Space Flight Research Relevant to Health, Physical Education, and Recreation

With Particular Reference to Skylab's Life Science Experiments

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Preface

In the following pages Dr. Wayne D. Van Huss and Dr. William W. Heusner, Professors of Physical Education, Michigan State University, and active researchers in MSU's Human Energy Research Laboratory, provide for the professional fields of health, physical education, and recreation an overview of the NASA studies that deal with the effects of space flight on the human organism.

The authors orient their readers to the setting of these life science studies, particularly Skylab's experiments, within the space program's vast range of projects and their numerous societal benefits. For graduate students, researchers, and directors of research, for instructional staff members dealing with physical fitness and measurement, and for state and local professional leaders in health, physical education, and recreation, the authors have opened the doors to new fields of study and new clues to principles of practice. Their work is supplemented by useful bibliographies, source lists, and charts and tables.

In line with its mandate "to expand human knowledge of phenomena in the atmosphere and space" and "to disseminate information concerning these activities and the results thereof," NASA is pleased to make this publication available. It appreciates the opportunity to work on this project with the leadership of the American Alliance for Health, Physical Education, Recreation, and Dance, particularly Dr. Raymond A. Ciszek, the Alliance's Associate Executive Director, who had responsibility for this project, and Professors Van Huss and Heusner, the authors. NASA also appreciates the helpful guiuance provided to the authors by the Life Science staffs at NASA Headquarters and the NASA Lyndon B. Johnson Space Center, and by the authors' colleagues, friends, and students. The NASA technical monitor for this project was Dr. Wayland E. Hull, Technical Assistant to the Director of Life Sciences, Johnson Space Center. Project coordinator was Dr. F. B. Tuttle, former director of NASA's educational programs.

Special acknowledgement is made of the contribution of Dr. William C. Schneider, NASA's Associate Administrator for Space Tracking and Data Systems, who, when Director of the Skylab Program, gave the necessary encouragement and support to make this project possible.

National Aeronautics and Space Administration
Washington, D.C.
June 1979

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Chapter I
Introduction

Interest in the development of rockets as potential vehicles for space travel was evident as early as World War I. Dr. Robert Goddard of the United States tested the first liquid propellant rocket in 1923 (ref. I–1). Dr. Hermann Oberth in Germany published his doctoral thesis "Die Rokete zu den Planeten raumen" (By Rocket to Interplanetary Space) the same year (refs. I–2 and I–3).

Dr. Goddard continued his rocket development with Guggenheim Fund and Smithsonian Institution support and then later became involved in military applications. Among Goddard's significant developments were the important propellant pump for liquid rockets and the bazooka for army use (ref. I–4).

Dr. Oberth published several paperback books. They received so much attention that he was recruited as the technical advisor for a science fiction movie in 1930. His real interest, however, was in the testing of his ideas with a working model. During his brief movie career, he attempted to build such a model. A 17-year-old volunteer helper who joined him in this work, the late Dr. Wernher von Braun, was destined to become a giant in rocketry.

Although a German rocket organization was formed, little money was available for research and development. The model built by Oberth and his colleagues was never tested, but Johannes Winkler did build and test a liquid propellant rocket in Germany in 1931 (refs. I–2, I–3, I–5, and I–6). Only when the military significance of the rocket was recognized did research funds become available. By 1937, the German Rocket Research Center at Peenemunde was built. The Peenemunde group developed the V–2 missile utilizing the original ideas of Goddard and Oberth.

When the Germans recognized that World War II was lost, the Peenemunde scientists decided to surrender to the Americans with the hope of continuing their work. Some 300 train-car loads of V–2 parts were transported from Germany to the United States. Only days later, Peenemunde was captured by the Soviets along with a considerable quantity of V–2 parts that had been left behind (refs. I–5 and I–6). In 1945, the German scientists came to White Sands, New Mexico, to work with the Americans. It is ironic and unfortunate that Dr. Goddard died that year.

Development of a Manned Launch Vehicle

During the period from 1950 to 1960, interest in satellites, long-range ballistic missiles, and especially the placing of man in orbit increased. It was an intensive period of investigation in rocket development. Many fuels were studied in the search for greater reliability, higher exhaust velocities, less weight, lighter thrust chambers, and higher combustion pressures. A point of historical significance is that Goddard founded the field of liquid propulsion (refs. I–1 and I–4) and that the V–2 served as the model for subsequent large liquid-fuel rockets (ref. I–5). The Army Redstone rocket, used for the initial suborbital flights of Alan Shepard and Virgil Grissom in 1961, was a direct descendant of the V–2 and was developed essentially by the Peenemunde team. The larger rockets from Atlas to Saturn V, used for the Moon missions, have been of the same basic type (refs. I–5, I–6, and I–7). The history of rocket development is covered in references I–1 through I–7.

The early missions, necessarily, were chiefly devoted to the engineering developments needed to get astronauts into space and back. With the development of the Saturn V for the Apollo Moon missions, in 1968–72, a reliable vehicle became available with sufficient power to propel astronauts into space and bring them back without undue risk. The engineering goal for this generation of space vehicles had been accomplished.

Formation of a Viable Space Agency

Rocket development continued after World War II primarily because of military missile priorities, including the construction of Intercontinental Ballistic Missiles (ICBMs) capable of delivering nuclear warheads. Although there was great interest in peacetime applications of space technology, the channels for adequate support of research and development did not exist. When the Soviets launched their first artificial satellite (Sputnik 1) on October 4, 1957, the impact on the American public was resounding. A Space Task Force of 35 experts was organized to put together a U.S. space program. In October 1958, the National Aeronautics and Space Administration (NASA) was formed. It was modestly funded for the task at hand, and Project Mercury began.

The Soviets further electrified the world on April 12, 1961, by the orbital flight of Yuri Gagarin in Vostok 1. The payload far exceeded our capabilities at the time. We were dangerously behind, and the American public didn't like it. A month later, on May 25, 1961, President Kennedy served notice that the United States must catch up with the U.S.S.R.'s space achievements. In August of that year, he presented to Congress a program aimed at putting man on the Moon before 1970. The program was approved wholeheartedly, even though the President estimated the undertaking would ultimately cost billions of dollars. In retrospect, the Soviets had done us a service in that their successes motivated our own scientific and administrative developments.

NASA leadership mobilized industry, science, and technology into a productive entity. The systems approach used in the solution of the technological problems of manned space flight serves as a viable model for many areas of applied research. The objectives of each stage of development were made clear. What appeared initially to be huge, insurmountable problems were subdivided and systematically solved or circumvented.

People in Space

Weightlessness and the austere environment of space opened a new field of investigation—space biology. Human beings had never before attempted to live in zero gravity. The first question was simple: Could individuals exist in space at all? Before anyone actually went into space, there was controversy concerning even the ability to swallow food in the weightless condition. Ample cause for concern existed because manned space flight involves the simultaneous application of multiple environmental stresses: weightlessness, ionizing radiation, temperature and humidity extremes, acceleration, circadian rhythm disruption, noise and vibration, and altered atmosphere gas concentrations (ref. I–8).

The early Soviet (Vostok I and II) and U.S. (Mercury 1–4) missions, in 1961, dispelled many of the apprehensions concerning space. They showed that people were able to function effectively during the acceleration periods of launch and entry, reasonable adaptations were made to weightlessness, and assigned tasks could be performed effectively during the mission. Although a state of nausea comparable to seasickness was reported by Titov in Vostok II, medical monitoring during these early flights showed that normal body functions were not significantly changed.

The Gemini program in 1965–66, permitted physiological testing of progressively longer space flights up to and exceeding the duration required for a Moon mission. In the 14-day flight of Gemini 7, medical studies were conducted inflight as well as before and after. The significant space-related changes found during the Gemini program were moderate loss in red cell mass, moderate orthostatic intolerance, moderate loss in work capacity, minimal loss in bone density, minimal loss of calcium and muscle nitrogen, and high metabolic cost of extravehicular activity (refs. I–8, I–9, and I–10). It was demonstrated for these flight durations that people could satisfactorily perform the assigned mission tasks, humans could adapt to the weightless environment, and could readapt to the Earth environment upon return (ref. I–11).

In the subsequent Apollo missions, resources during flight were concentrated on the complex lunar-landing program. Physiological data, therefore, were collected chiefly before and after the flights. The significant space-related changes found during the Apollo program, in 1968–72, were vestibular disturbance; inflight cardiac arrhythmia; reduced postflight orthostatic tolerance; reduced postflight exercise tolerance; postflight dehydration and weight loss; suboptimal food consumption during flight; decreased red cell mass and plasma volume; trends toward negative inflight balances of nitrogen, calcium, and other electrolytes; increased inflight adrenal hormone secretion; and no inflight diuresis (refs. I–8, I–11, I–12, and I–13). The Apollo findings served to confirm the earlier Gemini data and, as would be expected, raised new questions. Although the responses of the astronauts to the space environment in the Apollo missions were remarkably encouraging, more concentrated study of biomedical responses during prolonged space missions still was needed to determine how long a person could remain in space. The stage was set for the Skylab missions.

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Chapter II
The Skylab Missions

The successful Apollo missions marked the completion of the first phase in the exploration of space. Engineering sophistication was adequate to place human beings on the Moon and to return them safely. Astronauts had demonstrated the ability to navigate in space. They had been shown that they could exist in the space environment for the time duration of the Apollo missions without excessive physical losses. Further, they had demonstrated the ability to function in space as engineers and research scientists.

From the beginnings of the investigation of space, a broad program of research and application using unmanned satellites and probes had been continuing. Many significant contributions to human well-being on Earth, such as the development of communication and weather satellites, had already been made. A plethora of new research areas had developed, however, requiring investigation or at least confirmation of data collected. (For more details, see refs. II–1, II–2, and II–3.)

The need was evident for a manned space station that could stay in space for a prolonged period of time. Longer missions were needed to develop further the utility of space flight as a means of expanding and enhancing the well-being of mankind on Earth and of assessing the human potential for future space missions. In the Apollo program, astronaut-carrying spacecraft had been developed. Instruments for the observation of astronomical objects, solar-electric power supplies, communications equipment, computers, and attitude control systems had been developed and used. Life-support systems appeared adequate for prolonged space flight. Finally, the engineering and technological developments had attained sufficient sophistication to achieve the dream of the pioneers of space—placing a manned space station in orbit (ref. II–4).

Mission Plans and Objectives

The plans were for an initial 28-day Skylab mission followed at 3-month intervals by two 56-day missions. The third manned mission was later extended to 84 days. The objectives of the missions were to (a) conduct Earth resources observations, (b) advance scientific knowledge of the Sun and stars, (c) study the processing of materials under weightlessness, and (d) better understand manned space flight capabilities and basic biomedical processes (ref. II–4).

The study of Earth resources from orbit utilized remote-sensing techniques for the study of oceanography, agrarian productivity, water management, new oil and mineral fields, urban and rural growth, and ecology (refs. II–4 and II–5). The orbital paths of Skylab made possible survey coverage of the entire contiguous United States and more than 75 percent of the Earth's surface. Each of its 93-minute orbits was repeated every 5 days. Photographic, infrared, and microwave equipment provided pictures and measurements of the terrain beneath the craft for study by experts. Collaborating in these studies were 140 scientific teams from the United States and 20 foreign countries. (For excellent coverage and photographs of some of the Earth resources data, see ref. II–6.)

To advance knowledge of the Sun and the stars, research was directed toward understanding the phenomena within and around the Sun itself. Until the advent of the space program, it was possible to observe solar emissions only at wavelengths that could penetrate the Earth's atmosphere. Solar research is of inestimable importance since the Sun is the ultimate source of all energy on Earth. It controls our environment and all terrestrial life depends upon it. The Sun is an astrophysical laboratory, close at hand, which cannot be reproduced on Earth. The Sun also is the nearest star. Our understanding of stellar astronomy is dependent upon our understanding of the Sun (ref. II–5). (Some solar pictures are contained in ref. II–7).

The special condition of weightlessness makes it possible to process materials in operations that are impossible on Earth. Potential products range from composite metals with highly specialized physical properties to large, more perfect, crystals having valuable electrical or optical properties that cannot be achieved in a 1*g* environment (refs. II–4 and II–5).

The objective of better understanding manned space flight capabilities and basic biomedical processes was quite broad. It included study of the capabilities, limitations, and usefulness of humans to live and work in space effectively as well as investigation of the biological effects of a continued state of weightlessness. Prior to Skylab the longest missions had been Gemini 7 for 14 days, Soyuz 9 for 18 days, and the ill-fated Soyuz II for 24 days in which the cosmonauts died during reentry. The question of how long human beings could survive in a weightless environment required further investigation. The medical experiments were chosen to study the effects of long-duration space flights on the crew and to evaluate the metabolic effectiveness of a human in space in order to determine future logistics requirements, environmental control, and task planning. (See ref. II–8 for details of the life science research.) Major areas of investigation were nutrition, musculoskeletal function, cardiovascular function, hematology, neurophysiology, pulmonary function, and metabolism (ref. II–9).

Skylab Experiments

The experiments chosen for Skylab, after soliciting ideas from the scientific community and intensive screening and evaluation, are shown in table II–1. The magnitude of the tasks of Skylab are evident from the table. Likewise, the breadth of competence required of the astronauts to collect these data is impressive.

The Skylab workshop was planned to meet the unique needs dictated by the experimentation to be undertaken but, insofar as possible, incorporated hardware already developed for

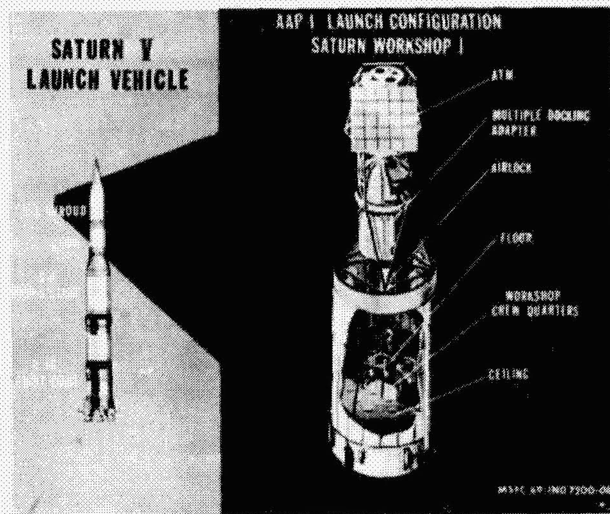

Fig. II-1. Skylab launch configuration and the Saturn V.

the Apollo program. As shown in figure II-1 (ref. II–11), the large Saturn V launch vehicle was used with the first and second stages (S–IC and S–II) providing the thrust necessary to place the workshop in orbit. The third stage of Saturn V (S–IVB), which had been used as a launch vehicle in the Apollo program, was converted to the Saturn workshop, also called Orbital Workshop (OWS). On top of this was placed an airlock module (AM), a multiple docking adapter (MDA), and an Apollo Telescope Mount (ATM). The intended configuration of the Skylab cluster is shown in figure II–2. Skylab was pressurized to 5 lb/in^2 with 3.7 lb/in^2 from oxygen and the remaining 1.3 lb/in^2 from nitrogen (ref. II–4). The oxygen partial pressure in this environment was close to that found at sea level. The atmospheric environment was comfortable.

Table II-1—*Skylab experiments*

Number	Title	Location on Skylab	Manned mission 1	2	3
	Solar studies				
S020	Ultraviolet and X-ray solar photography	OWS	—	X	X
S052	White-light coronagraph	ATM	X	X	X
S054	X-ray spectrographic telescope	ATM	X	X	X
S055	UV scanning polychromator spectroheliometer	ATM	X	X	X
S056	X-ray telescope	ATM	X	X	X
S082A	Extreme UV spectroheliograph	ATM	X	X	X
S082B	Ultraviolet spectrograph	ATM	X	X	X
	Stellar astronomy				
S019	UV stellar astronomy	OWS	X	X	—
S150	Galactic X-ray mapping	IU	—	—	X
S183	UV panorama telescope	OWS	X	X	—
	Space physics				
S009	Nuclear emulsion package	MDA	X	—	—
S063	UV airglow horizon photography	OWS	X	—	—
S073	Gegenschein and zodiacal light	OWS	X	X	X
S149	Micrometeoroid particle collection	OWS	X	X	X
S228	Transuranic cosmic rays	OWS	X	X	X
S230	Magnetospheric particle composition	ATM	X	X	X
	Earth resources experiments				
S190A	Multispectral photographic cameras	MDA	X	X	X
S190B	Earth terrain camera	OWS	X	X	X
S191	Infrared spectrometer	MDA	X	X	X
S192	Multispectral scanner	MDA	X	X	X
S193	Microwave radiometer/scatterometer and altimeter	MDA	X	X	X
S194	L-band radiometer	MDA	X	X	X
	Life sciences projects				
M071	Mineral balance	OWS	X	X	X
M073	Bioassay of body fluids	OWS	X	X	X
M074	Specimen mass measurment	OWS	X	X	X
M078	Bone mineral measurement	None		(Preflight and postflight)	
M092	Lower body negative pressure	OWS	X	X	X
M093	Vectorcardiogram	OWS	X	X	X
M111	Cytogenic studies of the blood	None		(Preflight and postflight)	
M112	Man's immunity, in-vitro aspects	OWS	X	X	X
M113	Blood volume and red cell life span	OWS	X	X	X
M114	Red blood cell metabolism	OWS	X	X	X
M115	Special hemotalogical effects	OWS	X	X	X
M131	Human vestibular function	OWS	X	X	—
M171	Metabolic activity	OWS	X	X	X
M172	Body mass measurement	OWS	X	X	X
S015	Effect of zero-gravity on single human cells	CM	X	—	—
	Material science & manufacturing in space				
M479	Zero-gravity flammability	MDA	—	—	X
M512	Materials processing facility	MDA	X	—	X
(M551)	Metals melting	MDA	X	—	—
(M552)	Exothermic brazing	MDA	X	—	—
(M553)	Sphere forming	MDA	X	—	—
(M555)	Gallium arsenide crystal growth	MDA	X	—	—
M518	Multipurpose electric furnace system	MDA	—	—	X
(M557)	Immiscible alloy compositions	MDA	—	—	X
(M559)	Microsegregation in germanium	MDA	—	—	X
(M560)	Growth of spherical crystals	MDA	—	—	X

Table II-1--*Skylab experiments*—Continued

Number	Title	Location on Skylab	Manned mission 1	2	3
(M563)	Mixed III-V crystal growth	MDA	—	—	X
(M565)	Silver grids melted in space	MDA	—	—	X
	Zero-gravity systems studies				
M487	Habitability/crew quarters	OWS	X	X	X
M509	Astronaut maneuvering equipment	OWS	—	X	X
M516	Crew activities and maintenance study	OWS	X	X	X
T002	Manual navigation sightings	OWS	—	X	X
T013	Crew/vehicle disturbance	OWS	—	X	—
T020	Foot-controlled maneuvering unit	OWS	—	X	X
	Spacecraft environment				
D008	Radiation in spacecraft	CM	X	—	—
D024	Thermal control coatings	AM	X	—	—
M415	Thermal control coatings	IU	X	—	—
T003	Inflight aerosol analysis	OWS	X	X	X
T025	Coronagraph contamination measurements	OWS	X	X	X
T027	ATM contamination measurements	OWS	X	X	X

Skylab student project

In addition to the above, 19 experiments by secondary school students were flown on Skylab; these were selected through a nationwide competition conducted by the National Science Teachers Association. (See ref. II-10.)

Source: Modified from reference II-4.

