JSC-08963

SKYLAB MISSION REPORT
THIRD VISIT

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Houston, Texas
July 1974

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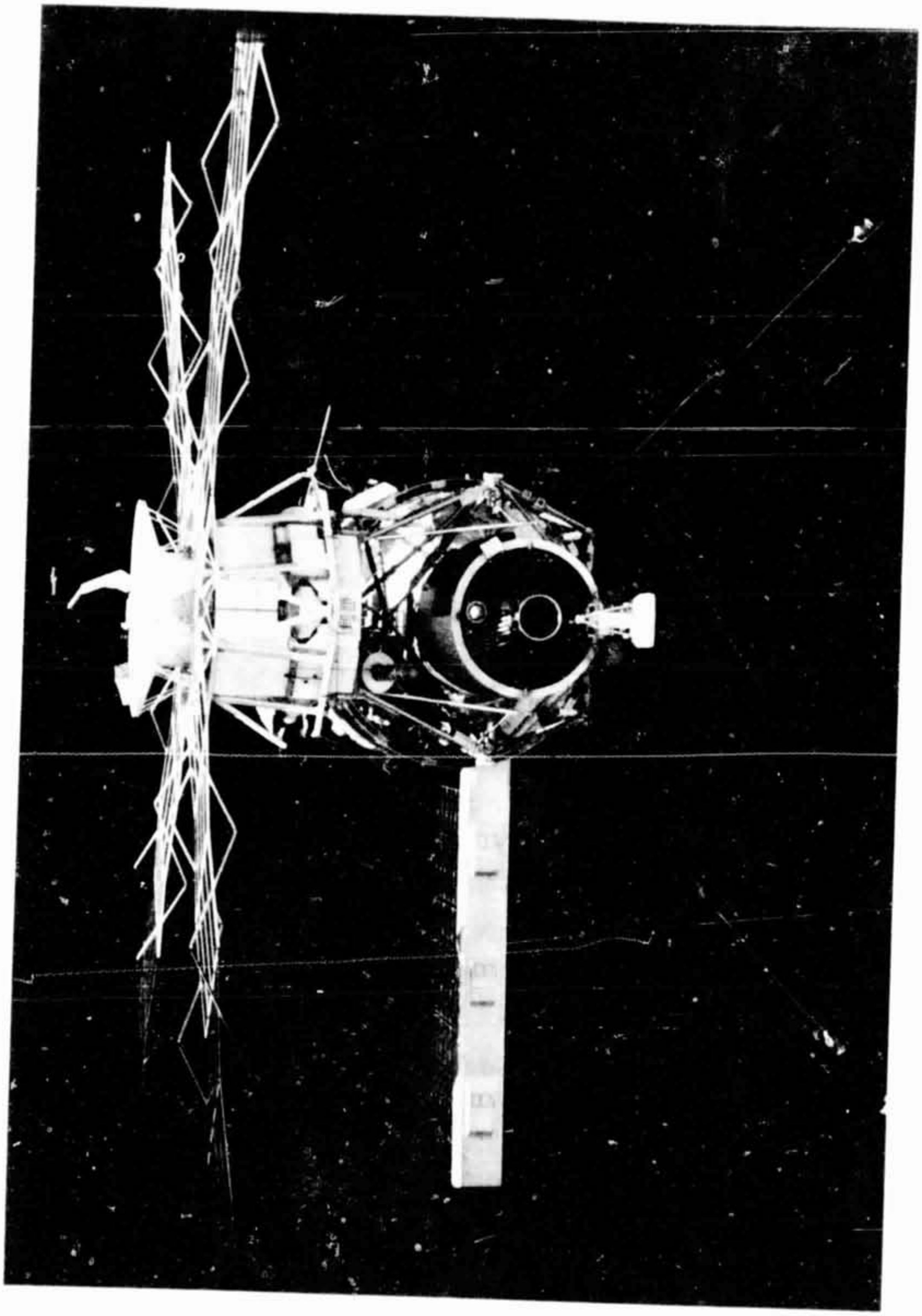

Saturn Workshop

FOREWORD

The Skylab program was established to determine man's ability to live and work in space for extended periods; to determine and evaluate man's physiological responses and aptitudes in the space environment and his postflight adaptation to the terrestrial environment; to extend the science of solar astronomy beyond the limits of earth-based observations; to develop improved techniques for surveying earth resources from space; and to expand the knowledge in a variety of other scientific and technological regimes.

The program activity was planned for four distinct phases of operation:

a. The placement of a Saturn Workshop into earth orbit;

b. The first visit, intended for a period of 28 days;

c. The second visit, intended for a period of 56 days, but extended to 59 days; and

d. The third visit, also intended for a period of 56 days, but extended to 84 days.

This report constitutes the Johnson Space Center's evaluation of the third Skylab visit. The report contains the information available 90 days after the completion of the visit.

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1.0 INTRODUCTION

This report contains an evaluation of operational and engineering aspects of the third Skylab visit. It includes the performance of the command and service module and the experiment hardware under Johnson Space Center management; the crew's evaluation of the visit; and other visit-related areas of interest such as biomedical observations. Where continued evaluation has resulted in the modification of findings reported previously, the new findings are included herein. Launch vehicle performance is contained in reference 1. Scientific results will be reported in accordance with reference 2.

In areas where applicable, a summary of system or experiment performance during all three visits of the Skylab mission is included. The information in the summary statements concerning the first two visits was extracted from references 3 and 4.

The command and service module consisted of basic hardware developed for the Apollo program. A description of the command and service module systems is given in reference 5. Descriptions of items furnished for the first time or which have not been described previously are contained in appendix A of this report.

The international system of units (SI) is used with the exception of certain units used in physiological measurements. Unless otherwise specified, time is expressed as Greenwich mean time (G.m.t.) in hours, minutes, and seconds, or in hours and minutes.

2.0 SUMMARY

The third visit space vehicle was launched at 14:01:23 G.m.t. (9:01:23 a.m. e.s.t.) on November 16, 1973, from Launch Complex 39B at the Kennedy Space Center, Florida. The vehicle was manned by Lt. Col. Gerald P. Carr, Commander; Dr. Edward G. Gibson, Scientist Pilot; and Col. William R. Pogue, Pilot. The launch was originally scheduled for November 10, 1973; however, an inspection of the launch vehicle revealed cracks in the first stage fins and the decision to replace all of the fins necessitated the launch delay. The planned duration of the visit was 56 days with the option of extending it to a maximum of 84 days, which was achieved.

The space vehicle consisted of a modified Apollo command and service module and a Saturn IB launch vehicle. All launch phase events were normal and the command and service module was inserted into a 150.1- by 227.08-kilometer orbit. The rendezvous sequence was performed according to the nominal timeline. Stationkeeping was initiated about 7 1/2 hours after lift-off and hard docking was achieved about 30 minutes later following two unsuccessful docking attempts.

Orbital Workshop activation was accomplished during visit days 2 through 4. Included in the activation was the reservicing of the Airlock Module primary coolant loop.

The Commander and Pilot experienced symptoms resembling motion sickness during the initial 3 days of the visit and the flight plan activities were adjusted accordingly. Crew health was good thereafter. The same medical experiments conducted during the first and second visits were continued during the third visit to assess the effects of the space visit on the crewmen. However, some changes were made in protocols and many new medical detailed test objectives were added.

Earth Resources Experiment Package observations were conducted throughout the visit. Thirty-nine data passes were performed with the full complement of instruments operating, and several additional data passes were made for special purposes such as instrument calibration. Although the data acquisition sites were mostly concentrated in the United States, Mexico, and South America, data were also obtained while over Europe, Africa, Asia, and Australia. In addition to the Earth Resources Experiment Package observations, about 850 visual observations and more than 2000 photographs were taken by the crew using hand-held cameras to document specific areas of interest on the earth.

The Apollo Telescope Mount was operated by the crew for a total time of approximately 519 hours with over 337 hours of solar, stellar, and Comet Kohoutek data being obtained. Some of the significant accomplishments were obtaining coverage of the Comet Kohoutek, a solar eclipse, the brightest coronal transient observed during the Skylab program, and two solar flares which included flare rise.

Twenty-eight experiments in the fields of astrophysics, engineering, and technology were included in the third visit and 235 crew man-hours were devoted to their performance. More than 200 man-hours were devoted to Comet Kohoutek observations with six special experiments plus the Apollo Telescope Mount instruments.

Orbital activities included four periods of extravehicular activity totaling approximately 22 1/4 hours. The first extravehicular activity was accomplished on visit day 7 and lasted 6 hours 34 minutes. The primary purpose of the activity — installation of film magazines in the Apollo Telescope Mount cameras — was accomplished satisfactorily. Other tasks accomplished included performing corrective maintenance on the experiment S193 (Microwave Radiometer/Scatterometer and Altimeter) antenna, deploying panels of experiment D024 (Thermal Control Coatings), deploying impact detectors of experiment S149 (Particle Collection), deploying detector modules of experiment S228 (Trans-Uranic Cosmic Rays), and deploying collector assemblies of experiment S230 (Magnetospheric Particle Composition).

The second and third extravehicular activiti. were conducted on visit days 40 (Christmas Day) and 44 to allow extravehicular photography of the Comet Kohoutek prior to and after perihelion. The instruments for experiments S201 and T025 were used for this purpose. Experiment S020 (X-Ray/Ultraviolet Solar Photography) was also conducted on the second and third extravehicular activities. Other tasks performed during the visit day 40 extravehicular activity consisted of replacing film magazines in the Apollo Telescope Mount cameras, pinning open the door of experiment S082A (Extreme Ultraviolet Spectroheliograph), manually repositioning the filter wheel on experiment S054 (X-Ray Spectrographic Telescope), and retrieving experiment S149 impact detectors. The duration of the second extravehicular activity was 6 hours 54 minutes, and the duration of the third extravehicular activity was 3 hours 29 minutes.

The fourth and final extravehicular activity was performed on visit day 80. The major tasks accomplished consisted of retrieval of the Apollo Telescope Mount film, an additional performance of experiment S020, and performance of experiment T025. Other tasks consisted of retrieval of modules, panels, assemblies and samples that were to be returned to the ground for analysis, and deployment of cassettes and panels for potential retrieval in the future. The duration of the fourth extravehicular activity was 5 hours 19 minutes.

The command and service module was undocked from the Saturn Workshop at about 10:28 G.m.t. on February 8, 1974. A flyaround inspection of the Workshop was made following undocking. Prior to entry, the crew was advised to disable reaction control system 2 because of a suspected propellant leak and the entry was made using only system 1. The command module landed in the Pacific Ocean at 15:16:54 G.m.t. on visit day 85 for a flight duration of 84 days 1 hour 15 minutes 31 seconds. The landing point was 289 kilometers southwest of San Diego, California. The spacecraft went into the stable II attitude upon landing but was uprighted normally and the command module and crew were taken aboard the recovery ship *U.S.S. New Orleans* approximately 40 minutes after landing.

With this third visit landing, the Skylab mission was concluded. The total flight time for the three visits was 4117 hours 14 minutes and 24 seconds during which the nine crewmen accrued a total of 12 351 hours 43 minutes and 12 seconds of flight time.

