JSC-09383

NASA TECHNICAL MEMORANDUM

NASA TM X-58160
March 1975

MEDICAL SUPPORT AND FINDINGS OF THE SKYLAB PROGRAM

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS 77058

1. Report No. NASA TM X-58160	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle MEDICAL SUPPORT AND FINDINGS OF THE SKYLAB PROGRAM		5. Report Date March 1975 6. Performing Organization Code JSC-09383
7. Author(s) Richard S. Johnston and Lawrence F. Dietlein, M.D.		8. Performing Organization Report No.
9. Performing Organization Name and Address Lyndon B. Johnson Space Center Houston, Texas 77058		10. Work Unit No. 951-17-00-00-72 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Memorandum 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Specific equipment used in carrying out Skylab medical experiments is outlined and illustrated. Also included are reviews of the techniques, frequency, and protocols of the tests designed to study the long-term effects of weightlessness on the human body. In-flight investigations were an evaluation of the cardiovascular system, a study of metabolic activity, investigations in the field of neurophysiology, the determination of changes in body fluids, a precise measurement of total body metabolism, and a study of crew performance by use of a time and motion experiment. Significant data obtained from in-flight and postflight tests are outlined.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
• Aerospace Medicine • Cardiovascular System • Medical Equipment • Musculoskeletal System • Orthostatic Tolerance • Sleep • Vestibular Tests • Weightlessness	STAR Subject Category: 52 (Aerospace Medicine)

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	40	$3.75

*For sale by the National Technical Information Service, Springfield, Virginia 22151

NASA TM X-58160

MEDICAL SUPPORT AND FINDINGS OF THE SKYLAB PROGRAM

Richard S. Johnston and Lawrence F. Dietlein, M. D.
Lyndon B. Johnson Space Center
Houston, Texas 77058

CONTENTS

TABLES

FIGURES

Figure		Page

MEDICAL SUPPORT AND FINDINGS OF THE SKYLAB PROGRAM

By Richard S. Johnston and Lawrence F. Dietlein, M.D.
Lyndon B. Johnson Space Center

SUMMARY

One of the prime objectives of the Skylab Program was to study the long-term effects of weightless flight on man. To carry out these investigations, a series of medical experiments was devised to study the physiological performance of body subsystems to provide an in-depth understanding of the adaptive changes that may occur as a function of mission duration and the alterations that might take place during the phase following reentry as the body readapts to activities in the one-g field.

The Skylab results indicate that humans can perform well during long-term space flight if they receive proper nourishment, exercise regularly, and get sufficient sleep. The design of the Skylab workshop also verified that man can work and live in the weightless environment with properly designed equipment.

INTRODUCTION

A major Skylab goal was to learn more about man and his responses to the space environment during missions lasting as long as 84 days. The results to date are necessarily preliminary because of the short time that has elapsed since the end of the program. In-depth cross-correlation of the voluminous multidisciplinary data will be completed by specialized working teams.

The Skylab medical experiments were conceived 6 to 8 years before the launch and remained essentially unchanged throughout the program. These studies have added immeasurably to our understanding of man, his physiological responses to and his capabilities in space. In one sense, the Skylab Program is the beginning of an in-depth study of man in this unique environment, because the Skylab manned missions have resolved some problems while inevitably raising some new questions.

This is a summary report briefly describing the medical support designed for the Skylab Program and the significant findings resulting from medical studies conducted during the 28-, 59-, and 84-day Skylab missions. The detailed biomedical results of the Skylab Program are published in a NASA report. "The Proceedings of the Skylab Life Sciences Symposium" (NASA TM X-58154), a two-volume NASA Technical Memorandum covering the Aug. 27-29, 1974, conference at the NASA Lyndon B. Johnson Space Center, can be obtained from the National Technical Information Service, Springfield, Virginia 22151, at a cost of $11.25.

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Système International d'Unités (SI). The SI units are written first, and the original units are written parenthetically thereafter.

PROJECT MERCURY - 1961 TO 1963

To view the Skylab medical data in their proper context, it is helpful to consider the medical aspects of the space program from an historical perspective. In 1961, both the United States and the U.S.S.R. were placing animals into orbital flight. The goal of these flights was to refute untested but plausible theories of catastrophic failures in various vital functions when such animals were suddenly thrust into weightless flight. Besides weightlessness, there are additional stresses to be dealt with in space; the most important of these are ionizing radiation, temperature and humidity, accelerations, circadian rhythm disruption, noise and vibration, and atmospheric composition. The factor of the greatest concern to man with his many gravity-influenced body systems was and continues to be null gravity. Many dire effects (some of them diametrically opposed) were postulated as direct consequences of exposing man to null gravity. Some of these predictions were anorexia, nausea, disorientation, sleepiness, sleeplessness, fatigue, restlessness, euphoria, hallucinations, decreased g tolerance, gastrointestinal disorder, urinary retention, diuresis, muscular incoordination, muscle atrophy, demineralization of bones, renal calculi, motion sickness, pulmonary atelectasis, tachycardia, hypertension, hypotension, cardiac arrhythmias, postflight syncope, decreased exercise capacity, reduced blood volume, reduced plasma volume, dehydration, weight loss, and infectious illnesses. A few of the predictions were later shown to be valid medical problems; happily, the majority were not substantiated by flight experience.

The first indications of cardiovascular or circulatory impairment related to U.S. space flights were the orthostatic intolerances exhibited by the pilot of the Mercury-Atlas 8 mission following his 9-hour flight and by the pilot of the Mercury-Atlas 9 mission after his 34-hour flight (ref. 1). Cardiovascular data from the last and longest Mercury flight included orthostatic intolerance and dizziness on standing, weight loss (dehydration), and hemoconcentration.

GEMINI PROGRAM - 1965 TO 1966

The biomedical studies conducted during the Gemini Program evaluated the magnitude of flight-related changes first noted in the longer Project Mercury flights and the other physiological changes that might occur in Earth-orbital flights of durations up to 2 weeks. Heavy emphasis was placed on evaluation of the cardiovascular system because the principal changes observed during

Mercury flights involved alterations in cardiovascular reflexes that regulate blood flow under a continuous hydrostatic gradient in the Earth gravity field.

The preflight, in-flight, and postflight studies conducted during the Gemini Program were intended to detect alterations in the functional status of the principal human body systems with increased flight duration. The results of these studies (refs. 2 and 3) indicated that some of the major human physiological systems undergo consistent and predictable changes as a result of space flight. The significant biomedical findings of the Gemini Program were a moderate loss of red cell mass, moderate orthostatic intolerance, moderate loss of exercise capacity, minimal loss of bone density, minimal loss of bone calcium and muscle nitrogen, and a high metabolic cost for extravehicular activity (EVA). These findings confirmed the orthostatic intolerance observed during Project Mercury and identified other minor problems.

APOLLO PROGRAM - 1968 TO 1972

In the 5-year span of the Apollo Program, 11 manned missions were completed: 4 prelunar Apollo flights (missions 7 to 10), the first lunar landing (mission 11), and 6 subsequent lunar exploratory flights (missions 12 to 17). The Apollo 13 mission did not complete its lunar landing because an oxygen tank exploded in the service module. It returned to Earth after a partial lunar orbit.

Biomedical studies during the Apollo Program were limited essentially to the preflight and postflight mission phases, with in-flight monitoring and observations. Vestibular disturbances were added to the significant biomedical findings incident to space flight during the Apollo Program.

Vestibular disturbances with nausea were noted by a Soviet cosmonaut during the 25-hour 18-minute Vostok 2 flight on August 6, 1961, and by the crews of later Soviet flights. No American astronauts had experienced any motion sickness symptoms until the early Apollo experience. In retrospect, however, the anorexia and reduced caloric intake observed on certain Gemini flights and later Apollo flights may have been early symptoms of vestibular disturbance. Thus, an additional problem area was introduced into the American space experience. This disturbance had long plagued the Soviet crewmembers and had been predicted in the early 1960's as a probable effect of weightless flight. Its belated appearance in the American space program probably was related to the relative immobility of the crewmen during Mercury and Gemini flights and to the absence of any rotation of the vehicles.

The biomedical findings in the Apollo Program generally confirmed the Gemini results of postflight dehydration and weight loss, postflight orthostatic tolerance decrease, and postflight reduction in exercise capacity. In addition, the decreased red cell masses and plasma volumes noted during the Gemini Program were confirmed but were less pronounced during Apollo.

One final observation deserving mention was the Apollo 15 cardiac arrhythmia episode. One of the crewmembers experienced a single run of bigeminy during the mission - the first significant arrhythmia observed during any American space flight up to that time. Two short bursts (9 and 17 beats) of nodal tachycardia were observed in the astronaut during the postponed Mercury-Atlas 6 launch attempt in 1962. At the time of the arrhythmia, the astronaut was lying in his couch preparing for the final countdown. No arrhythmias were subsequently observed either during the flight or following the historic 5-hour orbital flight. In the case of the Apollo 15 astronaut, it was first thought that a dietary deficiency of potassium might have been a contributory factor. Subsequent careful analysis of their mineral intake and mission simulation studies failed to prove this. The etiology remains obscure. Fatigue following vigorous lunar surface activities certainly was a factor. Other contributory factors are speculative and are likely to remain so.

SKYLAB PROGRAM - 1973 TO 1974

In assessing the biomedical effects of weightlessness on man during prolonged space flight, investigators are not examining absolute effects or responses. Clearly, man is not vegetating in space but is actually doing his utmost to maintain a high level of physical fitness and performance. Thus, the absolute detrimental effects of null gravity will, in most cases, have to be determined through the use and study of animals. Other points worth emphasizing are (1) that the principal studies or measurements made on space missions (including Skylab) are relatively inflexible once the conceptual design has been finalized and (2) that space-flight investigations are essentially field studies complicated by many attendant difficulties, in which the investigator is even farther removed from the experiment and the subject than in field studies on Earth. Finally, although the measuring equipment is highly reliable in performance and the astronaut is a superbly trained, perceptive scientist/observer in his own right, the circumstances fall short of the classical picture of the experimenting scientist in his fully equipped laboratory, constantly fine-tuning his equipment and personally performing experimental trials and collecting precious data. Despite these constraints, the efforts of the Skylab investigative team have resulted in a major contribution toward understanding man in his new environment.

The Skylab Program originally was called the Apollo Applications Program. The development of the medical experiments was initiated in the mid-1960's. The results from the Gemini Program were used to establish the studies required for various body systems. From this systems approach, individual experiments were developed to study the cardiovascular, musculoskeletal, hematologic, vestibular, and metabolic systems in the body.

The Skylab medical program met or exceeded all the planned objectives. Medical operations were conducted without major problems, and the medical equipment functioned flawlessly. The medical data received from the crewmembers were of high quality, and the complex computer reduction of this information was excellent. The quantity of information available from the three manned Skylab missions is staggering. Some investigators consider their results preliminary at this point, and the Skylab medical team must continue to integrate the results of individual studies to give a more comprehensive total understanding of what these data really mean. The Skylab results represent a significant stage in the development of space medical knowledge. Man can fly longer missions as required for future space exploration with greater confidence as a result of the Skylab Program medical results. The Skylab crewmen have demonstrated the versatility and ingenuity of man to make repairs, to carry out observations, and to conduct scientific studies.

OPERATIONAL EQUIPMENT

Several major medical subsystems were provided in the Skylab orbital workshop (OWS) to sustain the crewmen, to protect their health, and to support the medical studies.

The Skylab food system (fig. 1) was developed to provide a balanced and palatable diet that also met the necessary requirements for calories, minerals, and other related constituents of the metabolic balance experiment. Seventy foods were available from which the crew could select their in-flight diets. Food types included frozen, thermostabilized, and freeze-dried foods. Menus were

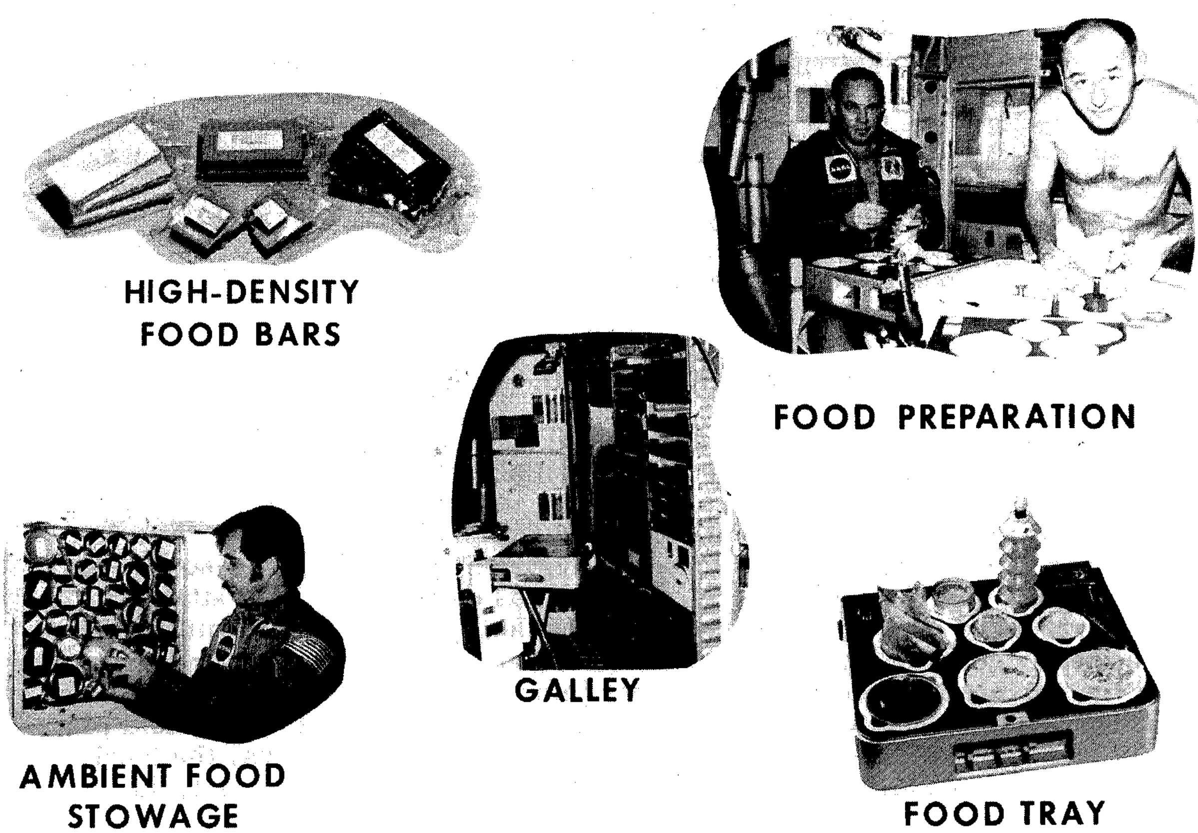

Figure 1.- Skylab food system.

planned for 6-day cycles. The crewmen were required to consume their planned food menus for 21 days before flight, throughout the flight, and for 18 days after flight.