Mission Schedules

The missions were planned so that the 91,000 kg (100-ton) experimental space station (Skylab) would first be launched unmanned, by the large Saturn V launch vehicle. One day after Skylab lift-off, an Apollo Command and Service Module (CSM) with three astronauts aboard was to be launched by the smaller Saturn IB vehicle. Using the service propulsion system, the CSM was to rendezvous with Skylab, dock at the axial part of the MDA, and complete the cluster shown in figure II–2. The crew would then enter the Skylab, prepare it for habitation, power down the CSM to maintenance levels, and then proceed with their assigned mission plans.

On the 27th day of the first manned mission, the crew were to prepare Skylab for storage in orbit. On the 28th day, they were to board the CSM, undock, deorbit, and land in the Pacific recovery area (ref. II–9). Approximately 60 days later, a second CSM was to be launched and to follow a similar rendezvous protocol. This next mission was open-ended to a 56-day duration. The third mission, originally scheduled for 56 days, was extended to 84 days.

The Orbital Workshop

The OWS was designed as a place where a crew of three could live and work for extended periods of time. Emphasis was placed on roomy, comfortable accommodations. The OWS was a cylinder 6.7 m (22 ft) in diameter and 14.6 m (48 ft) in length. The volume of approximately 963 cu m (34,000 cu ft) was equivalent to that of a moderate-size house. The area of the two living floors was approximately 66.88 sq m (720 sq ft). The roominess of the living area was truly impressive (fig. II–3). Handles and grips were mounted throughout the two compartments to enable the crew to move through the workshop while weightless. The floors were of aluminum alloy with triangular openings. The soles of the shoes worn by the astronauts in space each had a triangular cleat on the bottom that could be placed in the floor. A slight twist then would lock the foot in place (figs. II–4(*a*) and II–4(*b*)). Without the cleats, force could not be applied in a weightless environment without moving the body. The cleats provided a stable base from which leverage could be applied.

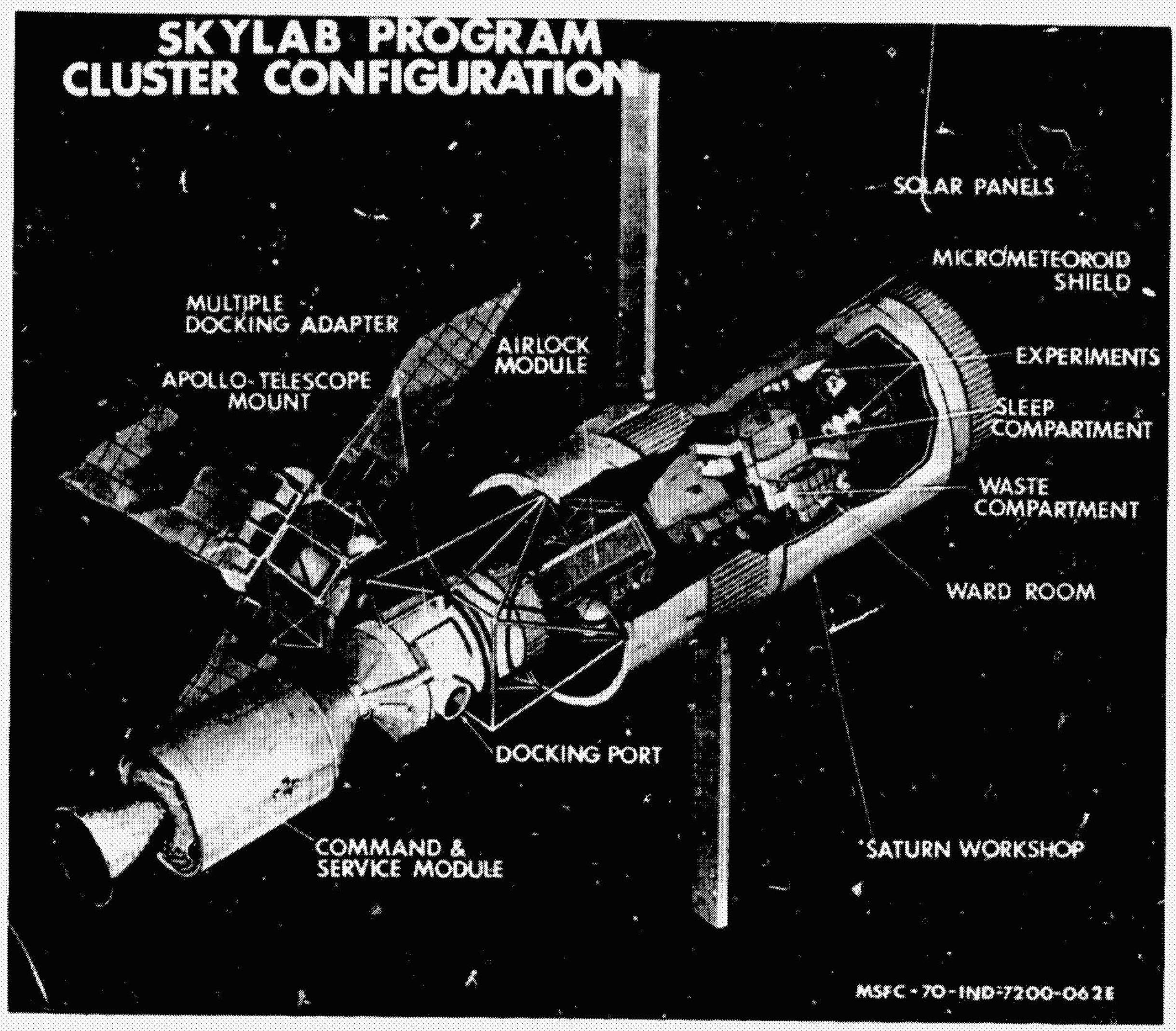

Fig. II-2. The deployed Skylab cluster.

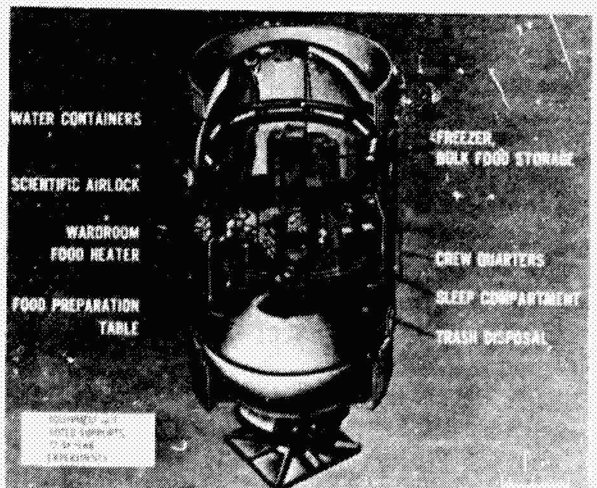

Fig. II-3. Orbital Workshop.

Weighing in Zero Gravity

Since the data to be collected involved the weighing of samples and since body-weight shifts of the crewmembers also required careful monitoring, there was a need for special weighing instruments. The problem was, How do you weigh someone or something in a weightless environment? The solution cleverly applied Newton's second law: Force equals mass times acceleration. A schematic of the device and a calibration curve are shown in figures II–5(*a*) and II–5(*b*) (ref. II–12). The force was provided by a spring (K), and the mass (M) was attached to a platform suspended as a pendulum by four parallel flexing strips. An optical pickup and an electric timer then measured the

Fig. II-4 (a). Astronaut shoes.

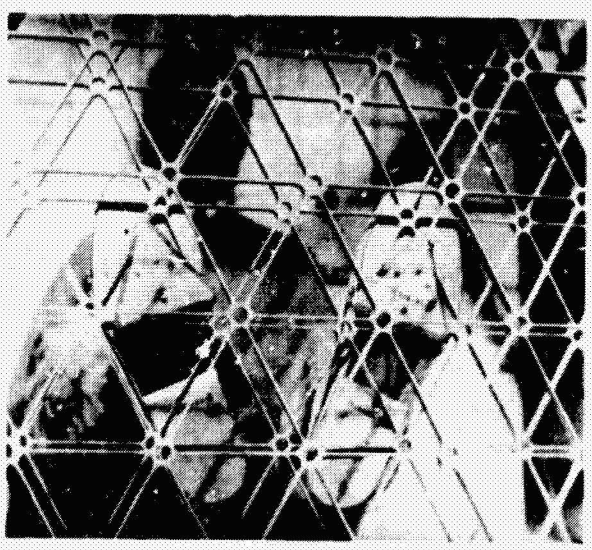

Fig. II-4 (b). Shoe cleat locking into grid floor.

period (t) of the spring-loaded pendulum. Time signals were converted to provide a direct readout in metric units. Different instruments based on the same principle were used for specimen and body-mass measurements (refs. II-4 and II-5). The instruments were both fast and accurate.

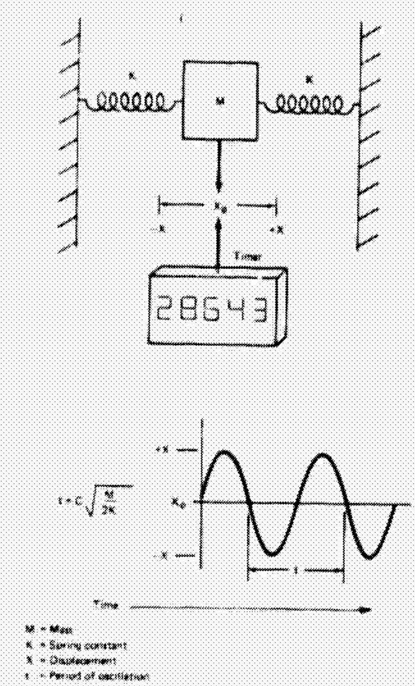

Fig. II-5 (a). Schematic of Spring/Mass Oscillator and its motion.

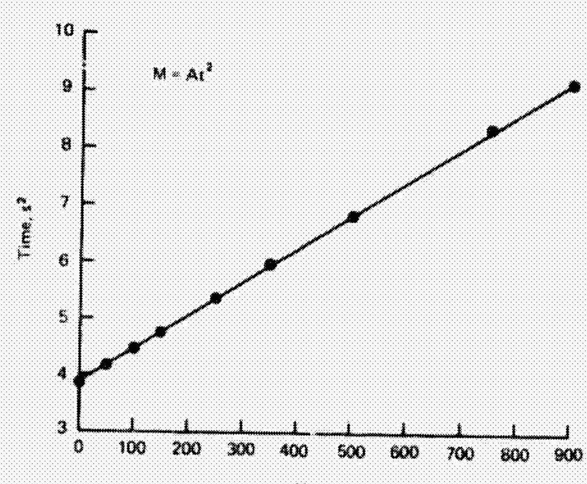

Fig. II-5 (b). Calibration curve Skylab 2 small mass measuring device, mission day-9. (From ref. II-12, p. 375.)

Objectives of Life Science Experiments

All of the experiments conducted on Skylab were unique and of inestimable importance to mankind. The medical studies are of special interest to the fields of health, physical education, and recreation. These studies were directed toward better understanding of muscle and bone development, heart function and blood circulation, blood development and immunity, perception, equilibrium, biorhythms, and cell growth.

Some experiments were specifically designed to gain additional information during longer missions of the negative effects observed during the earlier, shorter missions. These same experiments served to monitor any alterations in response induced by programs instituted to delay or prevent decrements in mineral balance, body fluids, orthostatic tolerance, blood volume, and body weight. Other studies were included to gain new information concerning circadian rhythms, metabolic activity, inflight vestibular function, inflight monitoring of orthostatic tolerance, red blood-cell metabolism, etc. The data collection for the life sciences projects alone would be exemplary. When it is considered that data also were collected for studies of the Sun, stellar astronomy, space physics, material science and manufacturing in space, zero-gravity systems, and spacecraft environment, the breadth of expertise and the extensive crew training are obvious.

Some of the life science experiments and their objectives were as follows (modified from ref. II–5):

Mineral balance—To determine the effects of space flight on the muscle and skeletal body systems by quantitative assessment of biochemical constituents of metabolic importance (i.e., water, calcium, phosphorous, magnesium, sodium, potassium, nitrogen, urea, hydroxyproline, creatinine, and chloride).

Bone mineral measurement—To determine by the photon absorptiometric technique the occurrence and degree of bone mineral changes that might result from exposure to the weightless condition.

Lower body negative pressure—to provide information concerning the time course of cardiovascular adaptation during flight and to provide inflight data for predicting the degree of orthostatic intolerance and impairment of physical capacity to be expected following return to the Earth environment.

Vectorcardiogram—To measure the vectorcardiographic potentials of each astronaut periodically throughout the mission so that flight-induced changes in heart function can be detected and compared with a preflight baseline.

Cytogenetic study of the blood—To make pre- and postflight determinations of the chromosome aberration frequencies in the peripheral blood leukocytes and to provide *in vivo* radiation dosimetry.

Blood volume and red cell lifespan—To determine the effect of Earth orbital missions on the plasma volume and the red cell populations with particular attention paid to changes in red cell mass, red cell destruction rate, red cell lifespan, and red cell production rate.

Red blood cell metabolism—To determine if any metabolic or membrane changes occur in human red blood cells as a result of exposure to the space-flight environment.

Human vestibular function—To obtain data pertinent to establishing the validity of measurements of specific behavioral/physiological responses influenced by vestibular activity under 1 *g* and zero *g* conditions; to determine human adaptability to unusual vestibular conditions, and to predict habitability of future spacecraft conditions involving reduced gravity and Coriolis forces; to measure the accuracy and variability in human judgment of spatial coordinates based on atypical gravity receptor cues and inadequate visual cues.

Metabolic activity—To determine if human effectiveness in doing mechanical work is progressively altered by exposure to the space environment. Secondary objectives were to evaluate the bicycle ergometer as an exercise device for long-duration missions and to evaluate ground-based reduced-gravity simulators.

Sleep monitoring—To evaluate sleep quantity and quality during prolonged space flight through automatic onboard analysis of electroencephalogram (EEG) and electrooculogram (EOG) activity and telemetry of results.

Time-and-motion study—To evaluate the effects of space conditions on time-and-motion characteristics of crew performance by measuring the similarities, differences, and relative consistencies between task activities in earth-based simulations and in zero-gravity spaceflight.

Body mass measurement—To demonstrate the feasibility of body mass measurement in the absence of gravity, to validate the theoretical behavior of the body mass measuring device, and to support those biomedical experiments requiring body mass determination.

Skylab Medical Experiments Altitude Test (SMEAT)

Although Skylab provided a unique laboratory for the study of physiological changes produced during prolonged space flight, it also represented a new order of complexity in space activities. Not only were the tasks of the crew complex, as already mentioned, but there were many new and modified instruments.

Pilot tests were needed for all protocols. NASA proceeded in a systematic manner with SMEAT, the acronym for Skylab Medical Experiments Altitude Test, a ground experiment which simulated a full 56-day Skylab mission. The physical facility was similar and the atmosphere was identical (70 percent oxygen, 30 percent nitrogen, at 5 lb/in²). The crew activities were representative, the timeline of events was that of an operational mission, and full mission support was provided. The simulation allowed testing of all crew procedures and equipment operations. Furthermore, final training of support personnel could be conducted, particularly in regard to data-collection techniques. The six objectives of SMEAT were to (a) obtain and evaluate baseline medical data, for up to 56 days, for those medical experiments that might be affected by the Skylab environment; (b) evaluate experiments, hardware, systems, and ancillary equipment; (c) evaluate data-reduction and data-handling procedures in a mission-duration time frame; (d) evaluate pre- and postflight medical support operations, procedures, and equipment; (e) evaluate medical inflight experiments, operating procedures, and crew checklists; and (f) train the Skylab medical operations team for participation in flight activities (ref. II-13).

From the viewpoint of research design, SMEAT was a necessity in that it provided quantitative data for 56 days under environmental conditions as similar as possible to the actual experimental situation. Only the gravitational effects, any effects attributable to the mental stress of the space situation, and possibly radiation effects would be different in the space environment. SMEAT provided baseline data that included the training effects resulting from frequent repetition of the same measures. It also provided baseline data for the Skylab atmospheric environment and comparative data to the standard sea-level atmospheric environment. All comparisons were essential for ultimate interpretation of the Skylab results.

The medical experiments conducted on SMEAT were those planned for Skylab: cardiovascular-hemodynamic, musculoskeletal-metabolic, endocrine-electrolyte, and neurophysiologic (ref. II-13). Detailed objectives for SMEAT were as follows:

1. Habitability considerations that included testing (a) the acceptability of food items; (b) the reliability of food packaging; (c) the functional adequacy of food storage, preparation, service, and cleanup; (d) the efficiency of whole-body cleansing; (e) the effectiveness of the housekeeping system; (f) the usefulness of the Skylab personal hygiene kit; and (g) the operation of the urine collection systems.
2. Physiology-health considerations that included evaluation of (a) the microbial population dynamics in the mouths of the crew; (b) the equipment designed to perform basic diagnostic microbiology tests; (c) the effects of confinement on crew microbial burdens and the microbial ecology of the chamber; and (d) the operational bioinstrumentation system designed to obtain physiological data during the launch, extravehicular and return phases, and to provide full-time monitoring of an ill crewman.
3. Atmospheric purification and control considerations that included (a) monitoring of trace contaminants, carbon monoxide, carbon dioxide, aerosol residuals, and dewpoint; (b) determining storage requirements for odor-absorbic elements; and (c) establishing the degradation of carbon dioxide and odor-absorbic elements.
4. Operational considerations that included acquiring and processing of biomedical data in a mode approaching that planned for Skylab.

The development of food for SMEAT and Skylab consumption was a complicated task. On the Apollo missions, balanced 2,500 cal/day diets were provided for each astronaut. Examination of their nutrient intake showed that most crewmembers had not consumed food at levels equivalent to their calculated requirements. The more prolonged Skylab missions dictated careful study of diets because of the greater duration and the fact that a number of the medical experiments were particularly dependent upon nutrient intake. The menu design criteria were rigorous, including (a) crew-food compatibility in terms of flavor, safety, allergic responses, gas formation, and fecal bulk and consistency; (b) adequacy in meeting nutritional requirements; (c) specific constituent intakes for medical experiments (e.g., calcium, sodium, protein); and (d) physical constraints of package size, storage, preparation equipment, waste disposal, and residue mass. This was a large task considering the planned mission durations. The foods selected and used were as follows (modified from ref. II-15):

Beverages—apple drink, cherry drink, cocoa, cocoa-flavored instant breakfast drink, coffee (black), grape drink, grapefruit drink, lemonade, orange drink, strawberry drink, and tea with lemon and sugar.

Wafer food—apricots (dried), bacon wafers, biscuit (cracker type), butter cookies, candy (hard), cheddar cheese crackers, dried beef (sliced), mints, peanuts (dry roasted), sugar cookie wafers, and vanilla wafers.

Rehydratable food—asparagus, beef hash, corn (cream style), corn flakes (sugar coated), chicken and gravy, chicken and rice, eggs (scrambled), green beans, macaroni and cheese, pea soup, peas (creamed), peach ambrosia with pecans, pork and scalloped potatoes, potato salad (German style), potato soup,

Table II-2—*Nutrient tolerance levels for SMEAT crewmembers*

M071	CDR [1]	SPT [2]	PLT [3]
Energy (cals) 2000–2800	2895 ± 20	3276 ± 15	3100 ± 22
Protein (g) 90–125 ± 10	115 ± 10	110 ± 10	123 ± 10
Calcium (mg) 750–850 ± 16	850 ± 16	850 ± 16	850 ± 16
Phosphorus (mg) 1500–1700 ± 120	1700 ± 120	1700 ± 120	1700 ± 120
Sodium (mg) 3000–4000 ± 500	3900 ± 500	4000 ± 500	4000 ± 500
Magnesium (mg) 300–400 ± 25	325 ± 25	350 ± 25	320 ± 25
Potassium (mg) 3000–4000 ± 200	3921 ± 200	4000 ± 2000	3915 ± 200

Source: reference II-15.
[1] CDR=Commander.
[2] SPT=Scientist Pilot.
[3] PLT=Pilot.

potatoes (mashed), rice krispies, salmon salad, sausage patties, shrimp cocktail, spaghetti and meat sauce, strawberries, sweet potatoes (mashed), turkey rice soup, and veal and barbecue sauce.

