Stand | 9 | 76.4 | 6.11 | 1.24 | 9 | 99.8 | 0.001 | 9 | 91.8 | 0.001 | 3 | 77.0 | n.s. |
| Systolic blood pressure (mm Hg*) | Control | 24 | 115.3 | 8.31 | 0.74 | 24 | 111.6 | n.s. | 24 | 118.0 | n.s. | 15 | 118.5 | n.s. |
| | −30 mm Hg* LBNP | 18 | 110.5 | 10.04 | 1.86 | 18 | 101.5 | 0.02 | 18 | 112.3 | n.s. | 15 | 112.7 | n.s. |
| | −40 | 18 | 107.7 | 10.66 | 1.15 | 18 | 96.3 | 0.01 | 18 | 109.7 | n.s. | 15 | 109.3 | n.s. |
| | −50 | 18 | 104.8 | 11.09 | 1.86 | 17 | 91.5 | 0.01 | 17 | 107.4 | n.s. | 15 | 107.2 | n.s. |
| | Recovery | 18 | 117.1 | 10.03 | 1.55 | 18 | 116.4 | n.s. | 18 | 123.2 | n.s. | 15 | 120.5 | n.s. |
| | Stand | 9 | 118.8 | 6.24 | 3.40 | 9 | 105.8 | 0.001 | 9 | 123.9 | n.s. | 3 | 120.7 | n.s. |
| Diastolic blood pressure (mm Hg*) | Control | 24 | 67.0 | 6.61 | 1.51 | 24 | 67.1 | n.s. | 24 | 67.7 | n.s. | 15 | 66.3 | n.s. |
| | −30 mm Hg* LBNP | 18 | 69.7 | 6.63 | 1.31 | 18 | 66.5 | n.s. | 18 | 67.4 | n.s. | 15 | 67.9 | n.s. |
| | −40 | 18 | 70.7 | 6.21 | 1.25 | 18 | 66.3 | 0.05 | 18 | 68.3 | n.s. | 15 | 70.0 | n.s. |
| | −50 | 18 | 71.8 | 6.84 | 2.01 | 17 | 66.6 | n.s | 17 | 69.1 | n.s. | 15 | 70.9 | n.s. |
| | Recovery | 18 | 71.0 | 6.32 | 0.89 | 18 | 73.4 | n.s. | 18 | 70.9 | n.s. | 15 | 69.4 | n.s. |
| | Stand | 9 | 81.0 | 5.22 | 4.46 | 9 | 80.2 | n.s. | 9 | 82.8 | n.s. | 3 | 80.7 | n.s. |

*1 mm Hg = $1.33 \times 10^2$ N/m$^2$

Note: N = Number of subjects
$\bar{X}$ = Group mean
$SD_i$ = Standard deviation of crewmember preflight summary means
$SD_t$ = Standard deviation of three preflight group means
p = Probability level

**Apollo Group Mean Values for Preflight Summary and Postflight Orthostatic Evaluations**

| Measurement | Protocol Condition | Preflight Summary | | | | Postflight Evaluations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Response | | | First | | | Second | | | Third | | |
| | | N | $\bar{X}$ | $SD_i$ | $SD_t$ | N | $\bar{X}$ | p | N | $\bar{X}$ | p | N | $\bar{X}$ | p |
| Pulse Pressure (mm Hg*) | Control | 24 | 48.3 | 6.34 | 0.81 | 24 | 44.6 | n.s. | 24 | 50.2 | n.s. | 15 | 52.1 | n.s. |
| | −30 mm Hg* LBNP | 18 | 40.9 | 6.09 | 0.61 | 18 | 35.2 | 0.01 | 18 | 44.8 | n.s. | 15 | 44.8 | n.s. |
| | −40 mm Hg* LBNP | 18 | 37.2 | 6.52 | 0.06 | 18 | 30.2 | 0.02 | 18 | 41.4 | n.s. | 15 | 39.4 | n.s. |
| | −50 mm Hg* LBNP | 18 | 33.1 | 6.59 | 0.06 | 17 | 24.8 | 0.02 | 17 | 38.2 | n.s | 15 | 36.3 | n.s. |
| | Recovery | 18 | 46.4 | 6.76 | 1.07 | 18 | 43.1 | n.s. | 18 | 52.2 | 0.05 | 15 | 51.0 | n.s. |
| | Stand | 9 | 37.8 | 6.44 | 7.47 | 9 | 25.6 | 0.02 | 9 | 41.0 | n.s. | 3 | 40.0 | n.s. |
| Calf circumference (cm) | Control | 24 | 37.47 | 1.626 | 0.072 | 24 | 36.38 | 0.05 | 21 | 36.85 | n.s. | 15 | 37.05 | n.s. |
| Calf volume Change (%Δ) | −30 mm Hg* LBNP | 18 | 1.62 | 0.512 | 0.060 | 18 | 1.45 | n.s. | 18 | 1.49 | n.s. | 15 | 1.45 | n.s. |
| | −40 mm Hg* LBNP | 18 | 2.32 | 0.597 | 0.050 | 18 | 2.09 | n.s | 18 | 2.26 | n.s. | 15 | 2.21 | n.s. |
| | −50 mm Hg* LBNP | 18 | 3.08 | 0.679 | 0.042 | 18 | 2.71 | n.s. | 17 | 3.04 | n.s. | 15 | 3.04 | n.s. |
| | Recovery | 18 | 0.54 | 0.270 | 0.029 | 17 | 0.27 | 0.02 | 18 | 0.66 | n.s. | 15 | 0.53 | n.s. |
| Stroke volume (ml) | Control | 9 | 85.8 | 4.49 | 0.15 | 7 | 74.1 | 0.02 | 9 | 79.2 | 0.05 | 9 | 80.4 | n.s. |
| | −30 mm Hg* LBNP | 9 | 73.7 | 6.00 | 1.05 | 7 | 60.3 | 0.01 | 9 | 64.9 | 0.05 | 9 | 66.3 | n.s. |
| | −40 mm Hg* LBNP | 9 | 63.8 | 6.96 | 1.58 | 6 | 49.3 | 0.025 | 9 | 56.4 | n.s. | 9 | 58.0 | n.s. |
| | −50 mm Hg* LBNP | 9 | 57.6 | 7.02 | 0.78 | 5 | 41.4 | 0.05 | 8 | 47.9 | n.s. | 9 | 50.2 | 0.05 |
| | Recovery | 9 | 86.9 | 3.37 | 1.36 | 7 | 79.4 | n.s. | 9 | 81.6 | n.s. | 9 | 82.7 | n.s. |

*1 mm Hg = $1.33 \times 10^2$ N/m²

Note: N = Number of subjects
$\bar{X}$ = Group mean
$SD_i$ = Standard deviation of crewmember preflight summary means
$SD_t$ = Standard deviation of three preflight group means
p = Probability level

## Urinalysis

**Table XI.—Urine Analysis (MA-9 Flight)**

| Date (1963) | Time | Total volume, cc | Specific gravity | Na, meq/l | K, meq/l | Ca, meq/l | Cl, meq/l | $PO_4$, mg% | Creatinine, mg% | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| Mar. 20 .... | 7:30 a.m. to 9:26 a.m. .... | 184 | 1.012 | 141 | 55 | 4.15 | 161 | 26.7 | 85 | Low residue diet. |
| Mar. 20 .... | 9:26 a.m. to 12:59 p.m. ... | 260 | 1.013 | 180 | 49 | 16.3 | 207 | 42.2 | 110 | |
| Mar. 20 .... | 12:59 p.m. to 4:45 p.m. ... | 420 | 1.014 | 129 | 40 | 10.1 | 159 | 56.6 | 86 | |
| Mar. 20 .... | 4:45 p.m. to 9:10 p.m. .... | 330 | 1.015 | 125 | 38 | 8.7 | 111 | 73 | 111 | |
| Mar. 21 .... | 9:10 p.m. to 1:00 a.m. .... | 340 | 1.012 | 137 | 17 | 7.5 | 100 | 58.3 | 102 | |
| Mar. 21 .... | 1:00 a.m. to 7:52 a.m. .... | 830 | 1.005 | 79 | 14 | 5.0 | 79 | 31.4 | 62 | |
| Mar. 21 .... | 7:52 a.m. to 12:46 p.m. ... | 470 | 1.011 | 143 | 42 | 10.3 | 174 | 26.6 | 94 | |
| Mar. 21 .... | 12:46 p.m. to 5:28 p.m. ... | 286 | 1.017 | 179 | 54 | 16.85 | 210 | 74.3 | 125 | |
| Mar. 21 .... | 5:28 p.m. to 11:35 p.m. ... | 600 | 1.015 | 189 | 41 | 7.6 | 178 | 48 | 105 | |
| Mar. 22 .... | 11:35 p.m. to 3:26 a.m. ... | 210 | 1.015 | 239 | 31 | 10.6 | 163 | 54 | ..... | |
| Mar. 22 .... | 3:26 a.m. to 5:36 a.m. .... | 110 | 1.018 | 216 | 34 | 25.5 | 165 | 55 | ..... | |
| Mar. 22 .... | 5:36 a.m. to 10:47 a.m. ... | 255 | 1.018 | 154 | 38 | 21.3 | 142 | 54 | 134 | |
| Mar. 22 .... | 10:47 a.m. to 6:35 p.m. ... | 300 | 1.020 | 116 | 47 | 20.85 | 86 | 135 | 152 | Before hangar simulated flight. |
| Mar. 23 .... | 6:35 p.m. to 1:20 a.m. .... | 360 | 1.023 | 131 | 51 | 18.9 | 119 | 75.4 | 142 | During hangar simulated flight. |
| Apr. 23 ..... | 6:00 a.m. to 6:50 a.m. .... | 32 | ..... | 196 | 58 | 7.75 | 158 | 146 | 144 | Simulated flight no. 1 (before). |
| Apr. 23 ..... | 6:50 a.m. to 12:35 p.m. ... | 394 | 1.020 | 226 | 85 | 3.04 | 220 | 70.8 | 106 | Simulated flight no. 1 (during). |
| Apr. 23 ..... | 12:35 p.m. to 5:08 p.m. ... | 122 | 1.022 | 195 | 51 | 5.95 | 187 | 68.6 | 98 | Simulated flight no. 1 (after). |
| Apr. 25 ..... | Unknown to 11:35 a.m. ... | 170 | 1.020 | 192 | 83 | 6.3 | 212 | 18.7 | 107 | Simulated flight no. 2 (before). |
| Apr. 25 ..... | 11:35 a.m. to 4:28 p.m. ... | 134 | 1.024 | 242 | 40 | 5.75 | 226 | 35.4 | 104 | Simulated flight no. 2 (during). |
| Apr. 25 ..... | 4:28 p.m. to 5:55 p.m. .... | 308 | 1.018 | 250 | 44 | 3.40 | 234 | 46.1 | 107 | Simulated flight no. 2 (after). |
| May 7 ...... | 6:30 a.m. to 8:30 a.m. .... | 64 | 1.020 | 115 | 56 | 13.9 | 198 | 103 | 152 | Procedures trainer (before). |
| May 7 ...... | 8:30 a.m. to 2:00 p.m. .... | 480 | 1.014 | 124 | 60 | 5.65 | 146 | 63.6 | 88 | Procedures trainer (during). |
| May 8 ...... | 9:15 a.m. to 1:40 p.m. .... | 540 | 1.012 | 137 | 79 | 7.4 | 166 | 41.6 | 74 | Launch simulation (during). |
| May 8 ...... | 1:40 p.m. to 6:00 p.m. .... | 360 | 1.012 | 137 | 53 | 3.2 | 125 | 43 | 104 | Launch simulation (after). |
| May 10 ..... | 7:30 a.m. to 11:45 a.m. ... | 180 | 1.023 | 148 | 85 | 17.8 | 176 | 45.7 | 130 | Simulated flight no. 3 (before). |

## Urinalysis (continued)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| May 10 .... | 11:45 a.m. to 2:00 p.m. .... | 170 | 1.025 | 198 | 72 | 20.7 | 219 | 76 | 114 | Simulated flight no. 3 (before). |
| May 10 .... | 2:00 p.m. to 6:30 p.m. .... | 320 | 1.023 | 181 | 83 | 13.4 | 201 | 97 | 115 | Simulated flight no. 3 (during). |
| May 10 .... | 6:30 p.m. to 10:05 p.m. .... | 80 | 1.026 | 200 | 71 | 6.9 | 165 | 148 | 139 | Simulated flight no. 3 (after). |
| May 13 .... | 6:30 p.m. to 9:00 p.m. .... | 440 | 1.025 | 177 | 54 | 19.95 | 165 | 128 | 137 | Before canceled flight. |
| May 14 .... | 9:00 p.m. to 2:50 a.m. .... | 225 | 1.024 | 165 | 32 | 10.0 | 107 | 161 | 152 | Before canceled flight. |
| May 14 .... | 2:50 a.m. to 7:30 a.m. .... | 680 | 1.012 | 120 | 49 | 5.6 | 128 | 12.6 | 56 | Collection device—canceled flight. |
| May 14 .... | 7:30 a.m. to 12:30 p.m. .... | 315 | 1.015 | 98 | 50 | 5.85 | 1109 | 34 | 104 | After canceled flight. |
| May 15 .... | 10:00 p.m. to 2:52 a.m. .... | 178 | 1.028 | 112 | 34 | 23.4 | 73 | 214 | 162 | Preflight. |
| May 15 .... | 2:52 a.m. to 3:55 a.m. .... | 25 | 1.025 | 98 | 48 | 12.4 | 89 | 185 | 165 | Preflight. |
| May 15 .... | 3:55 a.m. to 7:56 a.m. .... | 177 | ..... | 184 | 68 | 8.25 | 212 | 33.8 | 125 | Preflight (pad) bag no. 1. |
| May 15 .... | 7:56 a.m. to 12:29 p.m. .... | 195 | ..... | 213 | 69 | 14.1 | 236 | 28.4 | 131 | Inflight bag no. 2. |
| May 15 .... | 12:29 p.m. to 10:09 p.m. .... | 314 | ..... | 197 | 56 | 12.6 | 188 | 130 | 154 | Inflight bag no. 3. |
| May 16 .... | 10:09 p.m. to 7:15 a.m. .... | 333 | ..... | 120 | 38 | 17.7 | 128 | 125 | 169 | Inflight bag no. 4. |
| May 16 .... | 7:15 a.m. to 1:14 p.m. .... | 107 | 1.026 | 137 | 41 | 15.6 | 150 | 136 | 170.8 | Collection device. |
| May 16 .... | 1:14 p.m. to 9:30 p.m. .... | 70 | 1.031 | 107 | 96 | 16.4 | 126 | 240 | 177 | 1st voided sample. |
| May 17 .... | 9:30 p.m. to 1:05 p.m. .... | 475 | 1.026 | 41 | 62 | 20.95 | 29 | 149 | 148 | 2d voided sample. |
| May 17 .... | 1:05 p.m. to 9:12 p.m. .... | 315 | 1.020 | 29 | 54 | 24.3 | 59 | 68.5 | 148 | 3d voided sample. |
| May 18 .... | 9:12 p.m. to 12:00 p.m. .... | 605 | 1.023 | 29 | 70 | 17.4 | 41 | 114 | 139 | 4th voided sample. |
| May 20 .... | 8:00 a.m. to 10:15 a.m. .... | .... | 1.019 | 125 | 92 | 15.2 | 150 | 68 | 110 | 4 days after recovery (physical exam Patrick AFB). |

## Urinalysis (continued)

### Gemini VII Urine Chemistries
[All dates 1965]

| Determination | Command pilot | | | | | | | Pilot | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Preflight | Postflight | | | | | | Preflight | Postflight | | | | | |
| | Nov. 23 and Dec. 1 | Dec. 18 | | Dec. 20 | | Dec. 21 | | Nov. 23 Dec. 1 | Dec. 18 | | Dec. 20 | | Dec. 21 | |
| | | Measured | Percent of preflight | Measured | Percent of preflight | Measured | Percent of preflight | | Measured | Percent of preflight | Measured | Percent of preflight | Measured | Percent of preflight |
| Sodium, $\frac{\text{meg}}{24\text{ hr}}$ | 143 | 95 | 66 | 182 | 127 | 150 | 105 | 150 | 76 | 51 | 94 | 63 | ..... | ..... |
| Potassium | 71 | 118 | 166 | 93 | 131 | 90 | 127 | 70 | 60 | 86 | 89 | 127 | ..... | ..... |
| Chlorine | 141 | 89 | 63 | 168 | 119 | 145 | 103 | 141 | 67 | 48 | 73 | 52 | ..... | ..... |
| Calcium, $\frac{\text{mg}}{24\text{ hr}}$ | 228 | 269 | 118 | 260 | 114 | 210 | 92 | 184 | 89 | 48 | 105 | 57 | ..... | ..... |
| Phosphate | 1131 | 2133 | 188 | 936 | 83 | 978 | 86 | 1200 | 996 | 83 | 1345 | 112 | ..... | ..... |
| 17-hydroxycortico-steroids | 7.7 | 18.6 | 241 | 7.3 | 95 | 9.1 | 118 | 6.2 | 11.3 | 183 | 8.1 | 130 | 8.2 | 132 |
| Ephinephrine, $\frac{\mu\text{g}}{24\text{ hr}}$ | 7.8 | 16.4 | 210 | ([a]) | ..... | ([a]) | ..... | 10.2 | ..... | ..... | ..... | ..... | ..... | ..... |
| Norepinephrine | 50.3 | 103.0 | 204 | ([a]) | ..... | ([a]) | ..... | 42.7 | ..... | ..... | ..... | ..... | ..... | ..... |
| Aldosterone, $\frac{\mu\text{g}}{24\text{ hr}}$ | 26 | 75 | 288 | ..... | ..... | 28 | 108 | 26 | 47 | 181 | ..... | ..... | 60 | 230 |
| Creatine, $\frac{\text{mg}}{24\text{ hr}}$ | 2035 | 3297 | 162 | 1380 | 68 | 2070 | 102 | 2230 | 2003 | 90 | 2225 | 100 | ..... | ..... |

[a] Not significant.