Approximately 900 kilograms (1 ton) of food was stowed in the OWS at launch to provide approximately 400 man-days of food with approximately 10 percent overage. The ambient-temperature food was stowed in packages that contained a 6-day supply. The packages were moved by the crewmen to the galley area for intermediate stowage, preparation, and consumption. The galley area contained a freezer, a food chiller, and a pedestal that provided hot and cold water outlets, attachment points for three food trays, and restraints to permit each crewman to sit while eating. The food tray contained seven recessed openings for cans or other containers; three of these openings had heaters for warming the food. The food cans were designed with plastic membranes or other devices to restrain the food in zero g and to permit the crewmen to eat with conventional tableware. Drinks were packaged in powdered form in a bellows container with a drinking valve. Water was added from hot or cold water outlets, and the crewmen drank from the containers by collapsing the bellows. The variety in foods and the general design of the food system were acceptable to the Skylab crewmen. At the suggestion of the Skylab 2 crewmen, more and varied spices were included in the later missions to improve food flavor. The extension of the Skylab 4 mission for an additional 28 days required that 113 kilograms (250 pounds) of additional Skylab food would have to be launched in the command module (CM). This food weight and the resulting stowage volume were excessive, and it was therefore determined that a high-density, high-caloric-type food bar would be stowed in the CM to provide the caloric requirements for mission extension. The in-flight menus were modified to include the high-caloric bars with a food energy equivalent to approximately 3350 to 4200 kilojoules (800 to 1000 kilocalories) each day. For the Skylab 4 mission, approximately 45 kilograms (100 pounds) of Skylab food and drinks and 23 kilograms (50 pounds) of the high-caloric-type food bars were launched in the CM.

Waste Management System

The Skylab waste management system (fig. 2) included equipment for the collection, measurement, and processing of all urine and fecal material and for the management of waste such as equipment wrappers and food residues. The waste management compartment contained equipment used by the crew for the collection of urine and feces. Personal hygiene equipment was also stowed and used in this compartment. Fecal material was collected in bags attached under a form-fitted seat. The bag was permeable to gas but not to liquids. An electric blower actuated by the crewmen during use provided a positive airflow around the perineal area to carry the feces into the collection bag. After each defecation, the crewmen weighed the stool on a mass-measuring device and placed the fecal bag into a vacuum drying processor. After 16 to 20 hours, the fecal residue was removed and stowed for return to Earth for postflight analysis.

Urine was collected in a 24-hour pooling bag. A centrifugal fluid/gas separator, actuated at the start of urination, created a positive airflow to carry the urine into a liquid/gas separator where urine was separated and transferred

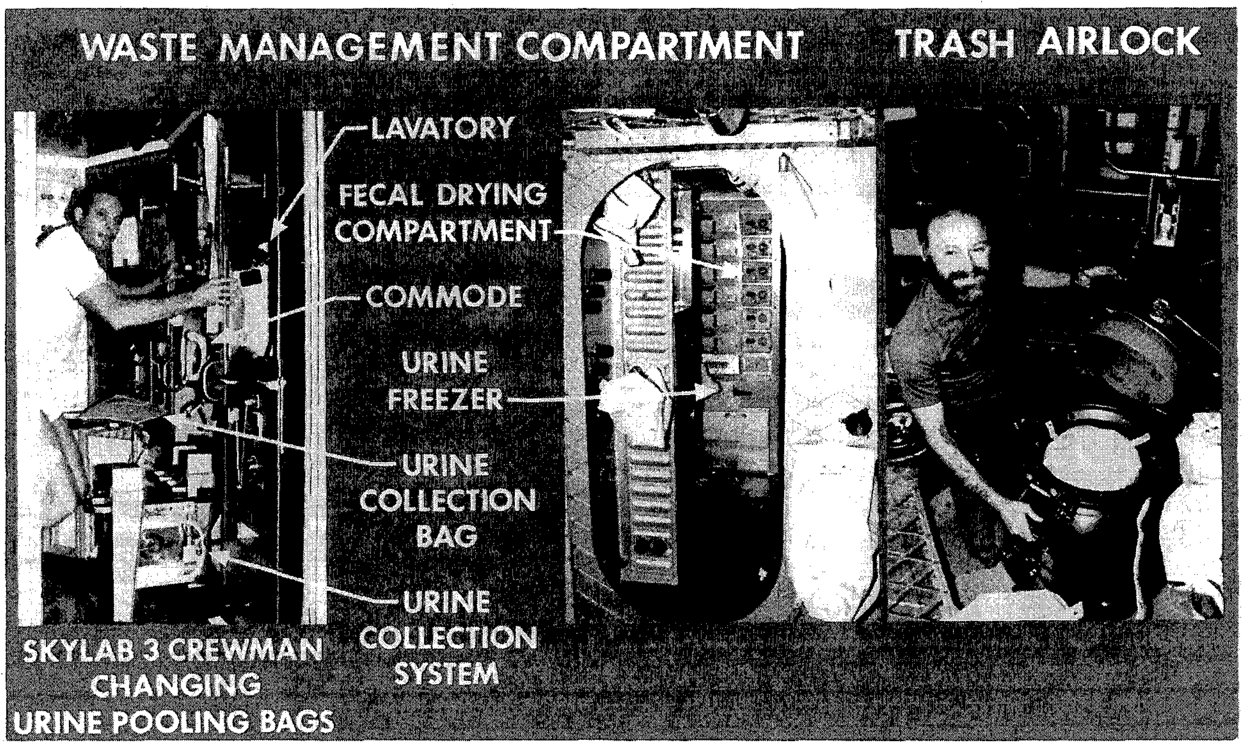

Figure 2.- Skylab waste management system.

into the pooling bag. A measured quantity of lithium chloride was added to each pooling bag before flight to permit calculation of urine volumes based on lithium dilution. In addition, the crewmembers used a gage to measure pooling bag thickness and thus provided real-time estimate of daily urine output. Each 24 hours, the crewmen collected 120 milliliters of urine from the pooling bags and placed these samples in a freezer for return and postflight analysis. The used pooling bag was discarded, and a new bag was installed for use each day.

Debris accumulated from food wrappers, equipment bags, towels, and so forth was discarded through an airlock into a large-volume tank in the OWS. The waste management system and trash airlock operated satisfactorily throughout the Skylab missions, and the crews reported complete satisfaction with the design of this equipment.

Operational Bioinstrumentation

Operational bioinstrumentation (fig. 3) was used by the three crewmen for certain critical mission phases such as launch and EVA. This system provided electrocardiogram (EKG) and respiratory data. Electrodes were affixed to the body and signal conditioners were contained in a belt worn on the undergarment. Throughout the Skylab Program, high-fidelity medical data were obtained, and the crewmen did not report any major problem with this system.

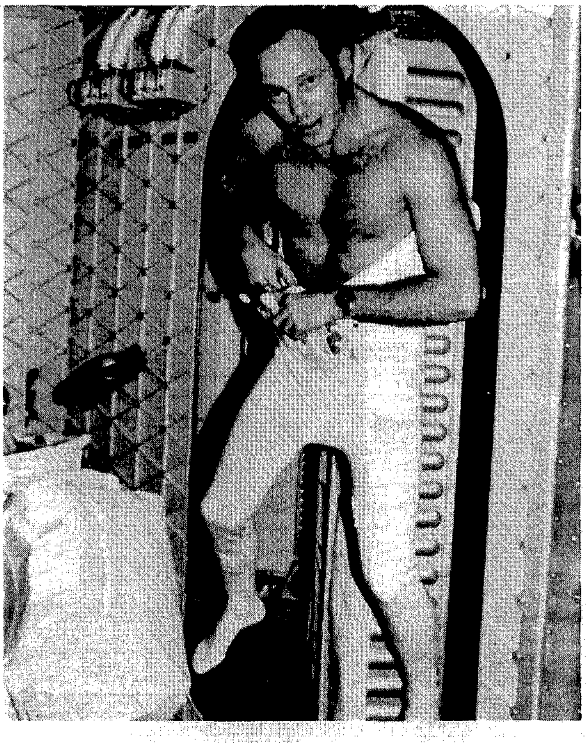

Figure 3.- Skylab operational bioinstrumentation.

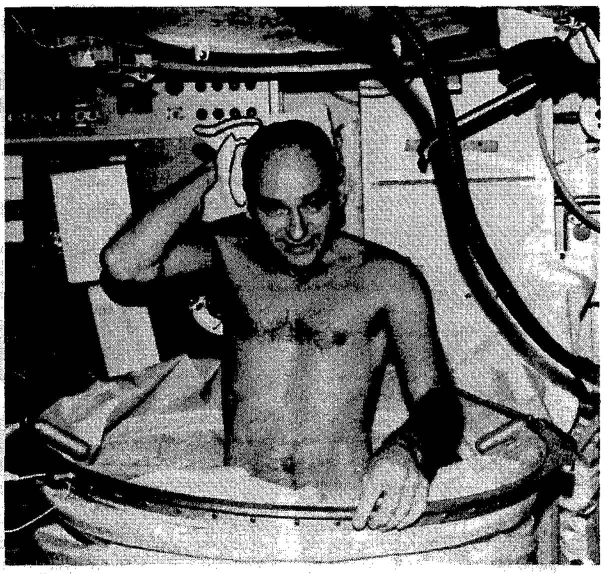

Figure 4.- Skylab shower in flight use.

Personal Hygiene

Provisions were included in the OWS for daily personal hygiene. Wet wipes, towels, toothbrushes, razors, deodorants, et cetera were provided to maintain body cleanliness. In addition, a shower (fig. 4) was provided to allow full body bathing. Warm water and liquid soap were available in limited quantity for one shower a week for each crewman. The shower head was contained in a collapsible cylindrical cloth bag. The Skylab crewmen reported satisfaction with the shower and other personal hygiene equipment; however, they indicated that too much time was required to collect the water and dry out the shower after use. Analysis of microbiological samples taken in flight from the Skylab crewmen indicate that the personal hygiene techniques used were quite adequate.

In-Flight Medical Support System

The in-flight medical support system (fig. 5) was designed to provide first-level medical diagnosis and treatment for the Skylab crew as required. The system was stowed in the wardroom and included diagnostic, minor surgery, dental, catheterization, and bandaging equipment. Microbiological equipment to collect airborne and surface samples during flight was also provided. Petri dishes, an incubator, a microscope, and a slide stainer were available. Sixty-two medications were stowed in modules for the three missions to ensure an adequate and fresh supply. Before flight, all Skylab crewmen underwent appropriate sensitivity testing for medications they might require during flight. The Skylab crewmen underwent 80 hours of paramedical training in the use of the in-flight medical support system.

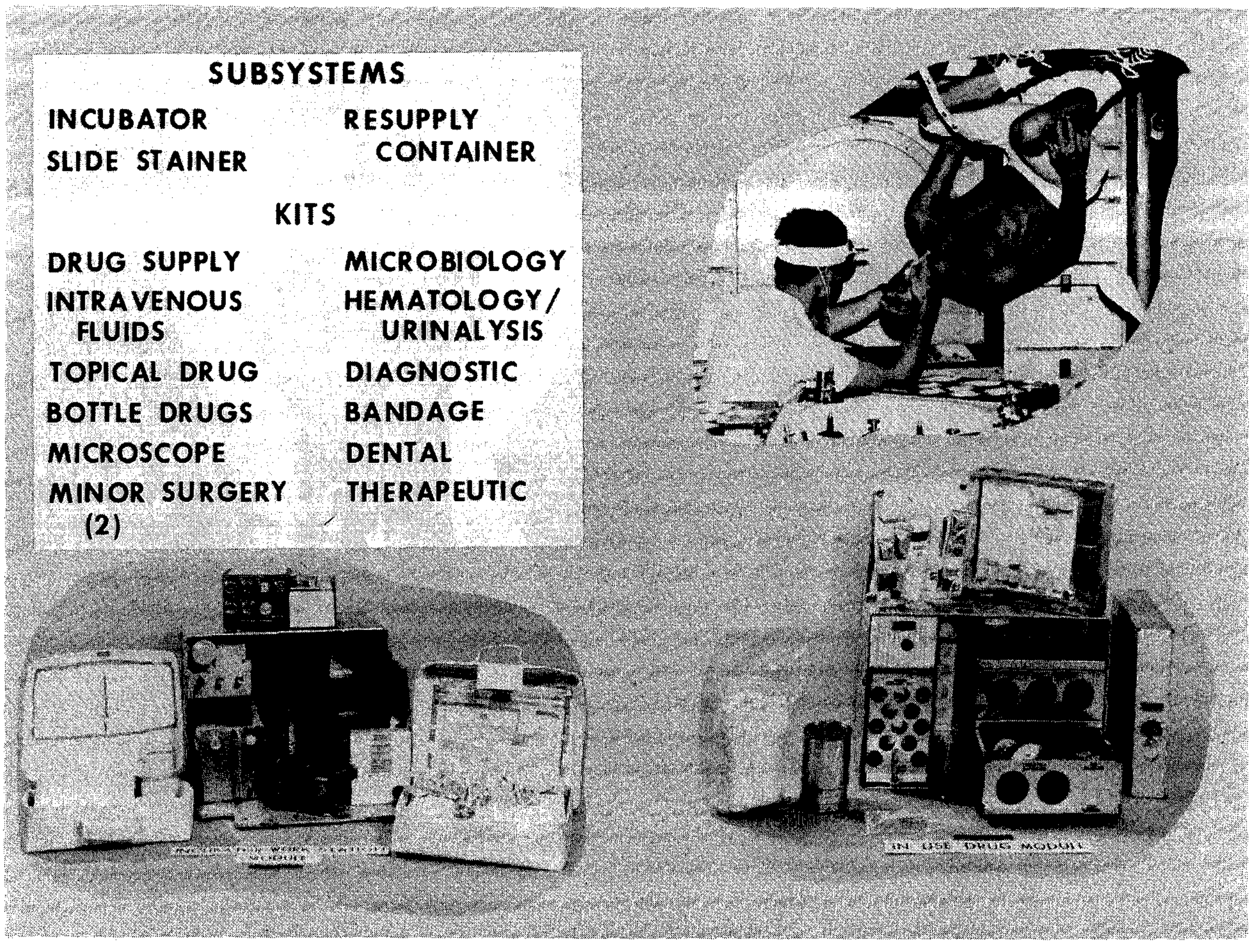

Figure 5.- Skylab in-flight medical support system.