Thermostabilized food—applesauce, butterscotch pudding, catsup, chili with meat, fruit jam, hot dogs (tomato sauce), lemon pudding, meatballs and sauce, peaches, peanut butter, pears, pineapple, tuna sandwich spread, and turkey and gravy.

Frozen food—beef (prime rib), bread (white), coffee cake, filet mignon, lobster newburg, pork loin with dressing and gravy, roll (prebuttered), and vanilla ice cream.

The nutrition tolerance levels calculated for the three SMEAT crewmembers with reference to the M071 mineral balance study are shown in table II-2. The estimated adequate daily energy levels for each of the crewmembers were calculated by the method recommended by the Food and Nutrition Board of the National Research Council (ref. II–14).

Selected SMEAT Experiments and Conclusions

SMEAT involved comprehensive testing of the medical experimental protocols to be used on Skylab and the collection of baseline 1*g* data; therefore, large quantities of information were generated. The experiments have been published (ref. II–15) and should be of interest to some readers because of their unique instrumentation and the breadth of sophisticated data collected. Brief conclusions from 13 selected experiments of SMEAT have been abstracted to reflect the systematic studies conducted prior to sending astronauts into space. Three of the experiments require further discussion because of special instrumentation, problems, or relevance to reader interests. The following abstracted conclusions of the selected studies are presented for perspective only. Interested readers are referred to the reference listed (ref. II–15).

Mineral balance—See text, p. 14.

Bone mineral measurement—Few deviations from baseline bone mineral measures were observed. One individual showed possible mineral loss in the *os calcis* and another gained mineral in the right ulna. The gain may be attributable to the heavy exercise routines of that crewmember. No changes were observed in the right radius.

Lower body negative pressure—Impaired orthostatic tolerance, manifested by the increased heartrate, diminished systolic and pulse pressures, and the increased tendency to syncope (faint) during LBNP or in the upright position were not observed.

Cytogenic studies of the blood—Minor chromosomal defects were noted but the chamber environment had no deleterious effect where chromosomal observations were concerned.

Blood volume and red cell life span—No significant shortening of mean red cell lifespan was observed. A slight increase in plasma volume (1.6 percent) was noted. There was no evidence of increased red cell production; however, there was a slight decrease in mean red cell mass and total hemoglobin. One subject, the scientist pilot, showed increases in red cell mass (+6.6 percent) and plasma volume (+13.7 percent) but had a large weight shift under vigorous conditioning.

Red blood cell metabolism—Significant decreases in glycolytic enzymes were noted.

Special hematology effects—Routine hematology measures were within the normal range with one exception: a significant lymphopenia in the pilot during posttest, possibly reflecting increased adrenal corticoid secretion.

Investigation of the immune system—Some changes in serum proteins were observed that were different from Apollo data, possibly due to some feature unique to space flight. The data suggest an immune reaction during the latter days of chamber stay possibly due to subclinical illness or challenge by a non-disease-producing agent. Essentially no changes were observed in reactivity of immune systems as typified by rate of RNA or DNA synthesis in small lymphocytes.

Metabolic activity—Unique online measurement techniques were developed. See text for representative data.

Time and motion—A general improvement was noted in both task and subtask performance over time. No evidence was found for deterioration of performance.

Sleep monitoring—It was determined that reliable objective data concerning sleep characteristics could be obtained online using automatic analysis. One of the two crewmembers measured from day 5 on showed essentially no change in sleep parameters. The other exhibited definite changes during the mission (e.g., increased sleep latency, increased time awake during the first third of the night, and decreased total sleep time.)

Bioassay of body fluids—A slight but significant decrease in potassium was noted. Increases in antidiuretic hormone appeared to be related to environmental temperature. Body fluid losses generally were proportional to body weight losses. No changes indicative of altered calcium were observed. Decreases were noted in glucocorticoids, possibly related to the hypobaric environment. Changes in catecholamine levels showed high individual variability. Enhanced renal secretion of amino acids was observed. These results must be interpreted in relation to stress, exercise, and nutrient balances.

Crew microbiology—States of microbial unbalance occurred, for the most part, only in those bacteria, yeast, and fungi that are not part of the true indigenous flow of the crewmembers. Confinement for 56 days in the simulated Skylab environment apparently does not mediate shifts in bacterial populations that have obvious clinical significance. The lack of buildup of skin flora suggests that the personal hygiene regimens were adequate. The fact that bacteria, yeasts, and fungi existed in high numbers, compared to a normal environment, both on surfaces and in the air, was considered significant. In the zero *g* situation, microbes may exist in the air for long periods, making the atmosphere particle count several orders of magnitude higher than normal. Continued long exposure could result in clinical manifestations.

Lower Body Negative Pressure Measurement

After orthostatic intolerance had been observed on the early missions, the lower body negative pressure (LBNP) device shown in Fig. II-6 was developed. It was utilized pre- and postflight for the Apollo missions. Because of the projected duration of the Skylab missions and previous history of orthostatic intolerance following exposure to the weightless environment, the LBNP was planned for inflight use in Skylab to monitor and document the time course of cardiovascular system alterations. This measure is taken by placing the subject in the canister, as shown, with an air seal around the body just above the iliac crests. The pressure within the canister is then reduced by a vacuum pump. During the lowered pressure, two plethysmographs (leg bands) measure volume changes in the calf. Blood pressures were measured automatically and vector-cardiographs (VCG's) were recorded from the Frank lead VCG. The test protocol for 25 minutes was as follows:

Period I (control)	5 min at ambient pressure (258 mm Hg)
Period II	1 min at −8 mm Hg (LBNP)
	1 min at −16 mm Hg (LBNP)
	3 min at −30 mm Hg (LBNP)

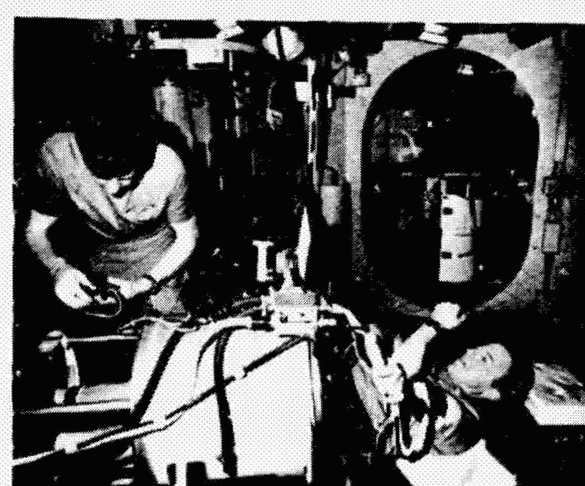

Fig. II-6. Operating the lower body negative pressure experiment on Skylab.

Period III	5 min at −40 mm Hg (LBNP)
Period IV	5 min at −50 mm Hg (LBNP)
Period V (recovery)	5 min at ambient pressure (258 mm Hg)

During the testing, one astronaut always served as an observer in case of syncope (fainting). Although few experimental effects were anticipated for SMEAT, the protocol and all related instrumentation required thorough testing because this test clearly was of extreme importance to extended stay in space.

Work Metabolism Measurements and Selected Results

The first attempts to evaluate metabolic effectiveness during work in space were undertaken in Skylab (ref. II–16). The investigators were faced with the challenge of developing a reliable online system. A mass spectrometer was used to determine the partial pressures of oxygen, carbon dioxide, nitrogen, and water in the inspired and expired gases. Rolling seal, dry spirometers were used to measure inspired and expired breath volumes. An analog computer was programed to derive minute volume, oxygen consumption, carbon dioxide production, and the respiratory exchange ratio each minute.

An electrically braked bicycle ergometer was used for the work testing as well as for the crew's personal exercise. The ergometer could be operated in three modes: set work, set heartrate, or sequenced heartrate steps. All tests used the set work mode. During the tests, heartrate and blood pressures were recorded periodically. The test protocol covered 26 minutes. The subject breathed into the mouthpiece at the start of the test (26 minutes to go) while seated on the ergometer as shown in figure II–7. He remained at rest until the 20-minute mark at which time he began pedaling at 50 to 80 rpm. The first work level, at approximately 25 percent of the subject's predetermined maximum aerobic capacity, was continued for 5-minutes. At the 15-minute mark, the workload was increased to 50 percent of maximum; at 10 minutes, it was further increased to 75 percent of maximum. At the 5-minute mark, the subject ceased pedaling and began a 5-minute recovery period. The loads were specific to the individual's capacity. For example, at 75 percent of maximum the commander's (CDR) load was 150 watts, the scientist pilot's (SPT) 260 watts, and the pilot's (PLT) 180 watts.

These data were important for several reasons. They were being collected in a 5 lb/in^2 environment with 67 percent oxygen, 1.8 percent carbon dioxide, 26.5 percent nitrogen, and 4.7 percent water. The effects of the high carbon dioxide value on the metabolic responses were not known in this combination. The environment was unique and required reference information. Representative data for exercise oxygen consumption ($\dot{V}O_2$), systolic blood pressure, and minute volume are shown in table II–3.

Mineral Balance Measurement

The investigators associated with the mineral balance experiment were faced with difficult problems (ref. II–18). Negative nitrogen and calcium balances had been observed on previous space missions. It was assumed that a continued loss of calcium from bone and the loss of muscle mass reflected by the negative nitrogen balance might be deterrents to extended space flight unless preventive measures could be found. It was essential that procedures be pilot tested in SMEAT for ultimate monitoring in the subsequent zero-g missions. Knowledge of dietary intake and analysis of excreta were required.

The controls needed for nutrient intake, of necessity, placed a difficult constraint on diet. For the two crewmembers whose physical activity levels were in the moderate range, body weight remained reasonably constant (table II–4). The third crewmember, the SPT, participated in a great deal of physical activity (ref. II–19). Since this crewman lost 19 lbs. during the experiment, it was evident that the diet, as planned, was not sufficiently flexible to cope

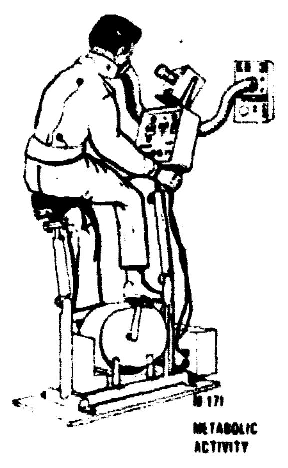

Fig. II-7. Measurement of work metabolic activity.

Table II-3—*Exercise values collected during SMEAT metabolic experiment*

	Systolic blood pressure					Minute volume					Oxygen consumption				
Commander	$\bar{X}$	S.D.	N	t	P	$\bar{X}$	S.D.	N	t	P	$\bar{X}$	S.D.	N	t	P
Level 1															
Pretest	121.4	13.1	11			22.0	2.7	9	−0.521	N.S.	.856	.071	12	1.459	N.S.
Test	128.5	7.4	26	−1.6873	N.S.	22.5	1.9	33			.898	.116	33		
Level 2															
Pretest	153.0	12.1	13			37.2	2.2	13	3.13	$p<0.01$	1.409	.071	16	0.0	N.S.
Test	145.6	8.9	23	1.9297	N.S.	35.0	2.0	33			1.409	.147	33		
Level 3															
Pretest	172.0	10.5	13			54.7	4.1	13	3.08	$p<0.01$	2.034	.107	16	0.930	N.S.
Test	172.2	13.2	32	−0.0536	N.S.	50.8	3.2	33			2.000	.143	33		
Scientist Pilot															
Level 1															
Pretest	126.1	5.7	11			42.5	3.1	14	−2.35	$p<0.05$	1.414	.100	14	0.066	N.S.
Test	135.1	12.1	31	−3.2483	$p<0.01$	45.2	4.5	32			1.416	.077	33		
Level 2															
Pretest	154.3	6.0	9			73.4	6.3	14	−2.71	$p<0.02$	2.310	.210	14	1.415	N.S.
Test	162.3	13.8	33	−2.5593	$p<0.02$	78.8	6.0	32			2.223	.144	33		
Level 3															
Pretest	166.3	9.4	9			117.3	13.5	14	−4.03	$p<0.001$	3.177	.303	13	0.198	N.S.
Test	185.3	7.6	33	−5.5863	$p<0.001$	133.0	8.2	32			3.195	.190	32		
Pilot															
Level 1															
Pretest	129.0	9.5	15			24.3	1.5	16	−4.09	$p<0.001$	.949	.059	16	2.893	$p<0.01$
Test	147.3	16.9	24	−4.3233	$p<0.001$	26.3	1.8	33			.886	.092	33		
Level 2															
Pretest	152.0	7.2	15			39.9	2.6	16	−4.61	$p<0.001$	1.540	.095	16	2.355	$p<0.05$
Test	165.6	9.9	27	−5.1090	$p<0.001$	43.7	2.9	33			1.463	.127	32		
Level 3															
Pretest	198.1	14.2	13			59.1	6.2	16	−3.22	$p<0.02$	2.247	.157	16	3.824	$p<0.001$
Test	191.3	3.8	33	1.7026	N.S.	64.6	4.1	33			2.080	.110	33		

Note—N.S.=Nonsignificant ($p>0.05$)
Source: Modified from reference II-17.

Table II-4—*SMEAT crew weights in pounds*

Crewmember	Start diet	Enter chamber	Exit chamber	End diet
CDR	159	157½	154¾	156
SPT	209	204	193¼	190 [1]
PLT	185¾	185½	185½	184½

[1] Diet was terminated one week prior to end of planned termination.
Source: reference II-19, p. 19-8.

with such high activity levels. The experience of the SPT was of significance to the Skylab program because some of the prime crewmen were quite large and inherently very active. Modification of the diet relative to physical activity was an important step, since regular exercise was recognized as being essential to the maintenance of cardiovascular capacities in the zero-*g* environment.

Mission Performance

The manner in which the Skylab missions were completed is a fascinating story that has received wide press coverage. It is a story of courage, ingenuity, and coordinated teamwork by flight and ground support personnel. Readers wishing more extensive coverage of the performance details are referred to Canby's fine article (ref. II-6).

New knowledge was obtained concerning astronauts' responses in the zero-*g* environment. There was reasonable stabilization of their physical reactions after about the 40th day in space. Upon return to Earth, the crew of the second manned Skylab mission (59 days) readapted more quickly than did those on the first mission even though they had been in space over twice as long (ref. II-20). The results were encouraging. On the basis of this experience, tentative approval was granted to extend the third manned mission to 84 days. It is significant that the members of the 84-day mission returned in even better physical condition than did the crews of the previous missions. Obviously, travel in space for prolonged periods is feasible.

Skylab was a scientific bonanza supplementing the unmanned satellite and the previous manned missions. Selected portions of the data most relevant to the fields of health, physical education, and recreation are reviewed in the next chapter.

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Chapter III
Selected Findings: Skylab Life Sciences Research

In August 1974, a symposium was held at the Johnson Space Center in Houston for the presentation of the results of the Skylab life sciences investigations. This symposium was a milestone in space biology and medicine. Unique data related to these prolonged missions in space were presented. The proceedings of the symposium, which have been published, are classic in both depth and breadth of information (ref. III–1).

This summary is intended to bring selected portions of the Skylab findings to the attention of professionals in the fields of exercise physiology, health, physical education, and recreation. Since a figure or chart often is better than lengthy descriptions for depicting findings clearly, pertinent graphs and diagrams from the original data have been included.

Crew Health

The precautions taken for crew health materially contributed to the success of the missions. A crew surgeon was assigned to each mission. For the last 21 days prior to each launch, the crew participated in a health stabilization program in which they were isolated from exposure to infectious diseases as a preventive to acute illness during the mission (ref. III–2). Before, during, and after the flight the crew surgeons gave careful surveillance to illness events and prescribed medications, nutrition intake and output, personal daily exercise, work-rest schedules, and the quantity and quality of sleep. For continuous clinical evaluation of the crew, the crew surgeon had access to the medically related experimental data, the monitored data relevant to radiological health, and the environmental data including toxicological evaluations (ref. III–3). Every evening the crew members had a private conference with their crew surgeon. In addition, each evening the crew received a medical status report containing a summary of the data obtained the last time the medical experiments were conducted. It also included body weight, water consumption, calories consumed, and any specific instructions for the next day (e.g., directions to alter a specific dietary component to maintain mineral balance). On a weekly basis, the crew conversed with one of the scientists from the medical science community. The crew thus knew their status, had the opportunity for private discussions with their flight surgeon, and periodically could discuss projects with the investigators (ref. III–4). Questions could be posed and answered. This, coupled with the astronauts' knowledge of the results of the medical testing, contributed to their peace of mind.

The crew received a daily flight plan based on the priorities of the various scientific studies. Early in the mission, it was found advantageous to have a weekly plan developed at a science planning meeting with the representatives of all disciplines assembled (ref. III–4). In the thirst for knowledge by all disciplines, it was inevitable that trade-offs were necessary. The team approach exemplifies the NASA cooperative effort. In most instances, the planning worked quite well. Only in the third manned mission, when the load became overwhelming to the crew, did the procedure require review (ref. III–5).

Crewmen on pre-Skylab missions commonly complained of insomnia. The three Skylab missions made possible the first objective measures of a human's ability to obtain adequate sleep during prolonged space flight. The findings support the view that astronauts are able to obtain adequate sleep in regularly scheduled 8-hour rest periods. Although alterations in sleep patterns occurred, they were not of the type to result in a significant degradation of work performance (ref. III–6).

A microbiology study was undertaken on Skylab to detect the presence of potentially pathogenic organisms and to obtain information regarding the responses of microbial flora to the space environment. Air samples were taken as were samples from multiple sites on the crewmen (e.g., ears, nose, throat, groin, urine, and feces). Inflight cross-contamination, colonization, and infection with *Staphylococcus aureus* demonstrated intercrew transfer of pathogens. The data showed that gross contamination of the Skylab environment did occur and there were several minor inflight disease events, but such events were not hazards that might limit long-term space flight (ref. III–7).

One of the early concerns about going into space was that the crew might receive excessive radiation. By the time of Skylab, however, premission analyses indicated that dose equivalents from trapped protons and electrons of the Van Allen belt, galactic cosmic rays, and normal onboard sources would be well below the limits adopted by NASA from the National Academy of Sciences recommendations for manned space flight. A possibility did exist of exposure from energetic solar particle events, high altitude nuclear tests, and unexpected problems in onboard sources. The dose equivalents received by the crew of the third manned mission (84 days) were the highest received in any NASA mission to date. The rates involved, however, were quite low. To place the results in perspective, the crew of the third flight could participate in a comparable mission once each year for 50 years before exceeding the career limits (ref. III–8).

A study also was made of the visual light flashes that had been reported during earlier flights. These light flashes are believed to be caused by primary cosmic ray particles and/or possibly by trapped particles larger than protons. A high flash rate of 15–20 per minute was observed in the South Atlantic anomaly (an area with high radiation activity). The significance of the flashes is not known. Whether they are of no consequence or potentially causative of retinal or other tissue damage requires further investigation (ref. III–9).

From previous experience with closed-loop environmental operations such as submarine cruises and manned chamber tests, it was known that trace gas concentrations could cause the missions to be terminated. The major toxicological consideration was to maintain low levels of contaminant gases in the spacecraft atmosphere. Following the loss of the micrometeoroid shield during the launch of the OWS, a significant toxicity problem did develop due to overheating of the rigid polyurethane foam used as a wall insulating material. Laboratory tests showed that decomposition due to heat probably had resulted in an excess release of toluene diisocyanate and that excessive amounts of carbon monoxide probably were present in the OWS.