3.0 SCIENCE

3.1 SOLAR PHYSICS AND ASTROPHYSICS

Experiments S019 (Ultraviolet Stellar Astronomy), S020 (X-ray/Ultraviolet Solar Photography), S063 (Ultraviolet and Visible Earth Photography) and S201 (Extreme Ultraviolet Electronographic Camera) were performed using the anti-solar scientific airlock. Solar exposure of experiment S149 (Particle Collection) was achieved by extravehicular deployment during the visit. Experiment S230 (Magnetospheric Particle Composition) was a passive experiment that required extravehicular retrieval of collector foils during the visit. Experiment S232 (Barium Plasma Observations) was performed from the command and service module windows in conjunction with an earth-launched rocket.

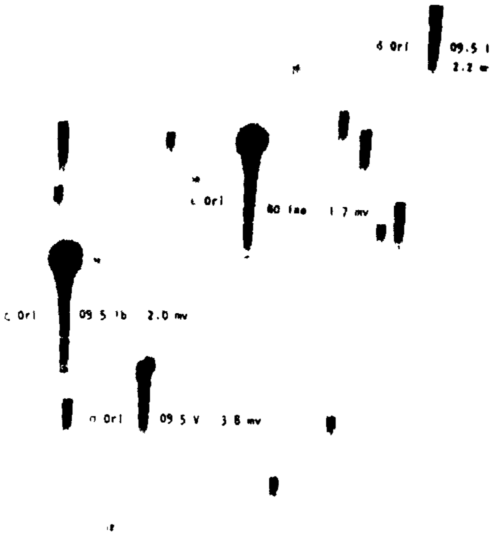
3.1.1 Experiment S019 - Ultraviolet Stellar Astronomy

The S019 experiment recorded stellar spectra in the 1300 to 5000 angstrom range from an objective prism spectrograph. The experiment objectives for the third visit were primarily based on obtaining spectra from Milky Way star fields and Comet Kohoutek. (A discussion of Comet Kohoutek observations is given in sec. 3.2.1.) Experiment operations on the third visit resulted in 121 frames of 60 star fields. Figure 3-1 is an example of two star fields photographed with the S019 experiment. Typically, a frame of experiment data contains one star with spectra extending to 1500 angstroms and four stars with spectra extending to 2000 angstroms per star field.

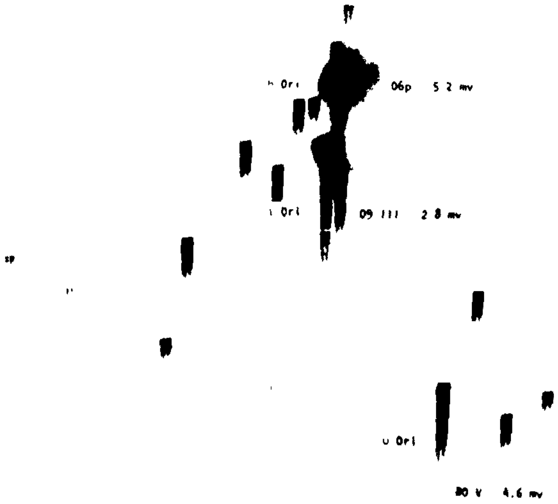
The replacement mirror for the articulated mirror system was installed on visit day 10. The crew commented that the new mirror was dustier than the old mirror and that three faint, narrow, white streaks were observed near the edge of the new mirror. A slight hand-mark smudge was inadvertently made on the new mirror surface during installation.

On visit day 11, the crew reported that the reticle light was not on when film canister 003 was used. The reticle light apparently was not turned off following the visit day 10 operations and this allowed the battery to discharge. When film canister 002 was used on visit day 27, its reticle light functioned properly.

On visit day 39, a problem was experienced with film canister 002 when the handle could not be moved into the slide retract position. On visit day 58, the canister was believed to have been restored to service when extra force was applied to the handle. While off-loading the film after the visit a slide was found jammed at an angle in the exposure gate track preventing the carriage from extending. Section 16.2.3 contains a discussion of this anomaly.



a) Starfield in region of Orion's belt.



b) Starfield in region of Sword.

The supergiant stars ζ and ε Orionis show very broad absorption lines with redward emission at C IV λ1548 (a) and at Si IV λλ1394, 1403, (b). The fact that these features are strongly correlated to the luminosity of the star is strikingly illustrated by the spectra of main sequence stars σ and μ Orionis in which only weak, sharp absorption at C IV is seen. In the giant stars δ and ι Orionis the Si IV features are much weaker than in the supergiants and emission at C IV is significantly weaker.

Figure 3-1.- Luminosity effects in experiment S019 ultraviolet spectra of early-type stars.

The articulated mirror system tilt and rotation unit counter condition worsened during this visit. On visit day 29, the crew reported seeing flakes of paint floating inside the rotation counter housing. On visit day 48, while the articulated mirror system was being used with experiment S063, the crew reported that the rotation counter hundreds and tens belt was not functioning. A malfunction procedure which enabled positioning the mirror to the nearest 175 milliradians by counting the number of revolutions of the rotation handle was used by the crew. The functioning units and tenths wheels of the counter were then used for the fine settings. This procedure allowed the articulated mirror system to remain functional for the balance of the visit. Section 16.2.4 contains a discussion of this anomaly.

On visit day 53, a problem occurred with film canister 003 when the handle could not be moved into the slide retract position using normal force. When approximately three times the normal force was applied, the handle moved. When the film was off-loaded after the visit, a loose nylon retainer was found. Section 16.2.3 contains a discussion of this anomaly.

The output stacks of film canisters 002 and 003 contained 56 and 81 transferred slides, respectively. A preliminary review of the experiment S019 film indicates that the spectra quality are good and fully recoverable by spectrophotometry but some film fogging did occur (about the same level as seen on the second visit film). Visual inspection of the spectra indicate that the ultraviolet reflectivity was improved by the mirror change.

3.1.2 Experiment S020 - X-Ray/Ultraviolet Solar Photography

The S020 experiment recorded solar spectra in the 10 to 200 angstrom range with a grazing incidence diffraction grating spectrograph. The experiment was originally planned to be operated from the solar scientific airlock; however, after the use of this airlock was lost to experiments because of the parasol deployment on the first visit, the experiment operations were performed during extravehicular activities. All hardware components functioned satisfactorily.

Nine photographs of the sun were taken during three of the four extravehicular activities of the third visit. The functional objectives for experiment S020 as revised for extravehicular operation were successfully completed and one of the major original objectives (spectra of a solar flare) was also obtained during one of the exposures. Solar spectral data exposures were made as follows:

a. Visit day 40 - four exposures (60, 30, 13, and 7.5 minutes)

b. Visit day 44 - one exposure (45 minutes)

c. Visit day 80 - four exposures (60, 30, 7.5 and 4 minutes)

Figure 3-2 shows two of the exposures from the third visit operations. On each of the photographs, more than 70 lines were recorded in the 111 to 205 angstrom range. These spectra are superior to others taken of this region; however, the quantity of spectral lines is significantly less than expected with almost no data obtained in the short wavelength portion below 110 angstroms. One exposure was lost because of an empty slot in a film magazine resulting from human error during preflight film loading.

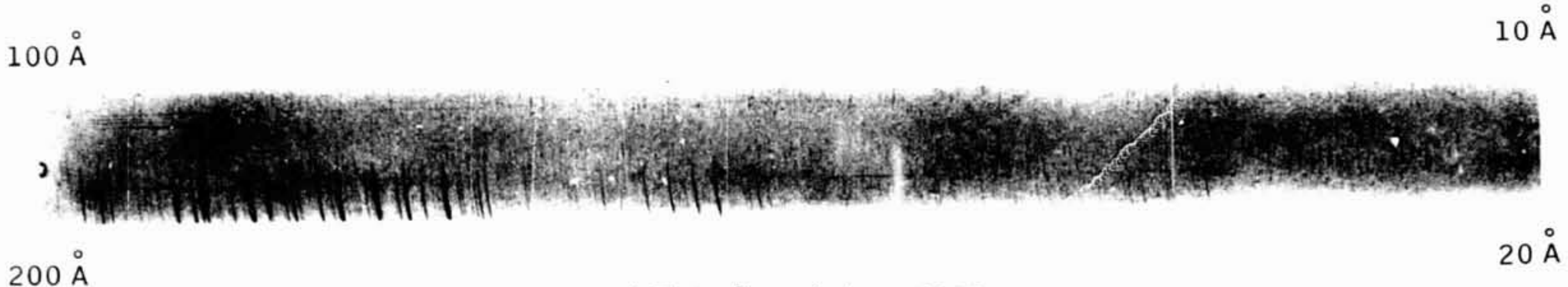
The lack of short wavelength data necessitated the measurement of filter transmission after recovery. The short wavelength (indium) filter had zero transmission below 110 angstroms, whereas the long wavelength (beryllium) filter had only slight degradation at wavelengths greater than those observed by this experiment. Spare filters of both types from the same manufactured lot as the flight filters showed no degradation when tested. The most probable cause of the zero transmission is contamination.

3.1.3 Experiment S063 - Ultraviolet and Visible Earth Photography

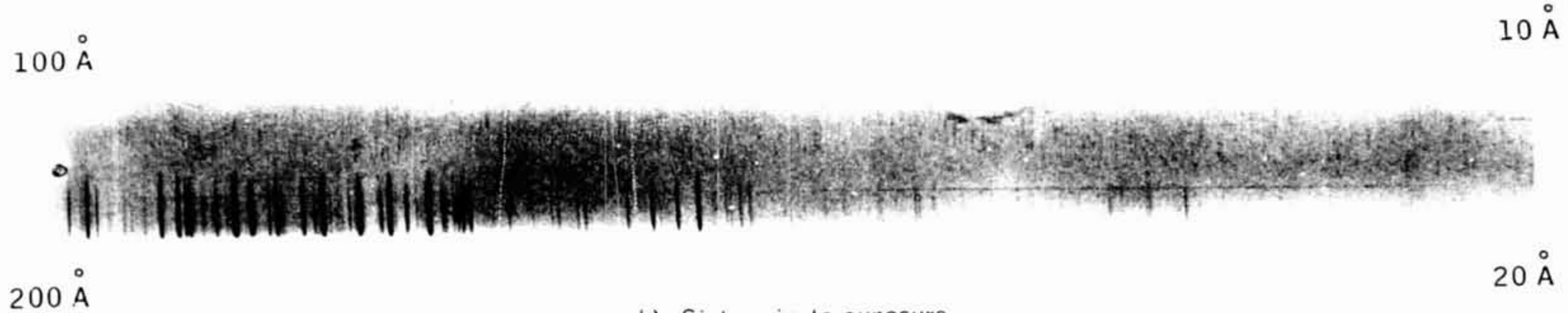
A total of 497 experiment S063 photographs were taken during the third visit. Photographs were made with the motor-driven 35-mm cameras, using various filter, lens and film combinations. The experiment objectives, which were to obtain spatial and spectral information on the earth's airglow, upper atmospheric ozone, auroras, noctilucent clouds and Comet Kohoutek, were successfully completed. The use of the experiment hardware for the comet observations is discussed in section 3.2.2.

Data were accrued in three modes during this visit. The ozone photographic mode was accomplished in the normal manner at the -Z axis scientific airlock and the wardroom window. The airglow photographic mode was accomplished by utilizing the experiment S063/articulated mirror system adapter and the articulated mirror system at the -Z scientific airlock. The 35-mm camera was also utilized in a hand-held mode at the windows for noctilucent cloud photography.

During the first airglow photography on visit day 26, manual operation of the camera was required because the battery had not been placed in the timer during experiment preparations. Another timer problem was caused by a discharged battery on visit day 30. The problem was corrected by installing a new battery and, after removal, taping it to the housing after each usage.



a) Forty-five-minute exposure.



b) Sixty-minute exposure.