Cardiovascular Counterpressure Garment

Cardiovascular counterpressure garments (fig. 6) were launched in the OWS for all three manned Skylab missions. These garments were designed to provide mechanical counterpressure to the lower extremities to reduce the postural hypotension effects following landing and operation under one-g conditions. The garment had a partial-pressure suitlike capstan along each leg. Inflation of the capstan by a pressure bulb provided a pressure gradient of 11 331 to 11 997 N/m^2 (85 to 90 torr) at the ankles to 1333 N/m^2 (10 torr) at the waist. The garments, donned by the crewmen before entry and inflated after landing, were used to provide protection during the postrecovery period. Inflation of the suits had a salutary effect on the signs of orthostatic intolerance (heart rate and blood pressure).

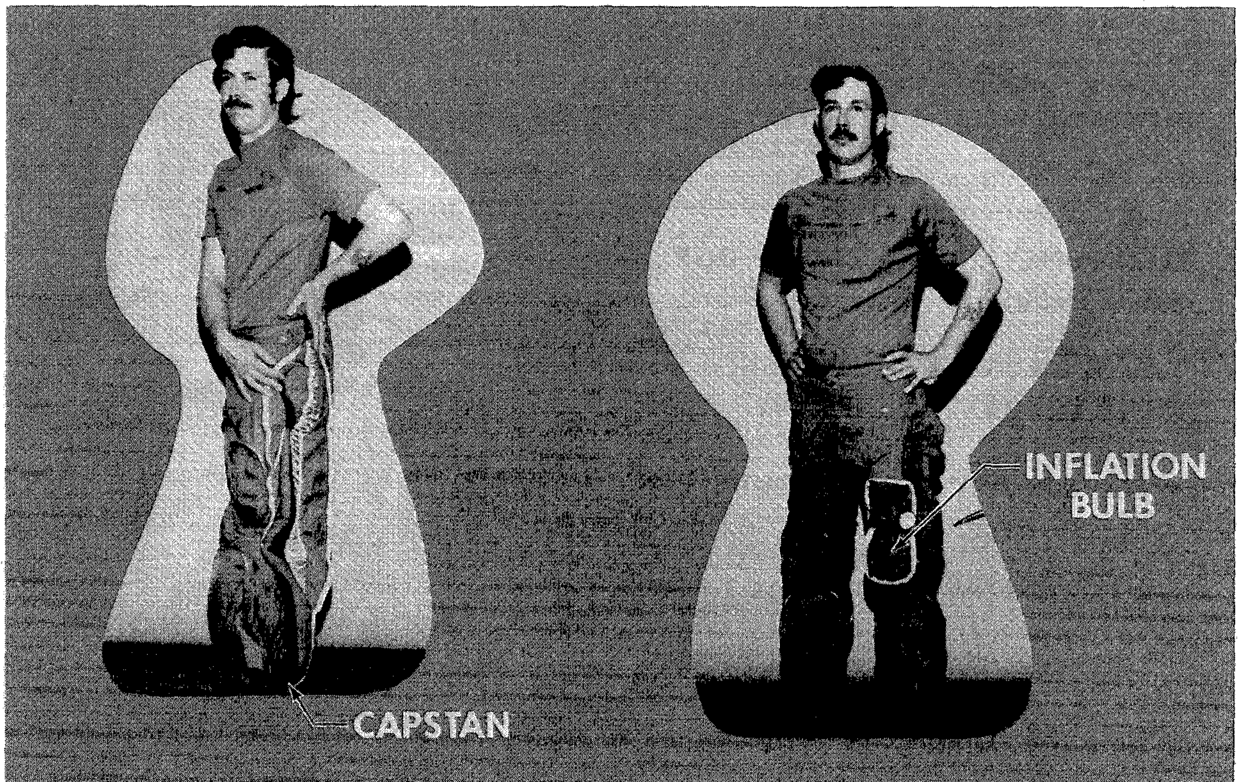

Figure 6.- Skylab cardiovascular counterpressure garment.

SKYLAB MEDICAL OPERATIONS

The medical operational planning for Skylab was much more complex than for any previous U.S. manned space mission. The logistics planning required for combining crew feeding, sample collection, baseline experiment data acquisition, crew medical examinations, crew health care, data processing, and flight management into an integrated plan that meshed with program milestones required a major medical team effort. The Skylab medical operations program (fig. 7) was initiated in June 1972 with a 56-day altitude chamber test; it was completed in April 1974 with the final postflight evaluations on the Skylab 4 crew.

The compression of the Skylab launches and the extension of the mission duration created an extremely heavy burden on the Skylab medical team. The medical experiments program was unique in that it not only provided scientific data but also served as the basis for real-time operational decisions for the commitment to longer duration flights. This meant that, at the end of the first two missions, the medical team had to make a recommendation on the extension for the next mission. The Skylab 3 preflight phase began before the Skylab 2 postflight phase was completed and after the preflight data collection for Skylab 4 had begun. The Skylab 3 mission was launched only 2 weeks after the Skylab

2 postflight studies were completed; Skylab 4 was launched only 5 weeks after completion of the Skylab 3 postflight medical studies. This quick turnaround required careful planning, establishment of priorities on samples and data processing, and dedication and tireless effort from all members of the medical team.

The Skylab medical experiment altitude chamber test (fig. 8) was a 56-day mission simulation performed in a 6.1-meter (20 foot) diameter vacuum chamber. The internal chamber arrangements were similar to the OWS crew quarters level, which contained the medical experiments area, the wardroom, the waste management compartment, the sleeping quarters, and the recreational areas. The prime objectives of the test were to acquire background data and to exercise the data management and processing techniques for selected medical experiments. The atmosphere in the chamber was maintained at a composition identical to that of the OWS, with a 70-percent-oxygen, 30-percent-nitrogen mixture at 34 474 N/m^2 (5 psia). Carbon dioxide levels were controlled at a nominal level of 667 N/m^2 (5 torr). Other test objectives included the evaluation of medical experiment and operational equipment, the evaluation of operational procedures, and the training of support personnel under simulated mission conditions. Using the actual flight mission as a model, the test consisted of

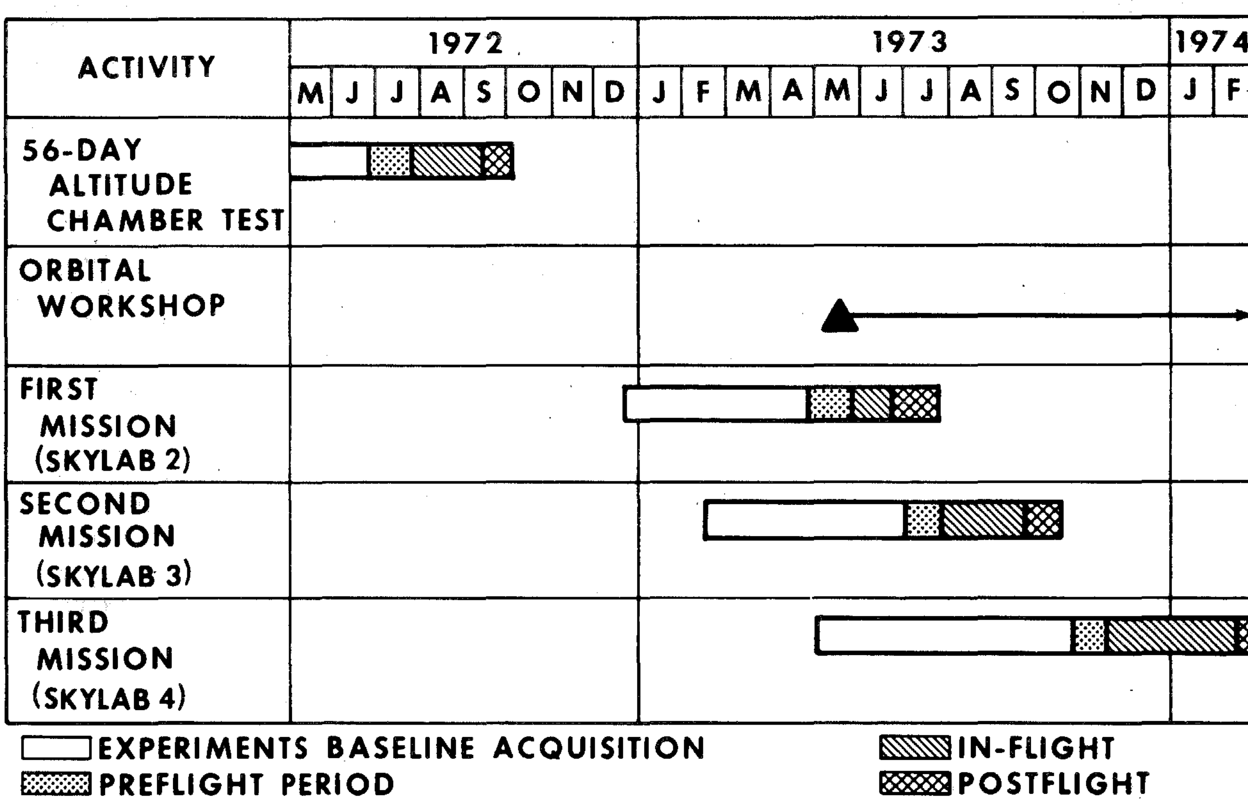

Figure 7.- Skylab medical operations program.

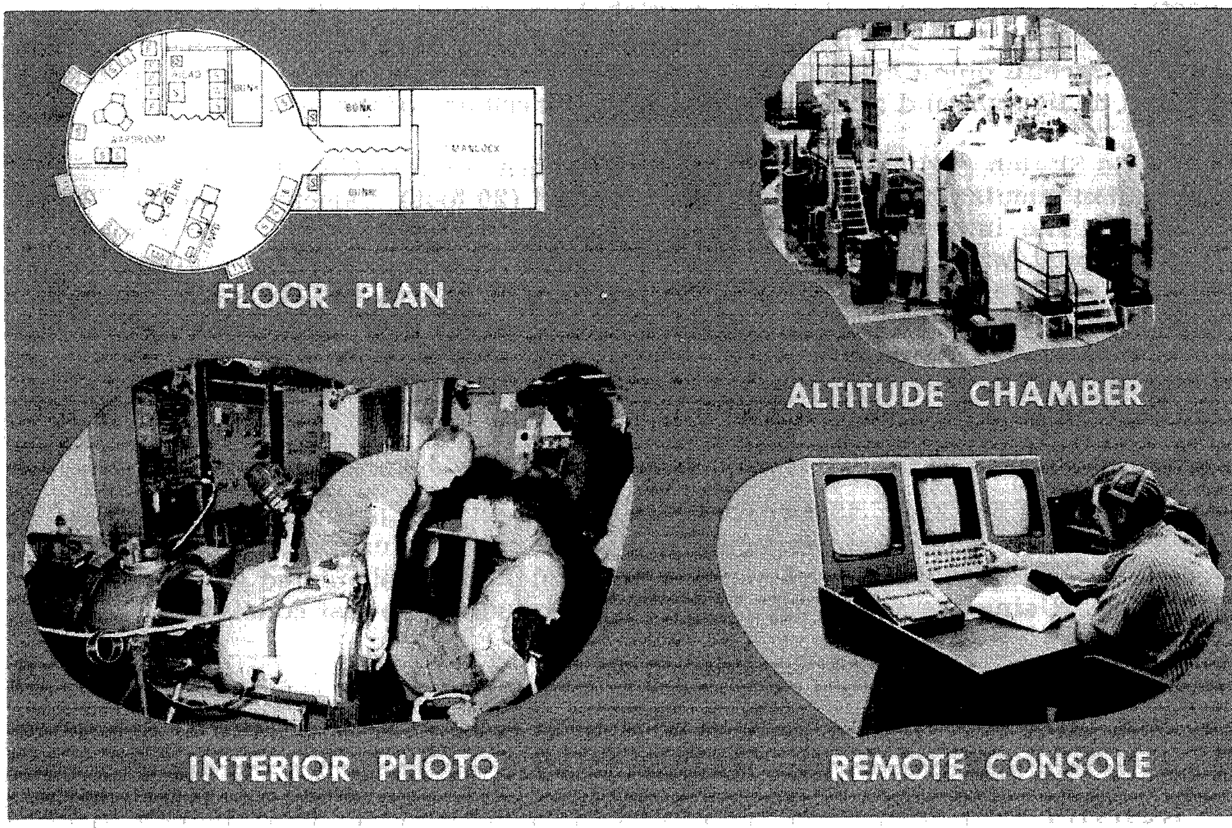

Figure 8.- Skylab medical experiments altitude test.

a 21-day prechamber phase, a 56-day chamber test, and an 18-day postchamber test period. All preflight and postflight medical protocols were performed using astronaut crewmen as subjects. The in-chamber test portion of the program was carried out under full mission simulation procedures and included the crew checklist, real-time mission planning, and data management. Communications with the crewmen were limited to one spacecraft communicator as carried out in the missions. Simulated network communications also were followed to evaluate the problems of loss of communication between the flightcrews and the mission control center that could be experienced in actual flight. A remote console was used by the medical team to develop and implement ground control procedures for flight. This test program was quite successful. The required baseline data were obtained, and equipment failures and problems were encountered that were corrected before flight. The ground support personnel became an effective team ready to carry out the complex flight program.