The first crew carried sensors to measure these gases. Prior to entry into the Skylab, pressurization-depressurization cycles were conducted to dilute any contaminating gases. The crew then assessed the concentration using analyzer tubes and found the contaminant gases within normal limits. The life-support system that contained activated carbon was specifically designed to remove trace levels of contaminating compounds. The procedure worked quite well for the remainder of the first manned mission and the two following missions were completed without further trace gas problems (ref. III–10).

Changes in Body Weight

Loss in body weight during space flight has been observed consistently. On Skylab, the body mass was systematically monitored using an electronically timed spring-mass oscillator that was an effective instrument (ref. III–11). A good number of the inflight medical experiments were undertaken to study the mechanisms related to shifts in body mass. A representative body mass pattern is shown in figure III–1. Each crewmember incurred a loss during the first days of the mission. There were individual differences in pattern, but in the first two manned missions the weight loss continued throughout the flight. The postflight recovery was relatively rapid, however, with the major portion of the weight being regained within 17 days. The 84-day mission was significant regarding body mass in that all of the crewmembers started to regain body mass inflight following the initial drop. On the third manned mission, both food and exercise were increased. The inflight metabolic costs were higher than anticipated. Possibly as a result of the increased food and/or exercise, the initial body mass loss of crewmembers on the third manned mission was slightly less and the recovery to preflight levels was faster.

Anthropometric Changes

When the Skylab crews were placed in the weightless environment, a number of anatomical and anthropometric changes occurred that have physiological significance. A postural change was observed, as shown in figure III–2, that resembles that of a quadruped. Due to the lack of a gravitational load, the thoraco-lumbar spine straightened and there was an increase in height. The height increase may have been caused by expansion of the intervertebral discs that were unloaded. The girth measures of the

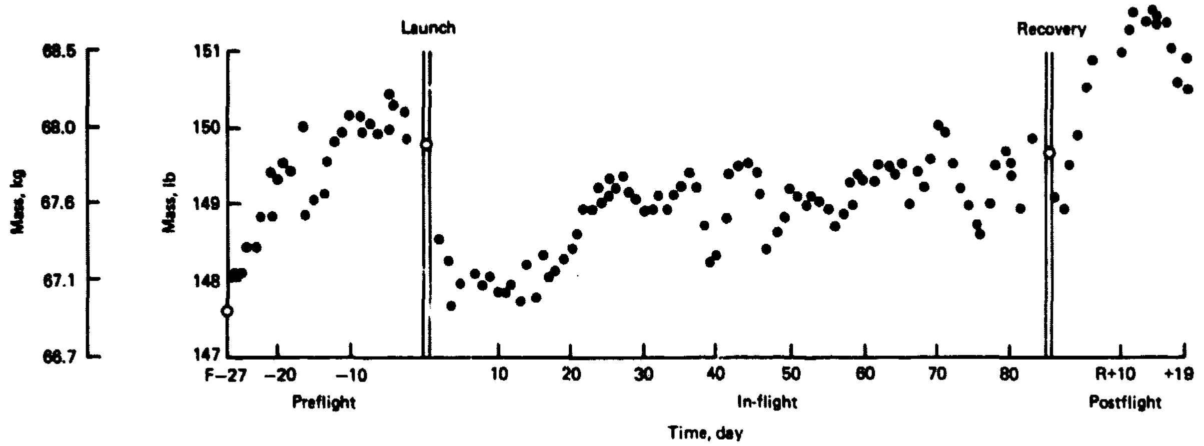

Fig. III-1. Body mass measurement of Commander, 3rd Manned Mission. (From ref. III-11, p. 383.)

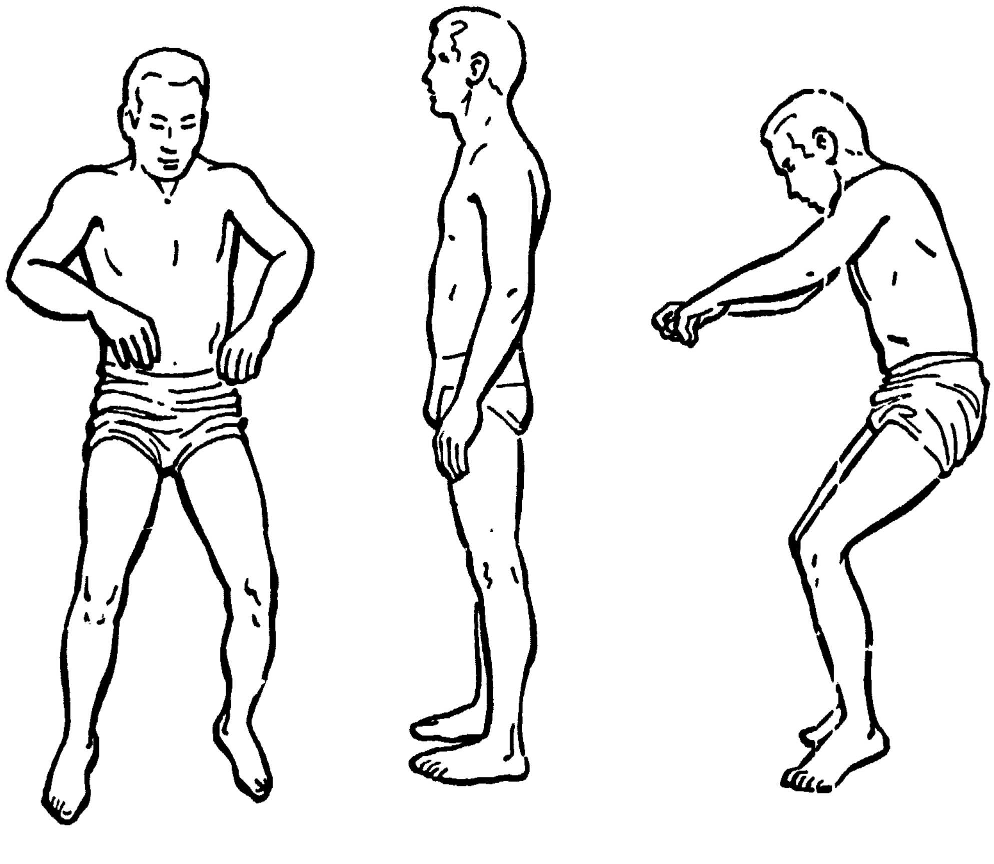

Fig. III-2. Postural changes. (From ref. III-12, p. 646.)

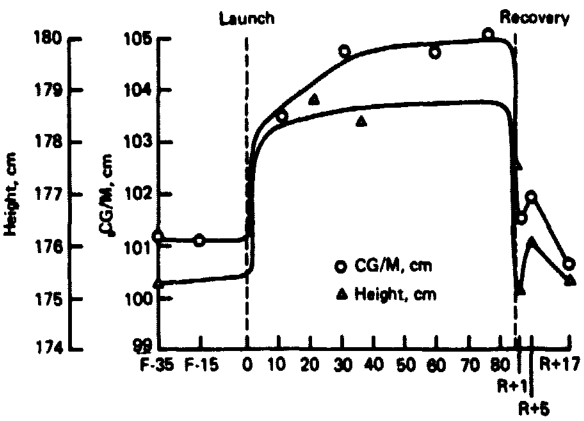

Fig. III-3. Center of gravity/center of mass, Skylab 4 Pilot. (From ref. III-12, p. 650.)

trunk, including the abdomen and chest, were reduced, probably due to the stretching of the torso. The center of mass inflight shifted 3–4 cm toward the head—a large shift. Figure III-3 shows height and center of mass measures on representative days before, during, and after the 84-day mission.

A series of carefully located limb-girth measurements made determinations of the volumes of the arms and legs possible. As shown in figure III-4, all crewmembers had lost more than 0.8 liters (27 oz) of extravascular fluid from the calf and thigh by the time of the first inflight measurements on day 3 (ref. III-12). On recovery, it was possible by four-camera stereophotogrammetry to test the validity of the girth measures. Figure III-5 shows the two values to be quite close. The biostereometric measures also confirmed the losses observed in leg volumes. The mean loss for the first mission was 1.68 liters (57 oz) as compared with 1.12 liters (41 oz) for the third mission. On day one postflight, the mean loss was 1.06 liters (36 oz) for the second mission as compared with 0.77 (26 oz) for the third mission. An apparent decrease in the loss of leg volumes was observed on succeeding missions. It is possible that this decrease was mediated by the increased inflight exercise. However, it is not clear whether the results were caused by prevention of muscular atrophy or by an effect on the cardiovascular system (ref. III–13).

Fluid Shifts and Blood Changes

Associated with the approximate 1 liter (34 oz) or 13 percent loss of total leg volume early

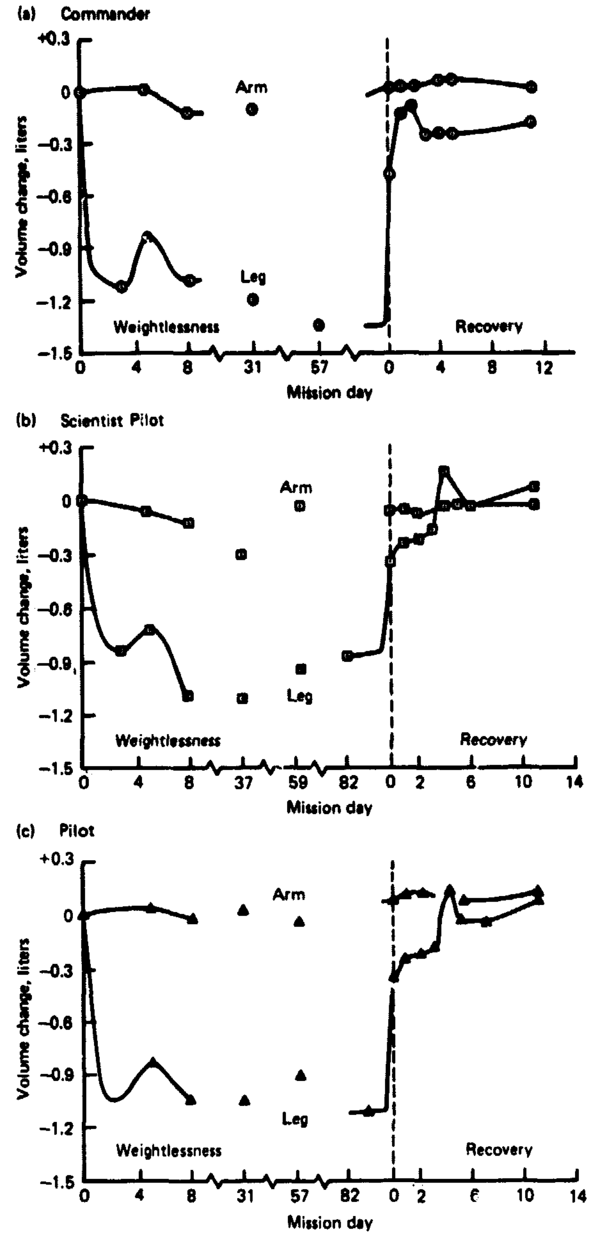

Fig. III-4. Change in left limb volumes Scientist Pilot, 3rd Manned Mission. (From ref. III-12, p. 649.)

in the mission, the face was puffy and the upper body veins were engorged. It is believed that with the loss of the hydrostatic forces associated with gravity, the body fluids moved more toward the head and to a "central volume" as shown diagrammatically in figure III-6. In infrared pictures taken during weightlessness, the foot and lower leg veins were not distended as they were when standing under 1*g*, whereas the jugular and veins of the temple and fore-

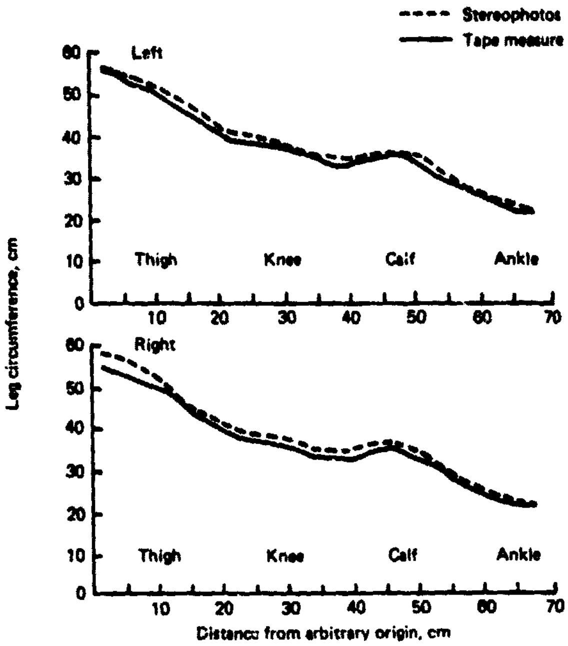

Fig. III-5. Comparison between tape measure and stereometric circumference measurements, ten days preflight, Commander, 3rd Manned Mission. (From ref. III-13, p. 419.)

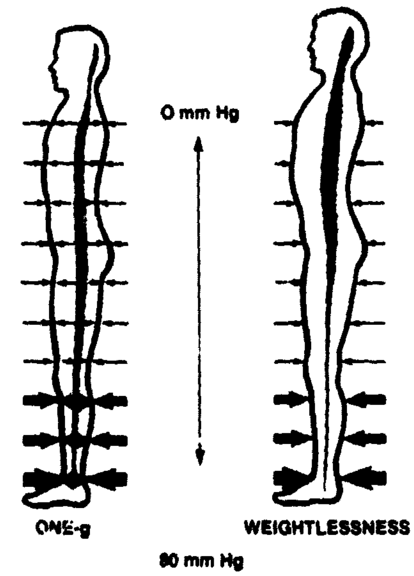

Fig. III-6. Fluid pressure/volume changes under weightlessness. (From ref. III-12, p. 656.)

head were completely full and distended (ref. III–12).

A reduction in the red cell mass was observed in the Skylab crewmembers. This is consistent with reductions observed in the previous Gemini and Apollo missions. The mean loss in the 28-day mission was greater than that found in the Apollo (14-day) crewmembers. It is important to note that the loss in the red cell mass immediately after the 22-day mission was greater than the loss observed after the 84-day flight.

Table III–1 reflects the beginning of recovery from the red cell loss observed in the 28-day mission. Improvement was observed in the 59-day mission, but by far the greatest improvement was observed in the 84-day mission. Significantly, a greater number of circulating reticulocytes (reflecting more regeneration) was observed following the longer mission, showing that the red cell mass does not continue to deteriorate in weightlessness. Apparently the body seeks a new homeostatic level. On the basis of this evidence it is clear that the initial

Table III-1.—*Red cell mass of Skylab crew members and controls*

		Crew				Controls			
Mission	Day [1]	CDR	SPT	PLT	$\bar{X}$	1	2	3	$\bar{X}$
		(ml)	(ml)	(ml)	(ml)	(ml)	(ml)	(ml)	(ml)
28 Day	Pre	2097	2088	2394	2193	1918	2213	1798	1978
	Post	1778	1763	2104	1882	1949	2299	1718	1989
				Difference	−311			Difference	+11
59 Day	Pre	1841	1780	2608	2076	2237	2250	1932	2140
	Post	1728	1427	2332	1829	2154	2259	1899	2104
				Difference	−247			Difference	−36
84 Day	Pre	1920	2030	1904	1951	2119	2197	1817	2048
	Post	1813	1851	1790	1818	2096	2187	1845	2043
				Difference	−133			Difference	−5

[1] Premission days were 29, 20, and 21 days before launch, respectively. Postmission day was the day of recovery.

Source: adapted from reference III-14, p. 498.

loss of red cell mass is no deterrent to more prolonged flights. The etiology of the red cell mass drop and alterations in reticulocyte counts observed at recovery is not known at this time (ref. III-14).

The metabolism of the red cells was investigated because previous studies had shown that the only mechanism responsible for the destruction of red cells by hyperoxia was peroxidation of unsaturated fatty acids in the red cell membranes. That is, oxidation of the fatty acids in the red cell membrane results in loss of integrity of the membrane and cell destruction. Hemolysis, or blood breakdown, could be attributed, therefore, to the peroxidation effect. In the Skylab missions there was no evidence of lipid peroxidation. Significant alterations in the glycolytic (glucose breakdown) intermediates and enzymes in the red cells were noted. These alterations, however, cannot be interpreted as evidence of red cell damage (ref. III-15). These data did not answer the etiology question concerning the loss in red cell mass. A postulated control mechanism associated with the fluid shift appears attractive (ref. III-12).

Orthostatic Tolerance Differences

The lower body negative pressure (LBNP) measure clearly was one of the most critical experiments monitored on the missions because it reflected cardiovascular deterioration that could have forced abortion of the mission. It is important that the crewmembers on the third manned mission of 84 days did not exhibit the magnitude of changes exhibited in the two earlier Skylab missions. The data obtained during flight served as a fairly accurate prediction of the postflight status of orthostatic tolerance. Measurement of LBNP in weightlessness imposed a greater stress upon the cardiovascular system than it did under 1*g* conditions.

Two representative graphs show the nature and magnitude of responses in this measure. Figure III-7a shows preflight responses and figure III-7b reflects inflight data for the same astronaut (ref. III-16). During flight the leg volume change is roughly twice that at 1*g* (6 volume percent compared to 3 volume percent). The systolic blood pressure drops from about 130 mm Hg to around 80 whereas under 1*g* conditions the pressure does not reach 100 mm Hg. The heartrate during flight shifted from about

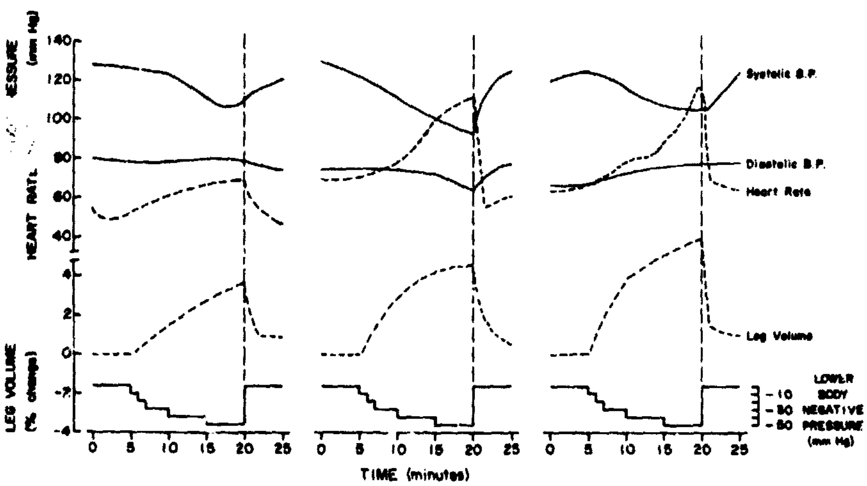

Fig. III-7 a, b, c. Cardiovascular responses of the Scientist Pilot, 3rd Manned Mission. (From ref. III-16, p. 556 and p. 582.)

70 beats/min to approximately 118. At 1*g* the heartrate increases from 58 to only 80 beats/min at the most. It is obvious from these data that the LBNP test was extremely stressful under weightless conditions.

The cardiovascular responses to LBNP showed the greatest instability, and orthostatic tolerance the greatest decrement, during the first 3 weeks of flight. The alterations in fluid distribution during early exposure to weightlessness create marked cardiovascular changes that impair orthostatic tolerance mechanisms within 4 or 5 days. After 5 to 7 weeks, the cardiovascular responses become more stable and the orthostatic tolerance appears to improve (ref. III–16). For example, figure III–7c shows the cardiovascular responses of the same astronaut in his last inflight test on mission day 82. Even though the percent change in leg volume was greater than on mission-day 6 and the heartrate pattern was similar, the systolic blood pressure did not drop below 100 mm Hg. Although the diastolic blood pressure increased slightly, a pulse pressure of about 30 mm Hg was maintained during the most rigorous part of the test. The astronaut had made an adaptation and was tolerating weightlessness better. Improved orthostatic tolerance was evident even though the calf girth continued to decrease (fig. III–8).