## Apollo Twenty-Four Hour Urine Results

| Parameter | Units | N* | Preflight Mean ± S. D. | Recovery +24 Hrs | Δ%** | +48 Hrs | Δ%** | +72 Hrs | Δ%** | +6 Days | Δ%** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specific gravity | SpGr | 30 | 1.019 ± .005 | 1.024 ± .006 | + .5 | 1.018 ± .007 | − .1 | 1.016 ± .005 | + .3 | 1.017 ± .004 | + .2 |
| Osmolality | Mosmo | 30 | 789 ± 238 | 1017 ± 569 | + 28.9 | 1373 ± 163 | + 74.0 | 1170 ± 996 | + 48.3 | 750 ± 288 | − 4.9 |
| Urine volume | ml | 30 | 1989 ± 494 | 1090 ± 599 | − 49.2 | 1541 ± 691 | − 22.5 | 1370 ± 674 | − 31.1 | 1805 ± 860 | − 9.3 |
| Sodium | mEq/24 hr | 30 | 173 ± 61 | 90 ± 60 | − 48.0 | 106 ± 45 | − 38.7 | 156 ± 75 | − 9.8 | 206 ± 57 | + 19.1 |
| Potassium | mEq/24 hr | 30 | 73 ± 19 | 43 ± 17 | − 41.1 | 54 ± 15 | − 26.0 | 50 ± 23 | − 31.5 | 68 ± 23 | − 6.9 |
| Chloride | mEq/24 hr | 30 | 156 ± 53 | 60 ± 42 | − 61.5 | 97 ± 51 | − 37.8 | 137 ± 67 | − 12.2 | 181 ± 60 | + 16.0 |
| Calcium | mEq/24 hr | 30 | 9.3 ± 3 | 7.8 ± 4.4 | − 16.1 | 9.5 ± 4.7 | + 2.2 | 9.9 ± 4 | + 6.5 | 12.4 ± 5.8 | + 33.3 |
| Magnesium | mEq/24 hr | 30 | 8.6 ± 2.7 | 5.7 ± 2.7 | − 33.7 | 5.7 ± 2.4 | − 33.7 | 6.9 ± 3.4 | − 19.8 | 9.7 ± 4.5 | + 12.8 |
| $IPO_4$ | mg/24 hr | 30 | 965 ± 267 | 956 ± 361 | − .9 | 804 ± 340 | − 16.7 | 832 + 381 | − 13.8 | 1107 ± 211 | + 14.72 |
| Creatinine | mg/24 hr | 30 | 1852 ± 468 | 1842 ± 660 | − .5 | 1669 ± 703 | − 9.9 | 1779 ± 565 | − 3.9 | 1945 ± 641 | + 5.0 |
| Uric acid | mg/24 hr | 30 | 825 ± 303 | 638 ± 268 | − 22.7 | 688 ± 346 | − 16.6 | 675 ± 274 | − 18.2 | 761 ± 249 | − 7.8 |

* Number of crewmen tested.
**Percent change from preflight mean.

**Serum and Plasma Enzymes Summary (MR-3 Flight)**

| | Normal range, units | Centrifuge | | | MR-3 flight | | |
|---|---|---|---|---|---|---|---|
| | | Prerun | Postrun | | Preflight | Postfight | |
| | | | + 30 min | + 2 hr | − 4 days | + 3 hr | + 45 hr |
| Transaminases: | | | | | | | |
| SGOT | 0-35 | 19 | 17 | 10 | 23 | 22 | 16 |
| SGPT | 0-20 | 4 | 4 | 9 | 0 | 6 | 8 |
| Esterase acetylcholine | [a]130-260 | 235 | 230 | 210 | 195 | 210 | 220 |
| Peptidase leucylamino | 100-310 | 240 | 220 | 310 | 360 | 415 | 400 |
| Aldolase | 50-150 | 25 | 28 | 19 | 28 | 38 | 41 |
| Isomerase phosphohexose | [b]10-20 | 12 | 11 | 11 | 5 | 15 | 7 |
| Dehydrogenases: | | | | | | | |
| Lactic | 150-250 | 200 | 190 | 235 | 185 | 170 | 190 |
| Malic | 150-250 | 190 | 155 | 220 | 225 | 190 | 220 |
| Succinic | Neg. | Neg. | Neg. | Neg. | Neg. | Neg. | Neg. |
| Inosine | Neg. | Neg. | Neg. | Neg. | Neg. | Neg. | Neg. |
| Alpha ketoglutaric | Neg. | Neg. | Neg. | Neg. | Neg. | Neg. | Neg. |

[a]ΔpH units.
[b]Bodansky units.

**Astronaut Peripheral Blood Values (MA-7 Flight)**

| Determination | Preflight | | Postflight | |
|---|---|---|---|---|
| | −7 days | −2 days | May 25, 1962 12:15 a.m. | May 26, 1962 12:00 m |
| Hemoglobin (cyanmethemoglobin method), grams/100 ml | 15.0 | 13.8 | 16.0 | 14.8 |
| Hematocrit, percent | 47 | 42 | 50 | 46 |
| White blood cells/mm$^3$ | 12,700 | 11,600 | 12,500 | 11,900 |
| Red blood cells, millions$^6$/mm$^3$ | 5.2 | ..... | 5.6 | 5.2 |
| Differential blood count: | | | | |
| Lymphocytes, percent | 25 | 19 | 27 | 37 |
| Neutrophiles, percent | 71 | 79 | 65 | 58 |
| Monocytes, percent | 2 | 1 | 3 | 2 |
| Eosinophiles, percent | 2 | 1 | 4 | 2 |
| Basophiles, percent | 0 | 0 | 1 | 1 |

**Blood Chemistry Findings (MR-4 Flight)**

| | Centrifuge | | | MR-4 flight | | | |
|---|---|---|---|---|---|---|---|
| | Prerun | Postrun | | Preflight | Postfight | | |
| | | +30 min | +2 hr | −4 days | +1 hr | +5 hr | +49 hr |
| Sodium (serum), meq/l | 147 | 141 | 143 | 142 | 140 | 144 | 141 |
| Potassium (serum), meq/l | 5.4 | 5.9 | 4.6 | 4.1 | 3.5 | 4.4 | 4.8 |
| Chloride, meq/l | 89 | 94 | 90 | 97 | 95 | 101 | 99 |
| Protein, total | 7.5 | 8.0 | 7.6 | 7.4 | 7.3 | 7.1 | 7.9 |
| Albumin, g/100 ml | 4.1 | 4.3 | 4.0 | 3.25 | 4.2 | 5.0 | 4.2 |
| Globulin, g/100 ml | 3.4 | 3.7 | 3.6 | 4.15 | 3.1 | 2.1 | 4.7 |
| Glucose, mg/100 ml | 78 | 118 | 95 | 94 | 136 | 105 | ..... |
| Epinephrine,[a] μg/l | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | ..... |
| Norepinephrine,[b] μg/l | 2.3 | 7.2 | 1.5 | 5.1 | 16.5 | 7.2 | ..... |

[a] Normal values: 0.0 to 0.4 μg/l.
[b] Normal values: 4.0 to 8.0 μ/l.

**Gemini VII Blood Chemistry Studies for Command Pilot**

| Determination | Preflight | | Postflight | | | |
|---|---|---|---|---|---|---|
| | Nov. 24 and Nov. 25, 1965 | Nov. 30 and Dec. 2, 1965 | Dec. 18, 1965 11:30 a.m., e.s.t. | Dec. 18, 1965 6:20 p.m., e.s.t. | Dec. 19, 1965 | Dec. 20 and Dec. 21, 1965 |
| Blood urea nitrogen, mg percent | 19 | 16 | 16 | 20 | 25 | 18 |
| Bilirubin, total mg percent | .4 | .2 | .3 | ..... | .3 | .4 |
| Alkaline phosphatase (B-L units) | 1.7 | 2.0 | 1.7 | ..... | ..... | ..... |
| Sodium, meq/liter | 147 | 146 | 138 | 140 | 144 | 143 |
| Potassium, meq/liter | 4.7 | 5.4 | 4.1 | 4.7 | 4.7 | 4.9 |
| Chloride, meq/liter | 103 | 103 | 100 | 102 | 103 | 106 |
| Calcium, mg percent | 9.0 | 9.2 | 8.6 | 9.2 | 9.0 | 9.2 |
| Phosphate, mg percent | 3.2 | 3.7 | 4.0 | 3.2 | 3.1 | 3.6 |
| Glucose, mg/100 ml, nonfasting | 71 | 90 | 98 | ..... | ..... | ..... |
| Albumin, g percent | 4.6 | 4.73 | 5.16 | ..... | 4.5 | 4.6 |
| Alpha 1, g percent | .23 | .26 | .08 | ..... | ..... | ..... |
| Alpha 2, g percent | .40 | .39 | .40 | ..... | ..... | ..... |
| Beta, g percent | .63 | .84 | .72 | ..... | ..... | ..... |
| Gamma, g percent | 1.03 | .97 | .72 | ..... | ..... | ..... |
| Total protein, g percent | 6.9 | 7.2 | 7.1 | 7.6 | 7.0 | 7.1 |
| Uric acid, mg percent | 6.8 | 6.6 | 4.6 | 6.0 | 5.9 | 6.0 |

**Routine Hematology Tests—Apollo**

- Red blood cell count
- Reticulocyte count
- Hemoglobin
    - Oxyhemoglobin
    - Carboxyhemoglobin
    - Methemoglobin
- Hematocrit
- Red cell indicies
    - Mean corpuscular volume
    - Mean corpuscular hemoglobin
    - Mean corpuscular hemoglobin concentration
- White blood cell count
- White blood cell differential
- Platelet count
- Total eosinophil count

## Table 2

## Special Hematology Tests

- Blood Volume Measurement
    - RBC mass
    - Plasma volume
    - Blood volume (calculated)
    - Serum iron turnover
    - RBC survival
    - Whole body hematocrit

- RBC Metabolism
    - Hexokinase
    - Phosphofructokinase
    - Glucose-3-phosphate dehydrogenase
    - Phosphoglyceric kinase
    - Pyruvate kinase
    - Adenosine triphosphate
    - 2, 3-diphosphoglycerate
    - Reduced glutathione
    - Glucose-6-phosphate dehydrogenase
    - Lipid peroxides

- Cellular Analysis
    - RBC electrolyte distribution (electron probe analysis)
    - RBC hemoglobin distribution (microspectrophotometry)
    - RBC morphology and ultrastructure (electron microscopy)
    - RBC age density separation
    - RBC sodium/potassium flux (isotope exchange)
    - RBC sodium/potassium concentration
    - RBC volume distribution

**Summary of Apollo Hematology Results**

| Parameter | Preflight Mean ± SD | Postflight Mean ± SD | | | |
|---|---|---|---|---|---|
| | | R+2 Hrs | R+1 Day | R+7 Days | R+14 Days |
| Red cell | 5.01 ± 0.31 | 4.92 ± 0.53 | 4.55 ± 0.34 | 4.56 ± 0.37 | 4.60 ± 0.30 |
| Reticulocyte | 0.98 ± 0.45 | 0.62 ± 0.23 | 0.58 ± 0.22 | 1.06 ± 0.39 | 1.18 ± 0.31 |
| Hemoglobin | 14.9 ± 0.7 | 15.4 ± 0.9 | 14.6 ± 0.9 | 13.9 ± 1.1 | 14.2 ± 0.9 |
| Hematocrit | 44.2 ± 2.2 | 44.2 ± 2.8 | 41.9 ± 3.1 | 40.9 ± 2.7 | 41.7 ± 2.6 |
| MCV[a] | 88.3 ± 3.7 | 90.5 ± 6.2 | 92.3 ± 5.5 | 90.2 ± 4.2 | 90.9 ± 4.3 |
| MCH[b] | 29.8 ± 1.3 | 31.5 ± 2.6 | 32.1 ± 2.3 | 30.5 ± 1.9 | 29.4 ± 6.7 |
| MCHC[c] | 33.8 ± 1.0 | 34.9 ± 1.6 | 34.4 ± 1.7 | 34.1 ± 1.0 | 34.2 ± 1.5 |
| Platelet | 218000 | 287000 | 225000 | 238000 | 261000 |
| White cell | 7000 ± 1800 | 8900 ± 3000 | 7300 ± 1900 | 6500 ± 1700 | 6500 ± 2200 |
| Neutrophil | 3900 ± 1100 | 6200 ± 2600 | 4000 ± 1100 | 3500 ± 1300 | 3900 ± 1800 |
| Lymphocyte | 2600 ± 700 | 2300 ± 1300 | 2700 ± 1100 | 2400 ± 800 | 2300 ± 800 |

[a]Mean corpuscular volume.
[b]Mean corpuscular hemoglobin.
[c]Mean corpuscular hemoglobin concentration.
The preflight mean represents the average of approximately 99 determinations (3 per crewman). The postflight means are average of 33 determinations or less (1 per crewman). Units in each case are standard with respect to routine hematology parameters.

**Summary of Changes in Red Cell Metabolic Constituents (Preflight vs Immediate Postflight Periods)**

| Parameter | Apollo Mission | | | | | | |
|---|---|---|---|---|---|---|---|
| | 7 | 8 | 9 | 14 | 15 | 16 | 17 |
| Hexokinase | + | 0 | 0 | ND | ND | ND | + |
| Phosphofructokinase | 0 | − | 0 | ND | ND | ND | + |
| Glucose-3-phosphate dehydrogenase | 0 | − | + | ND | ND | ND | + |
| Phosphoglyceric kinase | + | 0 | − | ND | ND | ND | + |
| Pyruvate kinase | ND | ND | ND | ND | ND | ND | 0 |
| Adenosine triphosphate | 0 | + | 0 | 0 | 0 | 0 | 0 |
| 2,3-diphosphoglycerate | ND | ND | ND | 0 | 0 | 0 | 0 |
| Reduced glutathion | − | 0 | + | ND | ND | ND | − |
| Glucose-6-phosphate dehydrogenase | ND | ND | ND | ND | ND | ND | 0 |
| Lipid peroxides | 0 | 0 | 0 | ND | ND | 0 | 0 |

0= no change, + = significantly increased, − = significantly decreased, ND = not done.