Premission Support

The premission support for the first manned mission started in December 1972 with the acquisition of the first baseline data for the lower-body negative-pressure (LBNP) and metabolic activity experiments (fig. 9). Additional baseline

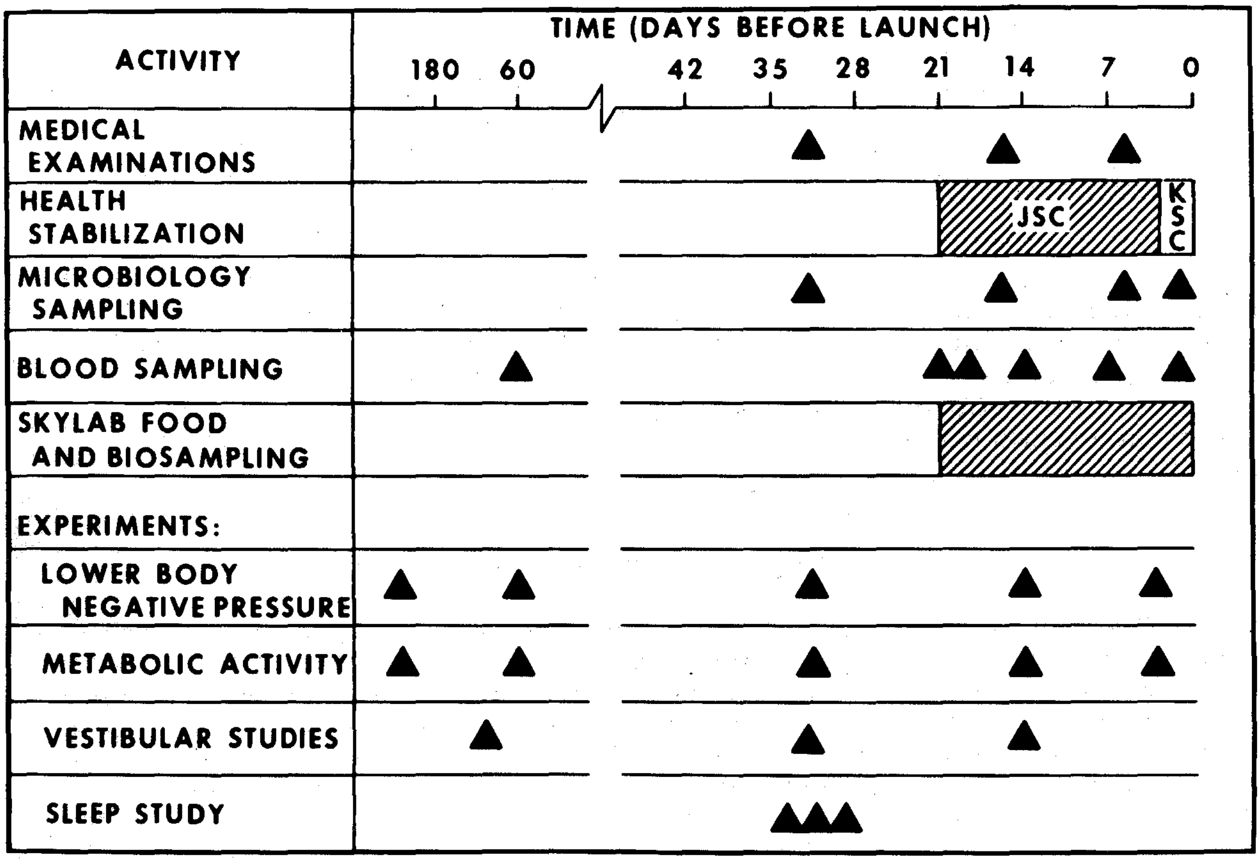

Figure 9.- Skylab preflight operations (typical mission).

tests were conducted in support of the medical experiments at designated periods up to approximately 1 week before lift-off. The baseline data were primarily obtained in an OWS one-g trainer. This full-scale trainer contained fully functional medical experiments and other operational hardware. Crew training and baseline data collection were combined for both the prime and the backup crewmen. A remote medical console and a data recording system were used to monitor the crewmen during training sessions and to train members of the medical team in control procedures and flight data reduction. This combination training and medical baseline data acquisition provided excellent experience for both the crewmen and the medical experimenter.

A comprehensive medical examination was performed on both the prime and backup crews 30 days before the scheduled launch, and additional baseline data were obtained for the experiments. The crewmen were placed in semi-isolation 21 days before lift-off to meet the requirements of a health stabilization program. The objective of this program was to protect the flightcrews from illnesses that might cause them to be removed from flight status and to preclude the occurrence of infectious disease in flight. All personnel who were required to work with the flightcrews were designated as primary contacts. To protect the crewmen, these individuals underwent extensive medical examinations and immunizations and were required to report all personal and family illnesses. Those primary contacts who would come into direct contact (within 2 meters) with the crew were medically screened each day and were required to wear surgical masks while in contact with the crew. Isolated crew quarters were established, and personnel access to designated primary work areas was rigidly controlled. The Skylab health stabilization program was quite effective, and no major problems were encountered.

During the isolation period, the flightcrew and backup crew diet was identical with the menus provided during flight. Daily collections of urine and fecal samples were also initiated. Medical examinations, microbiological and blood sampling, and experiment baseline tests were continued at the NASA Lyndon B. Johnson Space Center up to 3 days before lift-off. At that time, the prime and backup crews moved to the NASA John F. Kennedy Space Center for the launch.

In-Flight Operational Support

The management of the in-flight medical operations support and the necessary interactions with program management, other scientific disciplines, and the flight control team were accomplished through a medical management group. This medical group met each morning of the mission to review crew health status, to evaluate the current status of the medical studies, to discuss equipment or other operational problems, and to establish changes in experiment priorities. Health trend charts were plotted each day to provide experimental data that were useful in understanding crew health status. These charts included crew weight, caloric intake, quantity of sleep, heart rate and blood pressure under dynamic stress, urine volume output, and other pertinent information. The chairman of this medical group reported to a Flight Management Team on all medical matters and participated in operational decisions such as changing crew time lines, adjusting science requirements to ensure maximum use of crew talent and energy and of current science opportunities, and providing advice on major operational policy changes. This management scheme was extremely effective and was an important factor in the success of the Skylab Program.

The in-flight activities of the first manned Skylab mission are shown in figure 10 to illustrate the medical events for a typical Skylab mission. The first 2 to 3 days of each mission were spent in activation of the OWS. This operation included such tasks as system checkouts and activation, transfer of equipment from the CM to the OWS, and changing air filters. In-flight medical monitoring of the crew started at launch through the use of the operational bioinstrumentation system. During all EVA's, the crew was monitored utilizing this same system. The frequency of in-flight medical experiments for the Skylab 2 crewmen indicates the points at which various studies were performed or biological samples obtained during this mission. On all Skylab missions, the LBNP and the metabolic activity experiments were accomplished on approximately the fourth day of flight. Blood samples were collected weekly during the missions, and urine biosampling was done daily.

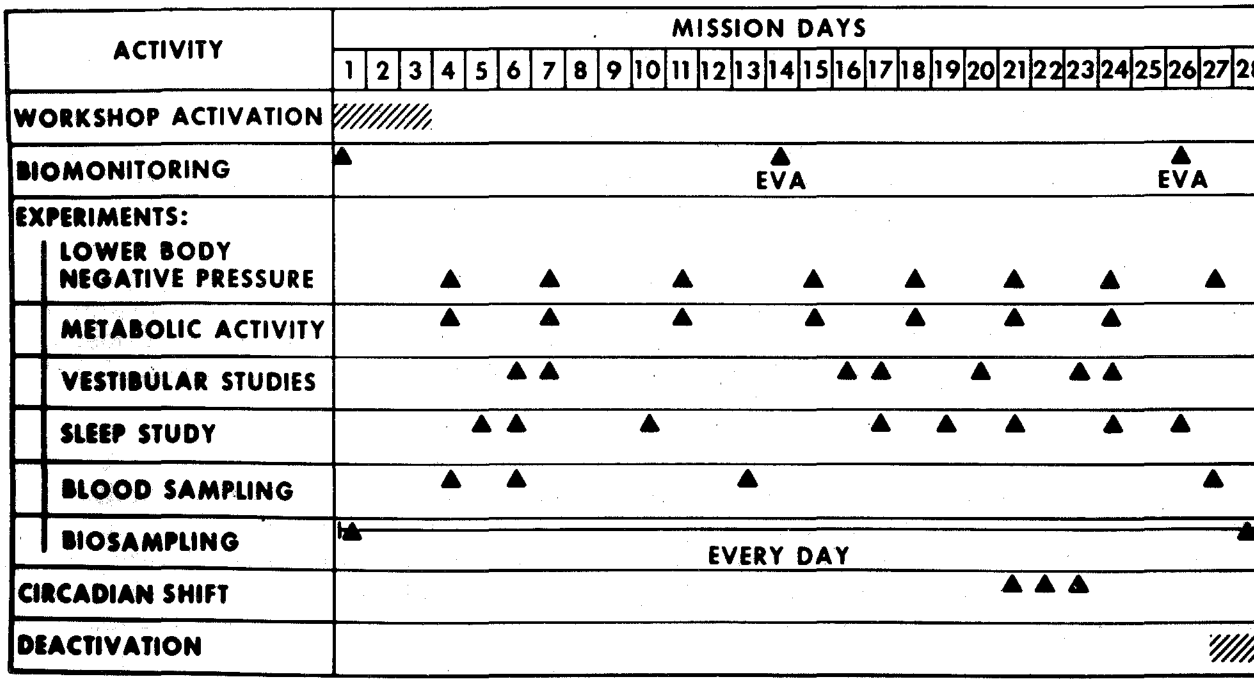

Figure 10.- Skylab in-flight medical support program.

During the flight phase, real-time monitoring of the medical experiments was accomplished only when the spacecraft was over a tracking station. In some instances, this meant a complete loss of communication with the crew and a loss of telemetered data during medical testing. To overcome this problem, all experiment data were recorded on board and subsequently telemetered through the tracking stations to the mission control center. Software programs were used to enable automatic computer reduction of the experiment data. The experimenters had a preliminary data printout within 24 hours after completion of an experiment test. During the latter part of all three Skylab manned missions, work/rest cycles were altered to adjust the length of the day before entry and the time of spacecraft landing.

The in-flight portion of the three Skylab manned missions lasted 171 days over an 8.5-month period. Throughout this long and arduous period, the interest, enthusiasm, and concern for the crews was maintained at the highest level by all members of the medical and the program management teams.

Postflight Activities

The recovery of the Skylab crewmen differed from the Apollo recoveries in several respects. The CM with the crewmen onboard was retrieved by the recovery aircraft carrier and was lifted directly on board. The crewmembers came out of the spacecraft onto a platform on the hangar deck. Spacecraft and crew retrieval took approximately 35 minutes from the time of splashdown. Specialized mobile laboratories were developed and equipped to acquire preflight and postflight medical experiments data. Six laboratories made up the complex. The laboratories were designed and made to be moved in a C-5A transport aircraft to enable the medical team to cover contingency landings if an early mission abort occurred. For a normal mission, the laboratories were flown to port and lifted onboard the recovery carrier. The mobile laboratories were designed with backup support systems such as electrical power, heating, and cooling. In addition, a central data unit was included to enable processing of medical data in a format compatible with the flight data. In use, the mobile laboratories proved to be excellent support facilities which expedited in large measure the conduct of post-recovery medical operations. The laboratories operated without problems and provided medical data of the highest fidelity.

Medical studies were initiated immediately after recovery operations. A summary of all postflight activities is shown in figure 11. For the Skylab 2 mission, the recovery day (R+O) testing lasted for approximately 10 hours and included a comprehensive medical examination as well as the acquisition of data for all major medical studies. In subsequent missions, the length of the R+O medical studies was shortened to reduce the crew day. The health stabilization

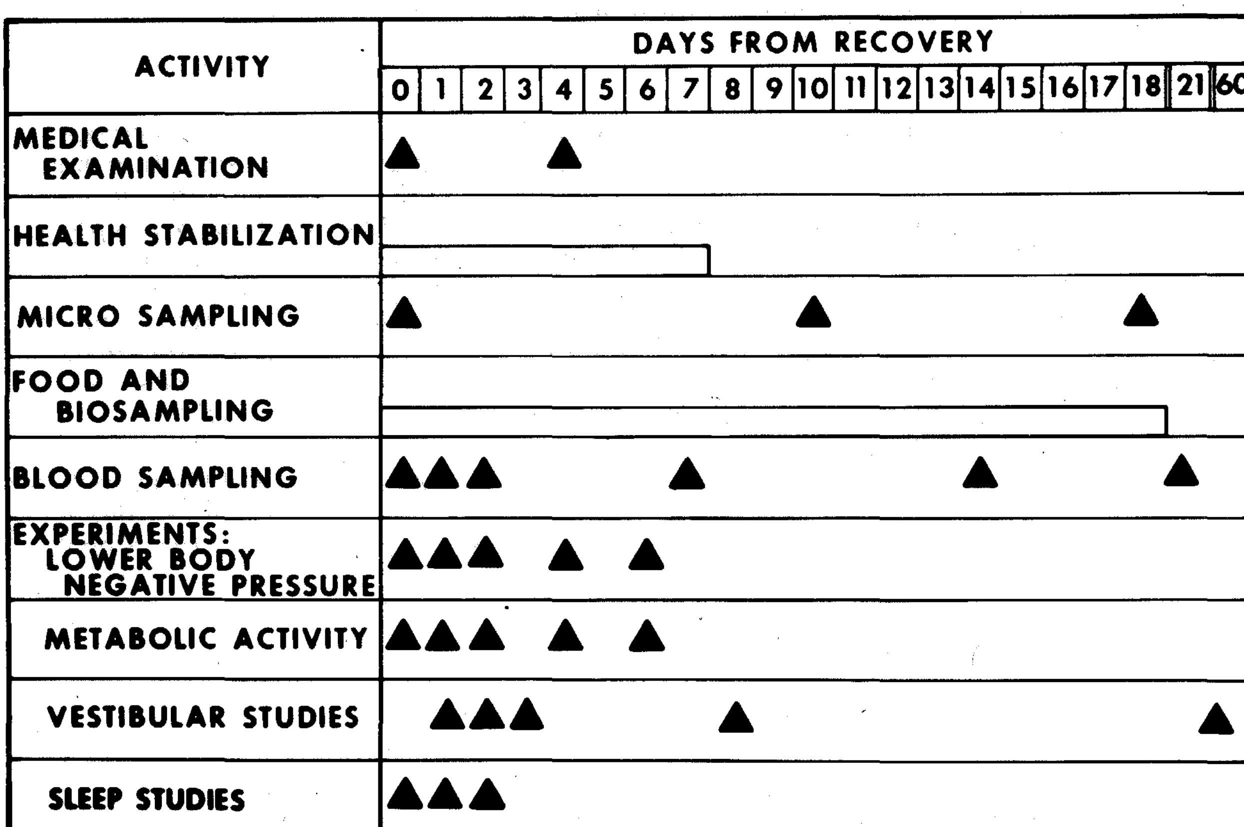

Figure 11.- Skylab postflight medical activities.

program was in force throughout the first week following recovery to protect the crews from infectious disease that might result from depressed immune responses after the relatively long isolation periods of the Skylab flights. Microbiological sampling, blood sampling, and biosampling were accomplished as shown in figure 11. Medical studies were completed on the days indicated. In all Skylab missions, medical testing was continued until preflight control levels were reached.