Hemodynamic Changes

Additional information related to orthostatic tolerance, the effects of fluid shifts, and the effects of blood volume changes was obtained by studying hemodynamic alterations in the legs under weightlessness. Venous compliance and arterial blood flow were determined by occluding venous flow with a pressure cuff above the knee and then recording volume differences from a midcalf segment by means of a volume transducer. Flow and compliance were determined by appropriate protocols. Muscle-pumping action was determined by placing the subject in the LBNP device at −30 mm Hg. After 3 minutes the astronaut made 10 maximal-effort isometric contractions, waited 1 minute, and then repeated the same number of contractions. The amount of blood collected under negative pressure and the amount remaining after pumping were determined (ref. III–17).

An increase in blood flow was observed in all astronauts during flight. Venous compliance slowly increased to day 15, slowly decreased to day 40, and then dropped to less than preflight values at recovery. After muscle pumping, the absolute blood flow increased several times. The compliance changes, when considered with the decreased blood volume, may provide

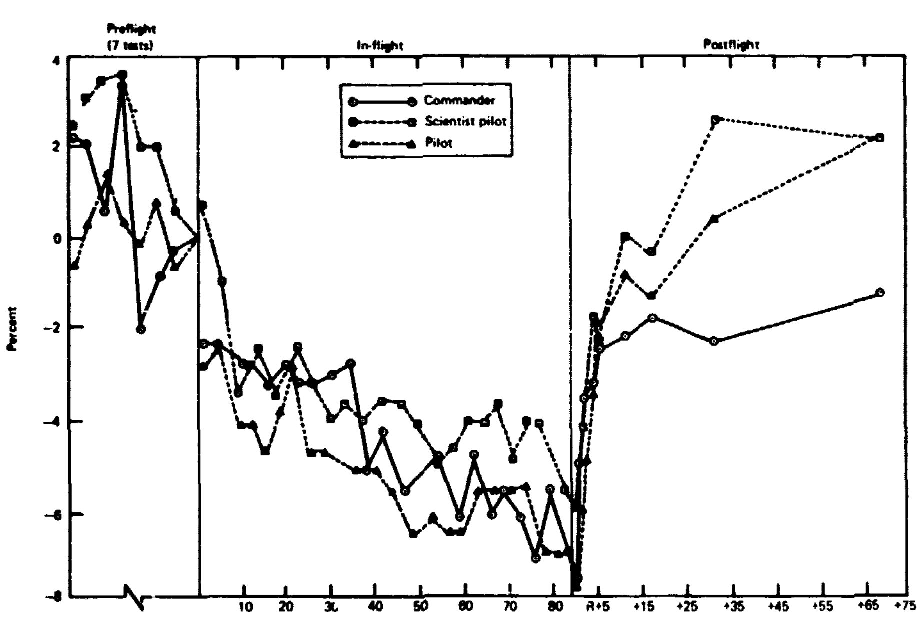

Fig. III-8. Calf girth of the three Skylab 4 crewmen measured just prior to each lower body negative pressure test. The mean $\frac{R+L}{2}$ of the right and left calf is shown. (From ref. III-16. p. 567.)

the basis for the changes in orthostatic tolerance, work capacity, and LBNP responses (ref. III-17).

Changes in Work Tolerance

The metabolic experiment using the bicycle ergometer at workloads approximating 25, 50, and 75 percent of the astronaut's maximal oxygen uptake capacity produced interesting and unexpected results. The hypothesis was that ability to perform physical work would be compromised during exposure to the weightless environment. Postflight testing of Apollo crews had shown statistically significant decreases in work tolerance. Although this was quickly reversible postflight, it was a concern for longer missions. The physiological parameters monitored during the exercise tests were respiratory gas exchange, blood pressure, and vectorcardiogram heartrate. *It is important to note that during exposure to the weightless environment the crewmen had no significant decrement in the parameters measured* (figure III-9). Readers interested in exercise physiology should see reference III-18.

Postflight, however, all crewmembers showed decrements in their ability to perform the tests as well as they had pre- and inflight. The indicators were higher pulse rates and oxygen consumptions for the same workloads, decreased stroke volume, and decreased cardiac output at the same oxygen consumption levels. *An interesting finding was that the amount of exercise performed inflight was inversely related to the length of time required postflight to return to preflight status and that there was no relationship to length of mission.* The crew of the 84-day mission, the longest, exercised the most and returned to preflight condition the quickest (ref. III-18). The investigators point out

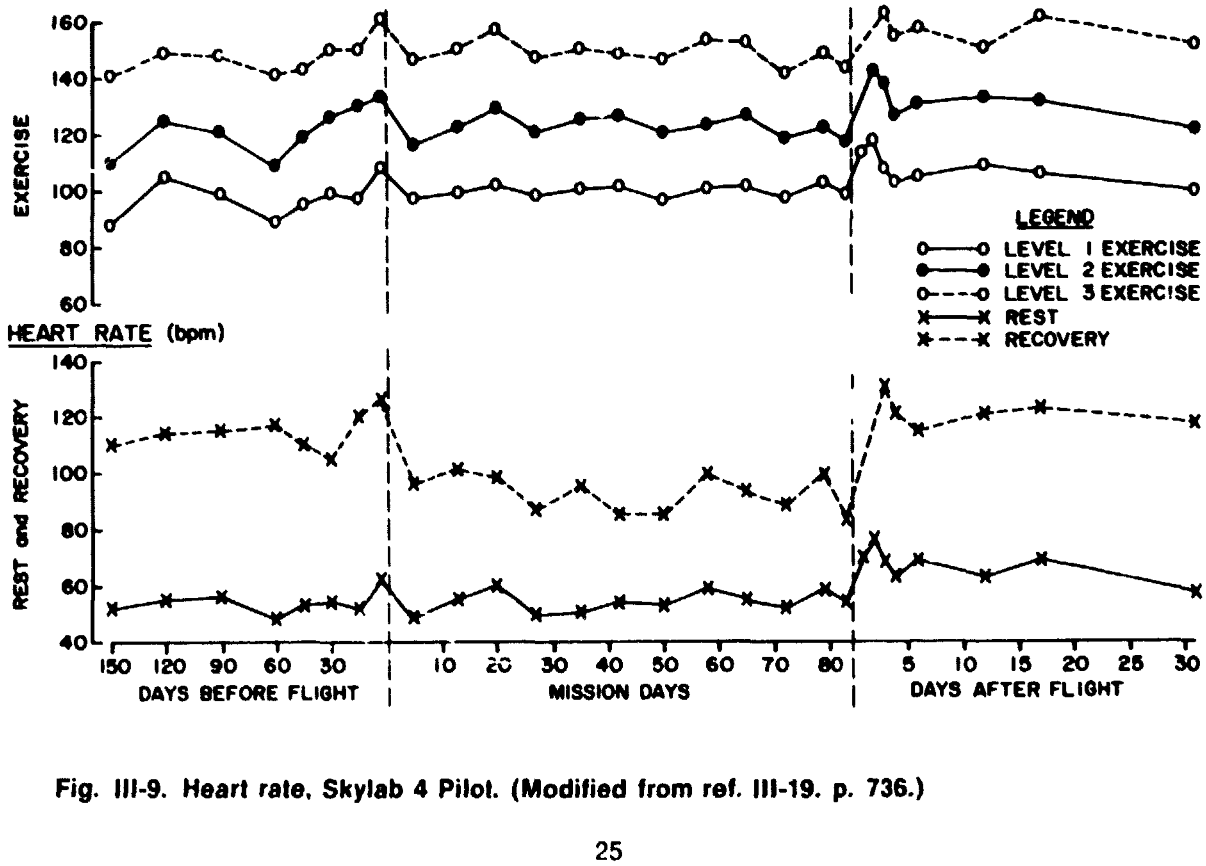

Fig. III-9. Heart rate, Skylab 4 Pilot. (Modified from ref. III-19. p. 736.)

that although the bicycle ergometer was an effective stressor of the cardiovascular system, additional provisions would have to be made on long-duration missions for maintaining muscular strength in antigravity muscles not exercised by the ergometer.

Mineral and Nitrogen Balance Alterations

The mineral and nitrogen balance studies were important in the Skylab program because

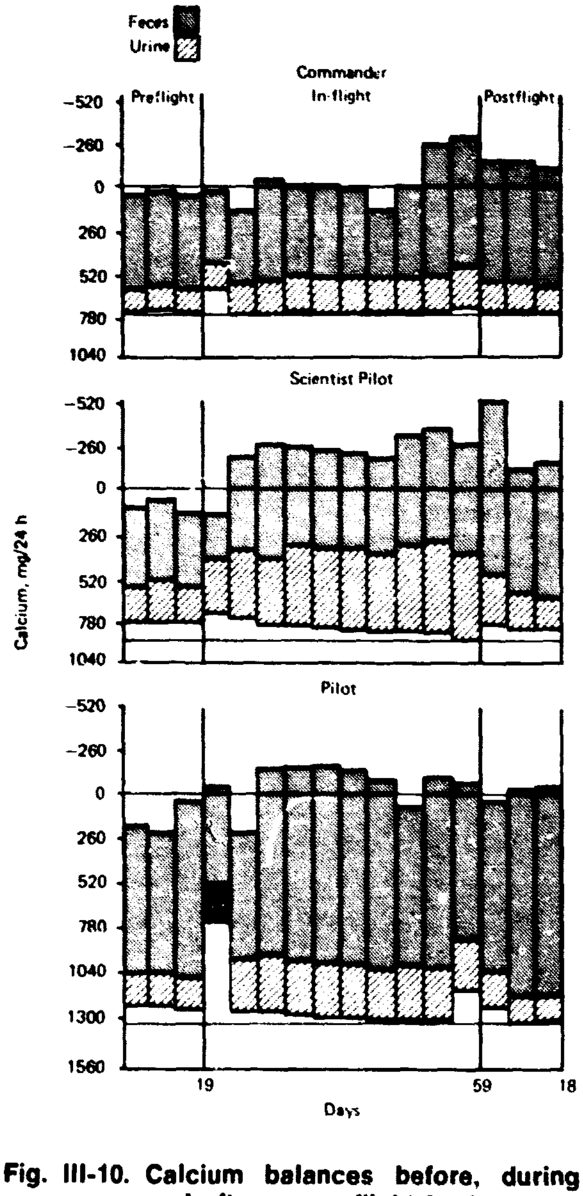

Fig. III-10. Calcium balances before, during and after space flight in the astronauts of the 59-day flight. (From ref. III-18, p. 362.)

of the consistent loss of calcium and nitrogen in earlier space flights. These studies are difficult to conduct under optimal laboratory conditions since they require not only complete control of the dietary intake but also intensive monitoring of urine and blood. Complete fecal and urine collections were required before, during, and following the flight. With the diet controlled, the urinary creatinine excretion, calcium excretion and calcium, magnesium, phosphorus, nitrogen, and potassium balances could be studied.

In the Skylab missions, increases in urinary calcium were observed inflight and the calcium balance data, as exemplified in figure III-10, showed that crewmembers continued to lose calcium during weightlessness. The scientist-pilot (SPT) on the 59-day mission, in particular, showed a marked negative calcium balance. Urinary hydroxyproline, which is indicative of skeletal turnover and breakdown, increased inflight. The mean increase was 33 percent in the first two flights. When coupled with the negative calcium balance and increased calcium excretion, the data clearly show that bone calcium is being lost during weightlessness. This loss occurred even though the astronauts exercised regularly (ref. III-18).

A question exists as to the particular bones from which calcium is lost. Although the study does not answer this question precisely, it does give some insight. Radiographic estimates of bone mineral loss were made of the distal right radius and ulna (forearm) and the central left calcaneus (heel bone). No losses in the radius and ulna were observed. Mineral losses in the calcaneus were not evident in the shorter 28-day mission, but losses were evident in the SPT of the 59-day mission and in the SPT and pilot (PLT) of the 84-day mission. The magnitude of the mineral losses was similar to those observed in bed-rest studies of the same duration (ref. III-20).

This investigation raises the question as to why no mineral loss was observed in the radius and ulna. The question cannot be resolved from the current data. The arms do not serve a truly antigravity function in that normally they do not support the body weight. In this case, the situation was complicated by the fact that the arms were used more than the legs for moving about the spacecraft. The stimulation of unaccustomed arm use may have prevented calcium loss from the radius and ulna, but there is no evidence to either support or refute this hypothesis. Certainly it can be said that the shift from 1*g* to zero *g* was more detrimental to the legs than to the arms.

Table III-2.—*Skylab crewmen bone mineral data postflight percent of baseline*[1]

Mission duration	Crewman	Left calcaneus	Right radius	Right ulna
28 days	CDR	+0.5	−0.5	−0.9
	SPT	−0.9	+1.4	+1.9
	PLT	+2.7	+0.2	+3.1
59 days	CDR	+2.3	−1.4	+0.4
	SPT	−7.4	+0.2	−1.6
	PLT	+1.4	−1 6	−0.4
84 days	CDR	+0.7	−1.1	−1.7
	SPT	−4.5	+1.0	0.0
	PLT	−7.9	−0.6	+1.4

[1] Postflight for 28-day and 59-day mission refers to recovery day, for the 84-day mission it was one day postflight. The value shown in the table is the postflight percent of the mean baseline established preflight.

Source: adapted from reference III-20, p. 397.

The question of mineral loss from the bones is a critical one, and there is a need to identify the bones that are losing minerals. Are vertebrae involved? If the bones become too weak from prolonged space flight, serious injury could result. Some individuals clearly lose calcium faster than others (see the data for the SPT of the second manned mission and the PLT of the third manned mission shown in table III-2). This matter requires a great deal more study. The effect of specific exercises on the mineral retention of bone has not been adequately investigated.

It is known that exercise involving additional load under 1*g* conditions increases both the density and the strength of bones (ref. III-21). Apparently specific exercises could be designed to serve a preventive role. The exercise regimens used in space to date, with the possible exception of walking or running on the Thornton treadmill, would hardly be expected to stimulate bone much because the loads have been relatively low. Exercise should not be ruled out as a potential preventive measure on the basis of the Skylab experience. Unless preventive measures are found, however, the calcium rate loss of 0.3 to 0.4 percent per month observed in Skylab could be a problem (ref. III-18). Project this rate of loss over a 3-year span and the bone loss would be excessive.

The average 24-hour urinary creatinine excretion was not changed under weightless conditions in the first two manned missions (28 and 59 days). Creatinine excretion is thought of as a function of the fat-free body mass (ref. III-22) with 1 gm of excreted creatinine corresponding to 17.9 kg (39.5 lb) of lean body mass (ref. III-23). The nitrogen balance results showed that there was a pronounced increase in urinary nitrogen excretion, while fecal nitrogen remained virtually unchanged. The mean shift in nitrogen balance for the crews of the first two manned missions from preflight to flight was approximately 4.0 gm/day (ref. III-18). The increased loss of nitrogen and phosphorus reflected substantial loss in muscle tissue. This coincides with the loss in leg vol-

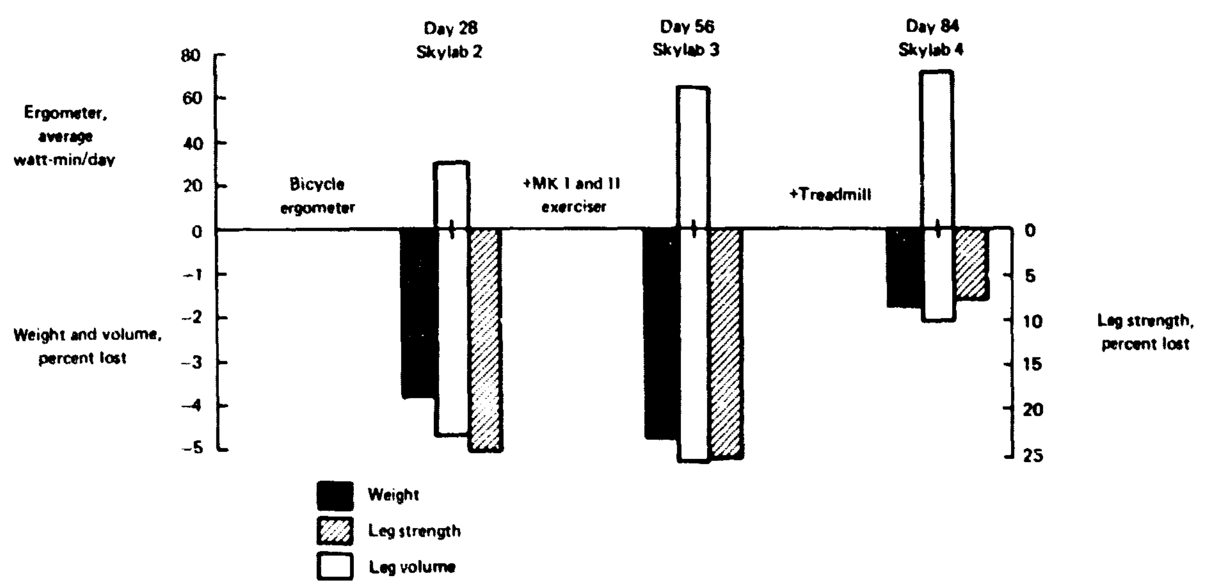

Fig. III-11. Exercise related quantities on Skylab missions. (From ref. III-24, p. 415.)

umes (refs. III-12 and III-13). The nitrogen balance results were not consistent with the creatinine excretion findings. There appears to be little question of loss in leg volumes, however, and the increased excretion of nitrogen and phosphorus is similar to that found in bedrest studies (ref. III-18). The data from the 84-day mission support the position that increased exercise helps to prevent the usual nitrogen loss observed in space. The loss in leg volumes was least on this mission (ref. III-13) and also there was a trend toward reduced nitrogen loss.

Exercise Regimens During Flight

A rapid disuse atrophy of the antigravity weight-bearing muscle groups appears to occur in the zero-*g* environment unless suitable exercise is provided as a preventive measure. For the first manned mission of 28 days, a bicycle ergometer and an isometric device were used for exercise. The losses of strength and of muscle mass, especially in the legs, were of sufficient magnitude that additional exercise times and programs were included in the second manned mission of 59 days. Two modifications of the Mini Gym (MKI and MKII) were made to provide additional exercises for the arms, trunk, and legs. The ergometer work was approximately doubled from 31.3 to 65.0 watt-min/kg.[1] This crew stayed in space over twice as long and, as indicated in figures III-11 and III-12, returned in essentially the same condition. However, relatively large decreases were observed.

For the third manned mission of 84 days, the crew worked on the bicycle slightly more (71 watt-min/kg), used the MKI and MKII exercisers, and in addition typically worked 10 minutes per day walking, jumping, or jogging on the treadmill shown in figure III-13. By angling the bungees, the equivalent of a slippery hill is created. High loads were placed on the calf muscles in particular. The device could not be used for aerobic work as fatigue was rapid (ref. III-24; this reference describes specific exercise programs and related quantitative data).