**Red Cell Shape Classification**

| Designation | Characteristic | Comments | SEM Criteria |
|---|---|---|---|
| Discocyte | Disc | Normal biconcave erythrocyte | Shallow but visible round depression in central portion of cell. |
| Leptocyte | Thin, flat | Flattened cell | No visible depression and no evidence of cell sphering (cell diameter normal or larger than normal). |
| Codocyte | Bell | Bell-shaped erythrocyte (appearance depends upon side of cell uppermost) | Single concavity with extruded opposite side or flattened ring around elevated central portion of cell. |
| Stomatocyte | Single concavity | Various stages of cup shapes | Swollen cell periphery with smaller concavity or concavity flattened on one side, indicating the beginnings of sphering. |
| Knizocyte | Pinch | Triconcave erythrocyte | Triconcave depression or cell with pinched area in center. |
| Echinocyte | Spiny | Various stages of crenation | Deformed and angular cell periphery with spicule formation. |

(From Kimzey et al., 1974)

## Hematology and Blood Chemistry (continued)

### Blood Volume Studies

| Mission | Plasma Volume (mean % change) | Red Cell Mass (mean % change) |
|---|---|---|
| Gemini 4 | −9 | −13* |
| Gemini 5 | −7 | −21 |
| Gemini 7 | +11 | −14 |
| Apollo 7-8 | −8 | − 2 |
| Apollo 9 | −9 | − 7 |
| Apollo 14-17 | −4±2 | −10± 1 |
| Apollo Controls | +10±2 | −1± 1 |

Red Cell Survival
($^{51}$Cr T ½ in Days)

| | Preflight | During Flight | Postflight |
|---|---|---|---|
| Apollo 7-8 | 25 | 28 | 25 |
| Apollo 14-17 | 24 | 23 | 27 |

*Calculated

## Summary of Apollo Serum Protein Results

| Parameter | Preflight Mean ± SD | Postflight Mean ± SD | | | |
|---|---|---|---|---|---|
| | | R+2 Hrs | R+1 Day | R+7 Days | R+14 Days |
| Total protein | 7.1 ± 0.1 | 7.3 ± 0.4 | 6.9 ± 0.3 | 6.7 ± 0.3 | 6.8 ± 0.3 |
| Albumin | 4.5 ± 0.1 | 4.5 ± 0.4 | 4.3 ± 0.4 | 4.3 ± 0.2 | 4.2 ± 0.4 |
| α1-globulin | 0.2 ± 0.01 | 0.2 ± 0.01 | 0.3 ± 0.07 | 0.2 ± 0.08 | 0.2 ± 0.09 |
| α2-globulin | 0.6 ± 0.02 | 0.7 ± 0.14 | 0.6 ± 0.18 | 0.6 ± 0.09 | 0.6 ± 0.08 |
| β-globulin | 0.8 ± 0.02 | 0.8 ± 0.10 | 0.7 ± 0.09 | 0.7 ± 0.06 | 0.7 ± 0.10 |
| γ-globulin | 1.0 ± 0.03 | 1.1 ± 0.21 | 1.0 ± 0.22 | 0.9 ± 0.17 | 1.0 ± 0.19 |
| IgG | 1022 ± 228 | 1076 ± 274 | 954 ± 235 | 949 ± 194 | 970 ± 188 |
| IgA | 187 ± 73 | 205 ± 86 | 174 ± 58 | 176 ± 62 | 221 ± 90 |
| IgM | 159 ± 73 | 164 ± 75 | 118 ± 37 | 157 ± 74 | 174 ± 64 |
| C3 | 84 ± 23 | 101 ± 28 | 84 ± 32 | 86 ± 29 | 103 ± 16 |
| Transferrin | 231 ± 31 | 225 ± 45 | 219 ± 32 | 218 ± 27 | 218 ± 17 |
| Haptoglobin | 136 ± 79 | 240 ± 121 | 189 ± 136 | 189 ± 120 | 180 ± 97 |
| Ceruloplasmin | 31 ± 5 | 38 ± 14 | 31 ± 7 | 35 ± 13 | 33 ± 11 |
| α 1-antitrypsin | 255 ± 61 | 283 ± 60 | 280 ± 69 | 263 ± 73 | 247 ± 66 |
| α 2-macroglobulin | 232 ± 91 | 282 ± 117 | 182 ± 33 | 226 ± 86 | 187 ± 31 |
| α 1-glycoprotein | 66 ± 17 | 74 ± 21 | 70 ± 21 | 77 ± 34 | 81 ± 25 |

The preflight mean represents the average of approximately 99 determinations (3 per crewman). Postflight means are averages of 33 determinations (1 per crewman). Values are expressed as gm% for first 6 parameters and mg% for the remainder.

## Biochemistry

**Normal Biochemistry Values for Apollo Astronaut Population**

| Parameter | Number of Crewmen | Two Standard Deviation Range |
|---|---|---|
| A. Serum | | |
| Osmolality | 112 | 267.2-313.7 |
| Sodium | 127 | 115.8-164.9 |
| Potassium | 126 | 3.5-4.7 |
| Chloride | 127 | 98.4-111.2 |
| Calcium | 126 | 8.9-10.3 |
| Magnesium | 128 | 1.7-2.7 |
| Inorganic phosphate | 128 | 2.3-4.7 |
| Blood urea nitrogen | 126 | 11.3-25.7 |
| Creatinine | 125 | 0.9-1.5 |
| Total protein | 131 | 6.2-7.8 |
| Albumin | 131 | 3.7-5.3 |
| Glucose | 98 | 85.4-111.5 |
| Triglycerides | 86 | 26.9-195.9 |
| Cholesterol | 125 | 113.1-261.1 |
| Uric acid | 126 | 4.4-7.9 |
| Total bilirubin | 122 | 0.1.5 |
| Alkaline phosphatase | 128 | 7.8-37.1 |
| Lactic acid dehydrogenase (RC) | 59 | 29.8-65.4 |
| (LKB) | 66 | 134.1-263.0 |
| Serum glutamic oxaloacetic transaminase (SGOT) (RC) | 59 | 14.2-44.8 |
| (LKB) | 67 | 9.5-22.1 |
| Creatine phosphokinase (RC) | 59 | 0.68.4 |
| (LKB) | 62 | 2.6-110.7 |
| B. Urine | | |
| 24-urine volume | 87 | 102-2746 |
| Specific gravity | 85 | 1.007-1.031 |
| Osmolality | 73 | 282-1110 |
| Sodium | 88 | 20.1-306.9 |
| Potassium | 88 | 18.6-128.4 |
| Chloride | 88 | 20.8-278.9 |
| Calcium | 88 | 0.8-16.9 |
| Magnesium | 88 | -30.5 |

## Biochemistry (continued)

### Apollo Biochemical Laboratory Techniques

| Constituent | Unitage | Method |
|---|---|---|
| **Serum Chemistries** | | |
| Sodium | mEq/L | Flame photometry (Henry) |
| Osmolality | milliosmols | Freezing point depression (Gambino) |
| Cholesterol | mg% | AutoAnalyser (Lieberman-Burchard) |
| Triglycerides | mg% | AutoAnalyser (Kessler & Lederer) |
| Magnesium | mg% | Atomic absorption (Willis) |
| Glucose | mg% | AutoAnalyser (Ferrocyanide reduction) |
| Inorganic phosphate | mg% | AutoAnalyser (Fiske & Subbarow) |
| Potassium | mEq/L | Flame photometry (Willis) |
| Chloride | mEq/L | Titration (Buchler-Cotlove) |
| Total bilirubin | mg% | AutoAnalyser (Jendrassic) |
| Direct bilirubin | mg% | AutoAnalyser (Jendrassic) |
| Calcium | mg% | Atomic absorption (Willis) |
| Uric acid | mg% | AutoAnalyser (Hawk) |
| Urea nitrogen | mg% | AutoAnalyser (Diacetyl monoxime/ Marsh et al.) |
| Creatinine | mg% | AutoAnalyser (Jaffe) |
| Alkaline phosphatase | International units | AutoAnalyser (Babson) |
| Creatine phosphokinase | milliunits/ml | Robot chemist (Oliver) |
| Creatine phosphokinase | International units | Rate reaction analysis (Boehringer-Mannheim) |
| Lactic dehydrogenase | milliunits/ml | Robot chemist (Wroblewski & LaDue) |
| Lactic dehydrogenase | International units | Rate reaction analysis (Boehringer-Mannheim) |
| Glutamic oxaloacetic transaminase | milliunits/ml | Robot chemist (Karmen, Wroblewski, & La Due) |
| Glutamic oxaloacetic transaminase | International units | Rate reaction analysis (Boehringer-Mannheim) |
| **Urine Chemistries** | | |
| Osmolality | milliosmols/24 hrs | Freezing Point Depression (Gambino) |
| Calcium | mEq/24 hrs | Atomic absorption (Willis) |
| Inorganic phosphate | mg/24 hrs (P) | AutoAnalyser (Fiske & Subbarow) |
| Specific gravity | None | Total solids |
| Chloride | mEq/24 hrs | Titration (Buchler-Cotlove) |
| Creatinine | mg/24 hrs | AutoAnalyser (Jaffe) |
| Volume | ml/24 hrs | Volumetric |
| Sodium | mEq/24 hrs | Flame photometry (Henry) |
| Magnesium | mEq/24 hrs | Atomic absorption (Willis) |
| Potassium | mEq/24 hrs | Flame photometry (Henry) |
| Uric acid | mg/24 hrs | AutoAnalyser (Hawk) |

## Biochemistry (continued)

### Summary of Apollo Serum Biochemistry Results

| Parameter | Unit | N | Preflight Mean S. D. | Recovery +2 hrs | Δ%*** | +1 Day | Δ%*** | +7 Days | Δ%*** | +14 Days | Δ%*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SGOT | mμ/ml | | | | | | | | | | |
| Missions 7-13 | | 21 | 29.5 ± 5.5 | 31.1 ± 6.6 | + 5.4 | 35.1 ± 9.9 | + 18.9 | 31.8 ± 5.9 | + 7.8 | 32.9 ± 6.9 | + 11.5 |
| Missions 14-17 | | 12 | 16.5 ± 3.7 | 15.8 ± 3.5 | − 4.2 | 16.3 ± 3.0 | − 1.2 | 13.3 ± 2.4 | − 19.4 | 14.0 ± 3.5 | − 15.2 |
| **Creatine phosphokinase | mμ/ml | | | | | | | | | | |
| Missions 7-13 | | 21 | 25.3 ± 22.7 | 18.7 ± 7.5 | − 26.1 | 35.2 ± 19.2 | + 39.1 | 16.3 ± 11.3 | − 35.6 | 16.8 ± 16.6 | + 33.6 |
| Missions 14-17 | | 12 | 70.9 ± 24.1 | 62.9 ± 45.4 | − 11.3 | 81.0 ± 62.2 | + 14.3 | 43.1 ± 21.8 | − 39.2 | 38.3 ± 12.9 | − 45.9 |

*Number of crewmen.
**Procedural change.
***% means percent change when compared to preflight mean.

## Summary of Apollo Serum Biochemistry Results

| Parameter | Unit | N* | Preflight Mean ± S. D. | Recovery | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | +2 hrs | Δ%*** | +1 Day | Δ%*** | +7 Days | Δ%*** | +14 Days | Δ%*** |
| Osmolality | Mosmo | 32 | 291 ± 3 | 289 ± 6 | − 0.7 | 290 ± 6 | − 0.3 | 293 ± 6 | + 0.7 | 294 ± 6 | + 1 |
| Na | mEq/l | 33 | 141.5 ± 0.9 | 140 ± 2.3 | − 0.4 | 140.9 ± 1.8 | − 0.4 | 142.8 ± 1.6 | + 0.9 | 143.0 ± 2.8 | + 1.1 |
| K | mEq/l | 33 | 4.1 ± 0.3 | 3.8 ± 0.3 | − 7.3 | 4.1 ± 0.3 | 0 | 4.1 ± 0.3 | 0 | 4.2 ± 0.2 | + 2.4 |
| Cl | mEq/l | 33 | 104.6 ± 2.2 | 104.0 ± 3.3 | − 0.6 | 104.2 ± 1.8 | − 0.4 | 105.7 ± 2.9 | + 1.1 | 106.6+ 2.3 | + 1.9 |
| Ca | mg/100 ml | 33 | 9.6 ± 0.3 | 9.7 ± 0.4 | + 1.0 | 9.5 ± 0.3 | − 1.0 | 9.5 ± 0.4 | − 1.0 | 9.6 ± 0.3 | 0 |
| Mg | mg/100 ml | 33 | 2.2 ± 0.2 | 2.1 ± 0.2 | − 5.0 | 2.2 ± 0.2 | 0 | 2.2 ± 0.1 | 0 | 2.3 ± 0.1 | + 5.0 |
| $PO_4$ | mg/100 ml | 33 | 3.6 ± 0.4 | 3.6 ± 0.6 | 0 | 3.4 ± 0.5 | − 6.0 | 3.8 ± 0.4 | + 6.0 | 3.7 ± 0.4 | + 2.8 |
| BUN | mg/100 ml | 33 | 18.5 ± 2.6 | 20.7 ± 3.8 | + 11.9 | 19.1 ± 3.4 | + 3.2 | 14.9 ± 2.4 | − 19.5 | 16.0 ± 2.9 | − 13.5 |
| Creatinine | mg/100 ml | 33 | 1.2 ± 0.1 | 1.3 ± 0.2 | + 8.3 | 1.2 ± 0.2 | 0 | 1.3 ± 0.2 | + 8.3 | 1.2 ± 0.2 | 0 |
| Total protein | gm/100 ml | 33 | 7.1 ± 0.3 | 7.3 ± 0.4 | + 2.8 | 6.9 ± 0.3 | − 2.8 | 6.7 ± 0.3 | − 5.6 | 6.8 ± 0.3 | − 4.2 |
| Albumin | gm/100 ml | 33 | 4.6 ± 0.3 | 4.5 ± 0.4 | − 2.2 | 4.3 ± 0.4 | − 6.5 | 4.3 ± 0.2 | − 6.5 | 4.2 ± 0.4 | − 8.7 |
| Glucose | mg/100 ml | 33 | 95.7 ± 7.3 | 105.1 ± 13.6 | + 9.8 | 93.4 ± 13.8 | − 2.4 | 99.1 ± 9.9 | + 3.6 | 94.2 ± 7.5 | − 1.6 |
| Triglycerides | mg/100 ml | 28 | 119.7 ± 77.4 | 90.6 ± 23.5 | − 24.3 | 95.0 ± 37.9 | − 20.6 | 113.2 ± 37.7 | − 5.4 | 157.9 ± 15.0 | + 31.9 |
| Cholesterol | mg/100 ml | 33 | 185.6 ± 36.3 | 174.4 ± 33.2 | − 6.0 | 149.8 ± 26.2 | − 19.3 | 165.9 ± 27.1 | − 10.6 | 179.6 ± 33.8 | − 3.2 |
| Uric acid | mg/100 ml | 33 | 6.1 ± 1.1 | 5.2 ± 0.9 | − 14.8 | 5.5 ± 1.0 | − 9.8 | 5.6 ± 1.1 | − 8.2 | 5.7 ± 0.9 | − 6.6 |
| Total bilirubin | mg/100 ml | 33 | 0.8 ± 0.5 | 0.9 ± 0.9 | + 12.5 | 0.7 ± 0.5 | − 12.5 | 0.5 ± 0.3 | − 37.5 | 0.6 ± 0.3 | − 25.0 |
| Alkaline phosphate | Int. units | 33 | 21.8 ± 4.0 | 22.3 ± 4.4 | + 2.8 | 21.8 ± 4.1 | 0 | 21.9 ± 4.8 | + 0.5 | 20.9 ± 5.1 | − 4.1 |
| **Lactic acid dehydrogenase | mμ/ml | | | | | | | | | | |
| Missions 7-13 | | 21 | 46.5 ± 7.7 | 46.0 | − 1.1 | 46.5 ± 8.5 | 0 | 46.5 ± 8.5 | 0 | 42.3 ± 5.4 | − 9.0 |
| Missions 14-17 | | 12 | 207.3 ± 24.2 | 186.4 ± 27.9 | − 10.1 | 196.7 ± 14.5 | − 5.1 | 189.5 ± 27.7 | − 8.6 | 180.0 ± 16.8 | − 13.2 |

## Biochemistry (continued)

### Significant* Serum Biochemistry Changes (Pre $\bar{x}$ vs. Recovery Day)

| Parameter | Direction of Change |
|---|---|
| Potassium | Decreased |
| Magnesium | Decreased |
| Creatinine | Increased |
| Lactic acid dehydrogenase | Decreased |
| Creatine phosphokinase | Decreased |
| Total protein | Increased |
| Albumin | Decreased |
| Blood urea nitrogen | Increased |
| Glucose | Increased |
| Triglycerides | Decreased |
| Cholesterol | Decreased |
| Uric acid | Decreased |

* Significant change is defined as $p<.05$.

## Nutrition Studies

### Fluid Intake and Output (MA-6 Flight)

| | Urine output (cc) | e.s.t. | Fluid intake | e.s.t. |
|---|---|---|---|---|
| Countdown | 0 | ..... | 0 cc | ..... |
| Inflight | [a]800 | 2:00 p.m. | [b]94 cc | 11:48 a.m. |
| Postflight, ship | 0 | ..... | 265 cc iced tea<br>240 cc water<br>125 cc coffee | 3:45 p.m.<br>6:30 p.m.<br>6:50 p.m. |
| Total | 800 | ..... | 724 cc | |

[a]Specific gravity, 1.016.
[b]119.5 grams of applesauce puree (78.7 percent water).

### Flight Crew Weight Loss to the Nearest Half Pound

| Gemini mission | Command pilot weight loss, lb | Pilot weight loss, lb |
|---|---|---|
| 3 | 3 | 3.5 |
| 4 | 4.5 | 8.5 |
| 5 | 7.5 | 8.5 |
| 6-A | 2.5 | 8 |
| 7 | 10 | 6 |
| 8 | ([a]) | ([a]) |
| 9-A | 5.5 | 13.5 |
| 10 | 3.0 | 3.0 |
| 11 | 2.5 | 0 |
| 12 | 6.5 | 7 |

[a]Not available.