OPERATIONAL EXPERIENCE

The launch of the OWS on May 20, 1973, and the subsequent failures impacted the medical program. The loss of the micrometeorite shield exposed the skin of the OWS, causing an increase in OWS temperatures. The partial deployment of the solar panels reduced the electrical power supply available for experiments and systems operations. The OWS failure also resulted in a 10-day delay in the launch of the first manned mission (Skylab 2), which meant that health stabilization, controlled feeding, and biosample collection periods had to be extended. The exposure of the OWS skin caused an elevation in both wall and spacecraft-air temperatures. The temperature increase for the early phase of Skylab is shown in figure 12. Maximum temperatures in this food stowage area exceeded 328 K (130° F). In

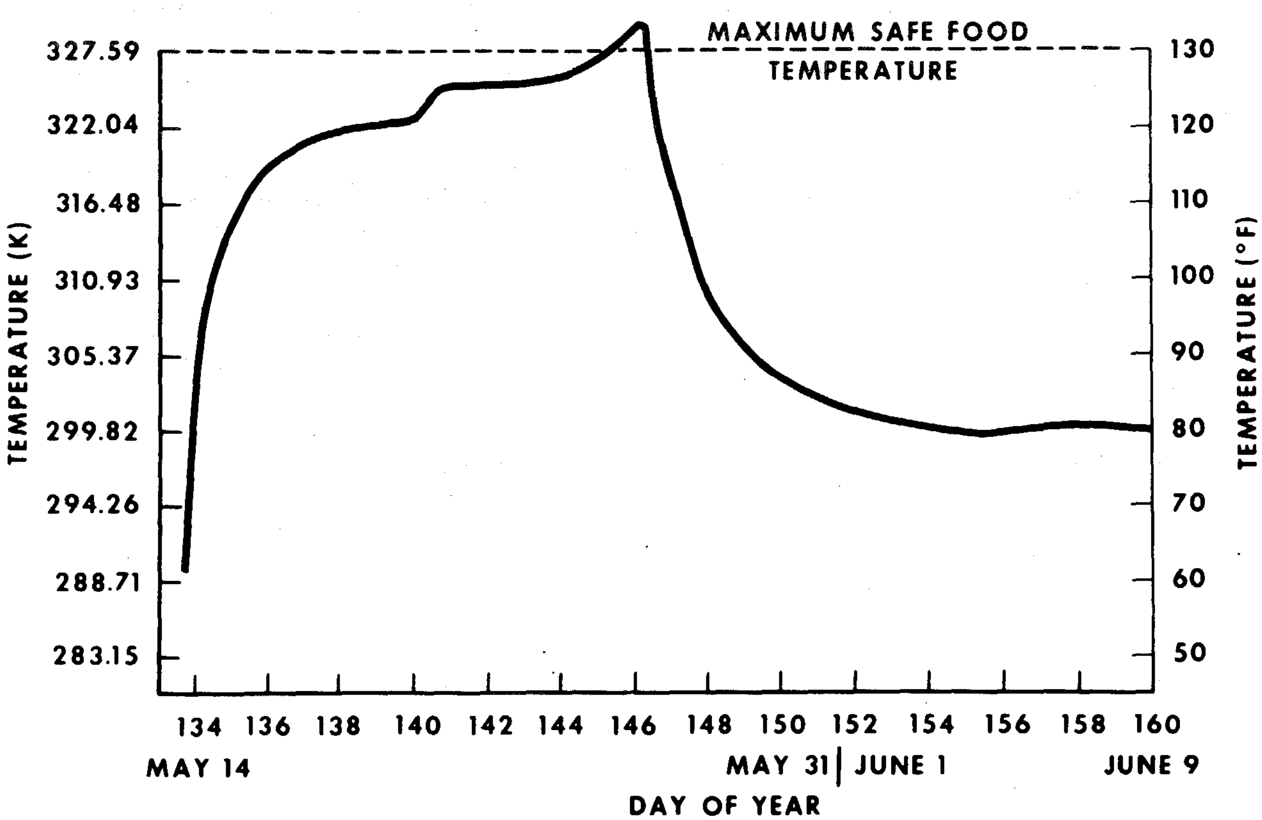

Figure 12.- Dry-food temperature profile.

the 10-day period before the launch of the Skylab 2 mission, a thermal screen was developed that the crew could deploy to shield and insulate the OWS. In the intervening period, however, the increase in temperature raised several questions for the medical team. Would the foods be spoiled or changed by the elevated temperature? Would other medical equipment be damaged by the increased temperature? Would the polyurethane walls of the OWS be heated to a point at which carbon monoxide (CO) or toluene diisocyanate (TDI) would be emitted into the spacecraft atmosphere? Immediate action was taken to perform ground-based test programs and to develop data and equipment that the crewmen could use to understand and/or to solve the possible problems.

Food test programs were initiated to study the effects of the increased temperature on microbial growth, food quality, and other characteristics. Identical foods were placed in thermal chambers and actual temperature data from the OWS were used for the thermal test profile. Periodic food sampling was accomplished to determine the biological and chemical composition changes and the effects on taste and palatability. No significant food failures were encountered during these tests, and the launch of the first manned mission proceeded without major alterations to the food system. The food test program was continued throughout the Skylab Program, however, and selected food samples were returned from the three missions for analysis.

Similar thermal testing was accomplished for many miscellaneous medical items, such as electrode sensors and sealed containers. The determination was made from these tests that certain medications should be resupplied by the Skylab 2 crewmen. Additional procedures and equipment were developed to allow the crew to replenish the conductive gel of the electroencephalograph (EEG) electrodes on the sleep study caps.

The potential toxicity problems associated with the OWS polyurethane wall insulation also were studied through thermal testing. It was determined that TDI and CO could have been present in the atmosphere. Before the launch of the first manned mission, equipment was provided in the OWS to monitor the OWS atmosphere for CO. Detector tubes and a pump were provided to enable the crewmen to determine CO levels by colorimetric comparison. Following the launch of the OWS, it was determined that additional trace gas detectors should be provided. Special tubes and adapters were built during the 10-day period between the launch of the OWS and the first manned mission. This equipment permitted the crew to withdraw an atmospheric sample from the airlock and then from the OWS before opening the hatch into these areas. In addition, special masks were provided to enable the crew to move into the OWS if the TDI and/or CO levels became toxic. The Skylab 2 crew found no TDI, and the CO concentration was less than 5 ppm.

The crew deployed the thermal screen on the second day of the first manned mission and the OWS wall temperatures began to decrease immediately. Within several days, the ambient gas temperature had dropped below 300 K (80° F). The elevated temperature in the OWS did delay the start of some medical experiments and undoubtedly influenced the results of the first medical studies; however, through the ingenuity of man and the efforts of the Skylab 2 crewmen, the mission and the workshop were saved from what appeared to be an obvious total failure.

Throughout the Skylab flight program, alterations in equipment and procedures were made to capitalize on the flight experience of the previous mission. The Skylab 2 crew recommended that the personal exercise program in flight be expanded in both duration and exercise type. To meet this recommendation, the exercise period for the Skylab 3 crew was expanded from 0.5 to 1 hour daily, and an additional exercise device was launched for the Skylab 3 crew. During the Skylab 4 mission, the duration of crew exercise was further expanded to 1.5 hours daily, and a unique treadmill device was used by the crewmen. The first crew also recommended that food palatability could be improved by the addition of spices. As a result, commercially available spices such as garlic salt, hot pepper, and similar condiments were carried by the Skylab 3 crewmen. For the Skylab 4 mission, liquid spices were carried to overcome problems the Skylab 3 crewmen had using the conventional spice dispensers in the weightless environment.

In addition to these equipment-associated changes, additional medical studies were added to both the Skylab 3 and 4 missions; these studies are shown in tables I and II. These additional studies demonstrate the flexibility afforded the medical team and the support given to this team by program management and the flightcrews.

TABLE I.- SPECIAL IN-FLIGHT TESTS ADDED

Test	Skylab 3	Skylab 4
Blood flow	X	X
Facial photograph	X	X
Venous compliance	X	X
Anthropometric measurements		X
Treadmill exerciser		X
Center of mass		X
Infrared anatomical photograph		X
Taste and aroma evaluation		X
Atmospheric volatile concentration		X
Light flash observations		X
Hemoglobin	X	X
Urine specific gravity	X	X
Urine mass measurement	X	
Stereophotogrammetry		X

TABLE II.- SPECIAL PREFLIGHT AND POSTFLIGHT TESTS

Test	Skylab 2	Skylab 3	Skylab 4
Echocardiography			X
Blood circulation time			X
Postural equilibrium test		X	X
Venous compliance		X	X
Muscle strength	X	X	X

TABLE III.- SKYLAB MEDICAL EXPERIMENTS

Number	Experiment
M071	Mineral balance
M073	Biochemistry of body fluids
M074	Specimen mass measurement
M078	Bone mineral measurement
M092	Lower body negative pressure
M093	Vectorcardiogram
M110	Hematology/immunology
M131	Human vestibular function
M133	Sleep monitoring
M151	Time and motion study
M171	Metabolic activity
M172	Body mass measurement

LIFE SCIENCES EXPERIMENTS

The Skylab medical studies listed in table III were designed along classical lines of medical and physiological research; that is, they were grouped in related studies according to their contributions to the understanding of the functioning of a major body system. The results from previous space flights influenced the planning for and the placement of emphasis in the new program. Experiments were developed to investigate the cardiovascular, musculoskeletal, hematologic, vestibular, metabolic, and endocrine systems. The performance of major medical experiments during flight provided a method of studying physiological changes as a function of exposure to weightless flight in contrast to the preflight and postflight studies performed for the Apollo missions and for all but one Gemini flight.

The equipment for the Skylab medical experiments (fig. 13) was located on the crew quarters level of the two-story OWS. The equipment occupied about one-third of the floor area of this level. The two consoles deployed against the OWS wall housed the electronic equipment related to the medical experiments.

Cardiovascular Studies

Two experiments were performed during the Skylab missions to study the responses of the cardiovascular system during weightless flight and on return to Earth and the one-g environment. The first of these experiments utilized an LBNP device to provide stress to the cardiovascular system. Continuous physiological observations were made on the responses to this stress. A photograph of a Skylab 2

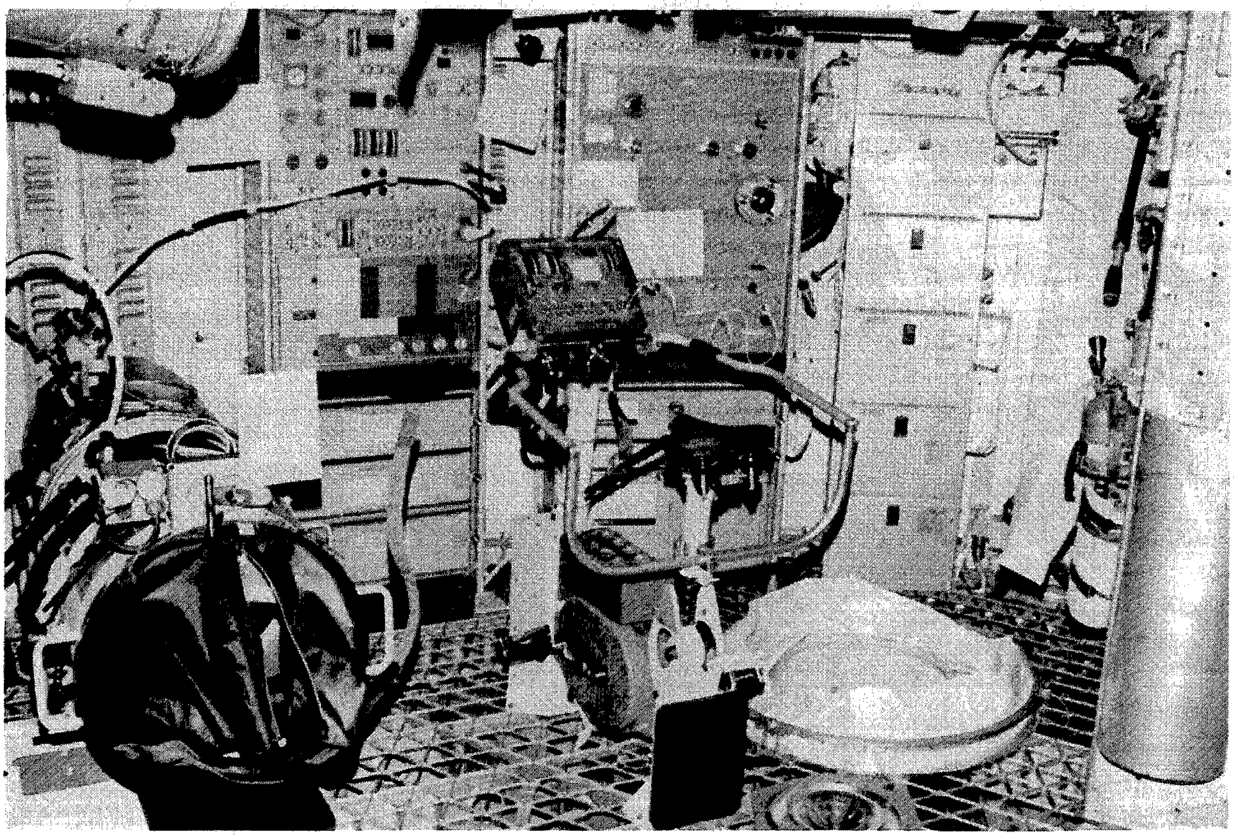

Figure 13.- Medical experiments (Skylab 3 photograph).

crewman in the LBNP device is shown in figure 14. The blood pressure cuff and the vectorcardiogram sensors were attached to the crewman. The elastic waist seal permitted negative pressure to be applied to the lower extremity of the crewman. A plot of the responses to a typical preflight protocol is shown in figure 15. The lower curve is the negative pressure levels applied for the 25-minute test. After an initial 5-minute rest period, negative pressure levels were applied at 4000, 5333, and 6666 N/m^2 (30, 40, and 50 torr) differential pressure for 5-minute intervals, followed by a 5-minute recovery period. The percentage of leg volume change furnished an estimate of the amount of blood pooling in the legs and is an index of peripheral vascular function. Diastolic and systolic blood pressures were measured every 30 seconds, and heart rate (obtained from the vectorcardiogram) rose from approximately 65 (baseline) to 80 beats/min at maximum negative pressure. A typical aborted protocol occurring on mission day 20 is shown in figure 16 and illustrates a presyncopal episode (early fainting symptons — sweating, lightheadedness, and tingling of extremities). In this test, 3 minutes into the 6666-N/m^2 (50 torr) pressure