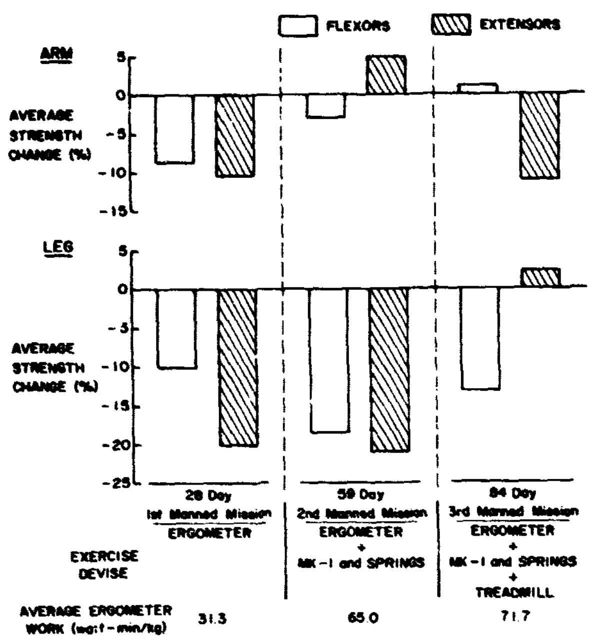

Fig. III-12. Average strength changes. (Modified from ref. III-24, p. 413.)

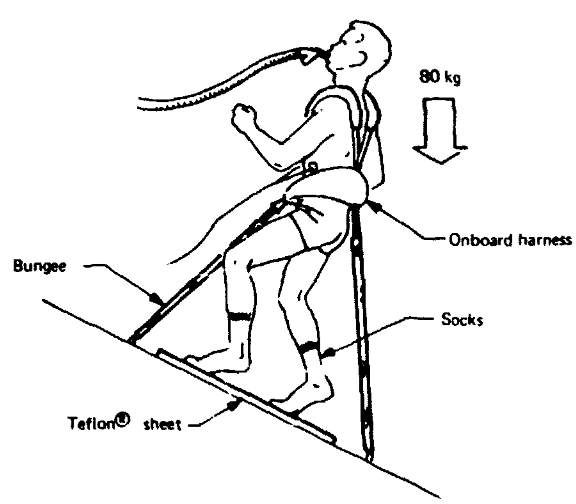

Fig. III-13. Treadmill arrangement. (From ref. III-24, p. 411.)

Responses to the Exercise Regimens

As shown in figure III-1 the crew of the third manned mission of 84 days returned in surprisingly good condition. There was marked improvement in weight, leg strength, and leg

[1] Watt-min/kg values indicate the amount of work accomplished per unit of body weight. For example, if a 70 kg man worked at a load of 150 watts for 20 min, 3000 watts of work would have been done (150 watts per min × 20 min). In watt-min/kg the value would be 42.9 (3000 watt-min ÷ 70 kg). In English units this would be 862 ft-lb/lb. (1 watt= 44.24 ft-lb/min; 1 kg.=2.2 lb.)

volume. This crew's leg volumes returned to preflight levels 11 days postflight. The reductions in loss of muscle strength and bulk were attributed to the exercise program and the additional exercise time. The MKI and MKII (Mini Gym devices) improved arm performance of the second and third manned missions, and the treadmill sharply reduced the loss of leg strength and mass in the third mission (ref. III-24). Apparently the basic ideas for reasonable preventive exercise regimens were derived in the Skylab experiments. If it can be shown that calcium is retained and bone strength is maintained in a similar manner, the exercise base for prolonged stay in a weightless environment would be adequate.

Changes in the Achilles tendon reflex time were observed in the first few days following the flight. During space flight there is little use of the legs as compared with that required in a normal 1*g* environment where the body weight must be supported. The sensory receptors of the legs, which reflect stretch and tension, are used less and the signal intensities are less due to the lack of weight. The sensory system appears to adapt quite easily to the weightless condition. With return to a 1*g* environment, initially there is an oversensitivity of the neuromuscular system. This may represent a brief period of hyperactivity of the proprioceptors in the servo feedback mechanism. A rapid readjustment to the less sensitive preflight levels follows (ref. III-25).

Time and Motion Studies

Time and motion studies were conducted for a number of inflight tasks (e.g., conduct of the LBNP testing, the experiment on metabolic activity, setting up the earth terrain camera, extravehicular activity (EVA), suit donning and doffing). Tasks were photographed at 6 frames/sec and analyzed on a specialized film viewer that controlled the rate of presentation and alignment. The crew responses were quite similar across all missions. Initially in the change from 1*g* to zero *g*, the performance time for the majority of work tasks increased. However, the performance adaptation was very rapid. By the end of the second trial at 7–11 days into the flight, about 50 percent of the times for all task elements were comparable to the last preflight measure. No evidence was found of performance deterioration attributable to long-duration exposure to zero *g* in Skylab (ref. III-26). This experiment clearly shows that adjustment to zero *g* requires some motor learning but that the learning takes place at a rapid rate.

One of the most interesting tasks was the donning of the space suit for EVA. The suits were made to fit each crewmember on the ground. In zero *g* the astronauts became taller, thus the suits were much harder to zip up. Further, it is difficult to apply force in zero *g*. A firm base is required from which force can be applied. Learning how to accomplish the simplest tasks required adjustments. Various methods of utilizing different types of restraints were studied (ref. III-26).

Vestibular Function Tests

Three factors were involved in the experiment on vestibular function: susceptibility to motion sickness, threshold for perception of angular acceleration, and the perceived direction of internal and external space. Interactions of sensory input to the vestibular apparatus and central nervous system activity are involved with the confounding effects provided by the weightless environment. Only cursory treatment can be given here, and only a few of the findings have been selected for the reader's interest.

In all rotation experiments inflight, the crews were virtually symptom free. They demonstrated a lower susceptibility to motion sickness aloft than in pre- or postflight tests. Under operational conditions, however, seven of the nine crewmembers experienced motion sickness. The drug combinations (*l*-scopolamine and *d*-amphetamine, and promethazine hydrochloride and ephedrine sulfate) were effective in the prevention and treatment of motion sickness. As yet, there is a lack of laboratory tests that accurately predict motion sickness in weightlessness. No inhibitory influences aloft were apparent that would reduce the effective sensitivity of the semicircular canals to angular acceleration (ref. III-27).

Upon return to 1*g* conditions, postflight decrements in postural equilibrium were observed. In an eyes-open test on a rail or balance beam, decrements were noted in only three astronauts. However, in the eyes-closed condition of the same test, a considerable decrease was observed postflight for all of them. After a rapid rate of improvement during the first postflight day, the recovery was slow until the return to preflight baselines was complete at about 2 weeks (ref. III-28).

All the astronauts were able to walk immediately after leaving the Command Module, but they did so with considerable difficulty. They tended to use a wide-stanced shuffling gait with the upper torso bent slightly forward. With each passing hour they regained proficiency in their ability to walk about unaided. By the second day there were few noticeable signs of instability. All astronauts reported following return that rapid head movements produced a sensation of mild vertigo (ref. III-28). They also reported a strange postflight sensation in the inner ear, like a tumbling sensation, but they did not feel as if they were tumbling in any certain direction. It apparently was an awareness of a sensory input that had not been experienced for some time (ref. III-29).

Biochemical Alterations

The biochemical data collected in the Skylab program present a wealth of information of great interest to anyone interested in stress physiology. The wide range of data includes routine blood measures used in clinical medicine as research-type endocrine analyses used to investigate the metabolic/endocrine responses to weightlessness. Changes have been reported, but the indepth interrelationships of the many parameters will require continued analysis.

A portion of the abstract presented by the investigators, Leach and Rambaut, merits quotation for the perspective it provides:

> . . . the measured changes are consistent with the hypothesis that a relative increase in thoracic blood volume upon transition to the zero-gravity environment is interpreted as a true intravascular volume expansion resulting in a fluid and electrolyte loss. These losses, in association with other factors, ultimately result in a reduced intravascular volume leading to increased renin and secondary aldosteronism. Once these compensatory mechanisms are effective in reestablishing fluid balance the crewmen are essentially adapted to the null-gravity environment. Although the physiologic cost of this adaptation is reflected by the electrolyte deficit and perhaps by other factors, it is assumed that the compensated state is adequate for the demands of the environment; however, this new homeostatic set is not believed to be without physiological cost and, without proper precautions, could reduce the functional reserves of the crewmembers. The general catabolic state found in returning space flight crewmen has been documented with negative calcium, phosphorus, sodium, potassium and nitrogen balances. Future research efforts will be directed toward the clarification of the basis for these physiological changes and the procedures required to prevent or lessen these changes on extended space missions. (Ref. III-30.)

The Skylab missions have made it clear that man can adapt to and function in the weightless environment for extended periods of time. No physiological changes were noted that would absolutely preclude longer duration space flights. The calcium loss results are inconclusive, and additional research is required to identify and understand the underlying mechanisms. Daily inflight personal exercise regimens coupled with appropriate dietary intake, sleep, and work and recreation periods are essential for maintaining crew health and well-being. When the research base has been developed further, additional preventive or remedial measures likely will be developed for mission durations in excess of 9 months (ref. III-31).

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Chapter IV
Significance To Health, Physical Education, and Recreation

It may be presumptuous to attempt to identify the contributions of Skylab and Skylab-related programs that are significant to health, physical education and recreation (HPR). Skylab is only one stage in the systematic process leading to continuing space exploration but is the culmination of space research and development up through Apollo. Continued investigations based upon current knowledge will follow. The findings and developments at this point are so voluminous that selections are necessary. Many of the contributions are of immediate significance. With others, *the state of the art has been advanced so far that the significance may not become evident for several years or even decades.*

There is also ultra-long-range significance in time intervals that are measured in terms of centuries. The identification of significant findings implies some prediction of the future. Prediction, however, is imperfect as reflected by the fact that in our history many of the truly important happenings and discoveries have not been recognized in their time. The findings selected as significant, therefore, reflect the professional views of the authors. The selections were made with full recognition of these limitations.

Health, physical education and recreation all are professional fields in that their research bases are drawn from a wide range of scientific disciplines. The fields are not discrete or well defined, but rather overlap each other. Therefore, *the findings and developments deemed to be significant are presented as collectively relevant to HPR. Further classification rests with the readers in accordance with their specific interests.*

The fields of HPR cannot be viewed in isolation as one assesses the significance of Skylab and Skylab-related work. What is good for mankind and education is good for HPR. In order to place the contributions of Skylab and the Skylab related programs in perspective, the contributions to mankind in general will be presented first. The more detailed contributions to HPR follow.

Significance to Mankind

Why conquer space? Today there are answers to this question: (a) Scientific knowledge from space about the Earth, the Sun, the universe, and about humanity is being obtained that could be obtained in no other way; (b) The space program has produced and is continuing to produce more useful new technology per dollar invested than any other organized activity in America today; (c) Space exploration is needed for the inspiration of modern man; (d) The space program furthers international cooperation and favors global peace (ref. IV-1).

The primary significance of the space program to mankind may be related to ultimate survival on this planet. Humanity faces overpopulation, pollution of the environment, and ultimate depletion of present energy sources. The problems are interrelated. With more people, more energy is required. To obtain this energy, the environment is polluted and our limited natural resources are further reduced. We have less than a century to solve this serious problem (ref. IV-2). In chapter I we expressed confidence that we will meet the challenge, for without energy our technological-scientific culture cannot be preserved. If this culture collapses, a large percentage of our population will die. A resolution must be found within the next 50 to 100 years.

The primary source of energy for Earth, from which all other secondary sources have been derived over millions of years, is the Sun. Glaser has pointed out that energy production in space, converting the energy of the Sun to electrical energy and beaming it back to Earth via microwave, currently is within the state of the art (ref. IV-3). This solution makes sense in that the feared thermal pollution would be dumped into the cosmic heat sink outside our atmosphere. At this time, the potential for helping solve the energy problem by the use of space is especially important to mankind.

The results of space research already have permeated our entire culture. Most of us do not realize the extent, depth, or significance of these contributions even though as laymen we have been keenly interested in the space program. It has been estimated that space research has stimulated the development and use of over 4,000 new products. This figure probably is conservative as NASA's Marshall Space Flight Center alone documented over 10,000 innovations in its ninth year of existence (ref. IV-4). One of the major contributions is miniature electronic instrumentation. Small pocket calculators and large-capacity, briefcase-sized computers for multiple purposes are well-recognized realities. Miniature sensors and telemetry units for monitoring biophysical changes also are well recognized. Devices have been developed for monitoring heartrate, electrocardiogram, blood pressure, respiration rate, temperature, blood flow, and many other physiological variables. The development of solid-state integrated circuitry to meet the space requirements of reliability, small size, light weight, and low-energy needs has served to revolutionize the electronics industry. As a result, not only are units smaller and better but also cost less.

Other products are pinpoint ball bearings that made possible the development of ultrahigh-speed dental drills; mercury-powered batteries such as those used in electric watches; rechargeable nickel-cadmium batteries that are used in electric razors, flashlights, and power tools; solid-state controls now used in some automobiles; nonchattering solenoid valves; the plastic designed for nose cones, now used for dishes and utensils that can tolerate large rapid temperature changes; fluxless aluminum solder; polychromic material that darkens when exposed to sunlight and now is used in self-accommodating sunglasses and windows; laser modifications; X-ray equipment with minimal radiation exposure; infrared food blanching; improved paints; ultra-thin aluminum foil; Pacifix, the rescue system that sends a radio signal for locating downed aircraft, now mandatory on all aircraft; accurate portable clocks; and many more (ref. IV-5).

INTELSAT (International Telecommunications Satellite Consortium) provides telephone and other communications between ground stations in different countries. Not only has the use grown, but also the costs have been reduced markedly even in a period of high inflation. Half-circuit costs from New York to Europe have dropped from $10,000 to $4,625, and San Francisco to Honolulu circuit costs have been reduced from $17,000 to $6,700 (ref. IV-6).

Educational television, although of recognized value, has had difficulty operating profitably in this country. A satellite system, using the line-of-sight path of the high-frequency waves, permits inexpensive extension of coverage. Although such a system is difficult to resolve in densely populated areas of this country, due to controversy over origination and control, it has major applications for the more sparsely populated areas of the United States and for underdeveloped countries with large populations and few trained teachers. The application is being tested in some 20 Government-sponsored research projects of the Department of Health, Education, and Welfare and the Department of Transportation. India, under contract with NASA, completed a successful demonstration of uses of the system for educational purposes (refs. IV-7 and IV-8).

Communications applications are far from complete. Medical and health information networks, information retrieval systems, time-shared data processing, consumer-data service, and other applications are feasible at this time (refs. IV-7 and IV-8).

Satellite applications for the navigation and control of moving vehicles are only partially developed. With three stationary satellites, or three points from a moving satellite, a ship at sea can be located to within hundreds of feet. The transit navigation system developed for the Navy utilizes this approach. To locate an aircraft requires four satellites because of the additional variable of altitude (ref. IV-9). Aircraft navigation on intercontinental flights would be more reliable using this approach. The satellite system also could allow precise aircraft control since, via computer, exact locations in three dimensions would be known and desirable courses could be determined.

Many Earth observations have been made by satellites and extended by Skylab. One of the meteorological applications is well known via television weather news programs that routinely present satellite pictures, particularly monitoring the paths of major storms. However, many other important but less-well-known applications have been made: water resources inventories; synoptic views of the Earth of special interest to geologists seeking mineral and energy resources; assessments of land use, including areas of high food production potential; multispectral techniques to distinguish healthy from diseased crops; procedures for more economical and more accurate mapmaking; observations of changes in the oceans, including thermal mapping and determinations of the location and biological productivity of fish; and evaluations of the extent and sources of pollution (refs. IV-7 and IV-8).

The manufacture of products in space offers one of the greatest potentials for the application of space technology. Certain biological materials, castings, alloys, and electronic crystals that are affected by gravity may be produced in the zero-*g* conditions of space. The potential for alloys and large semiconductor crystals was demonstrated on Skylab. On the basis of the crystals alone, continued development of more complex integrated electronic circuitry is expected (ref. IV-10). A new wave of beneficial products should result from the projected Space Shuttle missions.

International relations have been fostered by the space program. INTELSAT, for example, is a consortium of 102 nations. India was involved in the educational television experiments. The European Space Agency is collaborating with NASA on the Shuttle missions. The objective is to be of benefit to all mankind, and the openness with which NASA has operated has served to generate and foster international cooperation. The space program has been one of our best good will ambassadors abroad. It has demonstrated our capabilities and our cooperativeness and has enhanced U.S. prestige throughout the world (ref. IV-11).

The movement into space has triggered a reexamination of mankind's role in the universe and of information from antiquity in light of space-age evidence. The mere fact that von Daniken's and Sendy's books were best sellers reflects interest (refs. IV–12 and IV–13). Intriguing and controversial questions have been posed as to whether extraterrestrial visitors were present on Earth in antiquity. The significance to mankind is that re-examination of our heritage is taking place and this should result in further growth.

The space program with its systematic establishment of a research base and the needed hardware, has served to stimulate and excite the scientific community. The rigid restraints of reliability, low weight, and high-*g*-tolerance levels (to name but a few) necessarily imposed by the space program provided a scientific environment that demanded new solutions and new technological developments. This challenge was and is exciting to scientists regardless of whether or not they are directly involved in space research.

The astronauts as a group have served as excellent models for the youth of our nation. Intelligent, courageous, exceptionally well educated, articulate and personable young men, they were selected carefully and indeed became a credit to their country. Their charisma has helped them as ideals for young people. Their performance and maintenance of a wholesome image has been exemplary.

The advancement in communication and computer technology, both space related, have been only partially transferred to use in education at this time. A computer network is possible that could provide any student even in the smallest college with access to the great libraries of the nation (ref. IV–7). It is uneconomical and rather tragic that students and scholars spend the major portion of their time searching for desired information, a tedious task that a computer can do both faster and cheaper. The currently available technology would allow a question to be posed to a computer terminal and the signal to be transmitted via satellite to a central computer system (ref. IV–7). The answer could be returned to the computer terminal for printout in a matter of minutes. This is all possible today, but it requires organization, development and funding.

The potential of satellite use for beaming programs to remote areas has been proved. If the legal and political problems can also be solved (ref. IV–15) and useful "software" developed, major educational contributions apparently could be made to remote areas and to the less developed countries. However, the potential use of educational television has much broader implications for all segments of the educational community in terms of both economy and quality. Although television cannot replace the teacher, many aspects of teaching can be handled as well or better by television provided that the necessary programs are developed and made available.

In the few years since President Kennedy presented to Congress a program aimed at putting man on the Moon before 1970, the U.S. space program has made exceptional fundamental contributions to knowledge. This knowledge has served to provide new perspectives across education from kindergarten through graduate school. The extent and depth of the contributions is staggering: applications to mapping, navigation, communication, astronomy, ecology, physics, meteorology, physiology, medicine, geology, oceanography, engineering, agriculture, information science, and various types of technology. Some indication of the volume of these contributions is evident from selected references (refs. IV–1, IV–8, IV–11, IV–16 through IV–22).

Significance to Health, Physical Education, and Recreation

The significance of Skylab and Skylab-related programs to HPR is quite broad. Attitudes toward change, new products and delivery systems, assessment of land use, progress in research instrumentation, and the extensive contribution to the bodies of knowledge upon which our fields rest are presented in this section.

Attitude Toward Change. In good teaching it is essential to prepare one's students for the future insofar as possible. The Space Shuttle will become operational in the early 1980's. Clearly people will go into space progressively more as the costs of payloads decrease, to utilize space for its unique characteristics. Therefore, it is important that we teach about space, how it can be utilized, the effects of weightlessness, and the techniques to avoid physical deterioration. Changes are rapid in our current society. New technologies and new data are rendering obsolete many of the concepts and techniques currently being taught. No longer is it possible to teach materials and concepts that can be expected to be used throughout an individual's professional career.

Change has forced revisions in approaches to teaching. Rather than facts and skills alone being taught, more attention is being given to the techniques of reading and interpreting research and the bases for making judgments concerning implications and applications of new information. Students must be taught how to cope with change by keeping abreast of new findings and by continued study after leaving school. Without a healthy attitude toward meeting the challenge of change and coping with it, personal insecurities and fixed minds develop. Static concepts become dogma retarding the advancement of a culture. Our young people of today, as a group, are bright and well prepared; but they are growing up in a world that is insecure with its growing pains. It is important that our students become leaders in evaluating and reacting individually and independently in the face of change.