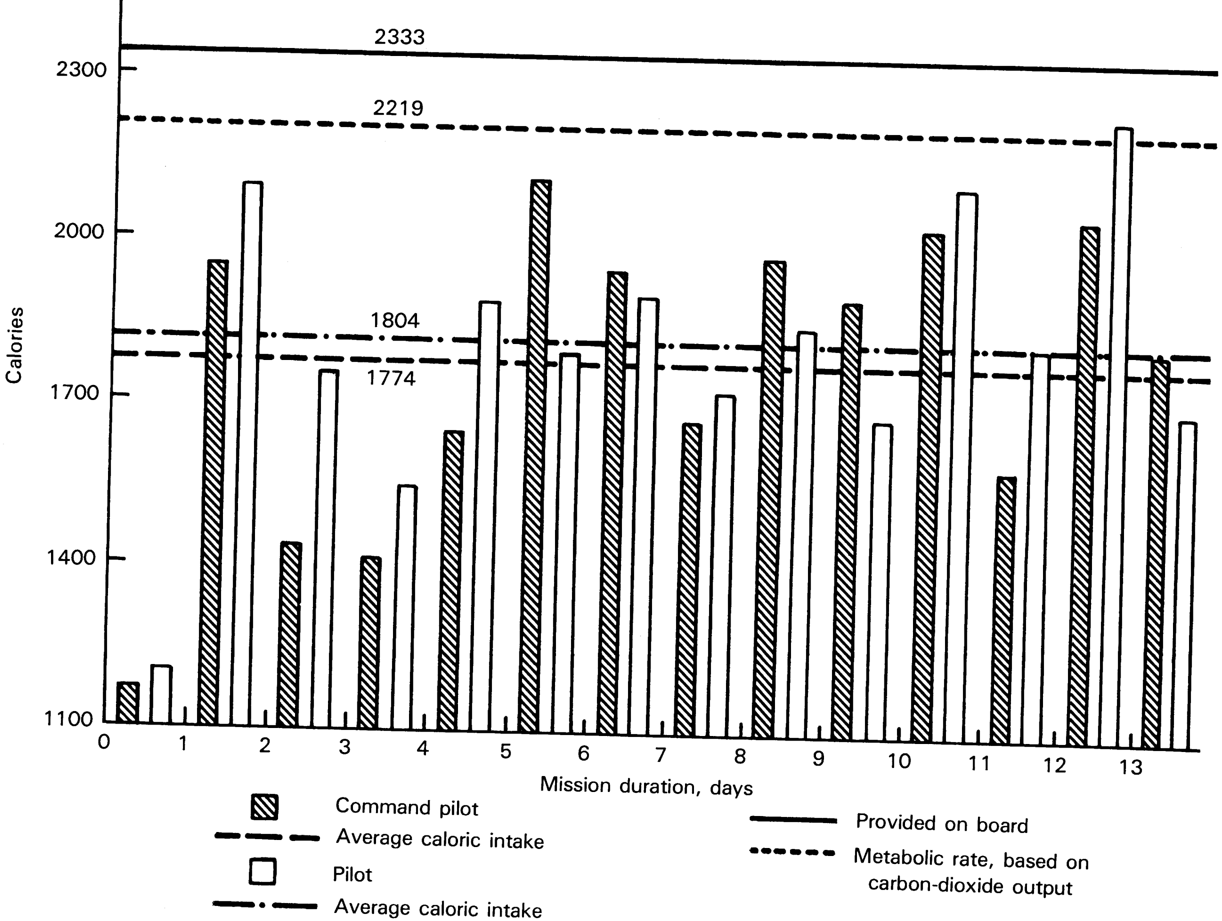



*Figure 16-16. Caloric intake on Gemini VII.*

## Nutrition Studies (continued)

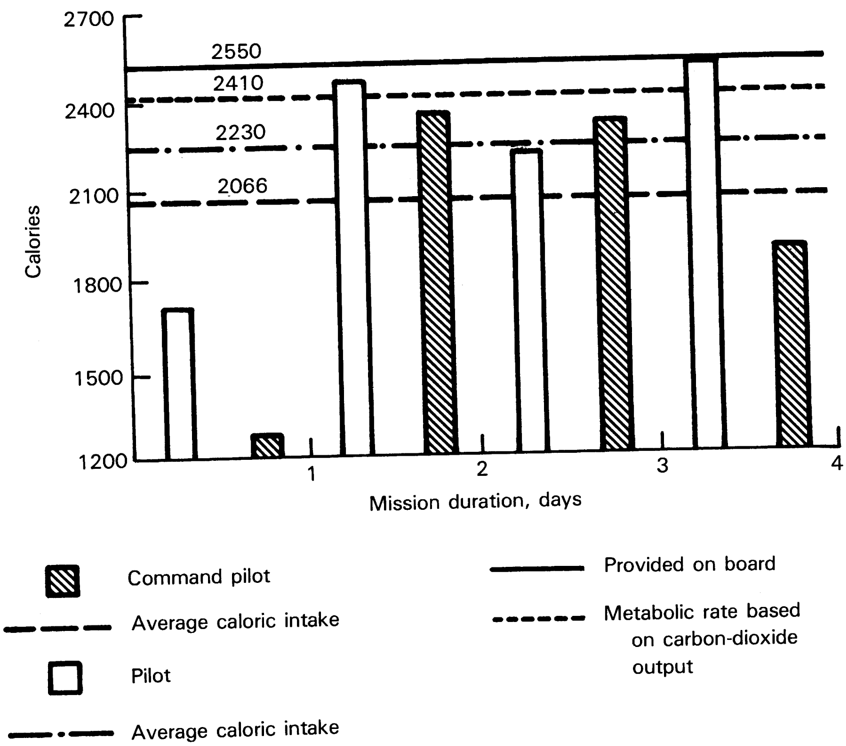



*Figure 16-14. Caloric intake on Gemini IV.*

Fig. 16-14. Caloric intake on Gemini IV.

## Nutrition Studies (continued)

**Total Weight Changes During and Following the Apollo Missions (Values in kilograms)**

| Mission Number | Crewman: Commander | Crewman: Command Module Pilot | Crewman: Lunar Module Pilot |
|---|---|---|---|
| | Weight losses during mission | | |
| 7 | −2.29 | −2.86 | −2.86 |
| 8 | −3.77 | −2.41 | −3.77 |
| 9 | −3.41 | −3.77 | −4.90 |
| 10 | −3.04 | −4.45 | −5.49 |
| 11 | −4.09 | −3.50 | −2.86 |
| 12 | − .82 | −3.54 | −6.36 |
| 13 | −4.54 | −5.04 | −3.04 |
| 14 | −1.73 | −5.90 | −3.00 |
| 15 | −2.18 | −1.54 | −3.59 |
| 16 | −4.81 | −4.04 | −2.63 |
| 17 | −4.56 | −2.68 | −3.06 |
| | Weight gains during first 24 hours following each mission | | |
| 7 | .75 | 3.50 | 4.00 |
| 8 | 2.75 | .75 | .50 |
| 9 | 2.75 | 8.50 | 4.25 |
| 10 | 2.25 | 1.75 | 1.50 |
| 11 | 6.00 | — | 4.00 |
| 12 | 2.00 | 4.00 | 3.00 |
| 13 | — | — | — |
| 14 | 1.00 | 7.00 | 1.00 |
| 15 | — | — | — |
| 16 | 2.50 | 3.00 | 2.50 |
| 17 | .25 | −1.50 | −2.50 |

## Nutrition Studies (continued)

**Balance of Water, Calcium, Phosphorus, Nitrogen, and Sodium During Apollo 17 Mission**

| Parameter | Control Measurement | | | Inflight Measurement | | |
|---|---|---|---|---|---|---|
| | CDR | CMP | LMP | CDR | CMP | LMP |
| **Water** | | | | | | |
| Intake, ml | 2666 | 3734 | 2268 | 2143 | 2705 | 2270 |
| Urine, ml | 1750 | 2516 | 1279 | 1120 | 1518 | 992 |
| Feces, ml | 63 | 146 | 73 | 68 | 142 | 116 |
| Water absorbed, ml | 853 | 1072 | 916 | 955 | 1045 | 1162 |
| Water absorbed, cc/kg body weight | 10.6 | 13.9 | 12.1 | 11.8 | 13.5 | 15.3 |
| **Calcium** | | | | | | |
| Intake, mg | 673 | 811 | 622 | 675 | 704 | 643 |
| Urine, mg | 98 | 204 | 118 | 117 | 182 | 89 |
| Feces, mg | 257 | 247 | 269 | 540 | 721 | 591 |
| Calcium absorbed, mg | 318 | 360 | 235 | 18 | −199 | − 37 |
| **Phosphorus** | | | | | | |
| Intake, mg | 1603 | 1883 | 1544 | 1430 | 1646 | 1438 |
| Urine, mg | 1139 | 1056 | 1087 | 1267 | 1561 | 1253 |
| Feces, mg | 239 | 227 | 281 | 280 | 592 | 510 |
| Phosphorus, absorbed, mg | 225 | 600 | 176 | −117 | −507 | −325 |
| **Nitrogen** | | | | | | |
| Intake, N/day/gm | 17.6 | 17.9 | 15.9 | 13.2 | 16.5 | 13.7 |
| Urine, N/day/gm | 14.0 | 13.3 | 16.7 | 15.7 | 16.4 | 15.0 |
| Feces, N/day/gm | 2.1 | 2.2 | 1.5 | 1.4 | 1.9 | 2.1 |
| Nitrogen absorbed, N/day/gm | 1.1 | 2.4 | − 2.3 | − 3.9 | − 1.8 | − 3.4 |
| **Sodium** | | | | | | |
| Intake, mEq | 216 | 209 | 185 | 168 | 205 | 163 |
| Urine, mEq | 149 | 139 | 192 | 143 | 164 | 135 |
| Feces, mEq | 2 | 5 | 3 | 17 | 26 | 7 |
| Sodium absorbed, mEq | 65 | 65 | −10 | 8 | 15 | 21 |
| **Potassium** | | | | | | |
| Intake, mEq | 99 | 117 | 95 | 73 | 81 | 97 |
| Urine, mEq | 75 | 81 | 82 | 76 | 75 | 89 |
| Feces, mEq | 4 | 7 | 5 | 12 | 13 | 16 |
| Potassium absorbed, mEq | 20 | 29 | 8 | −15 | − 7 | − 8 |

### Intake and Absorption Data—Apollo 16

Commander

| Day | Item | Water (gm) | kcal | Protein (gm) | Fat (gm) | CHO (gm) | Crude Fiber (gm) | Ash (gm) | Ca (mg) | P (mg) | Na (mEq) | K (mEq) | Mg (mg) | Cl (mEq) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F−3 | Total intake | 3645 | 3989 | 147.7 | 200.8 | 366.1 | 0 | 22.88 | 1033 | 2270 | 222.3 | 128.0 | 473 | 130.1 |
| | Feces | 54 | 108 | 6.7 | 1.7 | 7.3 | .86 | 2.10 | 269 | 298 | 4.4 | 8.7 | 127 | .3 |
| F−2 | Total Intake | 3442 | 3217 | 134.6 | 126.8 | 391.5 | 0 | 21.95 | 1130 | 1924 | 183.9 | 126.2 | 424 | 123.5 |
| | Feces | 123 | 351 | 15.8 | 12.5 | 22.4 | 3.25 | 5.40 | 919 | 851 | 3.6 | 25.3 | 364 | 1.3 |
| F−1 | Total intake | 2631 | 2402 | 103.5 | 92.9 | 265.7 | 0 | 14.24 | 580 | 1677 | 121.5 | 86.4 | 226 | 60.1 |
| | Feces | 76 | 276 | 16.8 | 9.3 | 12.5 | 2.17 | 5.39 | 945 | 803 | 20.9 | 22.5 | 342 | .6 |
| F+0 | Total intake | 1229 | 2047 | 79.9 | 115.3 | 166.0 | 1.69 | 11.74 | 561 | 1285 | 158.7 | 73.7 | 184 | 106.5 |
| | Feces | 36 | 78 | 5.2 | 2.4 | 4.1 | .44 | 1.70 | 340 | 249 | .7 | 7.4 | 120 | .009 |
| F+1 | Total intake | 2448 | 2421 | 81.8 | 84.2 | 412.4 | 8.98 | 19.3 | 882 | 1622 | 183.5 | 129.9 | 262 | 187.3 |
| | Feces | 82 | 321 | 16.1 | 11.3 | 15.9 | 3.00 | 8.4 | 1095 | 945 | 35.1 | 27.4 | 401 | 3.3 |
| F+2 | Total intake | 1750 | 1627 | 74.8 | 55.6 | 221.8 | 2.70 | 16.1 | 564 | 1106 | 184.7 | 77.5 | 140 | 148.5 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+3 | Total intake | 1629 | 2586 | 105.6 | 73.3 | 412.5 | 7.18 | 19.1 | 791 | 2002 | 207.9 | 129.4 | 242 | 168.9 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+4 | Total intake | 1846 | 2059 | 61.5 | 61.0 | 338.5 | 6.06 | 19.0 | 938 | 1144 | 175.2 | 152.4 | 192 | 121.1 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+5 | Total intake | 2029 | 2007 | 91.5 | 48.1 | 322.9 | 5.86 | 19.9 | 990 | 1624 | 123.0 | 81.9 | 252 | 103.7 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+6 | Total intake | 1869 | 2425 | 92.4 | 59.4 | 400.9 | 5.84 | 20.8 | 962 | 1481 | 219.9 | 147.0 | 276 | 186.3 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+7 | Total intake | 1907 | 2302 | 69.3 | 62.4 | 414.8 | 4.07 | 16.3 | 1037 | 1513 | 141.1 | 124.0 | 216 | 80.5 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+8 | Total intake | 1437 | 2405 | 96.9 | 103.3 | 269.8 | 6.00 | 19.9 | 1055 | 1683 | 253.5 | 133.1 | 272 | 169.5 |
| | Feces | 10 | * | 1.18 | 1.9 | 1.5 | .22 | 1.3 | 97 | 66 | 16.6 | 1.8 | 21 | * |
| F+9 | Total intake | 1216 | 1432 | 71.4 | 36.5 | 240.6 | 6.99 | 14.7 | 516 | 1072 | 130.0 | 101.1 | 197 | 167.2 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |

*Insufficient sample.

## Intake and Absorption Data—Apollo 16

| Day | Item | Water (gm) | kcal | Protein (gm) | Fat (gm) | CHO (gm) | Crude Fiber (gm) | Ash (gm) | Ca (mg) | P (mg) | Na (mEq) | K (mEq) | Mg (mg) | Cl (mEq) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Commander (Continued)** | | | | | | | | | | | | | | |
| F+10 | Total intake | 2301 | 2363 | 121.8 | 105.4 | 268.0 | 5.54 | 25.8 | 563 | 1472 | 253.3 | 100.0 | 209 | 200.5 |
| | Feces | 88 | 268 | 17.7 | 6.8 | 16.2 | 2.35 | 8.5 | 1927 | 1193 | 18.2 | 29.6 | 333 | 2.3 |
| R+0 | Total Intake | 2432 | 1816 | 71.5 | 76.6 | 200.3 | 0 | 12.19 | 728 | 1268 | 97.6 | 93.0 | 242 | 54.2 |
| | Feces | 59 | 145 | 8.9 | 4.4 | 9.0 | 1.42 | 3.36 | 654 | 456 | 1.3 | 15.7 | 167 | .4 |
| R+1 | Total intake | 2895 | 2744 | 97.9 | 92.3 | 388.2 | 0 | 13.80 | 755 | 1293 | 120.1 | 117.6 | 214 | 83.6 |
| | Feces | 156 | 329 | 22.4 | 4.9 | 22.5 | 5.85 | 7.95 | 1221 | 1039 | 5.5 | 45.9 | 374 | 1.1 |
| R+2 | Total intake | 1655 | 1101 | 48.1 | 58.8 | 95.4 | 0 | 8.93 | 314 | 881 | 91.7 | 83.4 | 143 | 61.0 |
| | Feces | * | * | * | * | * | .54 | * | * | * | * | * | * | * |
| **Lunar Module Pilot** | | | | | | | | | | | | | | |
| F−3 | Total intake | 4050 | 3369 | 120.7 | 114.0 | 352.5 | 0 | 18.20 | 811 | 1872 | 179.6 | 119.6 | 391 | 132.1 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F−2 | Total intake | 4285 | 3375 | 128.7 | 93.1 | 396.2 | 0 | 16.66 | 734 | 1743 | 147.2 | 113.3 | 362 | 117.3 |
| | Feces | 59 | 179 | 11.3 | 4.2 | 9.6 | 1.18 | 4.80 | 653 | 747 | 11.3 | 20.2 | 369 | .7 |
| F−1 | Total intake | 3348 | 2929 | 118.5 | 76.5 | 305.7 | 0 | 14.74 | 515 | 1914 | 130.2 | 98.5 | 353 | 83.2 |
| | Feces | 162 | 435 | 31.9 | 14.1 | 29.0 | 3.25 | 16.10 | 2121 | 1896 | 5.1 | 54.7 | 1008 | 3.4 |
| F+0 | Total intake | 1808 | 2233 | 69.7 | 111.4 | 252.2 | .67 | 11.32 | 669 | 1300 | 125.6 | 91.5 | 176 | 82.1 |
| | Feces | 71 | * | 10.8 | 5.3 | 9.2 | 1.54 | 4.07 | 653 | 601 | 1.8 | 19.0 | 320 | .8 |
| F+1 | Total intake | 2365 | 1980 | 64.4 | 56.6 | 328.9 | 4.29 | 16.7 | 596 | 1136 | 169.5 | 110.2 | 197 | 210.2 |
| | Feces | 87 | 306 | 17.2 | 10.2 | 14.5 | 1.92 | 6.5 | 931 | 70 | 4.4 | 29.9 | 443 | 1.8 |
| F+2 | Total intake | 1794 | 1588 | 59.4 | 51.1 | 244.0 | 2.92 | 13.4 | 507 | 938 | 140.7 | 83.7 | 136 | 167.3 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+3 | Total intake | 1484 | 1904 | 112.0 | 66.2 | 274.0 | 0.04 | 18.8 | 613 | 1027 | 209.3 | 129.6 | 227 | 190.7 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+4 | Total intake | 2059 | 1986 | 49.0 | 44.4 | 406.5 | 5.67 | 17.0 | 862 | 923 | 161.9 | 145.8 | 172 | 138.0 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |

*Insufficient sample.