Figure 3-2.- Typical examples of experiment S020 exposures.

The optical sight reticle could not be illuminated on visit day 30 because of a discharged battery. A malfunction procedure was uplinked which consisted of taping two C-cell batteries in series with two multimeter leads and plugging these into the battery housing. This allowed the reticle to be restored on visit day 55 for the remainder of the mission.

A preliminary visual review of the film indicates some large variations in image quality, thus the evaluation of data quality and the degree of experiment success will require some film processing enhancements and microdensitometry.

An out-of-focus condition when using camera 02 during the visit greatly reduced the usefulness of the ozone photography, and virtually negated the scientific value of the airglow photography. This anomaly is discussed in section 16.3.3.

3.1.4 Experiment S149 - Particle Collection

The S149 experiment collected micrometeorite data to support mass distribution, composition, and morphology studies of cosmic dust. One set of the experiment S149 collector cassettes was deployed by the third visit crew during the first extravehicular activity on visit day 7 and was retrieved during the second extravehicular activity on visit day 40. Another set of collector cassettes was deployed during the fourth extravehicular activity on visit day 80 for retrieval if the Orbital Workshop is ever revisited. The functional objectives for this experiment were successfully completed.

Generally, little evidence of particulate contamination exists. A silver slide and several copper slides were oxidized, but to a lesser extent than on the first solar exposure during the second visit.

A preliminary review of the cassettes has confirmed that a successful scientific exposure was obtained. These data are considered extremely valuable as are the data from previous exposures. The detailed analysis is in the initial stage and the first crater has been found.

Figure 3-3 is an electron micrograph of an impact crater found on a stainless steel surface exposed during the third visit. The number of impacts found is in general agreement with the second visit exposure. Only a very small area has been examined for sub-micron events, but even from this small area, it is clear that large numbers of small particles impacted the thin films. Information regarding micrometeoroid impact on the command module windows will be presented in supplement 1.

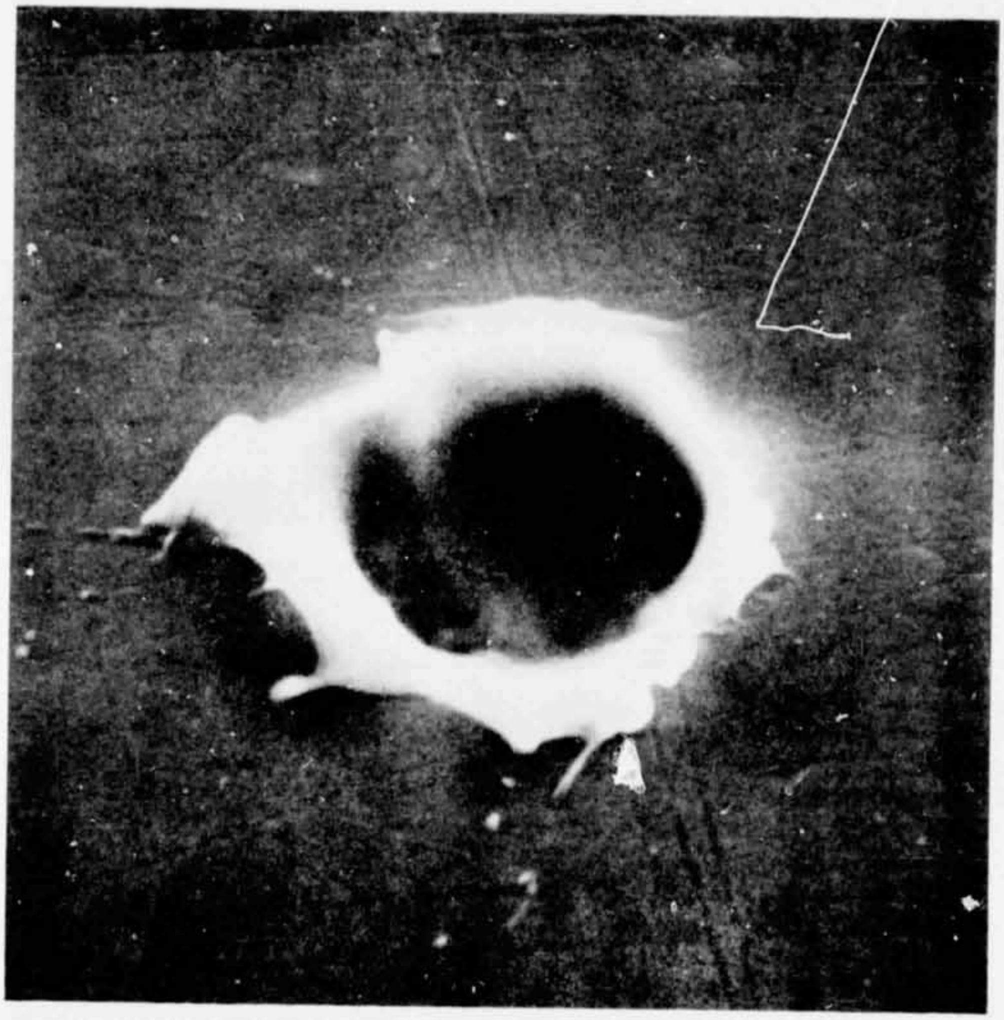


Figure 3-3.- Micrometeorite impact crater (approximately 2.5 microns in diameter).

3.1.5 Experiment S201 - Extreme Ultraviolet Camera

The hardware used for the S201 experiment was the backup hardware for the far ultraviolet photography of the earth from the lunar surface during the Apollo 16 mission. The equipment is described in appendix A.

The experiment S201 hardware performed well on the third vist. The The crew comments criticized only the "sequencer/operating light" on the control box as being too dim, and the wing bolts on the front cover which were difficult to tighten during the extravehicular activity.

The data collected by this experiment were basically obtained from three classes of targets. These classes were groups and clusters of galaxies where it was hoped that intergalactic hydrogen could be detected; individual stars and nebulae (fig. 3-4) from which a study will provide more information about the physical conditions of these objects; and the auroras and airglow of the earth's atmosphere. An additional objective was to use the S201 instrument to investigate the effects on the upper atmosphere produced by the passage of a rocket launched from the ground. Comet Kohoutek applications are discussed in section 3.2.3.

The three processed films show that the film transport system, when warm during the extravehicular activity, advanced the film as much as 10 centimeters between exposures. This compares to a 3- to 5-centimeter advance experienced in the cooler environment of the Workshop. Similar advances were experienced on the Apollo 16 mission and they were attributed to a reduction in film stiffness and thermal changes to the system. This reduced the number of exposed frames from 185 to 146 on the second film loaded; the other two films, exposed entirely in the Orbital Workshop, have all the frames exposed.

Some reduction in data quality was caused by water that condensed inside the film transports during the landing phase. This water caused fogging streaks and other irregularities in the processed film, degrading about 25 percent of the exposed frames. In addition, residual gas in the scientific airlock during experiment S201 operation apparently caused electric discharges at various times and these added to the background irregularities on the films. The most serious degradation was a progressive loss of camera sensitivity which mostly affected the third film loaded. Although the crew allowed the canister to outgas 30 minutes after scientific airlock depressurization before power was turned on, it appears that the central region of the photo-cathode was degraded by at least a factor of 2 during the first seven operations, totaling 168 minutes of use, and sustained further loss of sensitivity during the remaining 10 operations.

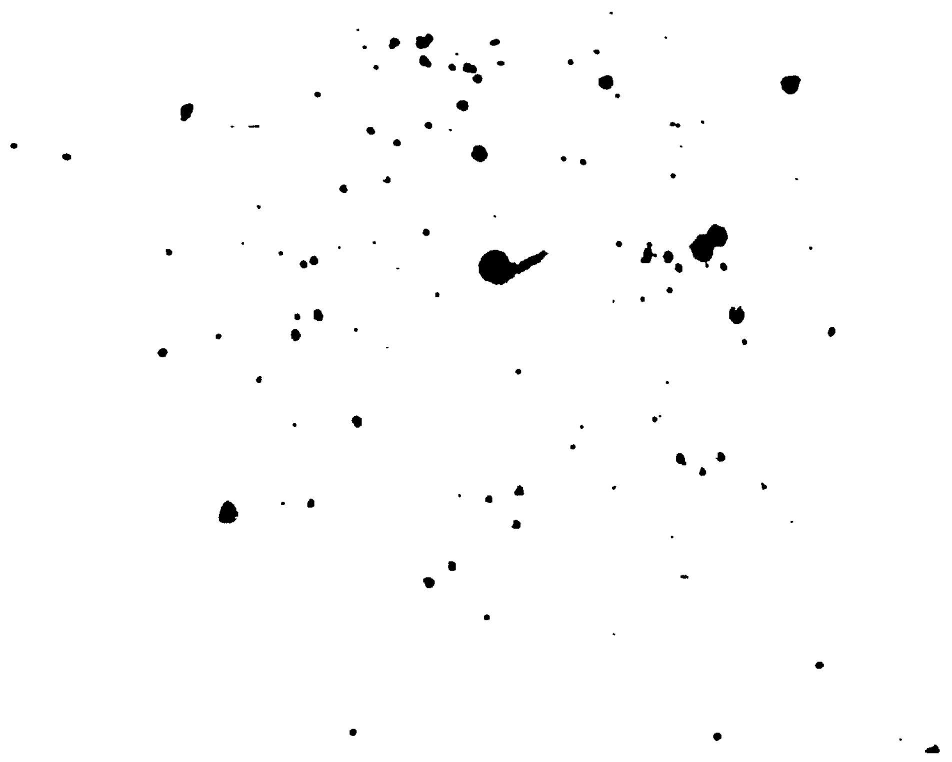


Figure 3-4.- Stars near the center of Gum Nebula.

3.1.6 Experiment S230 - Magnetospheric Particle Composition

The third visit crew returned the last two foil collectors of experiment S230 (ref. 5). One of the collectors had been left exposed at the end of the second visit to provide long-term (180 days) exposure information. This collector was found to be in good condition. The second collector, which was installed early in the third visit, was damaged by the air stream from the pressure equalization valve during repressurization of the Airlock Module after the final extravehicular activity. Two of the six foil strips were damaged; however, one strip can be completely reconstructed and 60 percent of the second strip is available for reconstruction. This will not significantly degrade the total data available from this collector.

Summary of results.- All five collectors from this experiment are in storage in Bern, Switzerland, where they will be subdivided and analyzed in a ultra-high vacuum mass spectrometer, a destructive analysis technique.

Preliminary data from the first two sets of foil sections to be processed indicate that the foils collected precipitated magnetospheric particles as expected. The fluxes are sufficiently large to measure several noble gas isotopes. Sufficient He^3 was detected relative to the He^4 present in the foils to identify the majority of particles precipitating in the aurora to be of solar wind origin.

3.1.7 Experiment S232 - Barium Plasma Observations

The S232 experiment investigated the earth's magnetic field through visual observations and photography of a high-altitude luminescent cloud of ionized barium. The barium was transported to altitude by a rocket launched from Poker Flat, Alaska. A shaped charge was fired when the rocket reached an altitude of 560 kilometers and the barium was propelled out to several thousand kilometers. The ionized particles tended to become oriented along the magnetic field lines, thereby providing a brief view of the local magnetic field geometry.