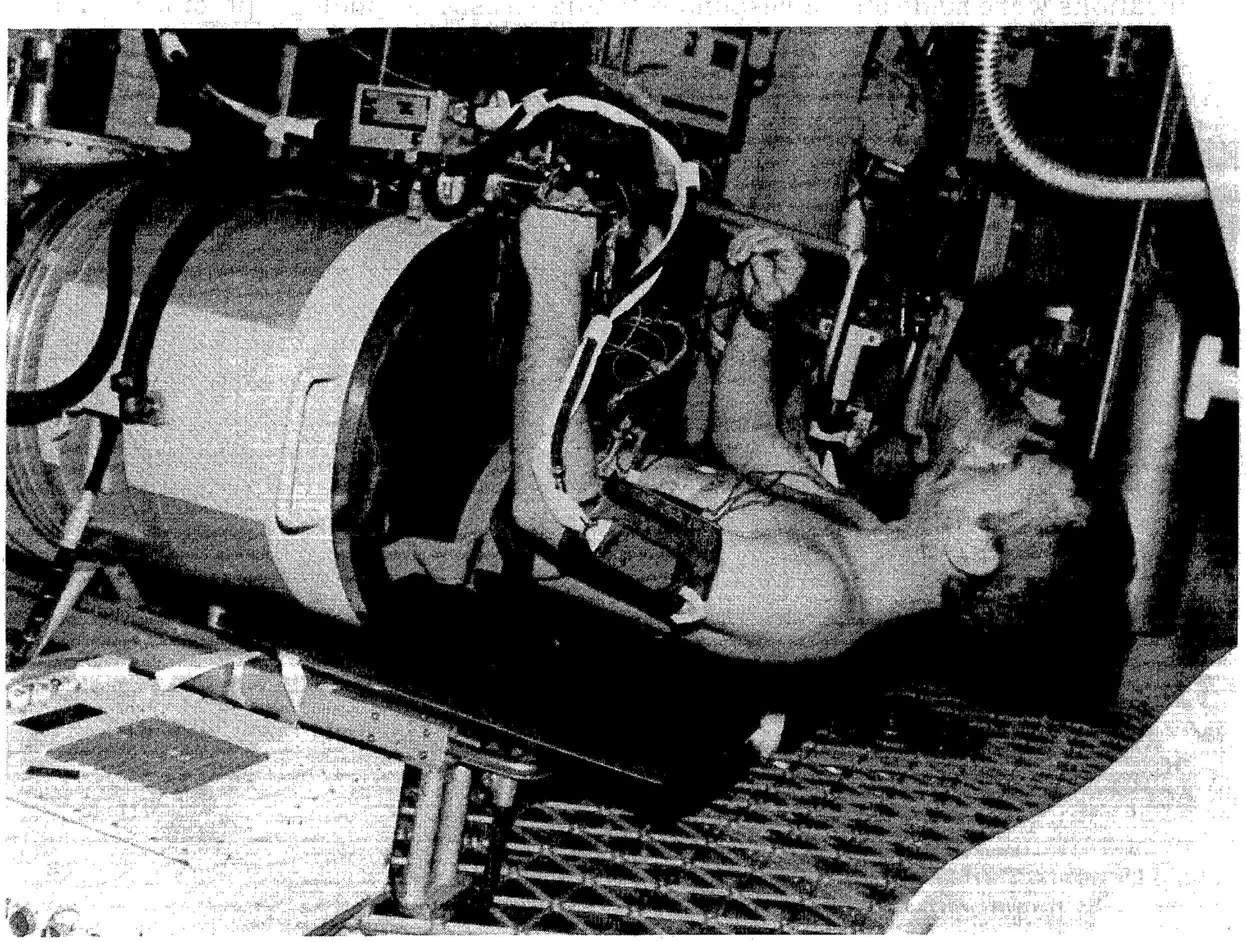

Figure 14.- Lower-body negative-pressure device in use.

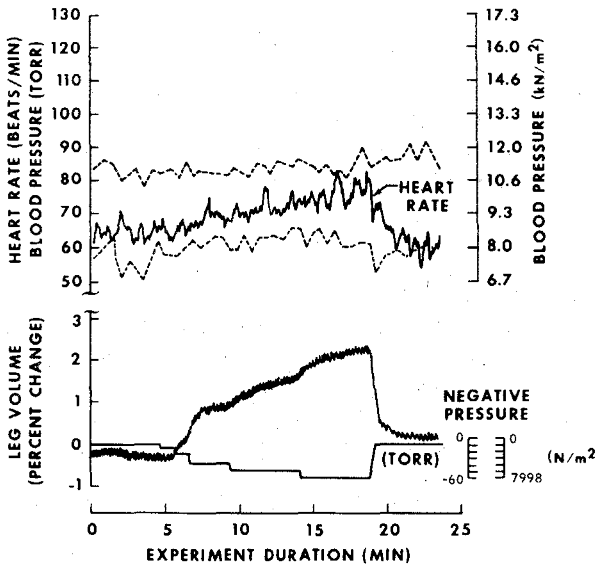

Figure 15.- Preflight response of Skylab 3 commander during LBNP test.

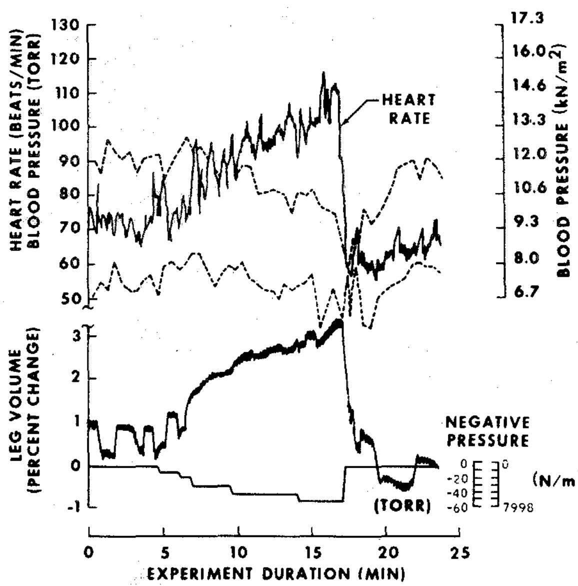

Figure 16.- In-flight (mission day 20) response of Skylab 3 commander during aborted LBNP test.

level, the subject elected to stop the test because of subjective symptoms. These were confirmed by the rise in pulse rate from 72 to 110 beats/min followed by a rapid decrease in heart rate. Systolic blood pressure fell rapidly and the pulse pressure narrowed. A comparison of mission day 58 in the Skylab 3 mission and the first test on recovery day is presented in figures 17 and 18. It is evident that the last in-flight LBNP test response was almost identical with that on recovery day.

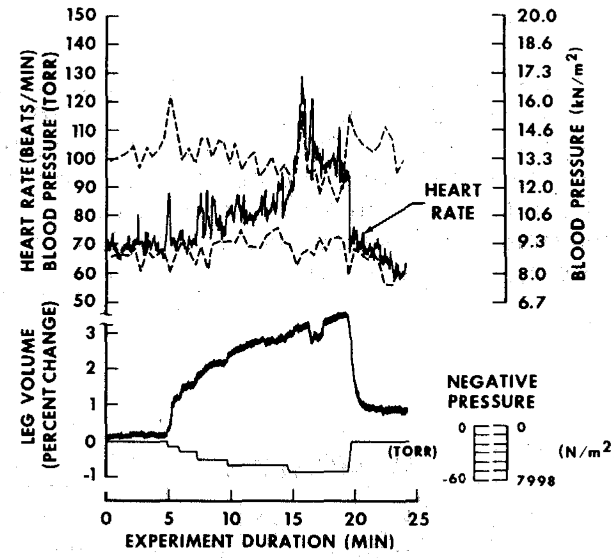

Figure 17.- In-flight (mission day 58) response of Skylab 3 commander during last LBNP test.

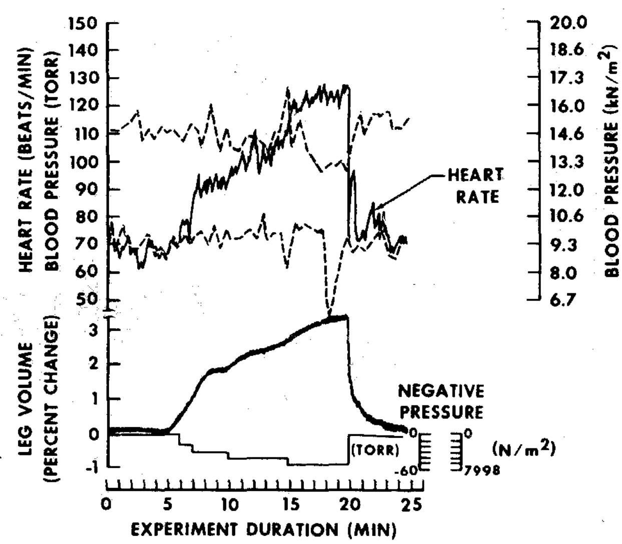

Figure 18.- First postflight response of Skylab 3 commander during completed LBNP test.

Throughout each mission, daily trend charts were maintained to determine whether significant changes in certain critical physiological measurements were occurring as the mission progressed. In the LBNP studies, heart rates at rest, at maximum negative pressure, and blood pressure data were plotted as a function of mission duration. The average resting heart rates for the crewmen during each of the three missions are summarized in figure 19. Preflight information was obtained to establish an individual baseline. During flight, resting heart rate was stable and slightly elevated for most crewmen. Postflight heart rates were determined in the supine position. The heart rates under 6666 N/m^2 (50 torr) negative pressure are shown in figure 20. In general, in-flight heart rates were elevated as compared with preflight rates. The arrows in figure 20 indicate the termination of an LBNP test during the flight. A total of 13 terminations occurred in 138 in-flight tests. Nine of the terminations took place in the first 26 days of the missions. Heart rates at maximum negative pressure on recovery day compared closely with those observed during the last LBNP test during flight.

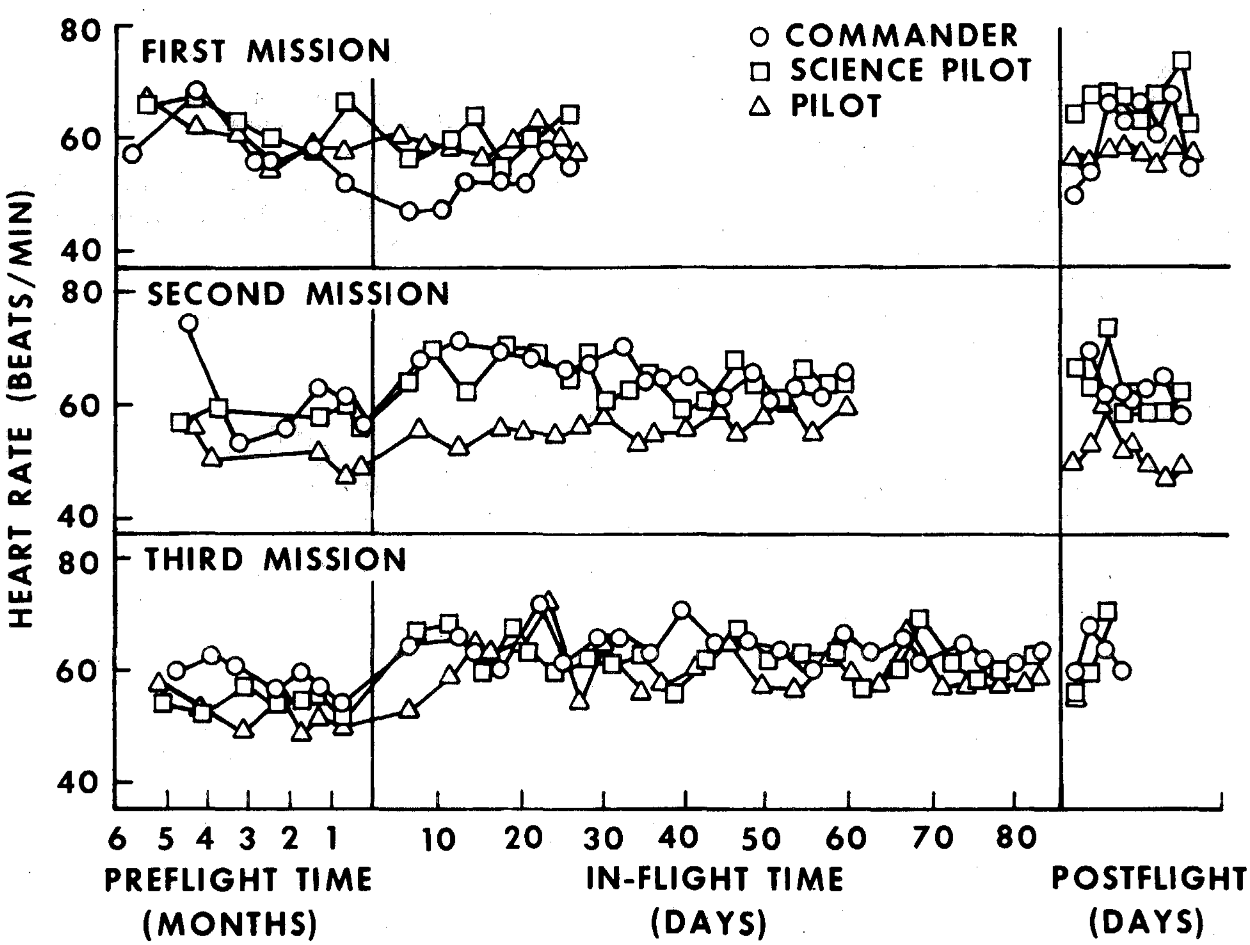

Figure 19.- Summary trend plot of crew resting heart rate.

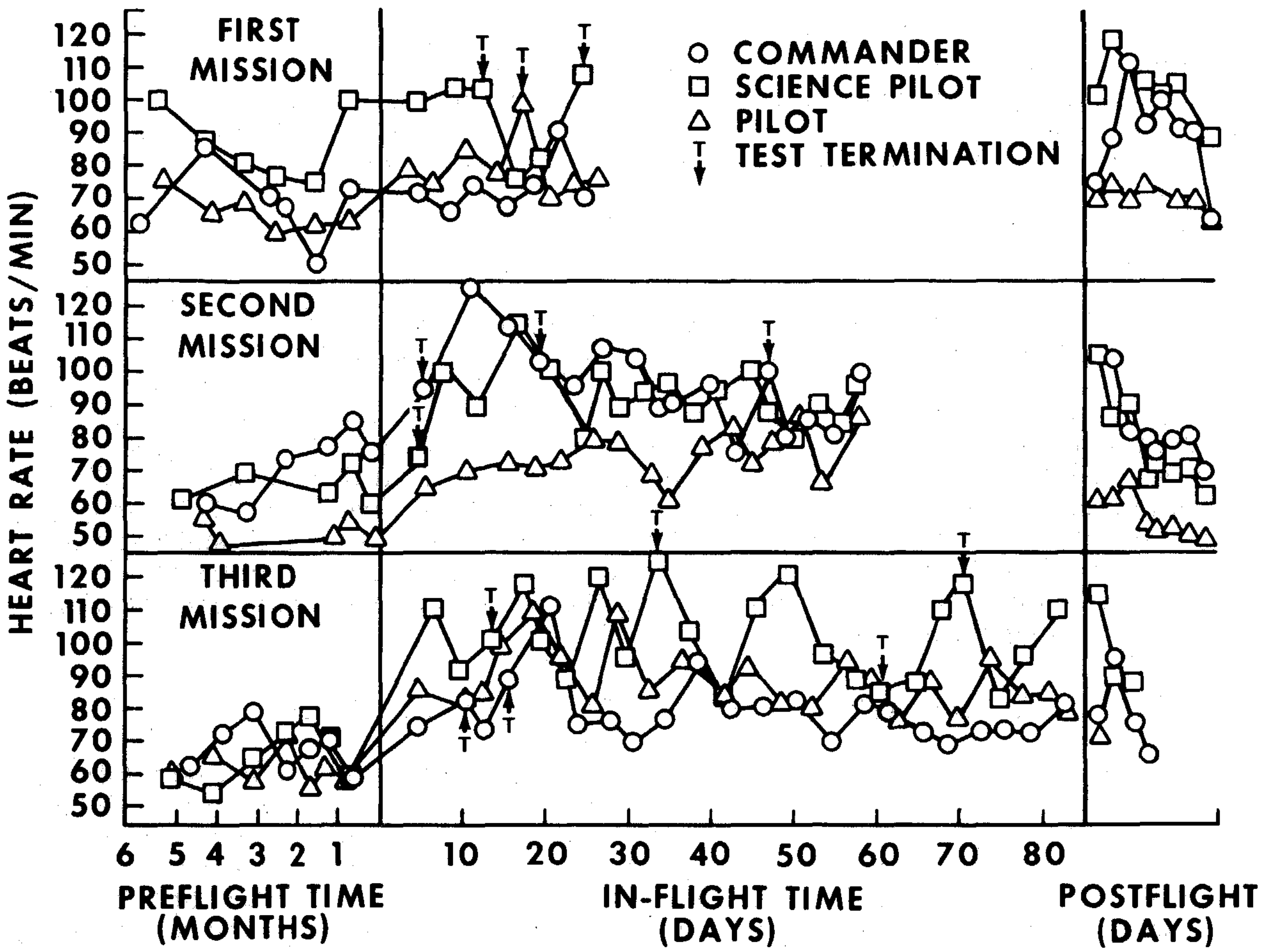

Figure 20.- Summary trend plot of crew responses to LBNP test at minus 6666 N/m^2 (50 torr) pressure.