## Intake and Absorption Data—Apollo 16

| Day | Item | Water (gm) | kcal | Protein (gm) | Fat (gm) | CHO (gm) | Crude Fiber (gm) | Ash (gm) | Ca (mg) | P (mg) | Na (mEq) | K (mEq) | Mg (mg) | Cl (mEq) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lunar Module Pilot (Continued) | | | | | | | | | | | | | | |
| F+5 | Total intake | 1968 | 1615 | 89.6 | 40.0 | 250.2 | 5.19 | 17.86 | 885 | 1354 | 102.3 | 76.9 | 232 | 96.0 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+6 | Total intake | 1995 | 2369 | 16.4 | 63.9 | 383.7 | 7.35 | 19.96 | 876 | 1607 | 192.1 | 148.6 | 283 | 150.4 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+7 | Total intake | 1756 | 2034 | 64.0 | 51.1 | 332.5 | 3.32 | 13.20 | 989 | 1329 | 133.4 | 114.2 | 175 | 81.2 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+8 | Total intake | 1783 | 2133 | 93.0 | 75.2 | 295.6 | 5.10 | 18.03 | 932 | 1582 | 187.5 | 126.4 | 268 | 180.0 |
| | Feces | 177 | 390 | 29.4 | 8.9 | 16.3 | 3.88 | 16.71 | 2191 | 1607 | 6.0 | 45.9 | 367 | 2.5 |
| F+9 | Total intake | 1126 | 1388 | 70.4 | 36.1 | 232.6 | 7.22 | 14.0 | 532 | 1027 | 127.6 | 142.3 | 177.3 | 168.1 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+10 | Total intake | 1645 | 1679 | 70.4 | 71.7 | 213.7 | 2.73 | 17.93 | 389 | 1114 | 153.5 | 93.3 | 177 | 178.0 |
| | Feces | 54 | 319 | 15.9 | 13.6 | 14.0 | 1.97 | 6.55 | 681 | 495 | 51.3 | 27.5 | 187 | 5.9 |
| R+0 | Total intake | 2298 | 2585 | 74.1 | 97.7 | 347.4 | 0 | 11.30 | 568 | 1147 | 129.3 | 87.8 | 165 | 85.2 |
| | Feces | 394 | 913 | 49.9 | 33.1 | 57.1 | 13.26 | 19.70 | 2636 | 2953 | 79.4 | 93.0 | 684 | 6.6 |
| R+1 | Total intake | 3175 | 3373 | 125.1 | 108.2 | 482.5 | 0 | 16.67 | 851 | 1705 | 166.0 | 120.1 | 264 | 100.8 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| R+2 | Total intake | 2246 | 2436 | 71.9 | 111.3 | 292.3 | 0 | 13.01 | 487 | 1245 | 142.7 | 84.7 | 185 | 98.3 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Command Module Pilot | | | | | | | | | | | | | | |
| F−3 | Total intake | 2141 | 2202 | 76.0 | 113.3 | 202.9 | 0 | 13.63 | 566 | 1141 | 130.1 | 98.0 | 305 | 101.5 |
| | Feces | 130 | 293 | 19.2 | 9.4 | 21.2 | 3.90 | 6.46 | 925 | 866 | 8.9 | 29.6 | 414 | 1.0 |
| F−2 | Total intake | 2610 | 1855 | 77.6 | 93.5 | 136.2 | 0 | 11.55 | 410 | 1004 | 100.3 | 94.3 | 322 | 90.1 |
| | Feces | 29 | (a) | 7.8 | 4.2 | 10.0 | .75 | 3.30 | 514 | (a) | 1.6 | 14.2 | 219 | .6 |

*Insufficient sample.

**Intake and Absorption Data—Apollo 16**

| Day | Item | Water (gm) | kcal | Protein (gm) | Fat (gm) | CHO (gm) | Crude Fiber (gm) | Ash (gm) | Ca (mg) | P (mg) | Na (mEq) | K (mEq) | Mg (mg) | Cl (mEq) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Command Module Pilot (Continued) | | | | | | | | | | | | | | |
| F−1 | Total intake | 2356 | 2338 | 78.2 | 82.2 | 303.9 | 0 | 12.10 | 434 | 1208 | 127.4 | 90.6 | 224 | 94.5 |
| | Feces | 99 | 329 | 22.3 | 9.3 | 12.6 | 1.89 | 7.00 | 1185 | 977 | 2.0 | 34.1 | 471 | 1.0 |
| F+0 | Total intake | 1753 | 2057 | 48.2 | 105.8 | 221.4 | 1.30 | 11.92 | 630 | 1046 | 167.7 | 91.1 | 175 | 109.1 |
| | Feces* | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+1 | Total intake | 1292 | 1394 | 30.0 | 58.0 | 201.3 | 3.38 | 11.7 | 382 | 681 | 136.7 | 79.1 | 110 | 194.0 |
| | Feces | 37 | 115 | 4.8 | 3.4 | 7.3 | 1.26 | 2.3 | 345 | * | 5.7 | 10.9 | 131 | .7 |
| F+2 | Total intake | 1227 | 1052 | 48.0 | 31.5 | 147.8 | 1.54 | 10.71 | 306 | 658 | 130.7 | 53.5 | 90 | 107.2 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+3 | Total intake | 1432 | 1706 | 83.2 | 46.3 | 267.5 | 4.41 | 12.5 | 614 | 1389 | 123.9 | 95.0 | 159 | 100.8 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+4 | Total intake | 1086 | 1115 | 25.1 | 24.5 | 200.9 | 1.68 | 5.70 | 400 | 495 | 55.2 | 45.4 | 97 | 41.0 |
| | Feces | 32 | 110 | 4.9 | 2.3 | 7.6 | 1.52 | 2.21 | 382 | 309 | 2.0 | 11.3 | 126 | .4 |
| F+5 | Total intake | 1476 | 1348 | 82.2 | 44.4 | 175.5 | 2.61 | 13.3 | 425 | 1216 | 124.2 | 82.6 | 165 | 85.7 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+6 | Total intake | 1089 | 1165 | 24.0 | 57.3 | 151.0 | 2.16 | 11.3 | 228 | 546 | 68.5 | 75.9 | 128 | 38.5 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+7 | Total intake | 1475 | 1437 | 48.6 | 24.7 | 233.8 | 2.29 | 10.0 | 856 | 995 | 99.4 | 91.7 | 118 | 52.5 |
| | Feces | 144 | 343 | 21.9 | 7.5 | 20.8 | 2.52 | 10.0 | 1612 | 1352 | 28.3 | 47.2 | 416 | 2.6 |
| F+8 | Total intake | 1186 | 1263 | 31.2 | 55.1 | 177.3 | 4.22 | 11.0 | 340 | 613 | 88.9 | 81.1 | 142 | 75.5 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+9 | Total intake | 1048 | 919 | 41.7 | 20.1 | 156.6 | 3.12 | 9.9 | 251 | 640 | 85.1 | 73.3 | 139 | 105.0 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| F+10 | Total intake | 1526 | 2037 | 103.2 | 90.7 | 224.7 | 2.94 | 17.7 | 714 | 1551 | 215.6 | 110.4 | 219 | 136.3 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |

*Insufficient sample.

## Intake and Absorption Data—Apollo 16 (Continued)

| Day | Item | Water (gm) | kcal | Protein (gm) | Fat (gm) | CHO (gm) | Crude Fiber (gm) | Ash (gm) | Ca (mg) | P (mg) | Na (mEq) | K (mEq) | Mg (mg) | Cl (mEq) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Command Module Pilot (Continued) | | | | | | | | | | | | | | |
| R+0 | Total intake | 2387 | 2084 | 58.3 | 94.8 | 250.1 | 0 | 10.75 | 474 | 1016 | 108.3 | 73.1 | 194 | 73.8 |
| | Feces | — | — | — | — | — | — | — | — | — | — | — | — | — |
| R+1 | Total intake | 2712 | 2474 | 83.8 | 112.6 | 289.0 | 0 | 13.76 | 670 | 1173 | 121.2 | 87.0 | 271 | 93.3 |
| | Feces | 190 | 428 | 26.2 | 7.6 | 26.8 | 3.32 | 9.87 | 1678 | 1365 | 8.3 | 53.5 | 477 | 2.1 |
| R+2 | Total intake | 1927 | 2022 | 64.1 | 101.0 | 216.2 | 0 | 11.93 | 488 | 1012 | 126.2 | 87.0 | 215 | 92.5 |
| | Feces | 62 | 214 | 13.4 | 3.7 | 13.0 | 1.36 | 4.67 | 791 | 655 | 1.8 | 25.2 | 234 | .8 |

## Nutrition Studies (continued)

### Nutrient Intake During Apollo Missions

| Mission Number | Mission Duration, Days, | Crewman | Nutrient, gm | | | |
|---|---|---|---|---|---|---|
| | | | Protein | Fat | Carbohydate | Fiber |
| 7 | 10 | CDR | 81 | 72 | 259 | — |
| | | CMP | 96 | 78 | 280 | — |
| | | LMP | 74 | 56 | 268 | — |
| 8 | 6 | CDR | 59 | 39 | 231 | — |
| | | CMP | 80 | 49 | 240 | — |
| | | LMP | 52 | 33 | 217 | — |
| 9 | 10 | CDR | 86 | 60 | 280 | — |
| | | CMP | 78 | 53 | 240 | — |
| | | LMP | 66 | 47 | 252 | — |
| 10 | 8 | CDR | 58 | 34 | 213 | — |
| | | CMP | 46 | 30 | 213 | — |
| | | LMP | 49 | 30 | 208 | — |
| 11 | 10 | CDR | 79 | 65 | 290 | — |
| | | CMP | 71 | 54 | 224 | — |
| | | LMP | 94 | 73 | 322 | — |
| 12 | 10 | CDR | 70 | 50 | 263 | 4.6 |
| | | CMP | 65 | 49 | 249 | 3.9 |
| | | LMP | 57 | 42 | 280 | 3.3 |
| 13 | 7 | CDR | 59 | 50 | 239 | — |
| | | CMP | 57 | 47 | 235 | — |
| | | LMP | 57 | 49 | 228 | — |
| 14 | 8 | CDR | 90 | 76 | 309 | — |
| | | CMP | 79 | 61 | 230 | — |
| | | LMP | 81 | 89 | 319 | — |
| 15 | 11 | CDR | 126 | 115 | 356 | 8.2 |
| | | CMP | 109 | 94 | 334 | 7.9 |
| | | LMP | 100 | 89 | 421 | 2.2 |
| 16 | 11 | CDR | 88 | 73 | 319 | 6.2 |
| | | CMP | 79 | 60 | 295 | 5.3 |
| | | LMP | 52 | 50 | 203 | 3.1 |
| 17 | 12 | CDR | 88 | 68 | 248 | 3.9 |
| | | CMP | 87 | 87 | 293 | 5.3 |
| | | LMP | 98 | 104 | 314 | 5.3 |

## Nutrition Studies (continued)

### Apollo Inflight Energy Intake Based on Body Weight [Values in kJ/kg/day (kcal/kg/day)]

| Apollo Mission Number | Crewmen | | |
|---|---|---|---|
| | CDR | CMP | LMP |
| 7 | 93.7 (22.4) | 128.8 (30.8) | 106.7 (25.5) |
| 8 | 80.8 (19.3) | 92.0 (22.0) | 84.5 (20.2) |
| 9 | 109.9 (26.3) | 97.0 (23.2) | 92.5 (22.1) |
| 10 | 71.1 (17.0) | 68.7 (16.4) | 66.1 (15.8) |
| 11 | 108.7 (26.0) | 90.8 (21.7) | 122.2 (29.2) |
| 12 | 109.9 (26.3) | 99.1 (23.7) | 101.1 (24.2) |
| 13 | 84.1 (20.1) | 71.9 (17.2) | 89.8 (21.5) |
| 14 | 123.4 (29.5) | 95.8 (22.9) | 117.2 (28.0) |
| 15 | 149.7 (35.8) | 141.8 (33.9) | 145.2 (34.7) |
| 16 | 125.5 (30.0) | 104.6 (25.0) | 135.4 (32.4) |
| 17 | 93.7 (22.4) | 123.8 (29.6) | 110.5 (26.4) |

### Comparison of Apollo Inflight and Ground-Based Average Energy Intake [Values in kj/kg (kcal/kg)]

| Mission Number | Crewman | Ground-Based Intake* | Inflight Intake* |
|---|---|---|---|
| 9 | LMP | 151.4 (36.2) | 92.5 (22.1) |
| 12 | CDR | 157.3 (37.6) | 109.9 (26.3) |
| | LMP | 147.3 (35.2) | 101.3 (24.2) |
| 16 | CDR | 184.1 (44.0) | 125.4 (30.0) |
| | CMP | 150.9 (36.1) | 104.5 (25.0) |
| | LMP | 176.8 (42.3) | 135.6 (32.4) |
| 17 | CDR | 129.6 (31.0) | 93.7 (22.4) |
| | CMP | 163.9 (39.2) | 123.8 (29.6) |
| | LMP | 130.8 (31.3) | 110.5 (26.4) |

*Mean value is 154.7 ± 18.4 kJ/kg (37.0 ± 4.4 kcal/kg)
**Mean value is 110.8 ± 13.8 kJ/kg (26.5 ± 3.3 kcal/kg)

**Summary of Blood-Pressure Data (MA-8 Flight)**

| Date | Procedure | Mean blood pressure, mm Hg | Systole | | | | Diastole | | | | Mean pulse pressure, mm Hg |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Number of determinations | Standard deviation, $2\sigma$ | Range, mm Hg | Mean, mm Hg | Number of determinations | Standard deviation, $2\sigma$ | Range, mm Hg | Mean, mm Hg | |
| | | | | | Preflight, clinical | | | | | | |
| Mar. 1959 | Lovelace Clinic dynamic tests. | 119/67 | 39 | ([a]) | 90 to 164 | 119 | 39 | ([a]) | 52 to 84 | 67 | 52 |
| July 25, 1962 | Special BPMS test | 104/75 | 27 | 92 to 116 | 94 to 116 | 104 | 27 | 62 to 88 | 64 to 94 | 75 | 29 |
| 1960 to Oct. 3, 1962. | Random clinical determinations. | 115/76 | 13 | 103 to 127 | 100 to 122 | 115 | 13 | 62 to 90 | 64 to 84 | 76 | 39 |
| | | | | | Preflight, BPMS | | | | | | |
| Sept. 22, 1961 | Mercury-Atlas dynamic simulation on centrifuge. | 133/96 | 11 | 111 to 155 | 115 to 150 | 133 | 11 | 68 to 124 | 76 to 120 | 96 | 37 |
| July 25, 1962 | Special BPMS test | 108/67 | 28 | ([a]) | 94 to 126 | 108 | 28 | ([a]) | 54 to 100 | 67 | 41 |
| May to Oct. 1962 | Hangar and launch complex tests. | 107/70 | 31 | 92 to 122 | 94 to 123 | 107 | 29 | 58 to 82 | 58 to 80 | 70 | 37 |
| Oct. 3, 1962 | Prelaunch (hangar, transfer van, and blockhouse). | 117/80 | 14 | 103 to 121 | 110 to 143 | 117 | 14 | 66 to 94 | 71 to 94 | 80 | 37 |
| | | | | | Inflight, BPMS | | | | | | |
| Oct. 3, 1962 | Inflight | 126/69 | 20 | 116 to 136 | 111 to 158 | 126 | 16 | 64 to 74 | 59 to 75 | 69 | 57 |
| | | | | | Postflight, clinical | | | | | | |
| Oct. 3 and 4, 1962. | Debriefing onboard carrier. | 112/78 | 12 | 92 to 132 | 94 to 120 | 112 | 12 | 70 to 86 | 70 to 84 | 78 | 37 |

[a] These data are included for completeness but the conditions were very different from the other procedures.