For example, before the turn of the century Morpurgo (ref. IV–23) observed hypertrophy of muscle fibers as a result of work. He discounted the possibility that hyperplasia (an increase in the number of fibers) might take place. Based primarily on this information, most students have been taught that the individual, as a result of heredity, has a given number of muscle fibers. Consequently, exercise programs commonly are believed only to modify existing fibers. For years this concept has been taken into consideration in developing exercise programs, and it has become fairly fixed as a scientific fact. But, what if new evidence showed that hyperplasia may occur? Depending on the nature of the evidence, it could force a shakeup in programs and the redevelopment of curricula. New data, in fact, have shown that hyperplasia may occur as the result of training (refs. IV–24 through IV–26). New interpretation is necessary. Are the data sufficiently conclusive to warrant redevelopment of curricula? Probably not at this time, but further research may indicate that revisions are necessary. An attitude toward change based on systematic research-to-practice models is indicated.

The results of aviation psychology research show that the greatest successes in aviation are achieved by those individuals who experience positive emotions from the very process of overcoming difficulties (ref. IV–27). Such mental adaptability to change likely must be experienced to be understood. Sports participation provides an excellent laboratory for strategy and adaptability to change in adverse situations. The well-known statement of Wellington, that the English warleaders were developed on the playing fields of Eton, has merit. In a competitive sports situation at any level, decisions regarding strategy must be made, modified, and executed. Responsibility for decisions is assumed in an emotionally charged environment where an excessive number of recommendations or commands may be provided by teammates or the coach. Training that includes probable emergency situations requiring decisions is important; it promotes confidence and serves as a prophylaxis of neuroemotional stress. Prepared decisions with additional modifications to be made in light of changing conditions promotes confidence in decisionmaking. The similarities between the formal training of astronauts in decisionmaking (ref. IV–27) and the pragmatic training of sportsmen are very close. In light of our rapidly changing society, HPR curricula probably should include more breadth of training in the decisionmaking process. All students would benefit from such experiences.

Responses to Multiple Stressors. The alterations produced in the body by multiple space flight factors (stressors) is one of the key problems of space biology and medicine (ref. IV–28). The research summarized by Antipov (ref. IV–28) and the SMEAT (ref. IV–20) and Skylab (ref. IV–19) data are highly relevant to HPR. The unique space environment imposes multiple stressors simultaneously. Some are immediate and act over relatively short periods (e.g., vibration, acceleration, noise, heat) while others act over longer periods (e.g., weightlessness, increased radiation, limited space, reduced motor activity, environmental gases, emotional stress) (refs. IV–28 and IV–29).

The term "stress" was introduced by Selye (ref. IV–30) to describe a nonspecific adaptive reaction of the organism to persistent stimuli in the environment. The stimuli (stressors) could be chemical, physical, biological, or psychological. A typical hormonal response involving the pituitary-adrenal axis was elicited. This has been called the general adaptation syndrome (GAS) and is evident in three stages: alarm, resistance, and exhaustion. The term stress, however, is now being used more broadly to include specific adaptations to specific stressors or any mobilization of the organism's resources when factors acting on the organism threaten working capacity or survival (ref. IV–27).

The GAS concept has been most useful in HPR and provides a basis for understanding the training phenomenon. Initial losses that occur early in training regimens such as decrements in performance capacity (ref. IV–31), decreases in the red cell count (ref. IV–32), and the common early weight gain in weight-loss programs parallel the alarm reaction. The resistance or adaptation phase is readily recognized in training studies, and the level of adaptation attained is related to the intensity and duration of the training regimen. The exhaustion phase is not seen in controlled human studies but is observed in animal studies when stressing agents are applied continuously for long periods of time.

It is interesting to note that patterns of adaptation are acquired. For example, assume that two groups of animals are studied: a control group and an experimental group. In this investigation, the control animals will be maintained under standard laboratory conditions, while the experimental animals are preconditioned to a cold environment by several weeks of exposure to progressive decreases in temperature. A stress response will be elicited in the experimental animals; but, if the exposure to cold is sufficiently gradual, these animals will pass through the alarm stage and into the resistance or adaptation stage.

Now assume that, following the conditioning period, both groups of animals are housed at normal temperatures for several months before being subjected suddenly to extreme cold (−10°F). The animals in the control group will die quickly during a severe alarm reaction, whereas the experimental animals that have acquired a specific resistance will survive for some time until finally the stage of exhaustion sets in (ref. IV–33). There is little question that such specific resistances are developed. Animals that have been stressed by early exercise regimens respond favorably to subsequent exercise programs (ref. IV–34).

The phenomenon of "cross resistance" has gained considerable attention in recent years. In one study, different experimental groups were stressed with exercise, restraint, and a noxious substance injected under the skin, while a control group was maintained under standard laboratory conditions. Following the conditioning period, all animals were subjected to a heavy stressor of a different type for several days prior to sacrifice. The animals' hearts were sectioned, stained, and examined for heart pathology. The control animals that had received no conditioning showed considerable pathology, whereas the hearts of the animals that had been preconditioned were essentially normal (ref. IV–35). The fact that the conditioned animals did not show pathology reflects a cross resistance.

Such information, if adequately supported by additional research, could be highly important to HPR. It would make good sense in our mechanized culture, which continually requires less and less physical work and which is changing so rapidly that future stresses cannot be predicted, to develop programs so that cross resistance can be obtained during the school years. Indeed, Dubos has recommended that our youth obtain such cross resistances through vigorous physical activity (ref. IV–36).

Current information suggests that the acquisition of cross resistance is only partially predictable. If animals that have been preconditioned by a moderate exercise program are subjected to a regimen of mild but annoying electrical shocks, the prior exercise has the protective effect of minimizing the anxiety-induced heart damage that usually accompanies a period of chronic shock exposure (ref. IV–37). Cross resistance is evident. On the other hand, if there is no prior exercise program but exercise and electrical shock regimens are initiated simultaneously as double stressors, an increased incidence of heart pathology is observed (ref. IV–37). In this case, cross resistance is not expected. In fact, the phenomenon of an increased stress response to concurrent double stressors often is called "cross sensitization."

It should be recognized that cross resistance has practical limitations. For example, prior exercise cannot alleviate the effects of some very debilitating stressors. Resistance to a lethal dose of irradiation is not altered by a program of previous exercise. Evidence is not available concerning the effects of exercise on sublethal doses of irradiation (ref. IV–38).

The combined Soviet and U.S. studies (ref. IV–22) and the Skylab resutls (ref. IV–19 and IV–20) have been very useful in extending the knowledge base regarding sequential and simultaneous applications of multiple stressors. The unique needs of the space program required accelerated research in this area. Although the data on cross resistance and cross sensitization are not fully interpretable at this time, much new information has resulted. For example, it is known now that the combined effect of simultaneously imposed stress agents may differ significantly from the effects produced by each factor individually (ref. IV–28). In different types of interactions the stressors may be mutually *additive, synergistic, or antagonistic*. An additive interaction is one in which the effect of a combination is equal to the sum of the individual effects of each of the factors. In a synergistic interaction, the combination of factors will yield a greater effect than the simple sum of the individual effects. The overall effect is less than the sum of the individual effects in an antagonistic interaction (ref. IV–28).

Some of the combined effects of various stressors that are presented by Antipov, et al. (ref. IV–28) provide good examples. With acceleration and hypodynamia (inactivity), acceleration tolerance is decreased. With acceleration and ionizing irradiation, the resistance to acceleration is increased 1 to 6 days following irradiation. Following day 7, the acceleration resistance is decreased markedly. With vibration and heat, a synergistic effect was observed. Heat alone (46.1°C, 20 min) did not cause death in rats, but vibration and acceleration (5–800 Hz, 17.5 *g*) caused the death of 7.5 percent. When rats were exposed to both heat and vibration, the mortality rate rose to 65 percent. On the other hand, prior vibration exposure reduced the effects of ionizing irradiation (if vibration stress is applied following irradiation, the effect becomes synergistic). Order, time sequence, number of stressors, and types of stressors all appear to be important in the ultimate response.

No complete model is available from which to work at this time. Selye's general models (refs. IV–30, IV–33, and IV–35) are helpful but are not adequate. Further research is needed. The successful solution to the problem of the combined influence of multiple stressors is important not only to preflight training and postflight rehabilitation of astronauts, but also to preventive medicine, patient care, and the development of school health and physical education curricula. The true values of the extensive endocrine, biochemical, nutritional, and physiological data obtained from SMEAT and Skylab in understanding multiple stress effects are yet to be realized. If Oscai is right that exercise in early life inhibits the later development of fat cells (ref. IV–39), if muscle fibers can be modified as is suggested by the early hyperplasia data (refs. IV–25 and IV–26), and if appropriate stressors can be identified to safely produce cross resistance in children, then new and highly important directions in curriculum development for HPR are indicated.

Astronaut Models for Young People. The astronauts were identified as exemplary models for young people. However, there is more to it than that. There are lessons for students and teachers alike. Repeatedly, some of the astronauts commented on their reactions to space. They expressed feelings of wonderment, of personal smallness, of love for family and for fellowman. "Something" happened to them. Certainly upon their return they were men apart. Was it something spiritual that resulted in an extra appreciation for mankind and life? The possibility cannot be discounted.

Possibly, in their preparations and during the actual space flights, the astronauts faced the most rigorous tests of their lives and found that they measured up to the challenge. The old saying, "From the hottest fire comes the strongest steel," may be applicable. Satisfaction comes from "measuring up." There is a lesson here. The worthwhile things in life still require intensive effort. It behooves each individual to set high goals and to work toward them. A cause outside one's self, which will aid others, is especially healthy.

The deceptively difficult professional fields of HPR need such dedication. Attitude, motivation, and self-respect are not only essential elements for a dynamic society but for a viable profession as well. Without question, major turnarounds are in order for large segments of HPR. By "measuring up," by transmitting our dedication and love for fellowman through our professional fields, we can and should be potent forces in the maintenance of all that is good in our society.

Ecology and Land Use. Remote sensing of the Earth from space, as undertaken in the Earth Resources Technology Satellite–1 programs (now called Landsat) (ref. IV–8), and extended in Skylab (ref. IV–40) is of primary importance in establishing ecological relationships to health, leisure. and recreation. The implications of remote sensing to leisure and recreation have been discussed in detail by Dunn (refs. IV–41 through IV–44). She has reviewed both direct and indirect applications. The direct applications mentioned suggest that remote sensing can be used to (a) monitor the changes in usage or function of open space and recreation facilities; (b) observe the environmental impact of recreation use on public and private lands; (c) locate pollutants and their sources both inside and outside of recreation resources; (d) detect diseases in biological systems; and (e) track free-living animals in their natural environment (e.g., bear, elk, whales, and elephants).

Indirect applications mentioned suggest that remote sensing can be used to (a) identify and observe natural geophysical, hydrological, biological, and climatological systems that affect recreation resources and their users; (b) monitor man-made transportation, communication, commercial, industrial, agricultural, and residential systems that affect recreation; and (c) acquire large amounts of information never available previously. In Dunn's view (ref. IV–41), the most important potential benefits to leisure research and recreation planning appear to be in this indirect sphere. New responsibility and accountability will be placed upon planners for the long-term effects of their actions. Remote sensing already appears to offer a means of achieving viable alternatives to the present unchecked rates of change in the social and physical environments. The work to date is encouraging regarding the potential of remote sensing in recreation planning. Greater communication is needed now between technology and the research and planning process (ref. IV–41).

Remote sensing provides a tool of particular importance to the ecology of our planet. Health-related implications are obvious. The developments initiated in the unmanned satellite programs (ref. IV–8) and extended in Skylab (ref. IV–40) have added an essential tool for continued data input. The growing population with its greater expectations for a higher standard of living consumes more resources, occupies more space, produces more waste, and puts more pressure on an already fragile earth environment (ref. IV–7). Change can be monitored systematically, and the research base for intelligent and responsible decisionmaking can be supplemented. Trends will become evident before they are irreversible or unmanageable.

Since the scope of remote sensing is broad and the types of sensors available are technical (i.e., microwaves, infrared, etc.), discussion of remote sensing must be limited. Water pollution, thermal pollution, air pollution, the relative health of the oceans, and extended effects from one geographic area to another already are being monitored. The significance to health, in particular community health, is evident. These data must be utilized by local, state, national, and international agencies in planning and control. The applications of remote sensing to agriculture, forestry, geography, and meteorology all have further indirect implications for HPR. (Further information may be found in refs. IV–7 and IV–8.) Large amounts of data have been generated over a relatively short period of time. The data must be scrutinized carefully by professionals in HPR and the most relevant results should be brought to bear on the profession immediately.

Bioinstrumentation. The rigid specifications regarding weight and reliability that were placed on instruments for space stimulated the development of microcircuitry. The need for continuous ground monitoring resulted in the design of unique light-weight sensors, transducers, telemetry units, and sophisticated computers with analog-digital interface capability for rapid calculation of large quantities of data. The changing needs of the space program also have served to accelerate the development of instruments for use in health care and research. Infant breathing monitors, X-ray enhancement, pressure transducers for intravascular measurement, improved heart pacemakers, biopotential electrodes, minute muscle accelerometers, radiation dosimeters, dry stained slides, and automatic blood pressure devices are just a few of the many examples.

Developments have continued through Skylab. The ergometer that could be operated in several modes (i.e., set work independent of pedal rates, work dependent upon pedal rate, and work adjusted to heartrate), the teflon treadmill, and the online procedures used to measure and calculate energy metabolism were unique. Another example mentioned earlier is the device used for mass measurement in a weightless environment. This new instrumentation has broadened the scope of research. Continued developments by manufacturers are to be expected. Today, for example, good single-channel telemetry units are available commercially to record exercise electrocardiograms. Low cost, multichannel telemetry transmitters and recorders with plug-in amplifiers or bridges for making various measurements are now within the state of the art.

The Integrated Medical and Behavioral Laboratory Measurement System (IMBLMS), which was developed for health monitoring in space, has applications on Earth. Health care services are inaccessible for many Americans, especially those living in remote areas or in the inner city. Health care services still suffer from a lack of communication and inadequate organization—factors that adversely affect their availability, cost, quality, and efficiency. Costs are high and health personnel are in short supply (ref. IV–45). The IMBLMS, manned by physicians' assistants, is under test. The remotely located field units are supported by a control center located adjacent to a hospital facility. New instrumentation, manned by paramedical personnel and equipped with two-way communications for consultation and emergency purposes, appears to be a viable option as a supplementary health delivery system.

Research on the Effects of Exercise. The research on exercise conducted at Harding College by H. Olree, R. Corbin, and C. Smith provided a basis for determining the exercise regimens and durations used on Skylab. They evaluated various durations of exercise and studied the effects of defined exercise programs using several modalities, including small commercial devices such as the Exer-genie and the Mini-gym. They found that riding a bicycle and running at comparable heartrates produced similar gains in physical fitness variables. Subjects who exercised at a heartrate of 180 beats/min made greater gains in physical fitness than did those exercising at heartrates of 140 or 160 beats/min. Subjects exercising 60 min/day made greater gains than those exercising 20 or 40 min/day at the same workload. Greater gains resulted in subjects who exercised 12 times/week than in those who exercised only 3 or 6 times/week. Subjects who discontinued training slowly deconditioned, but a moderate level of fitness could be maintained by exercising at a pulse rate of 160 beats/min for three 20-minute periods each week (ref. IV–46).

The Harding College findings are important for individuals prescribing exercise programs. The studies were well controlled and well executed in a sound research environment. More of this material should be published in the regular scientific journals. However, it is very difficult for active investigators to keep up on their writing chores, particularly when exciting programs such as Skylab and the Shuttle missions are underway.

The exercise data collected under 1*g* conditions in SMEAT (ref. IV–20) are quite valuable. The exercise data collected on Skylab are highly important as is shown in chapter III and in the outline below (refs. IV–47 through IV–49). In the joint U.S.-Soviet reviews there is a wealth of evidence on exercise. This source is important because the exercise studies are not in journals usually monitored by exercise physiologists.

Contributions to Our Body of Knowledge. A plethora of new research evidence has emanated from Skylab and Skylab-related efforts. This research is far too extensive to attempt to present in detail here. Fortunately, much of the work has been reviewed in the joint U.S.-U.S.S.R. publication *Foundations of Space Biology and Medicine* (ref. IV–22) or has been presented in some detail in the *SMEAT* report (ref. IV–20) and the *Proceedings of the Skylab Life Science Symposium* (ref. IV–19).

The following outline has been organized to identify relevant areas, to describe briefly the type of information presented, and to comment regarding the significance of the information to HPR. Selected recent review or research references are given. The interested reader wishing additional references may obtain them from the review bibliographies. The outline is intended only to aid in identifying new and potentially useful research findings.

I. Barometric pressure and gas composition (ref. IV-14).
   A. Altitude decompression sickness in relation to age, obesity, exercise, and oxygen breathing. (Significant effects of conditioning and leanness.)
   B. Oxygen breathing prior to work at altitude. (Effective prior to anaerobic work at altitude?)
   C. Cross-resistance effects of hypoxia.
   D. Hypoxia adaptations and chronic hypoxia adaptations. (Little is known concerning "hypoxia" training techniques. Enzyme shifts and mitochondrial alterations may be relevant.)

II. Thermal exchange and temperature stress (ref. IV-50).
   A. Comfort zones for various air velocities, humidity, clothing, and work levels. (Adds information relevant to sports environments. Supplements football clothing studies of thermal balance. See ref. IV-51.)
   B. Heat dissipation in exercise.
   C. Overheating and thermal tolerance.
   D. Models of human temperature regulation. (Model may be applicable to HPR fields.)

III. Gravitational biology; effects of forces above 1*g* (ref. IV-52).
   A. Estimated chronic acceleration tolerance.
   B. Growth and development under different gravity conditions. (May add to our knowledge concerning normal growth.)
   C. Effect of positive gravity on skeletal growth. (Relevance to bone changes under stressful training situations: Wolff's Law. See ref. IV-53.)
   D. Effect of positive gravity on muscle growth.
   E. Effect of positive gravity exposure on working capacity. (Animals reared under positive gravity conditions outperformed animals reared under 1*g* conditions.)
   F. Chronic acceleration effects on blood measures. (Relevant to stress and training.)
   G. Chronic acceleration effects on body composition. (Relevant to stress and training.)

IV. Prolonged linear and radial accelerations (ref. IV-54).
   A. Human resistance to accelerations.
   B. Effects of acceleration on physiologic systems such as cardiovascular, respiratory, nervous, and endocrine. (Better understanding of systems under stress.)
   C. Work capacity under prolonged acceleration.
   D. Adaptation to acceleration. (Relevance to "cross resistance.")
   E. Methods of increasing resistance to acceleration. (Highly relevant to physical training.)
   F. Adaptation to hypoxia. (Relevant to "hypoxic" training.)

V. Impact accelerations (ref. IV-55).
   A. Physiologic and pathologic effects of linear impact. (Data are highly relevant to sports injuries.)
      1. Head injuries. (Data related to concussion).
      2. Spinal impact. (Data related to spear blocking and spinal injuries of football.)
      3. Transverse impact.
   B. Tolerance limits. (Provides a base for sports.)
   C. Vertebral and intervertebral strengths. (Provides a base for sports.)
   D. Impact protection.
   E. Relations of physical inactivity. (Effects of exercise in development and maintenance of bone strength.)