The second cardiovascular experiment was designed to study changes in the electrical activity of the myocardium by vectorcardiographic measurement during exercise. This more comprehensive EKG provided a three-dimensional analysis of heart muscle electrical activity. Results of this experiment have shown very minor changes in electrical activity that are of no clinical significance. The reasons for these minute changes are not understood at this time.

In summarizing the results of the cardiovascular system evaluation, the following generalized comments can be made.

1. Cardiovascular deconditioning does occur during flight, but the change is adaptive in nature and stabilizes after a period of 4 to 6 weeks. This change does not impair crew health or performance in flight, and it is triggered by factors that tend to reduce circulating blood volume.

2. The LBNP test has proved to be a fairly reliable predictive index of postflight cardiovascular status. Cardiac arrhythmias have been rare: only one episode was noted early in the Skylab 2 mission during intensive personal exercise. This episode was interpreted as bursts of multiple, unifocal, ventricular, premature beats with no evidence of coupling. Other arrhythmias observed have been limited to isolated rare or occasional premature beats. Cardiac electrical activity has been within acceptable physiological limits as judged from the vectorcardiographic data.

3. The rapid postflight recovery of orthostatic and exercise tolerance after two of the three manned Skylab missions appears to be directly related to total in-flight exercise as well as to a graded, regular program of exercise during the postflight debriefing period. The postflight orthostatic intolerance and diminished exercise capacity are both related etiologically to a decreased effective circulating blood volume at one g, with consequent decreased venous return and cardiac output. Other factors to be considered are muscle imbalance, altered electrolyte flux, possible changes in venous tone or reflexes, and fatigue. No convincing incidence of myocardial damage as an etiological factor exists; however, transient cellular changes during the period of homeostatic perturbation would not be surprising.

Musculoskeletal Balance and Fluid/Electrolyte Studies

A series of experiments was performed to study calcium and nitrogen balance and the biochemistry of body fluids. In the mineral balance experiment, crew dietary intake was carefully controlled to maintain a nearly constant intake of electrolytes, proteins, and similar nutrients. The caloric intake level was established by the crew before flight to ensure adequate weight control and to satisfy appetites. Daily weights (fig. 21) were obtained on the body mass measuring device. Samples from the pooled daily urine output of each crewman were collected and returned to Earth with dried fecal residues for postflight analysis. Caloric intake was depressed early in all missions. This loss of appetite probably was associated with the motion sickness problems that occurred. Water intake and urine output remained relatively constant throughout all mission phases. In addition to these studies, mineral loss in selected bones was determined by a preflight and postflight measurement of bone density using a gamma ray scanning technique.

The significant findings in the musculoskeletal balance studies include the moderate loss of calcium, phosphorus, and nitrogen observed in the first two manned Skylab missions. Preliminary evaluation of data from the 84-day mission tends to support the general observation that these losses are comparable to those observed in subjects at bed rest. The average rate of loss observed was 6 grams of calcium per month or 0.5 percent of total body calcium per month. Complementary mineral losses in the os calcis were relatively low. These data indicate that missions of extended duration would be feasible without preventive or remedial measures.

The Skylab experience has provided evidence that the caloric requirements of space flight are identical with those for the individual on Earth – at least for high-activity missions such as Skylab. From Gemini and Apollo experience, it seemed that the individual in-flight caloric requirement was equivalent to approximately 1260 kJ/day (300 kcal/day) less than the caloric requirement on Earth. This judgment may have been influenced by the relatively low activity profiles of these missions and by the fact that the food provided was often not consumed. In retrospect, this anorexia may have been a manifestation of early motion sickness that was not recognized as such at the time.

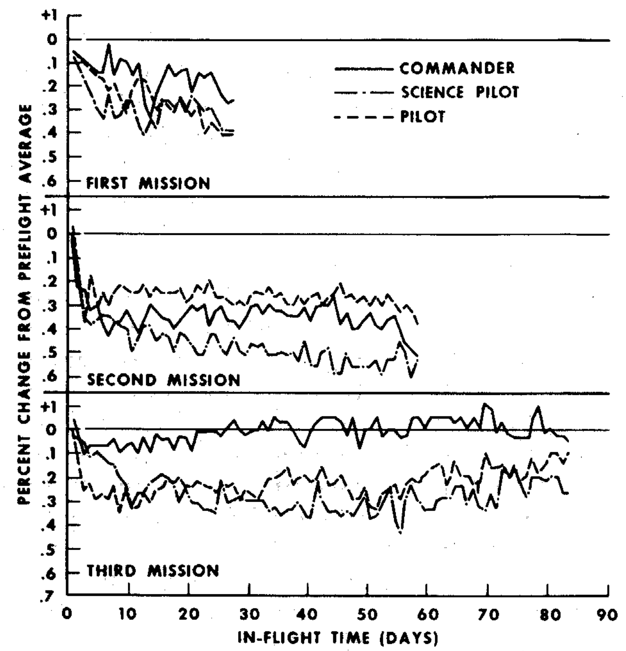

Figure 21.- Skylab crew health trend: body weight.

Renal function was unimpaired during flight because of a complex interplay of humoral and possibly hemodynamic factors. In addition, anthropometric studies performed on Skylab 4 support a cephalad shift of body fluids in zero g. With regard to the musculoskeletal system, the negative balances observed are due primarily to the absence of gravity. However, the correct combination of weight bearing, muscular activity, hormonal influence, and circulatory factors required to prevent these negative balances in bed-rest studies has not been defined at this point in time. Elevated cortisol secretion during flight helps to confuse the picture and doubtless contributes to nitrogen and potassium loss.

Sleep Studies

Sleep studies were performed on one crewman during each Skylab flight. The EEG signals were obtained from a specially designed cap (fig. 22). The crewmen wore the caps on selected nights in order to document sleep patterns. The EEG signals were recorded onboard and were converted by a simple computer system into digital telemetry signals that described the five stages of sleep. These sleep stages range from stage 1 (light sleep) to stage 4 (deepest sleep) and include rapid eye movement (REM) sleep or dream states. The sleep data from the three manned missions are summarized in figure 23. The percent of a single night's sleep spent in the various sleep stages and the total number of hours of sleep are shown. It is apparent that there was very little variation in the in-flight sleep patterns of the Skylab 3 crewman. Some variations were observed for the Skylab 2 crewman. The total number of hours of sleep was slightly reduced for the Skylab 2 crewman during flight, while the Skylab 3 crewman's hours of sleep were approximately the same as before flight. These preliminary data indicate that long-term weightless flight did not significantly alter the normal sleep patterns of the individuals studied. The results of these studies indicate that man is able to obtain adequate sleep during prolonged periods of time in space. The alteration in sleep patterns observed during Skylab missions was not significant and did not result in any degradation of performance. After flight, the crewmen exhibited some changes in sleep patterns that probably resulted from the readaptation to one g.

Figure 22.- Sleep-study cap worn by Skylab 2 crewman.

Blood Studies

Equipment was developed and flown to collect, process, and preserve in-flight blood samples (fig. 24). The crewmen acquired 10-milliliter blood samples with a conventional syringe and then transferred the whole blood into a preevacuated sample processor. The sample processor was then placed in a centrifuge to separate the plasma from the cells and to transfer the plasma into a separate collection vial for preservation. This transfer operation had to be accomplished automatically while the blood was being centrifuged because of fluid behavior characteristics at zero g. A cross-sectional drawing of the sample processor is shown in figure 25, which also illustrates how the equipment functions. Whole blood is transferred from the syringe through a septum into the processor. A spring-loaded piston is attached to the bottom of the sample processor, and the unit is placed in the centrifuge. During initial centrifugation, the cells and the plasma are separated. At this point, the centrifuge speed is increased to force the piston to drive the plasma vial septum past a needle and allow the plasma to flow into the vial. Following this separation, the plasma and blood cells are placed in a freezer and preserved for postflight analysis.

These in-flight blood samples and the preflight and postflight samples obtained from the crewmen were processed by a team of hematologists. Results have shown some loss in red blood cell mass, a decrease in plasma volume, and additional minor changes that are of no clinical significance. The loss in red blood cell mass appears to be a suppression of red cell production rather than a destruction of cells and apparently is not related to mission duration.

Exercise Capacity Studies

The in-flight response to exercise was studied through the use of a metabolic analyzer and a bicycle ergometer (fig. 26). In these tests, the crewmen exercised at three speed levels, and the physiological responses to this stress (heart rate, blood pressure, minute volume, oxygen consumption, and carbon dioxide production) were measured. The ergometry protocol was

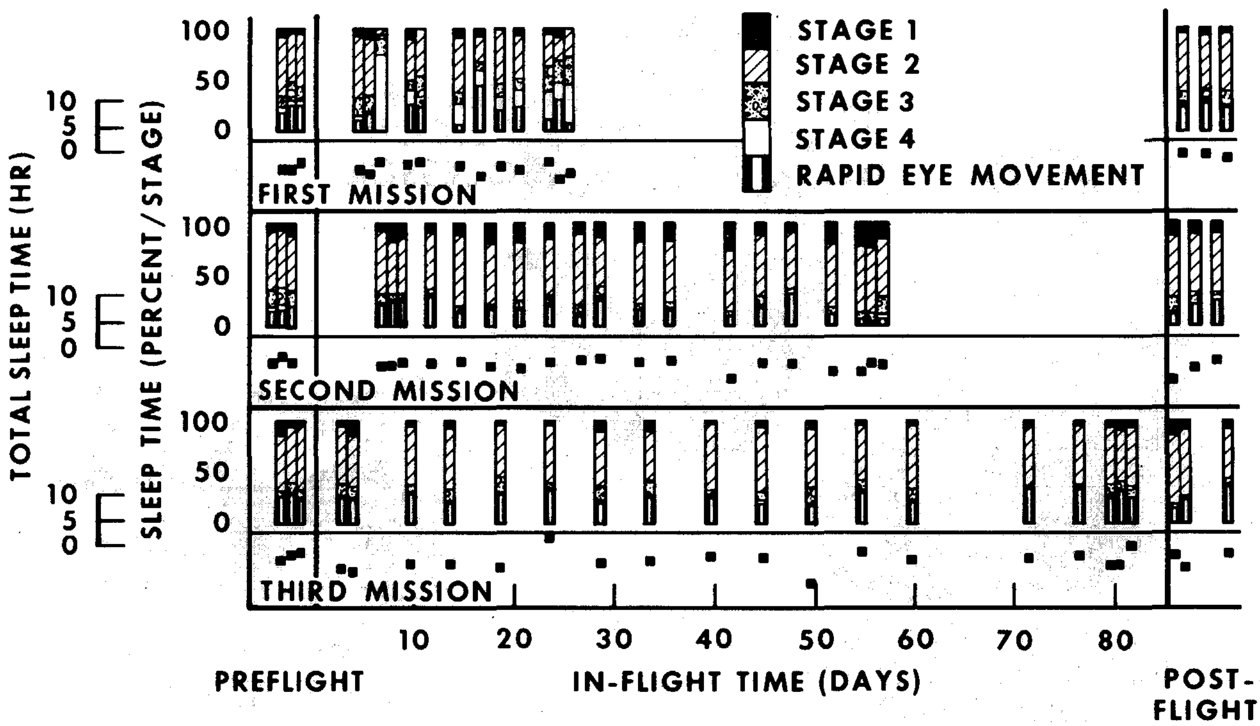

Figure 23.- Summary of Skylab sleep studies.

25 minutes in duration: 5 minutes at rest, 5 minutes at each of the three progressively higher work rates, and 5 minutes for recovery. In-flight results from these tests have shown no decrease in exercise or work capacity. Oxygen consumption and carbon dioxide production at given workloads were not altered. A plot of heart rate at maximum exercise levels is shown in figure 27. These data indicate that heart rate either decreased or remained stable during flight. All crewmen, however, showed a marked decrease in their response to exercise following recovery. Except for the Skylab 2 crewmen, this diminished exercise capacity returned to preflight levels 4 to 5 days after recovery. The reason for this decrease in postflight exercise capacity is not fully understood; however, it is believed that the apparent pooling of blood in the venous system after flight must contribute to this response.

Vestibular Studies

Vestibular function during flight was studied through the use of a rotating litter chair. One part of this study was the determination of susceptibility to motion sickness during rotation in the chair at varying rates of revolution with the concomitant performance of a series of head motions. The crewmen were trained to recognize the slightest symptom of motion sickness before flight, and their susceptibility or threshold was determined by this method. During flight, following an initial period of adaptation, all crewmen exhibited an increased tolerance to motion sickness as measured by an increased tolerance to higher rotation levels and an increased number of head motions without perceiving any motion sickness symptoms.