## Summary of Heart Rate and Respiration Data from Physiological Monitoring (MA-8 Flight)

| Date | Procedure | Duration of observation, hr: min | Heart rate, beats/min | | | | Respiration rate, breaths/min | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Number of determinations | Standard deviations, $2\sigma$ | Range | Mean | Number of determinations | Standard deviations, $2\sigma$ | Range | Mean |
| | | | | | Preflight | | | | | |
| March 1959 | Lovelace Clinic dynamic tests | Variable | 39 | ([a]) | 69 to 160 | 96 | | None recorded. | | |
| Sept. 22, 1961 | Mercury-Atlas centrifuge dynamic simulation | 1:07.5 | 75 | 50 to 78 | 48 to 78 | 64 | 25 | 9 to 15 | 7 to 18 | 12 |
| May 4, 1962 | MA-7 launch pad simulated flight | 1:09 | 24 | 53 to 91 | 58 to 88 | 72 | 19 | 10 to 22 | 10 to 24 | 16 |
| Apr. 17 and Aug. 14, 1962 | Hangar simulated flights | 9:47 | 87 | 52 to 78 | 51 to 76 | 65 | 19 | 14 to 26 | 14 to 24 | 20 |
| Sept. 10, 1962 | Launch pad simulated flight 1A | 3:09 | 69 | 45 to 65 | 43 to 72 | 55 | 68 | 14 to 26 | 10 to 28 | 20 |
| Sept. 14, 1962 | Launch pad simulated flight 2A | 2:35 | 68 | 54 to 82 | 52 to 86 | 68 | 68 | 14 to 30 | 12 to 28 | 22 |
| Sept. 28, 1962 | Launch pad simulated launch | 3:07 | 72 | 49 to 73 | 46 to 74 | 61 | 71 | 12 to 28 | 9 to 26 | 20 |
| Oct. 3, 1962 | Launch countdown | 2:33 | 61 | 64 to 80 | 58 to 88 | 72 | 61 | 17 to 23 | 16 to 26 | 20 |
| | | | | | Inflight | | | | | |
| Oct. 3, 1962 | Inflight | 9:13 | 220 | 50 to 102 | 56 to 121 | 76 | 220 | 11 to 27 | 10 to 43 | 19 |
| | | | | | Postflight, clinical | | | | | |
| Oct. 3 and 4, 1962 | Debriefing onboard recovery ship | Variable | 22 | 52 to 112 | 56 to 104 | 82 | | None recorded | | |

*These data are included for completeness, but the conditions were very different from the other procedures.

**Summary of Tilt Studies (MA-9 Flight)**

| Subject | No. of determinations | Pretilt | | | | | Tilt | | | | | Posttilt | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Heart rate, beats/min | | Blood pressure, mm Hg | | | Heart rate, beats/min | | Blood pressure, mm Hg | | | Heart rate, beats/min | | Blood pressure, mm Hg | | |
| | | | | | Range | | | | | Range | | | | | Range | |
| | | Mean | Range | Mean | Systolic | Diastolic | Mean | Range | Mean | Systolic | Diastolic | Mean | Range | Mean | Systolic | Diastolic |
| **Preflight** | | | | | | | | | | | | | | | | |
| Cooper preprocedure | 5 | 66 | 53 to 76 | 100/73 | 91 to 112 | 60 to 87 | 82 | 60 to 105 | 100/86 | 88 to 144 | 60 to 94 | 66 | 60 to 90 | 102/75 | 89 to 114 | 60 to 88 |
| Cooper postprocedure | 6 | 64 | 51 to 85 | 99/74 | 92 to 128 | 66 to 82 | 85 | 72 to 108 | 105/87 | 92 to 134 | 60 to 97 | 62 | 52 to 76 | 102/75 | 90 to 114 | 64 to 94 |
| Cooper and Shepard (all preflight tilts) | 15 | 67 | 55 to 85 | 100/71 | 90 to 112 | 60 to 82 | 86 | 60 to 117 | 107/86 | 88 to 145 | 64 to 98 | 64 | 52 to 80 | 103/72 | 90 to 114 | 60 to 94 |
| **Postflight** | | | | | | | | | | | | | | | | |
| Cooper[a] | 3 | 83 | 76 to 81 | 89/64 | 86 to 90 | 52 to 82 | 123 | 96 to 144 | 90/73 | 80 to 110 | 68 to 84 | 76 | 64 to 88 | 98/69 | 90 to 106 | 58 to 80 |
| Cooper[b] | 1 | 58 | 56 to 60 | 98/61 | 96 to 100 | 60 to 62 | 80 | 76 to 88 | 94/68 | 86 to 100 | 64 to 78 | 60 | 56 to 64 | 102/56 | 96 to 108 | 54 to 58 |

[a] Tilts between 1 and 7 hours after landing.
[b] Tilt 18 hours after landing.

## Physiological Measurements Made Before, During, and After Exercise Stress

| Variable | Preflight | | | Day of Recovery | | | | Day After Recovery | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Standard Deviation | Number of Observations | Mean | Standard Deviation | Probability Level | Number of observations | Mean | Standard Deviation | Probability Level | Number of Observations |
| $O_2$ consumption l/min STPD at a workload of: 900 kpm/min | 1.94 | 0.20 | 31 | 1.90 | 0.29 | NS | 23 | 2.09 | 0.33 | <0.05 | 23 |
| $O_2$ consumption l/min/kg STPD at a heart rate of: | | | | | | | | | | | |
| 160 beats/min | 33.1 | 5.6 | 31 | 28.2 | 6.0 | <0.005 | 27 | 32.9 | 6.3 | NS | 22 |
| 180 beats/min | 39.5 | 6.6 | 31 | 34.6 | 6.8 | <0.01 | 27 | 39.3 | 7.7 | NS | 24 |
| Systolic blood pressure (mm Hg)* at a heart rate of: 160 beats/min | 206 | 22.7 | 31 | 184 | 30.5 | <0.005 | 27 | 201 | 28.6 | NS | 27 |
| Systolic blood pressure (mm Hg)* at 15 l/mm cardiac output | 170 | 18.0 | 09 | 173 | 35.8 | NS | 09 | 180 | 32.7 | NS | 09 |
| Diastolic blood pressure (mm Hg)* at a heart rate of: 160 beats/min | 089 | 9.5 | 31 | 080 | 11.8 | <0.005 | 27 | 084 | 19.2 | NS | — |
| Mean arterial pressure (mm Hg)* at 15 l/min cardiac output | 111 | 15.0 | 09 | 109 | 17.5 | NS | 09 | 114 | 18.2 | NS | 09 |
| Minute volume (l/min BTPS) at an $O_2$ consumption of 2.0 l/min STPD | 52.4 | 7.7 | 31 | 54.7 | 8.8 | NS | 24 | 54.3 | 8.6 | NS | 22 |

*1 mm Hg = 133.3224 $N/m^2$

## Cardiovascular Studies (continued)

**Physiological Measurements Made Before, During, and After Exercise Stress—Apollo**

| Variable | Preflight | | | Day of Recovery | | | | Day After Recovery | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Standard Deviation | Number of Observations | Mean | Standard Deviation | Probability Level | Number of observations | Mean | Standard Deviation | Probability Level | Number of Observations |
| **Stress Period (Continued)** | | | | | | | | | | | |
| Cardiac output (l/min) at a heart rate of: 160 beats/min | 23.2 | 5.5 | 09 | 14.7 | 3.9 | <0.001 | 09 | 21.6 | 4.8 | NS | 09 |
| Arteriovenous $O_2$ difference, volumes percent, at a heart rate of: 160 beats/min | 14.4 | 1.6 | 07 | 13.6 | 1.4 | NS | 07 | 12.5 | 2.9 | NS | 07 |
| Arteriovenous $O_2$ difference, volumes percent, at an $O_2$ consumption of 2.0 l/min STPD | 11.6 | 1.9 | 09 | 12.9 | 2.2 | NS | 08 | 13.1 | 2.7 | NS | 07 |
| **Poststress Period** | | | | | | | | | | | |
| Heart rate beats/min | 121.9 | 12.0 | 26 | 128.7 | 13.0 | NS | 18 | 122.3 | 11.9 | NS | 13 |

**Physiological Measurements Made Before, During, and After Exercise Stress**

| Variable | Preflight | | | Day of Recovery | | | | Day After Recovery | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Standard Deviation | Number of Observations | Mean | Standard Deviation | Probability Level | Number of observations | Mean | Standard Deviation | Probability Level | Number of Observations |
| **Prestress Period** | | | | | | | | | | | |
| Sitting heart rate beats/min | 73.6 | 9.6 | 31 | 89.8 | 17.3 | $<0.001$ | 27 | 79.3 | 13 | NS | 24 |
| $O_2$ consumption l/min STPD | .279 | .064 | 25 | .291 | .087 | NS | 20 | .294 | .097 | NS | 17 |
| $CO_2$ production l/min STPD | .232 | .052 | 12 | .279 | .062 | NS | 9 | .271 | .051 | NS | 9 |
| Minute volume l/min BTPS | 8.07 | 1.26 | 16 | 9.79 | 2.74 | $<0.05$ | 11 | 10.0 | 2.57 | $<0.02$ | 12 |
| Respiratory exchange ratio | .85 | .08 | 13 | .88 | .11 | NS | 9 | .93 | .08 | $<0.05$ | 9 |
| Systolic blood pressure (mm Hg)* | 117 | 10.2 | 28 | 111 | 11.1 | NS | 24 | 117 | 9.0 | NS | 24 |
| Diastolic blood pressure (mm Hg)* | 78 | 6.3 | 28 | 79 | 5.8 | NS | 24 | 78 | 7.5 | NS | 24 |
| **Stress Period** | | | | | | | | | | | |
| $O_2$ consumption l/min STPD at a heart rate of: | | | | | | | | | | | |
| 120 beats/min | 1.54 | 0.33 | 31 | 1.19 | 0.38 | $<0.001$ | 24 | 1.49 | 0.32 | NS | 21 |
| 140 beats/min | 2.00 | 0.36 | 31 | 1.63 | 0.35 | $<0.001$ | 24 | 1.94 | 0.36 | NS | 21 |
| 160 beats/min | 2.50 | 0.42 | 31 | 2.06 | 0.38 | $<0.001$ | 24 | 2.41 | 0.45 | NS | 21 |
| 180 beats/min** | 2.98 | 0.50 | 31 | 2.52 | 0.43 | $<0.001$ | 24 | 2.85 | 0.56 | NS | 21 |

*1 mm Hg = 133.3224 $N/m^2$
**Six individuals actually tested to this level—others extrapolated
NS = Not significant
STPD = Standard temperature and pressure, dry
BTPS = Body temperature and pressure, saturated

## Musculokeletal Studies

### Bone Mineral Change Related to Calcium Intake

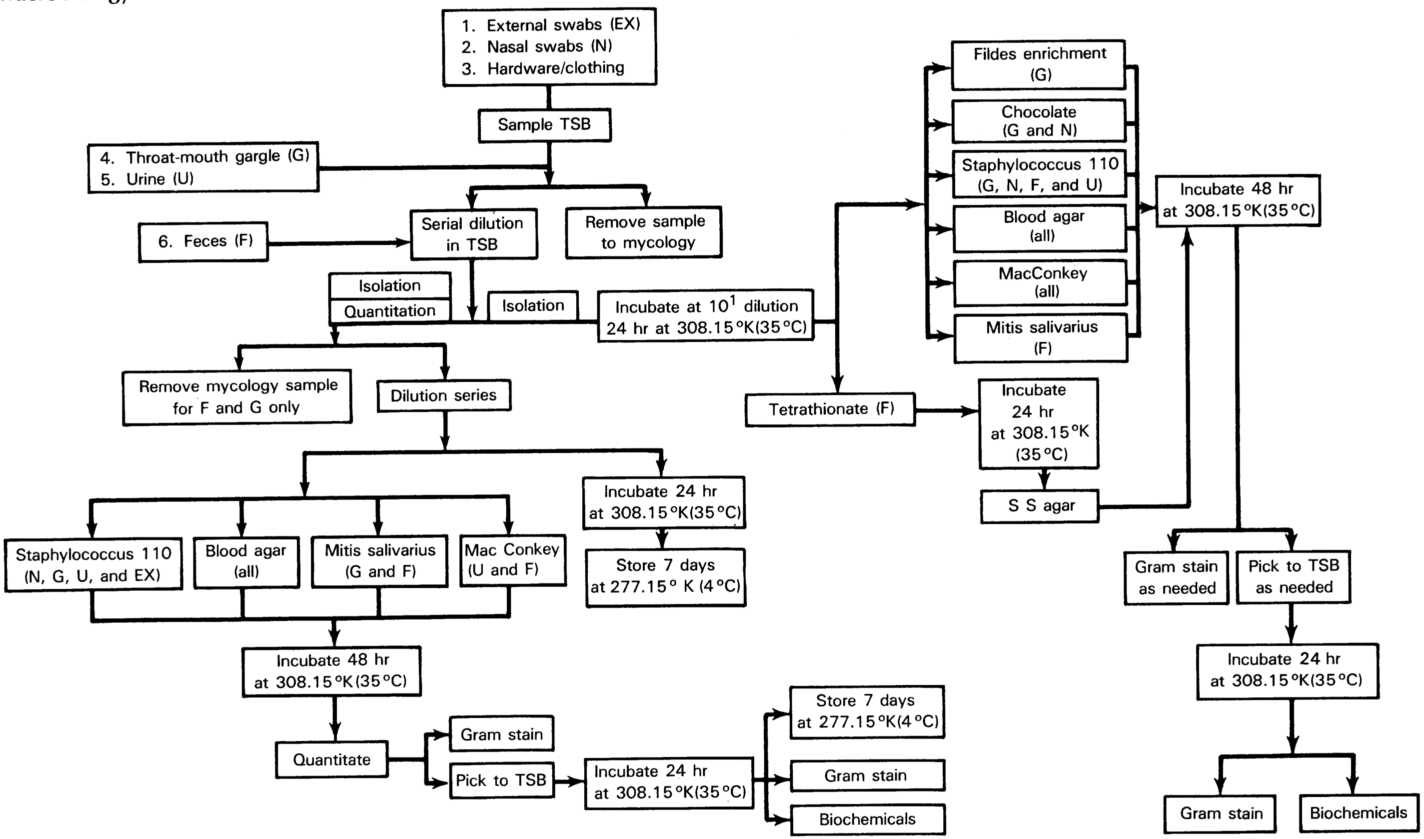
| Mission | Crewmen | Calcium (mg) | Os Calcis (percent) | Radius (percent) | Ulna (percent) |
|---|---|---|---|---|---|
| Gemini 4 | CP | 679 | − 7.8 | — | — |
| | P | 739 | −10.3 | — | — |
| Gemini 5 | CP | 373 | −15.1 | −25.3 | — |
| | P | 333 | − 8.9 | −22.3 | — |
| Gemini 7 | Cp | 945 | − 2.9 | — | — |
| | P | 921 | − 2.8 | — | — |
| | CDR | 644 | − 5.4 | − 3.3 | − 3.0 |
| Apollo 7 | LMP | 925 | + .7 | + 3.4 | + 2.1 |
| | CMP | 938 | + 2.3 | — | — |
| | CDR | 427 | − 2.1 | − 8.8 | − 6.4 |
| Apollo 8 | LMP | 366 | − 7.0 | −11.1 | −12.4 |
| | CMP | 479 | − 2.9 | −11.4 | −16.2 |
| | CDR | 802 | − 0.4 | − 0.1 | − 1.6 |
| Apollo 14 | LMP | 843 | + 3.7 | + 1.5 | − .3 |
| | CMP | 809 | + .5 | + 1.5 | + .3* |
| | CDR | 857 | − 6.7 | 0 | − 1.7 |
| Apollo 15 | LMP | 778 | − .6 | − .7 | − 3.5 |
| | CMP | 725 | − 7.8 | − 1.9 | − 3.1 |
| | CDR | 805 | + 1.2 | + 1.0 | − 2.2 |
| Apollo 16 | LMP | 705 | + .4 | + 1.5 | − 3.3 |
| | CMP | 468 | + .4 | + 2.1 | − 3.5 |