Opportunities to perform experiment S232 were limited because of the constraints of the requirement of good weather conditions at several ground viewing stations, the lighting (dawn or twilight) necessary for viewing the phenomena, and the Saturn Workshop's position in orbit. A successful rocket launch was made on visit day 12, and the Pilot observed and photographed the barium cloud. Approximately 25 photographs were taken during the dawn conditions, but visual contact with the cloud was lost as the Workshop came into daylight and the sunlight was reflected off the discone antenna.

No further opportunities occurred during the third visit for performing the S232 experiment.

3.2 COMET KOHOUTEK EXPERIMENTS

This section contains those experiments which were added specifically to collect data on Comet Kohoutek. Since Comet Kohoutek was discovered only a few weeks prior to the first visit, a great deal of activity was required to provide new hardware and develop operational techniques in a relatively short time. A program of experiments was selected which would cover the expected comet spectra.

Special extravehicular camera brackets, filters, and special film are examples of hardware which was developed for comet observations. This hardware, when integrated with that hardware already onboard the Orbital Workshop, functioned very well.

The Comet Kohoutek observations were part of a coordinated program which included ground observations; rocket, balloon, and aircraft operations; and unmanned spacecraft observations. The preliminary results from these investigations was the subject of a special conference at the Marshall Space Flight Center conducted on June 13 and 14, 1974. The proceedings will be published separately as a NASA report. Brief descriptions of only the experiments managed by the Johnson Space Center pertinent to the comet are presented in this section.

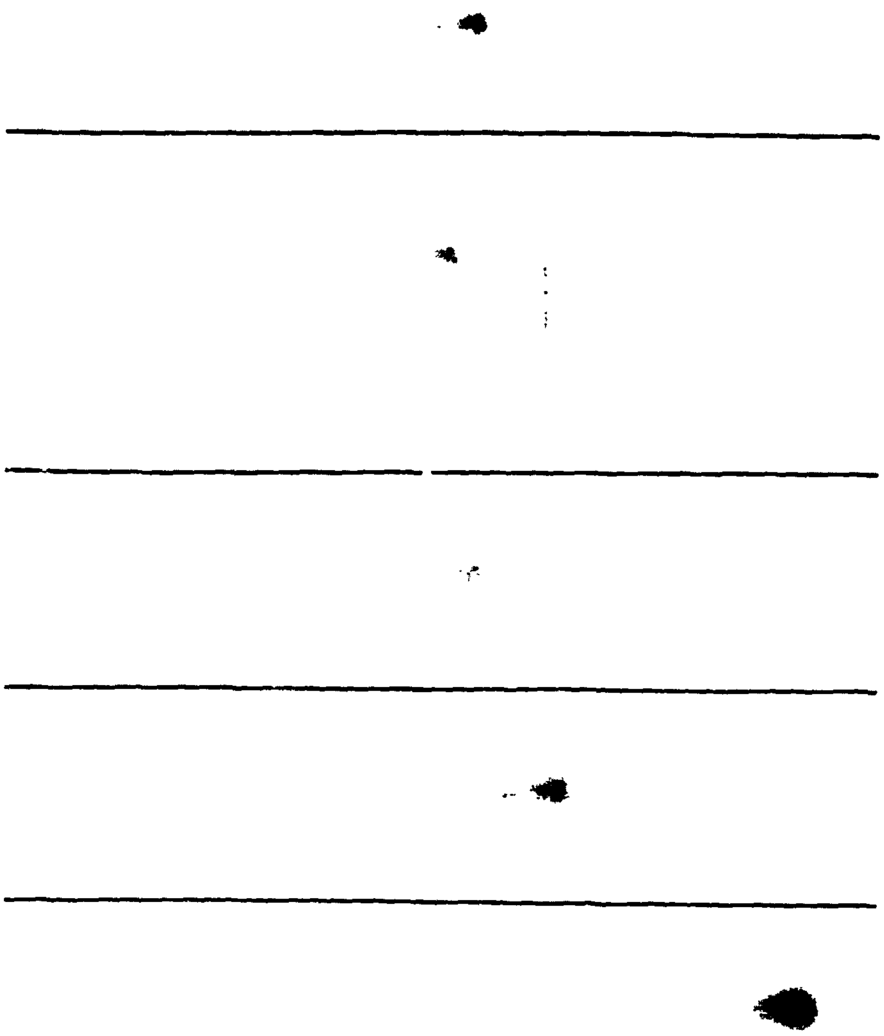
3.2.1 Experiment S019K - Ultraviolet Prismatic Imaging

One of the special objectives on this mission was spectroscopy of Comet Kohoutek. The same hardware was used with Comet Kohoutek observations as was used with experiment S019. Problems with the hardware are discussed in section 3.1.1.

Usable images of the comet were obtained on nine separate dates. Several of these are illustrated in figure 3-5. Although dispersion is evident in the nucleus of the comet, no data are visible in the wavelengths shorter than 3000 angstroms. This is due primarily to the less-than-expected brightness of the comet. However, the nuclear images of December 13 and December 16, 1973, and January 7, 1974, show a distinct image at the position of hydroxyl wavelength 3090, which should yield valuable data on the development of this emission band.

3.2.2 Experiment S063K - Ultraviolet and Visible Multispectral Photographic Imaging

A specially designed adapter was used with experiment S063 for handheld photography of Comet Kohoutek on two occasions. This adapter allowed the experiment T025 filter trays to be utilized for collection of S063K data.



From top to bottom, the dates and exposure times are: December 13 (200 sec), December 16 (270 sec), January 7 (400 sec), January 8 (500 sec), and January 11 (720 sec). Several stellar spectra appear on the exposure taken on December 16. The star directly below the comet, Pi Scorpio, was occulted by the comet five hours later. The double image of the nucleus on the first three dates is probably due to the separation of the hydroxyl wavelength 3090 image from the remainder of the blue-violet radiation.

Figure 3-5.- Objective-prism images of Comet Kohoutek obtained by Skylab experiment S019K.

There were also 15 periods of data collection utilizing both the T025 filter trays and canister assembly (with occulting disk removed) mounted onto the articulated mirror system at the -Z scientific airlock.

3.2.3 Experiment S201K - Hydrogen Lyman Alpha and Ultraviolet Photography

Over 500 frames of data were taken of Comet Kohoutek with this experiment. The problems discussed in section 3.1.5 resulted in some degradation of the data; however, over 40 usable lithium fluoride images and 40 calcium fluoride images of Comet Kohoutek that were taken on 10 separate days were received.

The photograph in figure 3-6 shows the Comet Kohoutek hydrogen halo. The oxygen halo exposure (fig. 3-7) taken during the visit day 40 extravehicular activity show a thin tail almost 35 milliradians long, which may be the dust tail scattering far ultraviolet sunlight. The photographs have revealed more about the comet's far ultraviolet emission than any other experiment. Thus, the experiment objective to photograph Comet Kohoutek was fulfilled.

3.2.4 Experiment T025K - Ultraviolet and Visual Bandpass Photographic Observation

Forty exposures were obtained of Comet Kohoutek during each of the extravehicular activities on visit days 40 and 44. However, the 35-mm camera used was subsequently determined to have malfunctioned and little or no useful data were obtained. This anomaly is discussed in section 16.3.3.

3.3 MEDICAL EXPERIMENTS

Medical experiments continued to be a major component of the working hours for Skylab throughout the third visit. Many new medical detailed test objectives were added and are discussed with the major associated experiments. Because the responses of the third visit crew did not indicate any significant fluctuations, a reduced frequency in performing the protocols for the lower body negative pressure and human vestibular function experiments was required in the early and mid-visit period. In contrast, extra hemoglobin and sleep monitoring data were collected to expand on the data in these categories. Because the visit was extended to 84 days, concentrated food bars rounded out the food intake schedule; the same extension forced the use of 36-hour urine sampling periods because the number of sampling bags was inadequate.

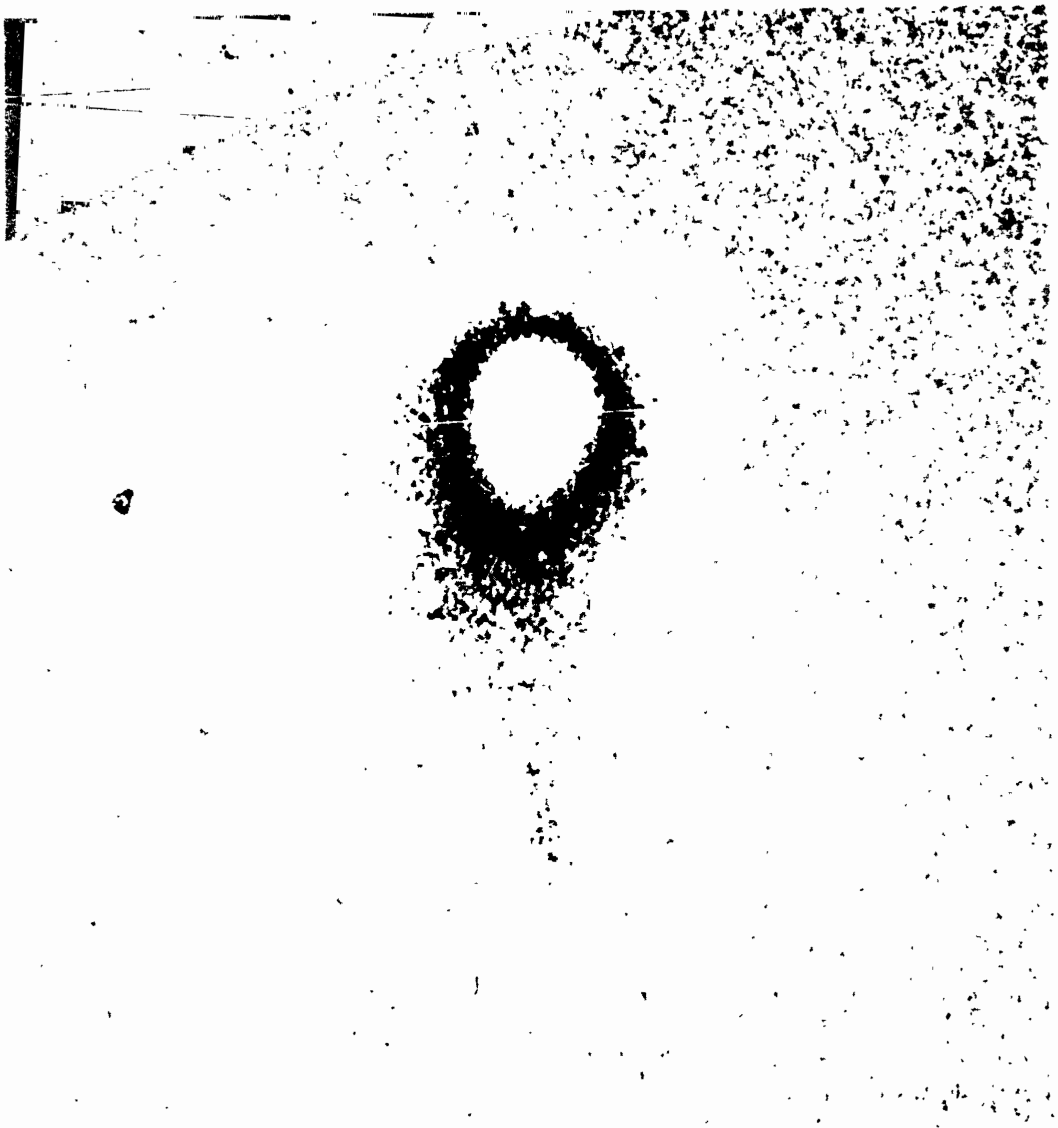


Figure 3-6.- Hydrogen halo around Comet Kohoutek.