VI. Angular velocities, angular accelerations, and Coriolis accelerations (refs. IV-56 and IV-57).
   A. Anatomical-physiological explanations of vestibular apparatus with pathways into the central nervous system. (Indepth treatment of the vestibular mechanism; of particular value to those interested in vestibular mechanism function.)
   B. Man's force environments: terrestrial and in weightlessness. (Force environment analyses of terrestrial and weightless conditions are unique. Concepts are of value in biomechanics.)
   C. Postural control and the rotary environment. (Treatment of vestibular sensor functions and their input into the central nervous system, relevant to those interested in complex movements and biomechanics.)
   D. Motion sickness: susceptibility and treatment.

VII. Effects of prolonged exposure to weightlessness on postural equilibrium (ref. IV-58). Changes in postural equilibrium from pre- to postmission. (Postural stability affected by prolonged weightlessness. Hypothetical mechanisms are particularly relevant to those interested in reflexes and "learned" patterns.)

VIII. Weightlessness (ref. IV-59).
   A. Working model of the influence of weightlessness on man (ref. IV-59). (Summary chart reflects state of data just prior to Skylab; see ref. IV-59, p. 319.)
   B. Body mass changes in Skylab (ref. IV-60). (Reflects losses early in mission but regaining of weight in longer missions. Measurement device is unique; see ref. IV-60, pp. 374–5.)
   C. Cardiovascular.
      1. Orthostatic tolerance — changes observed in Skylab missions (ref. IV-61). Comparison results under 1*g* conditions (ref. IV-62). (Crew of longest mission showed fewer changes than shorter missions. Orthostatic tolerance apparently not a deterrent to extended space flights.)
      2. Red blood cell mass, life span, and metabolism measured in Skylab (refs. IV-63 and IV-64) and under 1*g* conditions (refs. IV-65 and IV-66). (Red cell mass decreased early in flight, but in longer missions started regeneration. Significant questions regarding etiology and control mechanisms for changes.)
      3. Cardiac size (refs. IV-59, IV-67, and IV-68). (Cardiac size decreased in prolonged weightless environment. Decrements were not related to mission duration.)
      4. Electromechanical properties of the cardiovascular system (refs. IV-59 and IV-69). (Postflight temporary alterations in systolic time intervals suggested transient functional impairment in venous return and stroke volume. Good exercise data with measured systolic time intervals. Data reflect decreased blood volumes postflight.)
   D. Calcium balance and skeletal changes measured in Skylab (refs. IV-70 and IV-71) and under 1*g* conditions (refs. IV-72 and IV-73).
      1. Increases in urinary calcium observed in space. Calcium balance was not obtained in space in any of the missions (ref. IV-70).

2. No mineral losses observed in the *radius* and *ulna* based on radiographic estimates. Significant mineral losses observed in *os calcis* of two crewmembers (ref. IV-71).
3. Highly variable calcium loss and bone mineral loss among crewmembers exposed to weightlessness (refs. IV-70 and IV-71).
4. Physical activity for maintenance of skeletal integrity supported by hypodynamia and weightlessness studies (refs. IV-59, IV-70, and IV-71).

E. Muscular changes.
   1. Changes in muscular strength (ref. IV-47). (Muscular strength decrements observed in all missions. Use of progressively more intensive exercise regimens reduced the decrements indicating strength can be retained; see ref. IV-47).
   2. Nitrogen loss continued in space (ref. IV-70). (Nitrogen loss reflecting loss of muscle mass was never completely stopped; see ref. IV-70.)
   3. Muscle girths continued to decrease (ref. IV-74). (Losses of muscle girth and volumes were never completely stopped; see refs. IV-47 and IV-74. Data indicate that with further adjustments of exercise regimens that balance could be obtained. Refs. IV-47, IV-70, and IV-74 are highly significant to exercise physiology and use of exercise for preventive and rehabilitative purposes.)

F. Neuromuscular changes (ref. IV-75). (Significantly shortened Achilles tendon reflex times obtained postflight. Altered feedback and response due to lack of use and postural servo-feedback is proposed. These results coupled with peculiar gait postflight are significant to learning and biomechanics.)

G. Work performance.
   1. Time-motion study of selected work tasks conducted on Skylab (ref. IV-76) and under 1*g* conditions (ref. IV-77). (Performance of tasks under zero-g conditions required "learning" of the tasks. Increase in height in space makes donning space suit more difficult; see ref. IV-76. These data of interest in motor learning.)
   2. Work metabolism experiments conducted on all Skylab missions (ref. IV-48) and under 1*g* conditions (ref. IV-78). (No decrement noted in energy expenditure and associated measures in space; see ref. IV-48. Exercise programs in space reduced level of postflight decrements. Instrumentation and data of interest to exercise physiologists.)

H. Biochemical reponses.
   1. Measures taken in Skylab (ref. IV-79) and prior to Skylab (ref. IV-80) to evaluate fluid-electrolyte balance, regulation of metabolism and calcium balance, and adaptation to environment. (Exceptionally broad array of data including epinephrine, 17-ketosteroids, sodium, potassium, creatinine, growth hormone, ACTH, calcitonin, and aldosterone. These data significant in differentiating effects of weightlessness, adding information concerning adaptation to multiple stressors, specific effects of exercise regimens, and the interrelations of parameters measured.)

I. Anthropometric changes and fluid shifts by measures in Skylab of girth, leg and arm volumes, center of gravity, and observations of postural changes (ref. IV-49). (Arm girth and volume measures decreased slightly but leg girth and volumes decreased significantly in flight. Center of gravity was raised in body and postural changes related to greater tone in antigravity muscles were observed. These data are significant in anthropometric, body composition study. Anthropometric studies were supportive of the fluid redistribution.)

IX. Noise and vibration (ref. IV-81).
   A. Physiologic and psychologic effects of noise, preferred and nonpreferred octave bands, noise exposure indices, human tolerance levels, methods of protection. (Excellent summary, relevant to industrial and community health and to noise pollution.)
   B. Effects of vibration on cardiovascular system, muscles, and psychologic effects of vibration. (Criteria and limits of human exposure to vibration of interest in industrial and community health.)

X. Radio-frequency and microwave energies (ref. IV-82). Biologic effects of these energies and of electric and magnetic fields and their influences on human functional abilities. (Reviews pathophysiologic effects such as cataract formation, sterility, visceral, blood, cardiovascular, and central nervous system. Permissible levels and behavioral effects are presented. Data particularly relevant to family, industrial, and community health.)

XI. Ultraviolet, visible, and infrared rays (ref: IV-83).
   A. Reviews biologic effects and sources of each of the radiative energies. (Data of interest in family and industrial health and industrial management.)
   B. Standardization values and the pathologic effects that occur if they are exceeded. (Rate of learning has been shown to be affected. Is this of significance in family exposure?)

XII. Ionizing radiation (ref. IV-29). Effects of cosmic radiation and hazards from continued exposure. Biological effects of superheavy, high-velocity particles: chromosomal breaks, nonspecific sclerosis, neoplasms, and leukemia.

Radiation resistance and allowable dose levels (ref. IV-29). (Data significant to health and a factor to consider in longer space missions. Skylab crews have had the greatest exposure, but dose equivalent radiation was within limits set; see ref. IV-84. Observed light flashes believed to be associated with heavily ionizing cosmic particles; see ref. IV-85. These data extremely important to future long-duration space flights. No detectable effects on human embryonic lung cells in tissue culture observed on Skylab; see ref. IV-86. These data of extreme interest to radiobiologists and to industrial health professionals.)

XIII. Biological rhythms (ref. IV-87). Review of circadian rhythms, limits of daily patterns. Greater stress tolerated at certain parts of the day. Disruption of rhythms causes mismatching and lowered stress tolerance. Need indicated for maintenance of exercise to contribute to a sound pattern of wakefulness and sleep. (Data significant to coaches or to anyone wishing to be "up" at some given time. Disruption of pattern by crossing time zones or attempting to perform at other than habitual times will result in poor performance. "Jet lag" an important factor.)

XIV. Psychophysiological stress of space flights (ref. IV-27). Analysis of emotional stress, cosmonaut personality types that respond best, factors causing neuroemotional stress inflight, sensory deprivation and methods of overcoming it, response to multiple stressors, social psychology of space applied to organization of crews and personality types. Monitoring and prophylaxis of neuroemotional stress in cosmonauts. (Data highly relevant to structure of teams, understanding of multiple stressors, prevention and alleviation of neuroemotional stress in new space situations. Data on sensory deprivation and prophylaxis of its effects highly relevant to recreation and the basic concepts underlying recreation. Due to narrower environmental restrictions, space recreation assumes new limits and directions. These data equally significant to maintenance of mental-emotional health.)

XV. Combined effects of flight factors (ref. IV-28). Review of multiple stressors and alternative responses to the stressors. (Highly significant; brings together new information on "cross resistance" and responses to multiple stressors. Of great value to exercise physiology, curriculum planners, and to health.)

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Glossary

ACTH. The adrenocorticotropic hormone secreted by the anterior pituitary. Activates the adrenal in stress.

Adrenal corticoids. Secretions of adrenal cortex, glucocorticoids, or mineralocorticoid.

Aerobic capacity. The maximum amount of oxygen that can be taken up per minute.

Aldosterone. The principal electrolyte-regulating steroid secreted by the adrenal cortex.

Allergenic. Capable of producing an allergy.

Amino acids. Organic acid in which one of the hydrogen atoms has been replaced by NH_2. The amino acids are the basis for the proteins.

Anthropometry. The part of anthropology that deals with measurement of the human body.

Antidiuretic hormone. A hormone of the pituitary that suppresses the secretion of urine.

Arrhythmia. Variation from the normal rhythm of the heart.

Astrophysics. The branch of astronomy that deals with the physical nature of the heavenly bodies.

Atrophy. Decrease in size or a wasting away.

Blood plasma. The liquid component of the blood in which the corpuscles are suspended.

Calcitonin. Hormone involved in calcium balance. Action is antagonistic to parathyroid hormone.

Calorie. Amount of heat required to raise the temperature of 1 gm of water 1 degree C. One kilocalorie is the amount of heat required to raise the temperature of 1 kilogram of water 1 degree C.

Cardiac output. The amount of blood pumped by the heart per minute.

Cardiovascular. Referring to the heart, arterial, and venous system.

Calcium balance. Dietary ingestion-excretion balance of calcium. If balance is negative, calcium is being lost from bones.

Catecholamines. Usually refers to epinephrine and norepinephrine.

Central nervous system (CNS). The brain and spinal cord.

Chromosome. A rod-shaped or thread-like body of chromatin in the cell nucleus; carrier of genes.

Circadian rhythm. A rhythm with a period of about 24 hours, applied especially to the rhythmic repetition of phenomena in living organisms at about the same time each day.

Convection. Motions within a fluid resulting in transport and mixing of the components of that fluid.

Corona. The tenuous envelope of the Sun, beginning about 14,000 km above the solar surface and extended many million kilometers into space.

Cosmic rays. Radiation of intense penetrating power and high frequency impinging upon the Earth from outer space.

Creatinine. An alkaloid derivative of creatine. A product of muscle metabolism.

Cross resistance. Resistance to a stressor resulting from adaptation to a different stressor.

Cytogenic. Related to the formation of cells.

Diastolic pressure. The point of least pressure in the arterial vascular system.

DNA. Deoxyribonucleic acid, a complex organic acid believed to carry all the hereditary traits coded in sequence along its length.

Dosimeter. An instrument for measuring the accumulated flux of particle or photon radiations.

Ecology. The study of organisms and their environment as a whole

Electrocardiogram. A record of the changes of electric potential occurring during the heartbeat.

Electroencephalogram. A record of brain waves.

Electron. A negatively charged particle in the atom.

Electro-oculography. Oculography (recording eye movements) using electrodes to detect a standing potential difference between the front and back of the eyeball.

Electrophoresis. The movement of molecules through a fluid under the action of an external electric field. Positively charged particles migrate to the cathode and negatively charged particles migrate to the anode.

Enzyme. An organic compound capable of accelerating or producing by catalytic action some change in an organic substance for which it is often specified.

Epinephrine. Adrenalin secreted by the adrenal medulla and sympathetic nerve endings. Its action is to prepare the organism for "fight or flight."

Ergometer. A device for measuring energy expended or work done.

Exer-genie. A commercial exercise device primarily for strength development.

Exothermic. A process which releases, rather than absorbs, heat energy.

Extravascular. Outside the blood vessels or lymphatics.

Fatty acids. Any acid which in combination with glycerine forms fat.

Frank lead. Specific electrocardiograph lead for determining vectors.

g. A unit of force equal to standard gravitational acceleration on Earth, 980.665 cm (32.2 ft) per sec^2, at the Earth's surface.

Germanium. A metal used as a semiconductor in transistors.

Glucocorticoid. Hormones of the adrenal cortex that affect the metabolism of glucose. The principal glucocorticoid is cortisol.

Glycolytic. Refers to breakdown of glucose.

Hematocrit. An instrument for separating blood plasma from cells.

Hematology. Study of the blood, blood forming tissues, and diseases of the blood.

Hemodynamics. The study of blood circulation.

Hemolysis. The dissolution of the red blood cells with liberation of their hemoglobin.

Hg. Mercury.

Homeostasis. Balance of the internal environment of the body.

Humoral. Pertaining to fluid or semifluid substances in the body.

Hydrostatics. The science of the pressure and equilibrium of fluids.

Hydroxyproline. An imino acid found in the hydrolysis products of collagen; found in proteins of connective tissue.

Hyperoxia. An excess of oxygen.

Hyperplasia. Increase in muscle or organ size associated with an increase in numbers of cells.

Hypertrophy. Increase in size of a muscle or organ associated with increase in cell size but not in number of cells.

Hypodynamia. Inactivity. Very little physical activity.

Hypoxia. Deficiency of oxygen.

Infrared. Beyond the red end of the visible spectrum; denoting certain invisible heat rays.

Inhibition. The slowing down or arrest of function of an organ or part.

In vivo. In the living body.

Ionizing radiation. Radiation from galactic, cosmic, and solar sources and Earth's radiation belt capable of producing ions, directly or indirectly, in its passage through matter.

Ionosphere. Region of ionized gases surrounding the Earth extending from about 60 km (37 mi) to several hundred km (perhaps 350 mi).

Isometric contractions. Muscular contractions with no joint movement, from a fixed position.

Jugular veins. Large veins in the neck that return blood from the head.

17-ketosteroids. Any steroid with a ketone group in position 17; commonly used to designate urinary C_{19} steroidal metabolites of androgenic and adrenocortical hormones with this features.

Laser. From light amplification by stimulated emission of radiation. A device for producing light by emission of energy stored in a molecular or atomic system when stimulated by an input signal.

Lean body mass. The fat-free portion of the body composition usually considered without the skeletal weight. Considered to consist primarily of muscle tissue.

Leukocytes. White blood cells (i.e., neutrophils, eosinophils, basophils, monocytes, lymphocytes), which help maintain the body's immunity to infection and harmful bacteria.

Lipid peroxidation. Oxidation of fatty acids. Of particular importance relevant to peroxidation of cell membranes, resulting in "leaky" cells.

Lymphocyte. Lymph cell or white blood corpuscle without cytoplasmic granules.

Mass spectrometer. An instrument that determines atomic masses and the relative abundance of isotopes in an element.

Metabolism. The interchange of materials between living organisms and the environment by which energy for maintaining life is secured.

Microwave. Microelectric waves; the shortest wave lengths of the radio wave spectrum, including the region with wave lengths of 1 mm to 50 cm.

Mini-gym. A commercial exercise device.

Morphology. Branch of biology dealing with the form and structure of animals and plants.

Nitrogen balance. Dietary ingestion-excretion balance of nitrogen. If balance is negative, nitrogen is being lost indicating loss of protein.

Norepinephrine. A hormone secreted by the adrenal medulla in response to stimulation in the viscera.

One g. The gravitational attraction on Earth. At sea level the attraction is 32.2 ft/sec^2.

Orthostatic. Characterized by or caused by the erect posture.

Os calcis. The heel bone.

Oscillate. To swing back and forth as in a pendulum.

Osmolality. The property of a liquid to exercise an osmotic pressure because it contains an electrolyte in solution.

Partial pressure. Pressure of a single gas in a mixture. In air, at sea level (760 mm Hg) the oxygen percentage is 20.93% with a partial pressure of 159.07 mm Hg (760 mm Hg × 20.93%).

Pathogenic. Productive of disease.

Photogrammetry. The art and technique of taking accurate measurements by means of photographs.

Photometer. An instrument for measuring the intensity of light by comparing it with a standard.

Photon. A corpuscle or particle of light, a quantum of light.

Photosynthesis. The production of carbohydrates in plants under the influence of light, combining carbon dioxide and water in the presence of chlorophyll.

Plasma. The fluid part of the blood.

Plethora. A superabundance or excess.

Plethysmograph. An instrument for determining and registering variations in the size of an organ or limb.

Polychromic. Many colors. May refer to changes or absorption depending upon usage.

Prophylaxis. The prevention of disease.

Proprioceptors. Sensory receptors in joints and muscular system that provide information concerning stretch, position, and tension to the brain.

Protocol. The plan and rules of procedure for an experiment.

Proton. Positively charged nuclear particle in an atom.

Pulmonary function. Lung function; tests reflecting lung functions.

Pulse pressure. The difference between the systolic and diastolic blood pressure.

Radius. Large bone of the forearm.

Respiratory exchange ratio (R or RQ). The ratio of the rate of carbon dioxide output divided by the rate of oxygen intake.

Reticulocytes. Incompletely formed red blood cells.

RNA. Ribonucleic acid, a nucleoprotein found in the cell's cytoplasm.

Saturn V. The launch vehicle developed for the Apollo's lunar missions.

Semicircular canals. Structure in the inner ear responsible for the detection of angular acceleration.

Servofeedback. The proprioceptive mechanism that provides the basic information or feedback for adjustments in posture and movements to be made.

Shuttle missions. The missions scheduled for the 1980s in which reuseable vehicles will shuttle pay loads to and from orbits.

SMEAT. Skylab Medical Experiments Altitude Test.

Solenoid. A coil of wire in the shape of a cylinder with a current passed through it; when a bar of iron is placed in the cylinder, the iron core becomes a magnet causing movement. Useful in automatic units for turning valves or switches.

Spectroheliograph. Modified spectrograph that permits taking pictures of the complete solar disk in monochromatic light.

Spectrometer. An optical instrument for measuring the electromagnetic radiation spectrum.

Spirometer. An apparatus for measuring lung capacity.

Sputnik. The initial unmanned satellites placed in orbit by the Soviets, first on Oct. 4, 1957.

Stereophotogrammetry. Use of several pictures to provide for three-dimensional analysis in photogrammetry.

Stroke volume. The amount of blood pumped per beat of the heart.

Syncope. Fainting.

Synergistic. Cooperative action of discrete agencies such that the total effect is greater than the sum of the individual effects. With two synergistic stressors the response is much greater than the sum of the two.

Synoptic. Observing different objects, or different aspects of one object, at the same time.

Systolic pressure. The highest pressure attained during contraction of the heart. In blood pressure measurement it is the pressure at which the first heart sound is observed.

Telemetry. Radio transmission of data.

Thoracolumbar spine. Includes the twelve thoracic and the five lumbar vertebrae.

Toxicology. The study of toxic or poisonous substances.

Toxin. A soluble poison produced and liberated by certain bacteria and plants.

Transducer. An electronic sensor that converts one form of energy to another, typically sound or pressure into an electrical impulse.

Ulna. Small bone of the forearm.

Vectorcardiograph. An instrument for taking a graphic record of the magnitude and direction of the electrical potentials of the heart.

Venous compliance. Distension or flexibility of the veins.

Vertigo. Sensation of dizziness, giddiness, or of whirling or irregular motion.

Vestibular. Pertaining to the organs of the inner ear that provide a sense of equilibrium for animals and man.

Watt. A unit of power representing work per unit of time—1 joule/sec or 7.233 ft—lbs/sec, 746 watts = 1 horsepower.

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