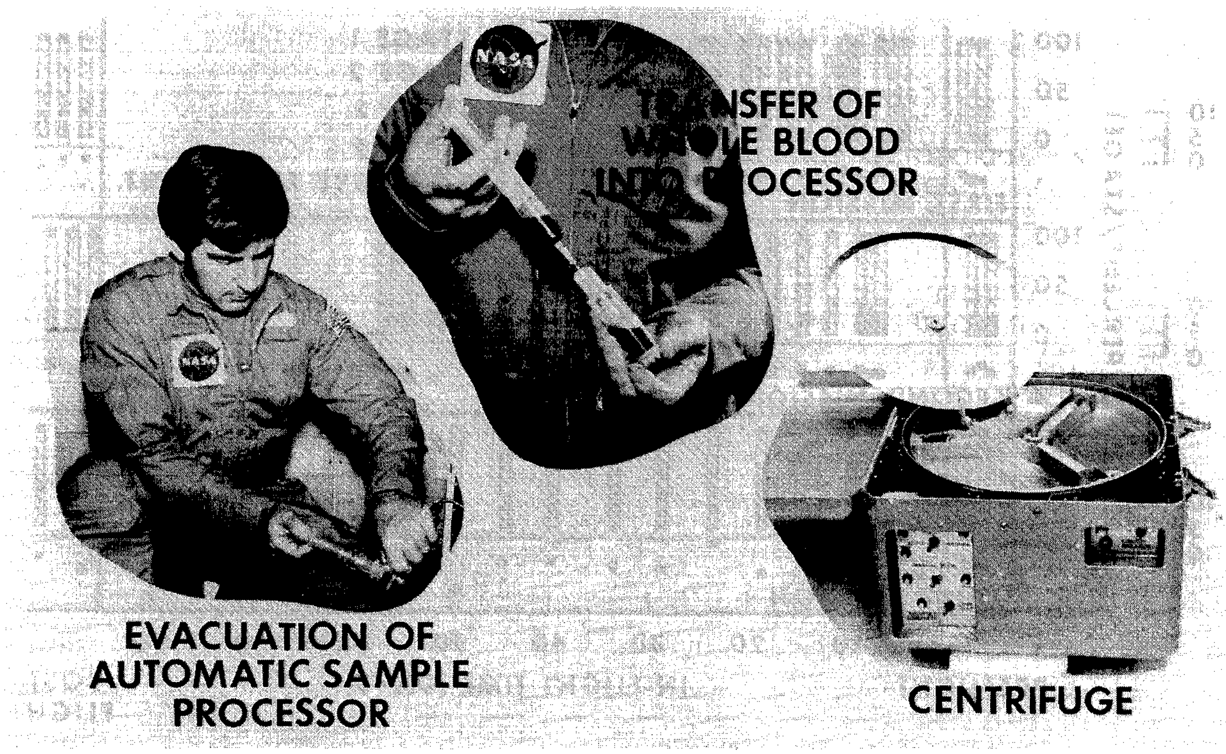

Figure 24.- Skylab in-flight blood collection system.

The individuals who demonstrated the highest preflight resistance to motion sickness as measured with the rotating litter chair were generally the individuals most susceptible to motion sickness during the first few days of the missions. This specific area of neurophysiology requires a more detailed investigation into the vestibular adaptive process and the fomulation of reliable preflight susceptibility (selection) tests. The use of anti-motion-sickness medications can provide protection to crewmen; however, the mechanisms involved in this complex problem must be understood more thoroughly.

Time and Motion Studies

In studies measuring in-flight performance capability, the crewmen were evaluated during the performance of a predetermined set of tasks. Ground-based studies established a baseline that permitted the investigator to evaluate skill retention and change in performance levels. Using the LBNP experiment as an example, the Principal Investigator has shown that the Skylab 4 crew exhibited progress in decreasing the time required to accomplish this complex experiment. By mission day 68, the crew had reduced the time required to accomplish the LBNP studies by 20 percent of their best preflight times.

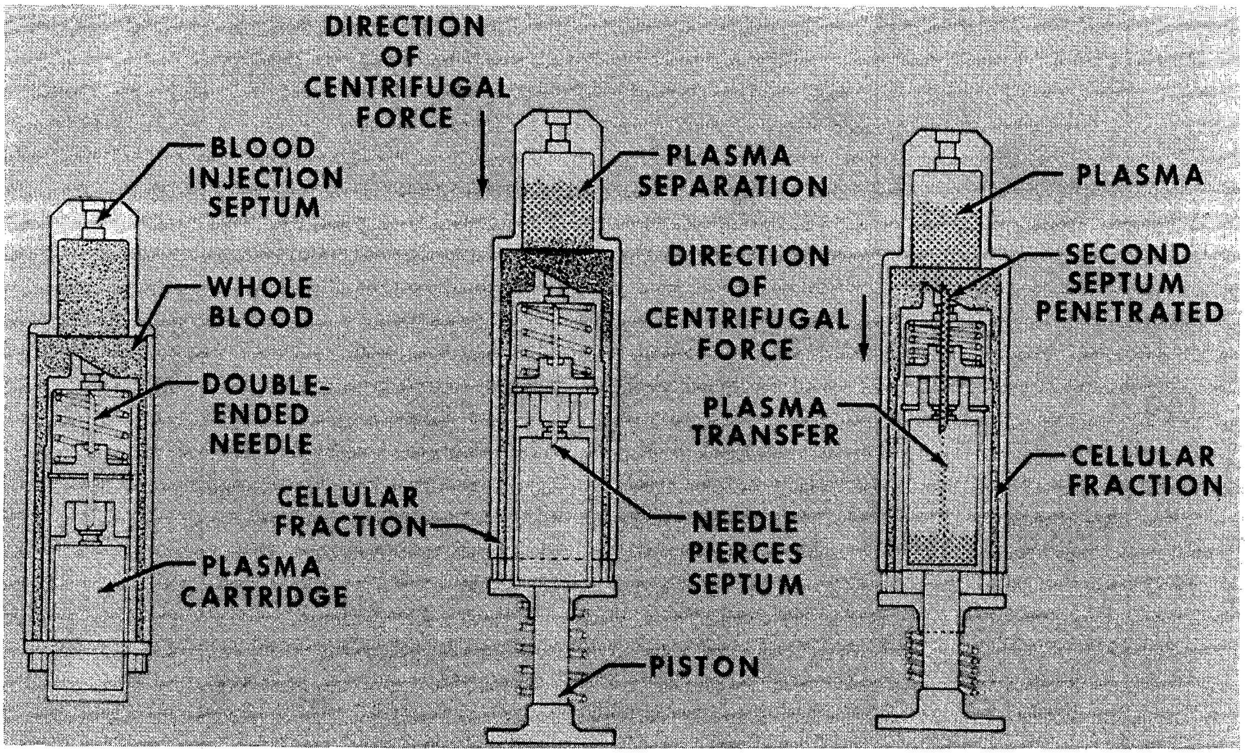

Figure 25.- Skylab blood sample processor.

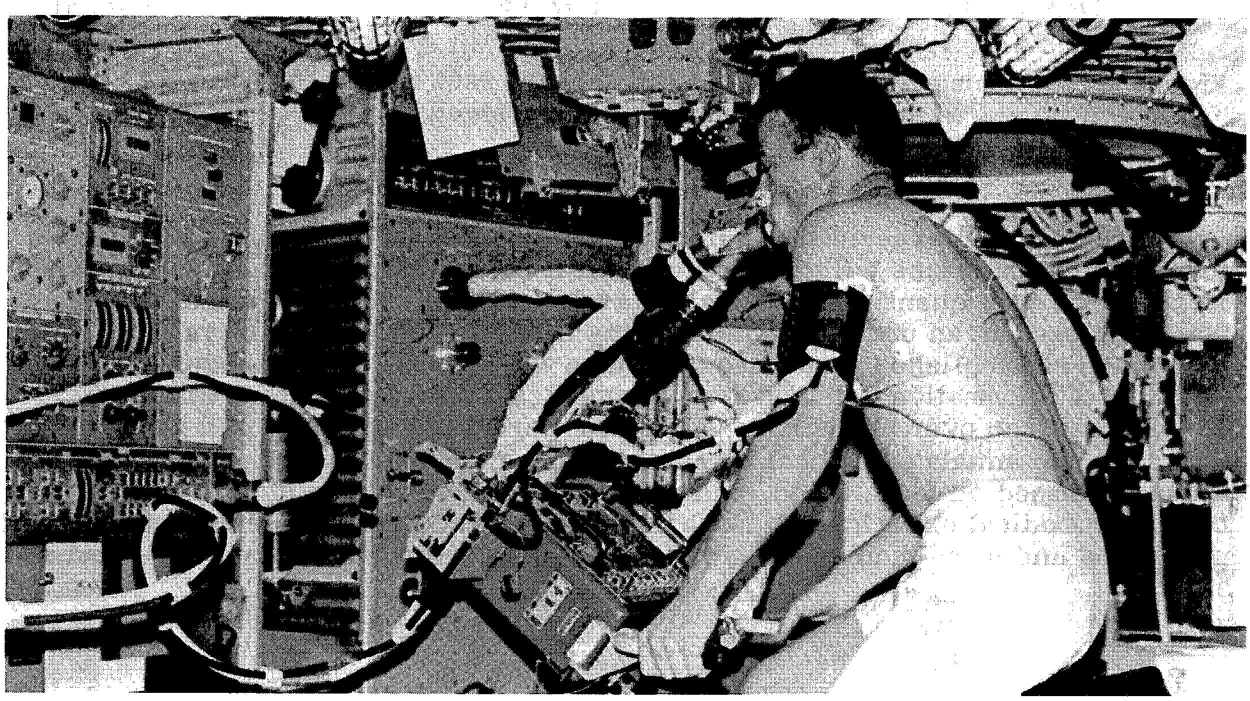

Figure 26.- Skylab 2 crewman performing exercise capacity study.

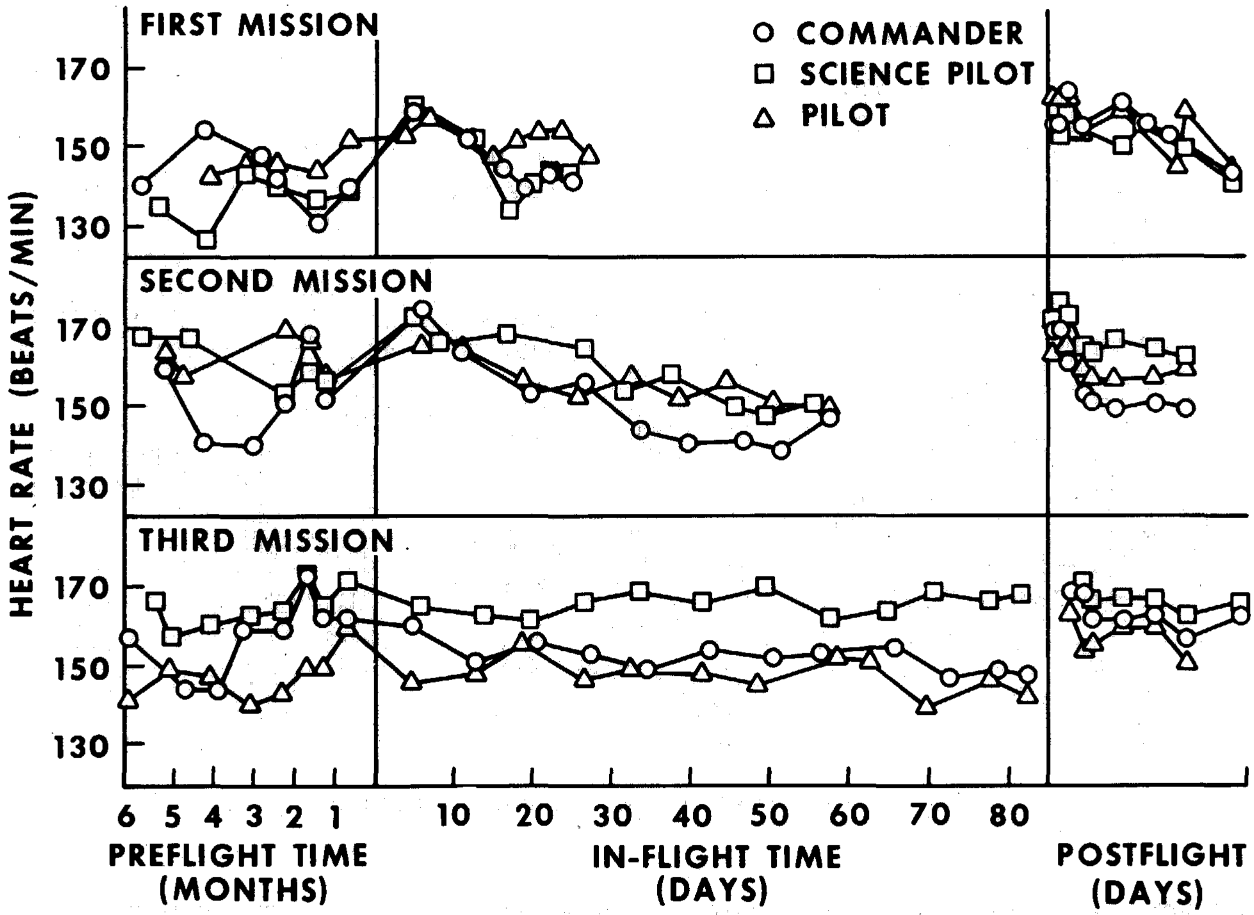

Figure 27.- Summary trend plot of crew heart rate responses to exercise at maximum exercise level.

The medical experiment equipment functioned flawlessly throughout the three manned missions. High-fidelity medical data were obtained for all experiments. The vast quantity of medical data available for reduction and analysis was processed in an orderly fashion. This reduction and analysis could not have been accomplished in a reasonable time without computer assistance. The quantity of information obtained from the medical studies conducted with the Skylab crewmen over a relatively short time period is staggering and perhaps unique in the annals of medical research. More than 700 000 biochemical analyses were performed on food, blood, and urine and fecal samples. In completing two of the major medical experiments, more than 18 000 blood pressure determinations were performed and more than 12 000 minutes of vectorcardiographic data were obtained.

CONCLUDING REMARKS

Most of the biomedical problems predicted during the early years of manned space flight relative to man and the space environment did not materialize during the total 171 days of the Skylab manned missions. Those physiological alterations that were documented by the Skylab medical experiments were generally accommodative in nature and were not serious enough to impair the ability of the crewmembers to work effectively in the weightless environment. In general, the Skylab medical findings confirmed and extended those of the shorter Mercury, Gemini, and Apollo flights.

Crewmen were carefully studied during the preflight, in-flight, and postflight phases of each Skylab mission. The principal findings resulting from the intensive Skylab biomedical studies were space motion sickness during early flight, moderate bone mineral losses comparable to those observed in man during prolonged bed rest, moderate cardiovascular deconditioning, and reduced effective circulating blood volume as reflected by the loss of red cell mass and plasma volume. In the early postflight phase, orthostatic intolerance was observed similar in degree to the late-mission responses to lower body negative pressure. Exercise intolerance was not observed during flight but was characteristic of the early postflight period.

Despite the foregoing observations, the Skylab medical experience has emphasized the ability of man to live and work effectively in space for extended periods of time. Appropriate nutrition, programed adequate sleep, work, exercise and recreation periods, and suitable work areas must be provided to maintain crew health and well-being.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, March 12, 1975
951-17-00-00-72

REFERENCES

1. Space Medicine in Project Mercury. NASA SP-4003, 1965.

2. Gemini Summary Conference. February 1-2, 1967, Manned Spacecraft Center, Houston, Texas. NASA SP-138, 1967.

3. Gemini Midprogram Conference, Including Experiment Results. February 23-25, 1966, Manned Spacecraft Center, Houston, Texas. NASA SP-121, 1966.