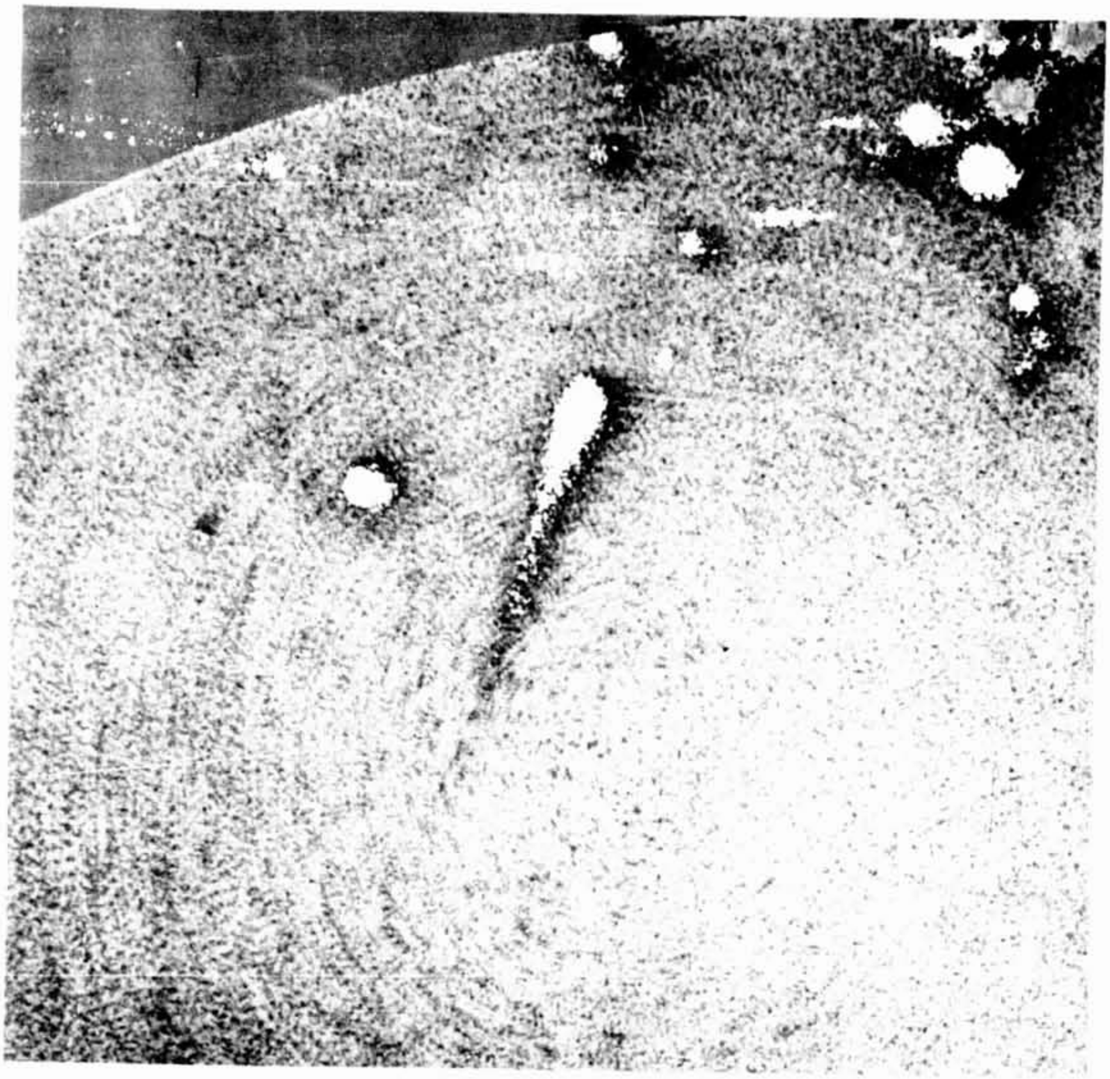


Figure 3-7.- Oxygen halo from Comet Kohoutek.

Figure 3-7.- Oxygen halo from Comet Kohoutek.

3.3.1 Experiment M071 - Mineral Balance

To extend the duration of the Skylab third visit from 56 to 84 days, the original set of menus was augmented with a series of high-density menus, which provided roughly one-half the calories from high-density food bars (see sec. 5.1), and the balance from conventional Skylab foods and Apollo beverages. The high-density menus contained more calcium and nitrogen, and less water than the original Skylab menus, but the other nutrients remained the same. The Skylab diet was instituted 27 days prior to the flight and a nearly uniform excretion of the nutrients had been achieved by the launch date. High-density menus were used every 3 days during the preflight and flight phases of the third visit.

The crew adhered very closely to their planned menus that were augmented by the calorie-adjustment foods provided for that purpose. Based on bomb-calorimetry of the food, the inflight energy intake levels, shown in the following table, indicate that energy consumption was within 100 kilocalories per day of the preflight level. Crew weight changes over the duration of the visit were very small as shown in figure 3-8. The Commander lost 0.05 kilogram, and the Scientist Pilot and Pilot each lost 1.4 kilograms in comparing the weights on launch day with the inflight mass measurement made on recovery day.

Crewman	Preflight period, kilocalories		Inflight period, kilocalories	
	Nominal menu	Actual consumption	Nominal menu	Actual consumption
Commander	3126	3153	3173	3200
Scientist Pilot	2926	3090	2919	3082
Pilot	3198	3195	3173	3276

Control of the dietary intake of nutrients was an adequate means of validating the predictions of the change in body composition during the course of the visit. Nitrogen intake was within 10 percent of the preflight values for every 6-day period, except that the Pilot fell 20 percent below the preflight mean level during the first inflight period, during which time he was nauseated. Calcium intake was 5 to 10 percent higher inflight than immediately preflight mainly because the last preflight high-density menu, which is high in calcium, was omitted at crew request. The use of additional calcium-rich foods toward the end of the visit resulted in one 6-day period for the Scientist Pilot and four 6-day periods for the Pilot during which the calcium intake was more than 10 percent over the preflight mean.

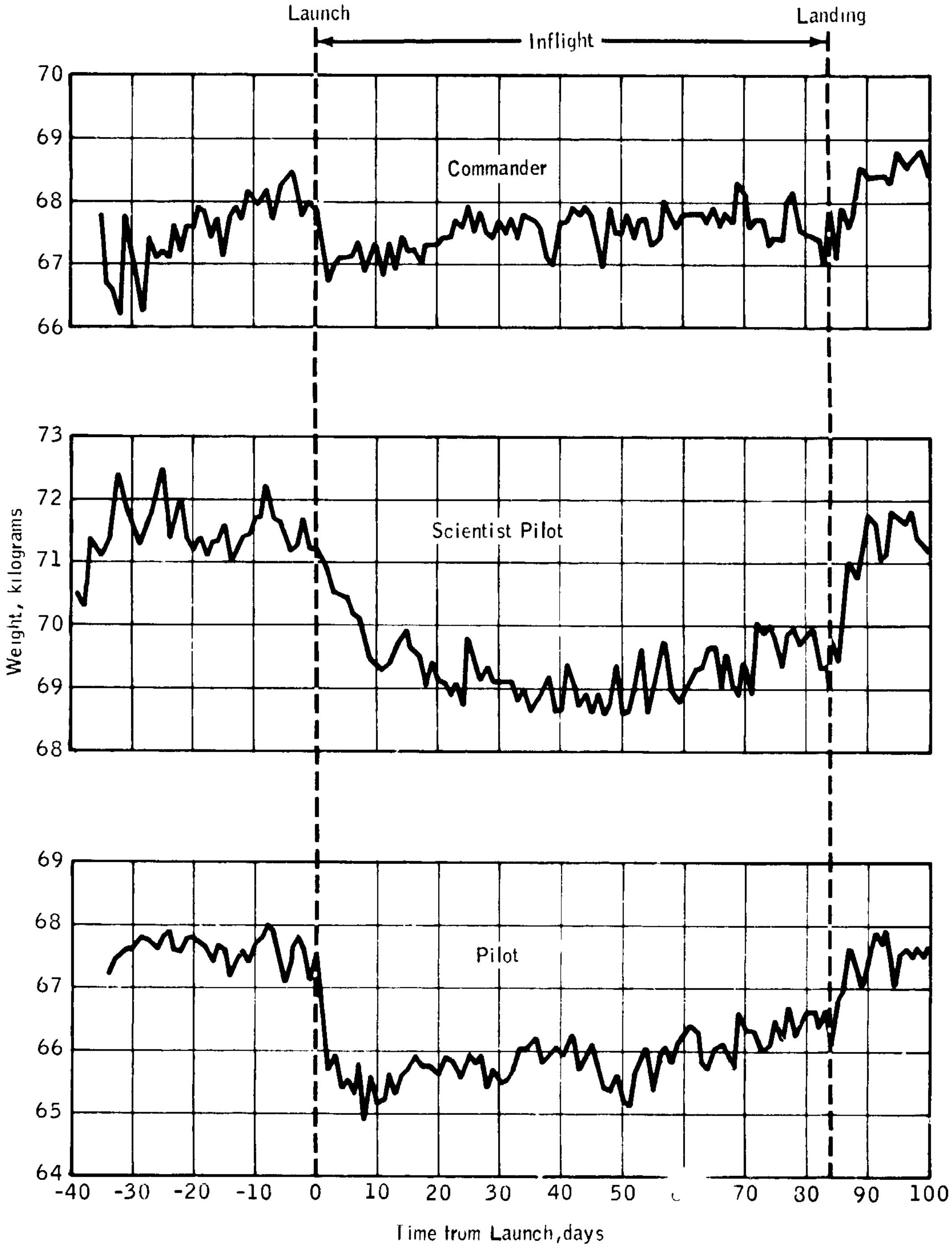


Figure 3-8.- Weight chart for third visit crewmen.

Inflight collection and return of fecal and urine samples was entirely satisfactory, with the loss of only one data point when a urine bag was not sampled before being emptied. Because of the shortage of urine sample bags, the crew made 36-hour collections of urine on 14 occasions instead of 24-hour collections between visit days 52 and 79. The impact of this procedure on the experiment was negligible.

The preflight urine and fecal analyses have been completed, but only the first few inflight urine and fecal samples have been analyzed at the time of this writing. In those inflight samples analyzed a rise in urinary nitrogen excretion was noted in all three crewmen in the first few days, similar to that seen on previous visits. In view of the minimal weight changes a negative nitrogen balance over a long period of the visit would be unexpected.

The overall conduct of the mineral balance experiment was entirely satisfactory during both the ground-based and inflight phases. The compromised experimental conditions that were accepted to permit the extension of the visit were more than compensated for by the scientific results from a visit of this duration.

Mineral balance studies were performed on the three Skylab visits. Results from the first two visits indicate that the composition of the body is changed during exposure to weightlessness as evidenced by significant losses of calcium, nitrogen, and other nutrients. Analysis of the third visit data are not yet complete; however, preliminary results show that the caloric requirements during exposure to zero gravity are near the one-g requirements.

Stereophotometric analysis of the body form consisted of stereometric photographs taken of each crewman four times during the preflight period and three times during the postflight period, with the last postflight measurement scheduled for 31 days after recovery. All imagery has been developed and is satisfactory. Analysis has been completed on two of the four preflight measurements, and is continuing on the remaining measurements.