*R + 1 measurement

### Mineral Changes in Other Bones Studied by X-Ray Densitometry

| Mission | Bone | CP (percent) | P (percent) | CDR (percent) | CMP (percent) | LMP (percent) |
|---|---|---|---|---|---|---|
| Gemini 7 | Distal talus | − 7.06 | − 4.00 | | | |
| | Capitate | − 4.31 | − 9.30 | | | |
| | Phalanx 4-2 | − 6.55 | − 3.82 | | | |
| | Phalanx 5-2 | − 6.78 | − 7.83 | | | |
| Gemini 5 | Distal talus | −13.24 | − 9.87 | | | |
| | Capitate | −17.10 | −16.80 | | | |
| | Phalanx 4-2 | − 9.86 | −11.80 | | | |
| | Phalanx 5-2 | −23.20 | −16.98 | | | |
| Gemini 4 | Distal talus | −10.69 | −12.61 | | | |
| | Capitate | − 4.48 | −17.64 | | | |
| | Phalanx 4-2 | − 4.19 | − 8.65 | | | |
| | Phalanx 5-2 | −11.85 | − 6.24 | | | |
| Apollo 7 | Central talus | | | −3.6 | + 1.8 | +2.9 |
| | Phalanx 4-2 | | | −9.3 | + 2.0 | −6.5 |
| | Capitate | | | −4.1 | + 3.3 | −3.4 |
| Apollo 8 | Central talus | | | −2.6 | − 2.8 | −3.2 |
| | Phalanx 4-2 | | | −2.2 | − 2.4 | +4.8 |
| | Capitate | | | −9.6 | −12.1 | −6.7 |
| Soyuz 9 | Phalanx II | — | − 4.1 | | | |
| | Phalanx III | − 5.0 | − 5.0 | | | |
| | Phalanx IV | − 3.1 | − 4.3 | | | |
| | Phalanx V | − 4.7 | − 8.9 | | | |

## Microbiology

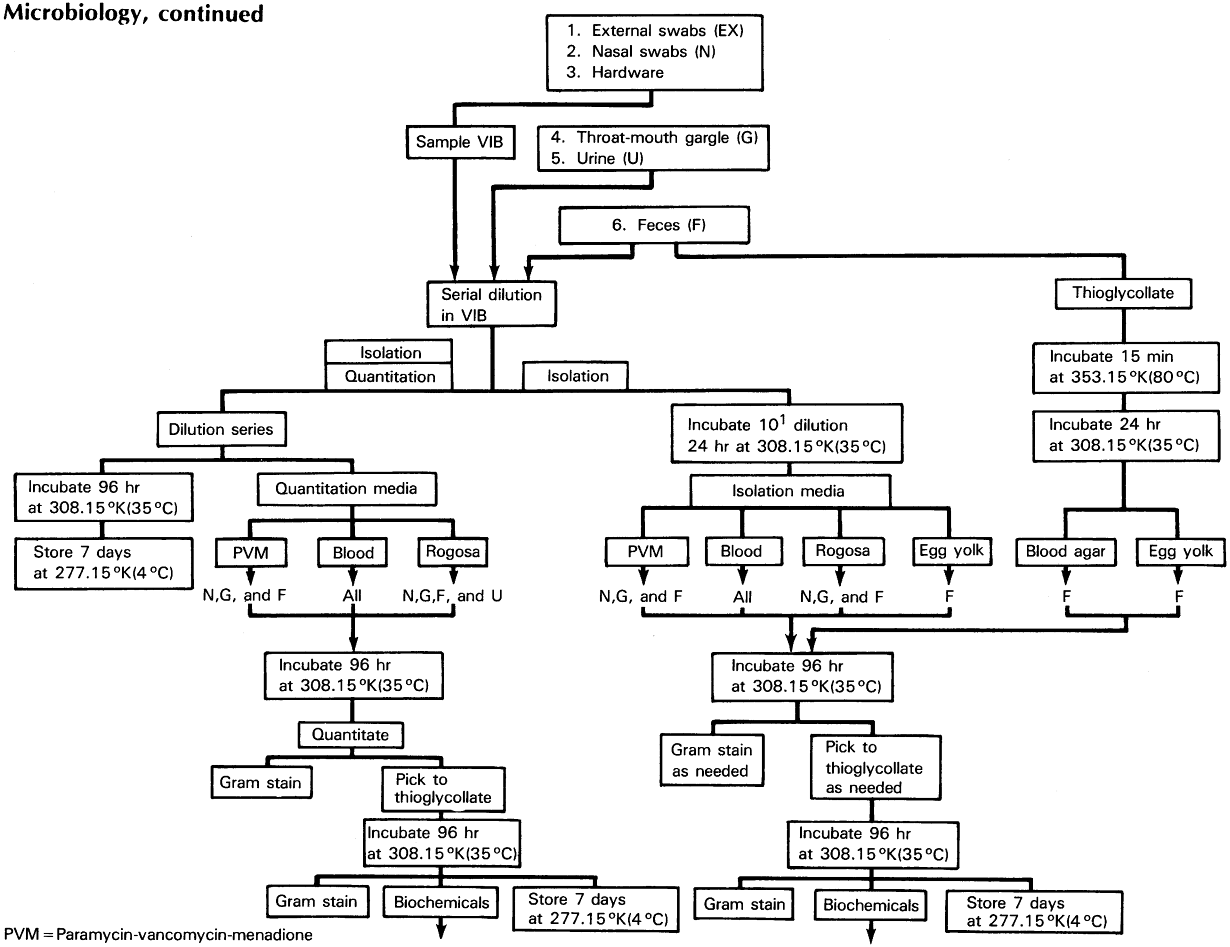



NOTE: S S = Salmonella-Shigella

*Figure 1. Crew bacteriology protocol for aerobic scheme.*

Figure 1. Crew bacteriology protocol for aerobic scheme.

## Microbiology, continued




PVM = Paramycin-vancomycin-menadione

Figure 2. Crew bacteriology protocol for anaerobic scheme.

## Microbiology, continued

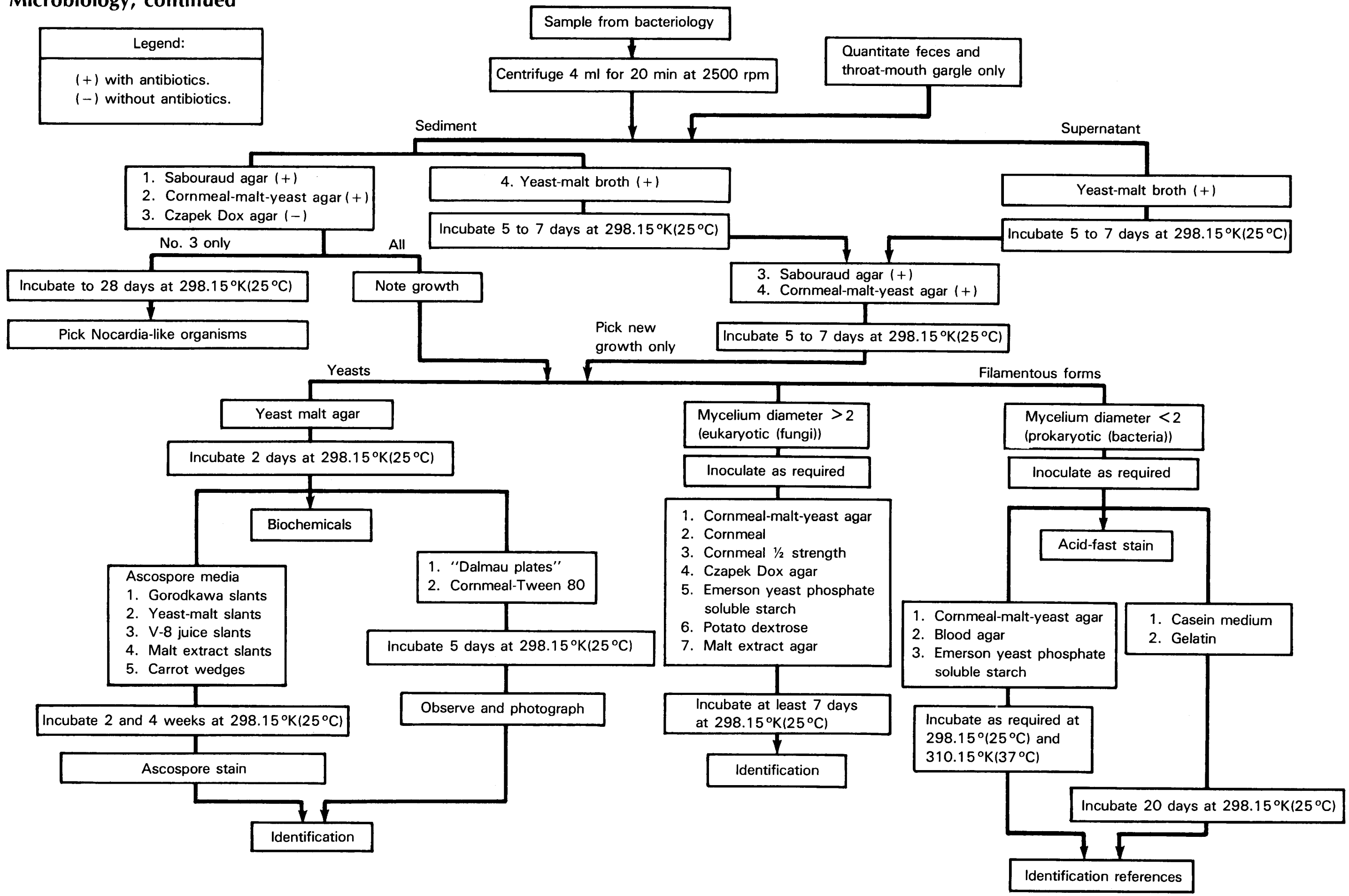
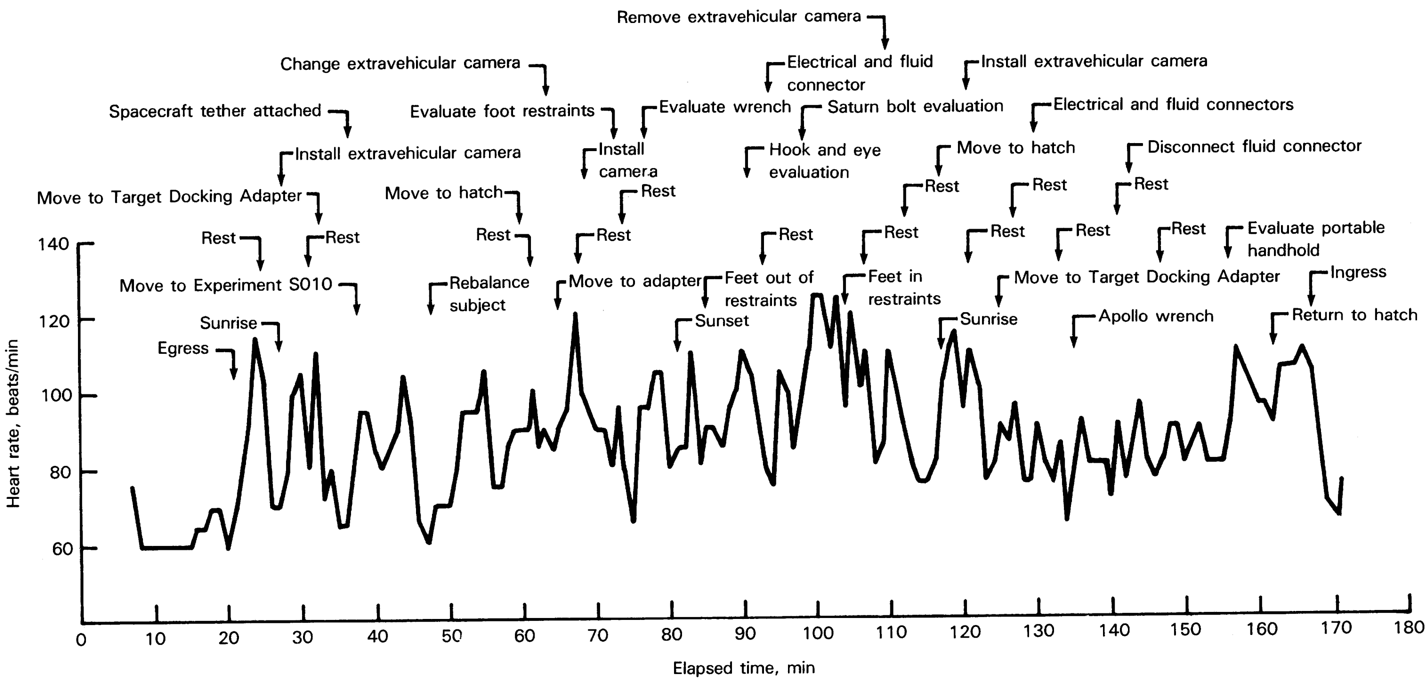



Figure 3. Crew mycology protocol.

**Table 10 Medically Important Microorganisms Isolated from the Apollo CM**

| Microorganism | Areas of Isolation by Apollo Mission | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 | | 8 | | 9 | | 10 | | 11 | | 12 | |
| | Preflight | Postflight | Preflight | Postflight | Preflight | Postflight | Preflight | Postflight | Preflight | Postflight | Preflight | Postflight |
| *Aspergillus fumigatus* | —[1] | M.C.[2] | — | M.C. | — | F.[3] | — | — | — | — | — | — |
| Coliform | — | F. | — | — | — | — | — | — | — | — | — | — |
| *Herellea* species | — | F. | — | — | — | — | — | — | — | — | — | — |
| *Klebsiella aerobacter* | — | — | — | — | — | — | — | — | — | — | — | F. |
| *Proteus mirabilis* | — | — | — | — | — | — | — | — | — | — | — | F. |
| *Pseudomonas maltophilia* | — | S.A.[4] | — | — | — | — | — | — | — | — | — | — |
| *Pseudomonas pseudomallei* | — | — | — | — | — | — | — | F. | — | — | — | — |
| *Pseudomonas* species | — | — | — | D.G.[5] | — | — | — | — | — | — | — | — |
| *Staphylococcus aureus* | — | D.G. | — | — | — | F. | M.C.<br>D.G.<br>F.<br>S.[6] | — | — | — | — | S.<br>M.C. |

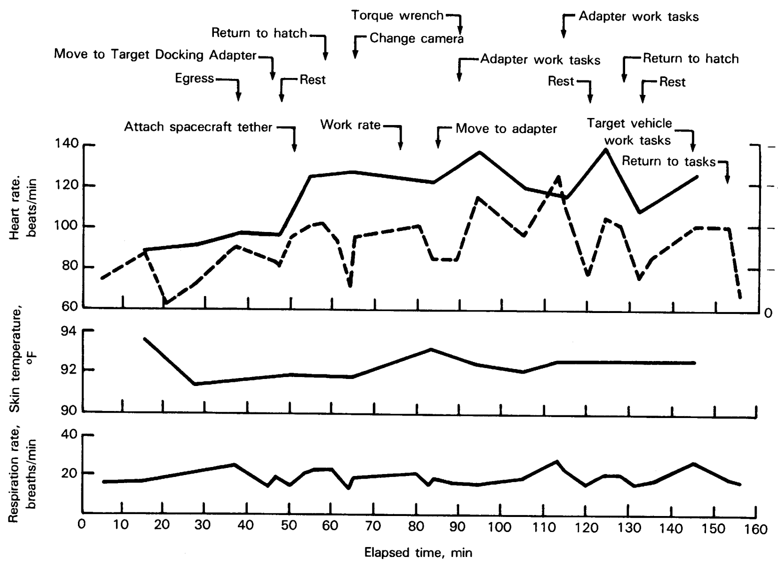
[1] Indicates no pathogenic organism found.
[2] M.C. = Maneuver Controller
[3] F. = Floor
[4] S.A. = Shock Absorbers
[5] D.G. = Drink Gun
[6] S. = Strut




(a) Gemini XII pilot.

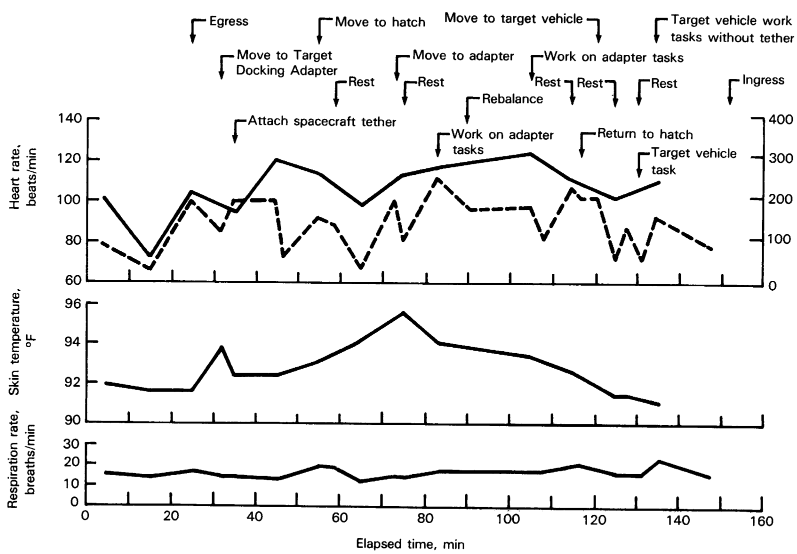
Figure 10-2. Heart rates from underwater simulations.