Preflight and postflight stereoscopic photographs were taken of the Skylab crewmembers. Stereoscopic photographs were attempted in flight on the third visit. Analysis of the photographs from the first two visits revealed a loss of volume from the body. Most of the loss occurred in the legs, and probably resulted from disuse atrophy of skeletal muscles. The data from the third visit have not as yet been reduced or analyzed, although the data appears to be of good quality except for the inflight photographs.

On the third visit, a standardized skin measurement technique was used in which the same observer measured the thickness of folds of skin at six points on the body surface using Lange skinfold calipers. Measurements of a specific region of the triceps, subscapula (under the shoulder blade), and abdomen were made on both sides of the body four times during the preflight period and three times during the postflight period. Some reduction in the mean triceps skinfold thickness was noted on all three crewmen, but only the Pilot showed a statistically significant loss. After pooling the results for the three crewmen and making appropriate adjustments for differences in skinfold thicknesses, the crew, as a whole, lost about 10 percent of the skinfold thickness covering the triceps. The significant losses in the triceps skinfold measurements more likely represent a regional fat loss rather than a generalized loss, which failed to appear in the other measurements. An interesting speculation is that such a regional loss may be connected to the increased use of the arms in zero gravity.

3.3.2 Experiment M073 - Biochemistry of Body Fluids

The preflight biochemistry of body fluids experiment operations were successfully completed with minimum losses of data. Excellent baseline values of all experimental parameters were obtained for each crewman. The fluid intakes were reasonably well maintained throughout the inflight period; the sodium content appears to be slightly elevated.

The inflight collections were satisfactory; however, the extension of the visit to 84 days resulted in a majority of the urine samples being only one-half size (approximately 50 milliliters rather than 122 milliliters) in volume. A preservative of 10 grams of boric acid was added to the urine pooling bags every other day to prevent sample degradation in the event the urine freezing unit should fail. Several bags were reused because of an inadequate number of pooling bags. Also, 36-hour pools were initiated to compensate for the shortage of sampling bags. The data from these days will be grouped for 72-hour periods and the mean 24-hour excretion will be obtained. The freezer temperature was maintained; however, the addition of the boric acid to the urine pool precluded the analysis of several compounds in the samples to which the boric acid was added.

A preliminary review of the inflight data reveals metabolic changes in each man, suggesting a process of adaptation to the space flight environment. These changes were manifested by an apparent aldosteronism that resulted in some sodium conservation and slight losses of potassium. Total body exchangable potassium was decreased 4 to 12 percent in the three men. Cortisol was significantly elevated in the inflight and postflight samples from all three men. Epinephrine and norepinephrine were decreased in the inflight sample and increased in the postflight sample.

Summary of results.- The data collected compare very favorably with the overall results of the first two visits with the main difference being in the early phase of each visit.

3.3.3 Experiment M074 - Specimen Mass Measurement

Both of the experiment M074 specimen mass measurement devices were operative for use in measuring food residue and fecal masses during most of the third visit.

On visit day 81, the rubber specimen restraint broke loose from the frame of the device that was located in the waste management compartment; however, the unit located in the wardroom was used successfully during the remaining 3 days of the visit.

Inflight calibrations were performed three times on each of the mass measurement units. Three of the four mass measuring device calibration weights were misplaced early in the visit, thus limiting the calibration to two points (0 and 500 grams) on the devices.

Summary of results.- The specimen mass measurement device demonstrated reasonably good stability throughout all three visits, far better than that required for operational purposes. These instruments demonstrated routine mass measurement in space (for the first time) and performed adequately for medical support purposes. In addition to the problems encountered on the third visit, an electronic package failed during the first manned visit and the package was subsequently replaced during the second Skylab visit.

3.3.4 Experiment M172 - Body Mass Measurement

The body mass measuring experiment was conducted daily by each crewman. The device demonstrated accurate and simple mass measurement of the body in zero gravity. For human mass measurements, repeatability of ±50 grams was demonstrated, while the absolute maximum error was estimated to be +400 grams or less.

On visit day 78, the crew reported that the thumb release mechanism was inoperative, requiring actuation by use of the side release lever.

The body mass measuring device was calibrated three times during the visit. The device had excellent performance and stability; for example, urine samples were measured to an accuracy of a few grams when adequate calibration means were available. The practicality of making mass measurements, other than of the human body, was demonstrated on the most difficult material to measure using this method, namely liquids. Urine was measured during the second visit and Coolanol fluid during the third visit.

3.3.5 Experiment M078 - Bone Mineral Densitometry

Bone mineral measurements were performed on the right radius and ulna (wrist bones) and the left os calcis (heel bone) three times during the preflight period and at varying times during the postflight period. All measurements were performed without difficulty and all data were obtained satisfactorily.

No bone mineral losses were observed in the radius and ulna of any of the third visit crewmen. However some loss of bone mineral from the os calcis was noted in the Scientist Pilot on the first day after recovery and some loss was noted in the Pilot on both the first and fourth day after recovery. No loss of bone mineral was noted in the os calcis of the Commander.

Summary of results.- In summary, the postflight bone mineral findings of the three Skylab crews suggest that the bone mineral losses seen in weightlessness mirror the change patterns established from bed-rest studies. No losses were seen in the radius and ulna on any crewman on any of the visits. Bone mineral loss from the os calcis was found after each visit as follows:

First visit: Scientist Pilot - on first day after recovery.

Second visit: Scientist Pilot - showed some significant loss which returned to the baseline levels between 60 to 90 days after the flight.

Third visit: Pilot - on first and fourth day after recovery. Scientist Pilot - on first day after recovery.

These changes do not represent a significant hazard for missions of the Skylab visit durations.

3.3.6 Experiment M092 - Lower Body Negative Pressure

A crew-implemented plumbing modification to the experiment vacuum source was accomplished prior to the first usage by the third visit crew. The modification was made to obtain a vacuum source for the experiment while precluding the propulsive venting vehicle disturbances experienced on the previous visits. The experiment was connected to the vented S-IVB stage liquid oxygen tanks which were being used as waste compartments. Operation of the modified system was satisfactory throughout the third visit.

The Commander and Scientist Pilot each served as subjects 22 times during the third visit and the Pilot 23 times for experiment M092. Presyncopal reactions necessitated termination of the test after about 4 minutes of exposure at 0.67 newton per square centimeter negative pressure by the Pilot on visit day 10 and by the Scientist Pilot on visit day 14. On visit day 16, the Commander terminated his test 2-1/2 minutes early because of lightheadedness and a rapidly falling blood pressure. The changing of the Commander's protocol from the morning to the afternoon may have contributed to the early termination. Definite evidence of a vasovagal reaction was present in the first two early terminations, but was not seen in the Commander's records. On visit day 34 and visit day 71, the Scientist Pilot again felt it necessary to stop his test short during the 0.67 newton per square centimeter negative pressure phase. Inadequate sleep and fatigue may have been contributory factors. On visit day 61, although the full protocol was completed, the Scientist Pilot appeared to be developing a presyncopal reaction with pallor, slight dizziness, and decreasing heart rate and blood pressure. The ambient temperature within the Workshop at this time was 300° K, and the Scientist Pilot's next test on visit day 65 was conducted in the morning to avoid the higher afternoon temperatures.

On visit day 75, the crew was unable to obtain blood pressure readings using blood-pressure cuff 011. The problem was attributed to a broken lead in the microphone. Therefore, a backup cuff was used during the remainder of the visit. Section 16.2.6 contains a discussion of this anomaly.

In almost all cases, the inflight resting heart rates of all three crewmen were elevated slightly above the preflight ranges. This characteristic was least pronounced in the Commander who sometimes demonstrated low resting heart rates early in the visit. After 6 weeks of flight, the Commander's resting and stressed heart rates were usually close to or within preflight ranges. By the end of 7 weeks, the Pilot also showed a tendency toward lowered resting and stressed heart rates.

Increases in calf volume during negative pressure, as in the first and second visit crewmen, were much higher than the preflight values. These increases. which reached to as high as 9 or 10 percent in the Scientist Pilot and Pilot, made it necessary to replace the reference band with a backup band after visit day 37. The reference band was returned to verify the authenticity of the high readings.

The loss of calf girth in the third visit crew was smaller than in either the first or second visit crew. Neither the initial loss nor the subsequent downward trend was as great as previously recorded, and after the first 6 or 7 weeks, no consistent downward trend occurred.

The postflight cardiovascular responses to lower body negative pressure appeared to be quite similar to those observed in the second visit crew. By the fifth day after flight, the resting and stressed heart rates were very close to the preflight ranges.

Special experiment M092 tests were conducted as detailed test objectives. Preflight and postflight echocardiographic studies were performed on each third visit crewman to evaluate the effects of prolonged Skylab environment exposure on the left ventricle size and performance. Applying brief, low-amplitude pulses of high-frequency (2.25 mHz) ultrasound waves to the anterior chest wall, and measuring the timing and amplitude of reflected waves provided a safe, noninvasive assessment of cardiac dimensions. Strip chart recordings were made to generate a continuous series of measurements throughout the cardiac cycle. The preflight and postflight assessment of the left ventricle internal dimension, thickness, stroke volume, end-diastolic volume and ejection velocity were made at rest and during lower body negative pressure. The latter studies were performed to evaluate the interrelation of cardiac size and cardiac performance at different cardiac volumes. The left ventricle size was progressively decreased in preflight studies by lower body negative pressure. In addition to reducing cardiac volume transiently by lower body negative pressure, attempts were made in the postflight period to increase cardiac volume by lower body positive pressure (by inflating the crewman's countermeasure garment) and by passive straight leg raising.

During preflight and postflight studies, high-quality echocardiograms were obtained from the Commander and the Pilot. Because of a normal variation in chest configuration, echocardiograms from the Scientist Pilot were of a lesser quality, but probably still adequate for precise measurement. The results of echocardiographic studies must await careful analysis of records, including a direct visual comparison of the preflight and postflight echocardiograms. Continuing echocardiographic studies are planned for further analysis of changes observed in the early postflight period.

Infrared facial photographs were made six times each on the Commander and Pilot and five times on the Scientist Pilot during the conduct of experiment M092.

Leg blood flow testing was performed seven times each on the Commander and Pilot and six times on the Scientist Pilot, all after lower body negative pressure experiment sessions. Leg blood flow was studied by placing a blood pressure cuff just above the knee and inflating it to 0.4 newton per square centimeter pressure. This pressure effectively blocked all venous outflow from the leg until the cuff pressure was exceeded, with arterial blood inflow being relatively unchanged. This action produced an increase in lower leg volume which was measured by means of the leg volume measuring system. The initial rate of volume change was the normal flow of blood into the leg. Once venous runoff began, the outflow equaled the inflow and no further volume change occurred. At that point, the amount of blood accumulated by the cuff pressure (vascular compliance) was measured. Leg vascular compliance (i.e., the volume of blood pooled at a given pressure) was found to increase some 6 to 7 times over the first 10 to 12 days of the visit in two of the crewmen. By day 40, when the measurements were resumed, this had decreased slightly and appeared to continue to decrease slightly through the remainder of the visit. The Commander showed an inflight increase of 2 to 3 times the preflight level. On return to one g, the compliance rapidly decreased in a matter of hours. These data in conjunction with a decreasing blood volume correlate well with the observed lower body negative pressure response.

Muscle pumping of blood from the legs back to the heart was measured by placing a crewman at 0.4 newton per square centimeter negative pressure for 5 minutes to pool the blood in the legs, followed by the crewman performing 10 isometric contractions of the leg muscles. The leg volume measuring system cuff recorded both the amount of blood pooled in the legs and the amount removed by pumping. As was expected from the leg blood flow studies, increasing amounts of blood were accumulated in the legs during the first 10 to 12 days of flight and then this level was retained for the remainder of the flight. Preflight tests showed that the muscle pumping would remove approximately one-half of the blood present, and this percentage remained relatively unchanged in flight, although the absolute amount of blood remaining in the legs was much greater in flight. On return to one g, this mechanism returned to normal within 2 to 3 days.

3.3.7 Experiment M093 - Vectorcardiogram

A total of 21 inflight exercise vectorcardiograms was obtained on each crewman (nine using the experiment M093 protocol and 12 using the metabolic activity experiment protocol). No significant protocol violations occurred and 99 percent of the data were usable.

The initial evaluation of postflight data indicates a rapid return of the various vectorcardiogram parameters toward preflight value . Inflight and postflight vectorcardiogram alterations seem to follow the trends observed on the previous two visit crews.

3.3.8 Experiment M110 Series - Blood Collection

The collection of preflight baseline data for these experiments began 35 days prior to launch and continued through the morning prior to launch in an orderly fashion. Preflight baseline values were established for each parameter.

Blood withdrawal and centrifugal separation of plasma were accomplished eight times on each crewman during the visit. The first samples were collected on visit day 3 and the last samples on visit day 82. A measurement of the hemoglobin concentrations was made of each inflight blood drawing except the last. Two additional hemoglobin determinations were completed using the finger-stick technique. Two of the 24 samples collected were not as planned in that one sample had only one-half the normal amount, and the other sample was severely hemolyzed. All other samples appeared to be in satisfactory condition and contained the normal amount (4.0 millimeters) of plasma.

Upon return, the inflight blood samples were transferred to a 203° K freezer until thawing and distribution of aliquots to the principal investigators of experiments M071, M073, M112, M113, M114, and M115.

Analyses of samples aboard the recovery ship showed that the red cell count, hemoglobin concentration, and hematocrit were slightly elevated on recovery day as compared to preflight levels. These concentration-dependent parameters began to drop immediately and, by the third day after recovery, were significantly lower than both the preflight and recovery day values. Between the third and fifth day after recovery, a slight but significant increase in the reticulocyte percent, absolute count, and reticulocyte index was evident in samples from all three crewmen. The red cell mass had declined on recovery day in this crew, though the mean red cell mass loss of 6.8 percent was less than that observed on the two previous visit crews. The lymphocytes on recovery day were again nonresponsive to an in vitro challenge, but had recovered their normal response by the third and seventh day after recovery.

Summary of results.- The results of the third visit are very similar to those observed after the second visit. Based upon the preliminary results, no new findings will be evidenced by the increased length of this visit; and no hematological indications are evident that show man is unable to survive for unlimited periods in space, aside from some subtle changes in white cell responsiveness and regulation of red cell production and plasma volume.

3.3.9 Experiment M131 - Human Vestibular Function

In contrast to the first two manned visits, no preflight vestibular habituation protocol was prescribed for the third visit crew. The fact that no structured procedures were recommended stemmed from two factors. First, there was no clear evidence that attempts to habituate the first two crews to stressful vestibular stimulation in the experiment M131 rotating chair had any value in protection against motion sickness when the crew entered weightlessness. Second, the crew expressed a strong desire to engage in other activities which might increase their tolerance to vestibular stress upon entering zero gravity. This latter activity consisted primarily of flying acrobatic maneuvers (Appendix G) in high performance jet aircraft (T-38) at periodic intervals prior to the third visit launch.

The acrobatic maneuvers began around mid-September and soon progressed to 2 to 3 hours per man per week right up to launch time. Variable maximum g-loadings were produced by these maneuvers and examples of these loadings are shown in the following table.

Maneuvers	Stress, g
Loops	4 to 5
Immelmanns	4 to 5
Cuban eights	4 to 5
Wing overs	3

One other significant component of the maneuvers consisted of rapid aileron rolls both to the left and to the right, with the head being maintained in different fixed positions during these rolls.

Preflight data of sufficient quality and quantity were obtained on each of the third visit crewmen on all portions of the M131 experiment. These included measurements of semicircular canal response thresholds by means of the oculogyral illusion test, basic susceptibility to motion sickness, and spatial localization.

Two of the crewmen experienced symptoms indicative of motion sickness upon initial entry into weightlessness, with the most severe symptoms being manifested by the Pilot. The Commander reported only a mild premeal epigastric awareness. Complete recovery from these symptoms occurred after visit day 3 and, from that point on, all crewmen were dramatically free of symptoms as normally provoked by the experiment M131 motion sickness test protocol. By visit day 12, all crewmen were able to perform the maximum required number of head movements (150) at the maximum rotating chair revolutions per minute (30) with no symptoms. All motion sickness testing was discontinued after visit day 29, and testing was not resumed again until visit day 73, at which time a special motion sickness test was conducted. The special test required each crewman to first rotate clockwise for 150 head movements at 30 revolutions per minute and then immediately repeat the protocol with the direction of chair rotation reversed. The special clockwise/counterclockwise protocol was performed by all crewmen with no symptoms reported. Five motion sickness tests were performed during the visit by the Commander and four each were performed by the Scientist Pilot and Pilot. (The special clockwise/counterclockwise test is considered to be one test.)

The Commander's performance was very stable on the oculogyral illusion portion of the M131 experiment and the ability to detect the illusion was slightly increased in comparison with the preflight baseline performance. Relative to the preflight performance of both the Scientist Pilot and Pilot, both crewmen demonstrated greater variability and a decrease in their ability to perceive the illusion. The greatest change was manifested by the Pilot. Each of the three crewmen performed a total of six successful oculogyral illusion tests during the visit.

Three complete spatial localization tests were performed by each crewman. A preliminary analysis of these data indicate slight shifts in localization and slight changes in variability relative to the preflight measurements. Hardware operations were normal during all phases of the M131 experiment.

No significant symptoms of motion sickness were experienced by the crew during rotating chair postflight testing on the first, second, and fifth days after the visit. The postflight tests were conducted at a rotational rate of 30 revolutions per minute. Neither the time course nor the completeness of the crew's return to preflight levels of susceptibility have been determined. As of this time, no significant changes relative to the preflight baselines have been noted with either the oculogyral illusion or spatial localization tests; these tests, however, are not complete.

The acrobatic flying experience apparently had some effect in increasing each crewman's preflight tolerance to vestibular stress. All of the crewmen, especially the Commander and Scientist Pilot, had a much higher threshold of susceptibility to motion sickness at the end of the experiment M131 preflight baseline data collection period than they had at the beginning of the baseline period. This constantly changing baseline was not observed in previous crews.

The fact that the Commander experienced mild symptoms and the Pilot acquired severe symptoms very early in the visit suggests that the preflight-acquired increased vestibular tolerance did not transfer to the weightless environment. Furthermore, any valid conclusions about the effectiveness of preflight vestibular training procedures were completely confounded by the fact that all crewmen were on a mandatory schedule of anti-motion-sickness drug use during the first 3 days of the visit. About 10 days before launch, each crewman was subjected to one test at 30 revolutions per minute in the experiment M131 rotating chair to test the effectiveness of his chosen anti-motion-sickness drug in preventing symptoms. All crewmen completed the required 150 head movements with no symptoms reported, thus indicating the effectiveness of the drug during ground tests.

In addition to the experiment M131 protocol, several special vestibular-related tests were performed during the preflight and postflight periods on each of the crewmen. The first of these special tests used a series of narrow metal rails on which the crewmen were required to balance both with their eyes open and closed. In comparison with the preflight baseline performance, none of the crewmen demonstrated any deficit on this postural equilibrium task when tested with their eyes open on 1, 4, and 11 days after recovery. However, with the eyes closed, all crewmen showed a very significant decrement 1 day after recovery. Some improvement was observed 4 days after recovery and, by 11 days after recovery, all crewmen were back to the preflight levels of performance.

Measurements were performed on each crewman 5 days before launch, and 1 and 11 days after recovery to detect the presence of positional and spontaneous nystagmus, using standard electronystagmographic techniques. Data analyses are not complete at this time; however, preliminary evaluations indicate that no unusual nystagmus occurred in any of the crewmen during the postflight test period.

Standard clinical audiometry tests were performed on each crewman 30 days before launch and 1 and 11 days after recovery. No significant postflight changes in hearing were observed in any of the crewmen.

Summary of results.- The most significant data yielded from experiment M131 was in the area of motion sickness. Five of the nine Skylab crewmen experienced some degree of discomfort that resembled motion sickness during the first several days of the visit. Following this initial period of adaptation, all crewmen became essentially immune to motion sickness as provoked by the experiment M131 protocol. This increased tolerance to vestibular stress transferred to the postflight period for all crewmen. The first and second visit crews did not return to their baseline levels of susceptibility until approximately 60 days after recovery.

No overall trends have been detected with either the oculogyral illusion or spatial localization tests; however, detailed comparisons of data from the three visits are not complete. Some crewmen tended to see the oculogyral illusion with slightly greater frequency inflight while others saw the illusion with equal or slightly lesser frequency than preflight. The important fact is that all crewmen could see the illusion in zero gravity and this indicates that the semicircular canals of the inner ear were intact and were functioning normally.

No hardware anomalies occurred, except for the chair restraint problem that was satisfactorily resolved before the second visit launch.

3.3.10 Experiment M133 - Sleep Monitoring

The sleep monitoring experiment was performed by the Scientist Pilot three times preflight, 18 times inflight, and three times postflight. On 17 of the inflight sleep monitoring nights, satisfactory real-time data were obtained. Magnetic tape recordings were made of each inflight performance and these tapes were returned for analysis by the principal investigator.

The experiment, originally approved for only the first and second visits, was added to the third visit approximately 1 month prior to the launch. The experiment was originally approved for eight performances on the third visit because only nine caps were available in the Workshop. However, initial inflight tests demonstrated that the caps could be reused successfully several times if additional electrolyte was applied to the electrodes. As a result of these inflight tests, additional inflight experiment performances were approved.

Analysis of the first and second visit tapes confirmed that tape recorder 1 became inoperative during the first visit. Therefore, on the third visit, all inflight data were recorded on tape recorder 2. This necessitated changing the magnetic tape at the midpoint of the third visit. On visit day 51, the Scientist Pilot reported erratic calibration readings when the preamplifier cable was moved. This resulted in the loss of approximately 75 percent of the data for the preceding sleep period. The cable was replaced with a spare and operation was satisfactory. This anomaly is discussed in section 16.2.2.

A preliminary analysis of the third visit data shows a marked decrease in total rest and total sleep of the Scientist Pilot during the first 35 days of the visit. After 35 days, the Scientist Pilot appeared to approach his preflight baseline level and displayed an increase in the deeper stages of sleep and a corresponding decrease in lighter stages of sleep. The very preliminary analysis indicates that the changes observed in flight on the third visit correspond to some extent with those seen during the 28-day first visit (table 3-I). The first-visit Scientist Pilot showed a decrease in total sleep time, a decrease in sleep latency, a slight increase in the stage 4 percentage sleep, and a decrease in stage 2. The second-visit Scientist Pilot showed no significant change in total sleep time or sleep latency, but stage 3 decreased significantly postflight, and stage 4 showed a significant decrease during and following the visit (table 3-I). Both the first and second visit subjects showed a decrease of the rapid-eye-movement stage of sleep near the termination of their visits and increases of the rapid-eye-movement stage postflight.