## Extravehicular Activity Studies, continued




(b) Gemini XII pilot.

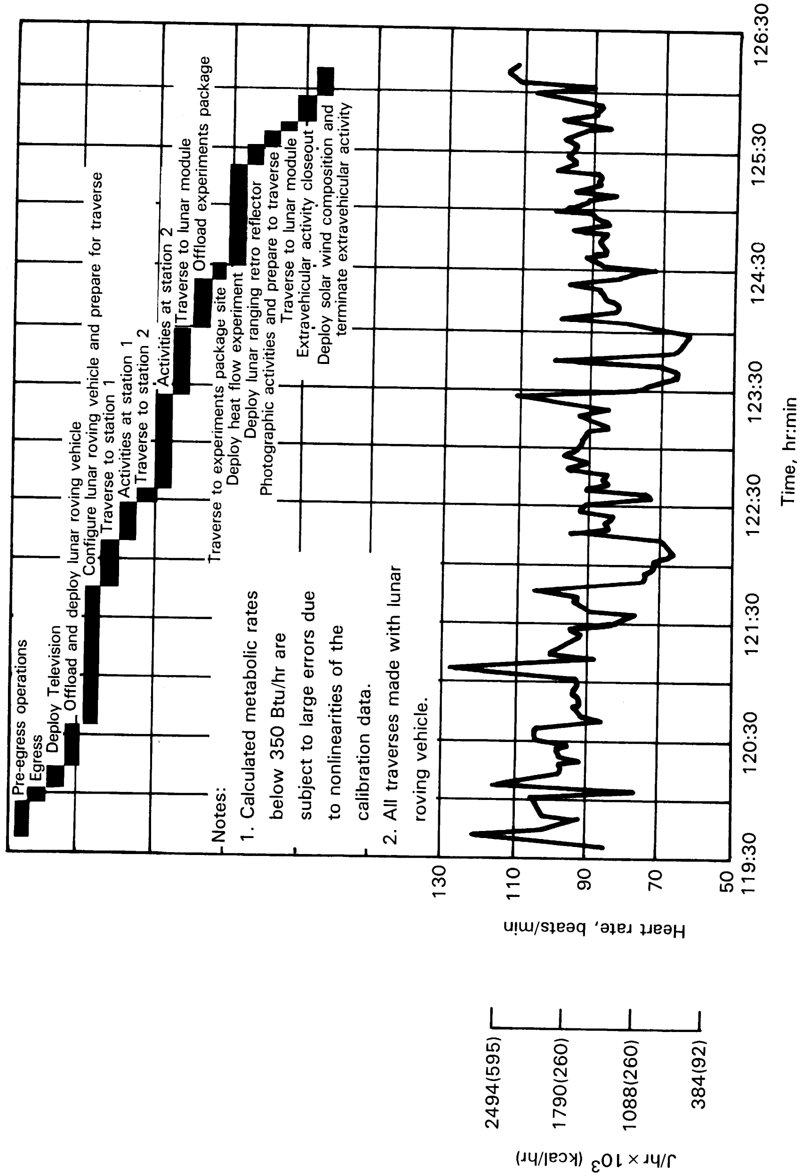
*Figure 10-2. Continued.*




(c) Gemini XII pilot.

*Figure 10-2. Concluded.*

# Extravehicular Activity Studies, continued




(a) Commander.

Figure 1. Heart rates and calculated metabolic rates of the Apollo 15 Commander during EVA-1.

## Extravehicular Activity Studies (continued)

### Metabolic Expenditures for the Apollo 15 Commander During EVA-1

| Surface Activity | End Time (hr:min) | Duration (min) | Average Metabolic Rate J/hr × $10^3$ (kcal/hr) |
|---|---|---|---|
| Preegress operations | 119:51 | 12 | 1569 (374) |
| Egress | 119:59 | 8 | 1726 (412) |
| Television deployment | 120:11 | 12 | 1895 (452) |
| Lunar roving vehicle (LRV) offloading and deployment | 120:32 | 21 | 1463 (349) |
| LRV configuration | 121:45 | 73 | 1239 (296) |
| LRV traverse (LM to station 1) | 122:11 | 26 | 513 (122) |
| Station 1 activities | 122:29 | 18 | 1032 (246) |
| Geological site selection | 122:15 | 4 | 1045 (249) |
| Radial sample | 122:24 | 9 | 852 (203) |
| Traverse preparation | 122:29 | 5 | 1343 (321) |
| LRV traverse (station 1 to station 2) | 122:35 | 6 | 486 (116) |
| Station 2 activities | 123:26 | 51 | 1196 (285) |
| Description and documented sample | 122:57 | 22 | 1120 (267) |
| Comprehensive sample | 123:05 | 8 | 1212 (289) |
| Double core tube | 123:16 | 11 | 1112 (265) |
| 500-mm photography and traverse preparation | 123:26 | 10 | 1444 (345) |
| LRV traverse (station 2 to LM) | 124:00 | 34 | 617 (155) |
| ALSEP offloading | 124:24 | 24 | 1054 (252) |
| ALSEP traverse (LRV) | 124:33 | 9 | 795 (190) |
| Heat flow experiment deployment | 125:24 | 51 | 1184 (283) |
| Laser ranging retroreflector deployment | 125:33 | 9 | 1393 (333) |
| Photography and traverse preparation | 125:38 | 5 | 1394 (333) |
| LRV traverse (ALSEP site to LM) | 125:43 | 5 | 1343 (321) |
| EVA closeout | 125:58 | 15 | 1305 (311) |
| Solar wind composition experiment deployment and EVA termination | 126:11 | 13 | 1701 (406) |

## Extravehicular Activity Studies (continued)

### Metabolic Expenditures During Apollo Lunar Surface Extravehicular Activities

| | | | Metabolic Rate, J/hr × 10³ (kcal/hr) | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mission No. | EVA No. | Crewman | ALSEP Deployment | Geological Station Activity | Overhead | Lunar Roving Vehicle Operations | Total For Activities | Duration (hr) |
| 11 | 1 | CDR | 818 (195) | 1023 (244) | 899 (214) | | 949 (227) | 2.43 |
| | | LMP | 1267 (302) | 1471 (351) | 1269 (303) | | 1267 (302) | 2.43 |
| 12 | 1 | CDR | 864 (206) | 1017 (243) | 1232 (294) | | 1028 (246) | 3.90 |
| | | LMP | 1006 (240) | 1028 (245) | 1119 (267) | | 1054 (252) | 3.90 |
| | 2 | CDR | | 913 (218) | 902 (215) | | 922 (221) | 3.78 |
| | | LMP | | 1058 (253) | 1038 (248) | | 1054 (252) | 3.78 |
| 14 | 1 | CDR | 762 (182) | 1230 (294) | 920 (219) | | 843 (202) | 4.80 |
| | | LMP | 947 (226) | 729 (174) | 1084 (259) | | 980 (234) | 4.80 |
| | 2 | CDR | 494 (118) | 996 (238) | 895 (213) | | 959 (229) | 3.58 |
| | | LMP | 851 (203) | 1120 (267) | 894 (213) | | 1054 (252) | 3.58 |
| 15 | 1 | CDR | 1182 (282) | 1153 (275) | 1417 (338) | 639 (152) | 1159 (277) | 6.53 |
| | | LMP | 1369 (327) | 778 (186) | 1226 (293) | 435 (104) | 1033 (247) | 6.53 |
| | 2 | CDR | 1019 (243) | 1227 (293) | 1202 (287) | 624 (149) | 1054 (252) | 7.22 |
| | | LMP | 1110 (265) | 792 (189) | 1116 (266) | 414 ( 99) | 854 (204) | 7.22 |
| | 3 | CDR | 1095 (261) | 1013 (242) | 1303 (311) | 578 (138) | 1086 (260) | 4.83 |
| | | LMP | 962 (230) | 788 (188) | 981 (234) | 447 (106) | 854 (204) | 4.83 |
| 16 | 1 | CDR | 869 (207) | 905 (216) | 1146 (273) | 725 (173) | 917 (219) | 7.18 |
| | | LMP | 1081 (258) | 1125 (268) | 1154 (275) | 666 (159) | 1065 (255) | 7.18 |
| | 2 | CDR | | 933 (223) | 1044 (249) | 470 (112) | 822 (197) | 7.38 |
| | | LMP | | 1023 (244) | 987 (236) | 438 (105) | 874 (209) | 7.38 |
| | 3 | CDR | 966 (231) | 983 (235) | 518 (124) | 854 (204) | | 5.67 |
| | | LMP | | 1013 (242) | 1107 (264) | 430 (103) | 864 (207) | 5.67 |
| 17 | 1 | CDR | 1192 (285) | 1094 (261) | 1267 (302) | 506 (121) | 1150 (275) | 7.20 |
| | | LMP | 1166 (278) | 1255 (300) | 1193 (285) | 472 (113) | 1139 (272) | 7.20 |
| | 2 | CDR | | 1094 (261) | 1267 (302) | 506 (121) | 864 (207) | 7.62 |
| | | LMP | | 1255 (300) | 1193 (285) | 472 (113) | 874 (209) | 7.62 |
| | 3 | CDR | | 1094 (261) | 1267 (302) | 506 (121) | 980 (234) | 7.25 |
| | | LMP | | 1255 (300) | 1193 (285) | 472 (113) | 990 (237) | 7.25 |
| Mean | | | 1018 (244) | 1018 (244) | 1123 (270) | 518 (123) | 980 (234) | |
| Total time (hr) | | | 28.18 | 52.47 | 52.83 | 25.28 | 158.74 | |

CDR = Commander
LMP = Lunar Module Pilot

# Appendix F

## NASA'S LIFE SCIENCES PROGRAMS: FISCAL YEAR APPROPRIATIONS, 1961-1978

The following two charts analyze NASA's life sciences budgets in relation to total agency appropriations for research and development and program office appropriations for research and development. These figures have been derived from NASA Budget History files, NASA History Office, and from congressional reports of NASA authorizations and appropriations. The individual figures are reasonable approximations rather than exact totals, however, as budget figures were frequently revised, supplemented, and reprogrammed. Moreover, NASA's budget requests for any fiscal year were actually requests that were to be programmed over three-year periods, and the actual expenditures during any given year varied according to the programming. The reader should note, in addition, that the figures for FY 1965-1971 do not reflect appropriations for space medicine inasmuch as space medicine was not a line item for budgetary purposes during those years. Space medicine received funds through several manned spaceflight program offices on an item-by-item basis; reconstruction of the actual space medicine allocations is virtually impossible. Further, life sciences appropriations before FY 1961 were limited to space medical operations within the Space Task Group and were not broken out for budgetary purposes.

**Chart 1. Life Sciences R&D Appropriations Compared to Total NASA R&D Appropriations, FY 1961-1978 (in millions of dollars)**

| Fiscal Year | NASA Total | Life Sciences Total | Life Sciences Percentage |
|---|---|---|---|
| 1961 | 670.5 | 5.0 | 0.7 |
| 1962 | 1 151.0 | 13.3 | 1.2 |
| 1963 | 2 514.8 | 34.3 | 1.4 |
| 1964 | 3 011.9 | 56.5 | 1.8 |
| 1965 | 1 047.9[a] (OMSF: 2 941.2) | 41.8[b] | 3.9[c] |
| 1966 | 1 071.8[a] (OMSF: 3 203.9) | 49.3[b] | 4.2[c] |
| 1967 | 844.3[a] (OMSF: 3 024.0) | 58.3[b] | 6.9[c] |
| 1968 | 881.6[a] (OMSF: 2 809.2) | 61.6[b] | 6.9[c] |
| 1969 | 731.5[a] (OMSF: 2 177.5) | 57.3[b] | 7.8[c] |
| 1970 | 792.0[a] (OMSF: 2 031.8) | 41.6[b] | 5.3[c] |
| 1971 | 667.8[a] (OMSF: 1 431.0) | 15.0[b] | 2.3[c] |
| 1972[d] | 1 838.4 | 25.9 | 1.4 |
| 1973[d] | 1 814.9 | 29.6 | 1.6 |
| 1974[d] | 1 658.5 | 25.8 | 1.2 |
| 1975[d] | 2 157.2 | 19.8 | 1.0 |
| 1976[e] | 1 994.7 | 20.6 | 1.0 |
| 1977[e] | 2 047.7 | 22.1 | 1.1 |
| 1978[e] | 2 159.2 | 33.3 | 1.5 |

[a] Figures do not include OMSF R&D budget as space medicine figures unavailable.

[b] Figures do not include space medicine allocations.

[c] Percentages do not reflect adjustment for OMSF and space medicine figures; were these figures available, percentages probably would be much lower.

[d] Life sciences appropriations divided between OMSF and OSSA.

[e] Life sciences appropriations to OSSA Division of Life Sciences.

**Chart 2. Life Sciences R&D Appropriations Compared to Total R&D Appropriations for Individual Program Offices, FY 1962-1978 (in millions of dollars)[a]**

| Fiscal Year | OSSA | | | OART | | | OMSF | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Life Sciences | Life Sciences Percentages | Total | Life Sciences | Life Sciences Percentages | Total | Life Science | Life Sciences Percentage |
| 1962 | 361.2 | 3.1 | 0.9 | 91.6 | 2.4 | 2.6 | 563.1 | 7.9 | 1.4 |
| 1963 | 586.9 | 13.7 | 2.3 | 255.9 | 9.8 | 3.8 | 1 503.6 | 10.8 | 0.7 |
| 1964 | 746.9 | 21.5 | 2.9 | 317.2 | 13.2 | 4.2 | 2 713.1 | 21.8 | 0.08 |
| 1965 | 732.4 | 28.5 | 3.9 | 331.3 | 13.3 | 4.0 | | b | |
| 1966 | 783.2 | 34.4 | 4.4 | 288.6 | 14.9 | 5.2 | | b | |
| 1967 | 576.1 | 42.0 | 7.3 | 268.2 | 16.3 | 6.1 | | b | |
| 1968 | 552.9 | 41.8 | 7.6 | 318.7 | 19.8 | 6.2 | | b | |
| 1969 | 453.2 | 37.9 | 8.4 | 278.2 | 19.4 | 6.9 | | b | |
| 1970 | 519.7 | 19.7 | 3.8 | 272.3 | 21.9 | 8.0 | | b | |
| 1971 | 565.7 | 12.9 | 2.3 | 102.0 | 2.1 | 2.1 | | b | |
| 1972 | 552.9 | 6.1 | 1.1 | | | | 1 285.5 | 19.8 | 1.5 |
| 1973 | 679.2 | 6.1 | 0.9 | | | | 1 135.8 | 23.5 | 2.1 |
| 1974 | 602.0 | 4.8 | 0.8 | | | | 1 056.5 | 21.0 | 2.0 |
| 1975 | 417.3 | 4.8 | 1.2 | | | | 1 235.8 | 15.0 | 1.2 |
| 1976 | 434.1 | 20.6 | 4.7 | | | | | | |
| 1977 | 379.0 | 22.1 | 5.8 | | | | | | |
| 1978 | 405.7 | 33.3 | 8.2 | | | | | | |

[a]For FY 1961 and 1962, the Office of Life Sciences Programs was allocated $13.2 million for research and development, approximately 1.4 percent of the total R&D allocation for those two fiscal years authorized in 1961.
[b]Figures for allocations for space medicine research and development are not available for these years.

# Index

# About the author

John A. Pitts received a B.A. in history from Northwestern University, a M.A. in modern European history from the University of Utah, and a Ph.D. in the history and sociology of science from the University of Pennsylvania, where he was a Josiah Macy Foundation Fellow.

After completing work on *The Human Factor*, Pitts joined the Naval Research Laboratory (NRL) as an historian from 1982-1985. In August 1985, he was granted a leave of absence from the NRL to accept a three-year appointment as Command Historian, V Corps, U.S. Army, in Europe.

Pitts is primarily an applied historian, who concentrates on analyzing operational problems and substantive issues of concern to managers and decision makers within the Defense R&D communities. Although he writes occasional articles and book reviews for professional journals and is currently completing a monograph history of underwater acoustics, the typical products of his research (analytical reports, background papers, and processed oral histories) are intended for internal use, rather than publication.

Pitts currently lives in Bad Homburg, West Germany, with his wife and three daughters.

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