TABLE 3-I.- AVERAGE NIGHTLY VALUES OF SELECTED SLEEP CHARACTERISTICS

Sleep characteristics	First visit			Second visit			Third visit		
	Preflight	Inflight	Postflight	Preflight	Inflight	Postflight	Preflight	Inflight	Postflight
Total rest time[a], hours	7.8	6.9	8.9	7.5	7.32	7.8	8.06	7.56	7.67
Total sleep time[a], hours	6.9	6.0	8.5	6.4	6.31	6.6	7.29	6.69	6.53
Total awake time[a], hours	0.84	0.72	0.38	1.1	1.01	0.53	0.77	0.87	0.82
Sleep latency[a], minutes	37.8	18.0	11.4	12.0	12.6	9.6	16.2	15.6	7.8
Stage 1, percent	5.3	6.0	5.1	8.8	8.9	10.2	8.9	6.76	9.4
Stage 2, percent	54.8	43.4	56.6	56.3	59.7	57.8	58.5	58.5	66.1
Stage 3, percent	14.8	16.0	12.2	17.4	17.5	10.1	7.1	8.8	2.7
Stage 4, percent	2.9	16.7	1.1	2.8	1.4	0.4	0.2	0.5	0.05
Stage REM[b], percent	22.2	17.9	25.0	14.7	12.1	21.6	25.3	25.3	21.8

[a] Terms defined in appendix G.

[b] REM - rapid eye movement stage of sleep.

The alterations of the inflight sleeping patterns showed no adverse effect upon the crew performance capability.

3.3.11 Experiment M151 - Time and Motion Study

All photography requirements were accomplished with the exception of documenting one experiment M509 (Astronaut Maneuvering Equipment) test. In addition to the requirements, four experiment M092/M093/M171 tests were photographed.

Only a partial screening of the returned 16-mm film from the third visit has been completed. A correlation of this visit voice-dump data with telemetry indicates that the third visit results will compare favorably to those of first and second visits.

The third visit data appear to support the theory that 7 to 14 days are required to fully adapt to the zero-gravity environment. The time initially required depends on the nature of the task, and the type and frequency of preflight training accomplished.

The third visit crew bettered their best experiment M092 preflight performance time on their second inflight test which was performed on visit days 10 and 11. There was some variability in the performance time until visit day 30 when the crew consistently began to improve until they were bettering their best preflight time by almost 20 percent.

The importance that good fidelity preflight training has on early inflight performance was demonstrated during the first extravehicular activity. The third visit crew completed the task originally planned for two separate extravehicular activities in one 6 1/2-hour extravehicular activity. The increased efficiency is attributed to the neutral buoyancy training which allowed end-to-end task simulation in the same manner as in zero gravity.

The third visit is significant in that the crew continued to improve their skill in working in zero gravity and they returned to earth in good mental and physical condition.

3.3.12 Experiment M171 - Metabolic Activity

All experiment M171 hardware functioned normally during the third visit. Twelve inflight experiment M171 tests, spaced 5 to 8 days apart, were obtained on each crewman. The ergometer received additional use as a daily exerciser for each crewman. Crew inflight physiological responses to exercise were essentially within the preflight baseline ranges throughout the visit. A decreased vital capacity was observed inflight in all the crewmen, but the decrease did not appear to interfere with their ability to exercise. Evaluation of the postflight pulmonary function tests indicates no significant differences from values obtained preflight, including vital capacity. Immediately postflight, however, all crewmen exhibited a significant decrement in their response to the experiment exercise protocol as compared to the preflight or inflight responses. The most obvious indications of this were in elevated heart rates and decreased a cardiac output for the same workload and oxygen consumption. A significantly decreased postflight stroke volume was observed only in the Commander. All of the changes were of the same order of magnitude as noted in the previous Skylab crews, but the third visit crew returned to normal more rapidly. Preflight baseline range values for most parameters were attained 4 days after recovery.

3.3.13 Experiment S015 - Zero Gravity Effects on Human Cells

The hardware for experiment S015 was flown only on the second Skylab visit. The following data are in addition to the data previously reported in reference 4.

The experiment S015 hardware operated normally. The 20-power and 40-power time-lapse 16-mm photomicrographs produced films of excellent quality. The live cell specimens in growth curve module 2 were returned viable and have been subsequently subcultured and banked using deep freeze techniques to make them available for future research. Few live cells remained in growth curve module 1. There was no discernible evidence to indicate a reason for the lack of more live cells in growth curve module 1. The number of live cells returned by growth curve module 2 fulfilled the requirements of this experiment.

Summary of results.- At this time, no change is indicated in the zero gravity growth rate, cell cycle, or gross cellular morphology. Further detailed analysis is being conducted in the following areas:

a. Electron microscopy

b. Scanning electron microscopy

c. Microspectrophotometry

d. Phase microscopy

e. Interference microscopy

f. Anoptral-phase microscopy

g. Karyotyping

h. Chromosome banding

i. Motion picture analysis

    1. Rate of cell movement

    2. Size, location and distribution of cell organelles

    3. Mitosis

    4. Pinocytosis

3.3.14 Visual Light Flash Phenomena

The light flashes observed on the Apollo missions have been generally attributed to the passage of heavy cosmic nuclei (atomic no. ≥ 6) through the retina. Cerenkov radiation from relativistic particles is believed to be responsible for some flashes. As such, the flash rate is strongly latitude dependent for an observer in earth orbit. This effect is a consequence of geomagnetic cutoff and the steep energy spectrum of cosmic ray fluxes. In other words, only cosmic particles with very high energy can reach orbital altitudes near the equator, while particles with lower energies can be incident near the magnetic poles. Therefore, polar cosmic ray fluxes are much larger than equatorial fluxes. The dependence of the light flash frequency on latitude was verified by data collected on the Skylab third visit.

In addition to providing this important verification, the experiment provided extremely interesting data relative to light flashes in the South Atlantic Anomaly area (fig. 3-9). The observed light flash frequency increased dramatically when the Workshop passed through the South Atlantic Anomaly area. Since this is in a region of relatively high geomagnetic cutoff, trapped radiation, rather than primary cosmic rays, is assumed to have caused most of the flashes observed in this area. Many of these flashes have the same characteristics as those observed in low cutoff regions and on the Apollo missions, so it is plausible that the same types of heavy cosmic particles are responsible. Alpha particles and heavier nuclei have been observed as components of the outer radiation belt, but no known observation has been made of heavy nuclei in the inner belt. If heavy particles are the cause, the third visit data are the first indication of the presence of such nuclei in the inner zone of trapped radiation.

Further measurements of particles in the South Atlantic Anomaly area must be made to definitely determine whether the flashes observed there are due to trapped protons or to heavier nuclei. Further exploration of

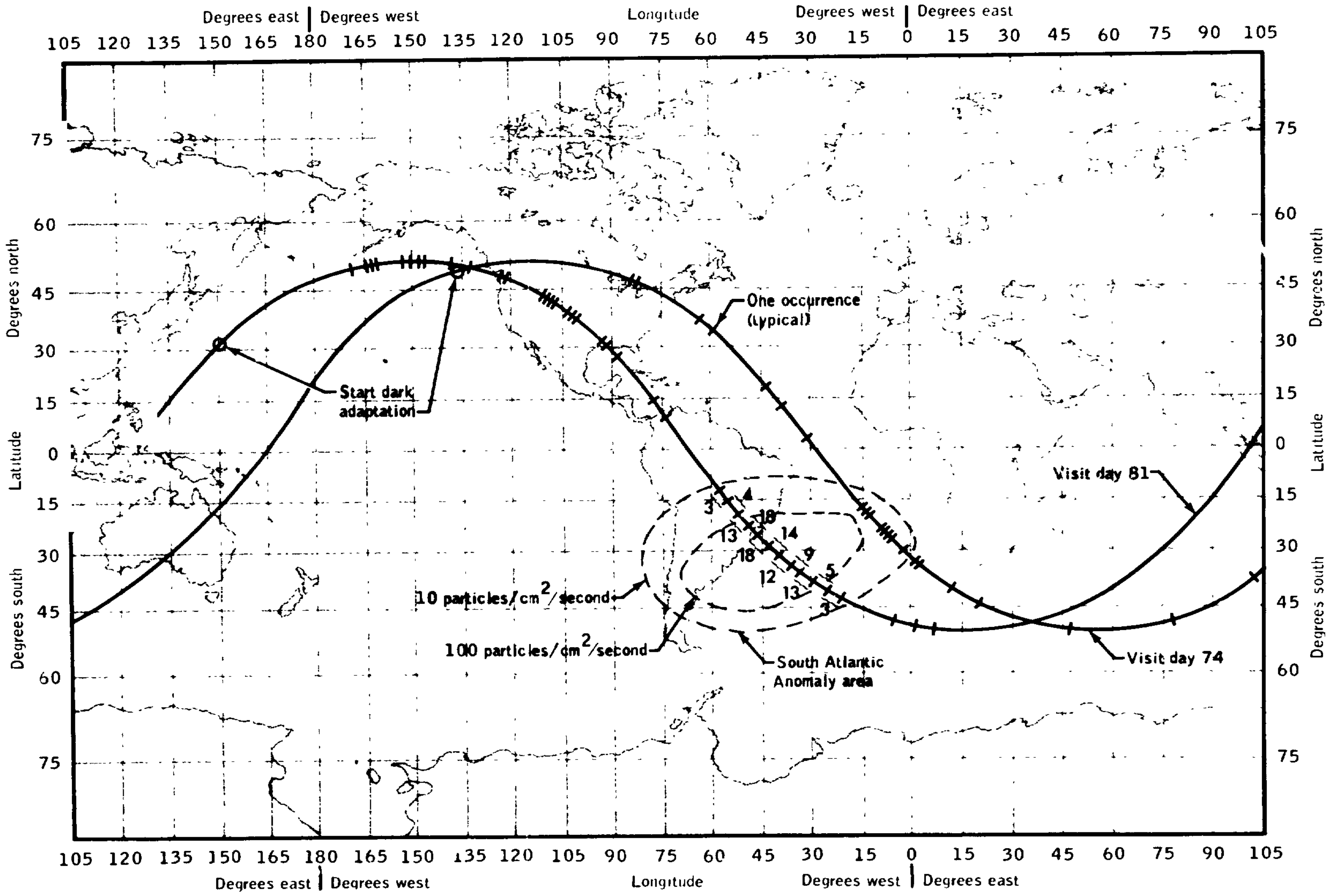


Figure 3-9.- Occurrences along ground track for the two visual light flash sessions.

the light flash phenomena is planned as part of the Apollo-Soyuz Test Project. Data from that mission should aid in the interpretation of the Skylab findings. Data from this experiment, however, provides a sound basis for the premise that the visual light flashes are caused by cosmic rays. Supplement 2 will provide an overall evaluation and analysis of the data obtained from this experiment.

3.3.15 Testing and Preservation of Muscle Function

The loss of muscle function, including strength, coordination, and endurance is of major importance under weightlessness. Virtually no spontaneous leg exercise exists in zero gravity. The maintenance of the leg and back function is most critical for several reasons. The ability to walk must be maintained and certain vascular functions of the leg must be preserved. Loss of arm strength would cause relatively little disability on return to the one-g environment.

The preflight and postflight muscle function testing on the crewmen from all visits was accomplished with Cybex equipment, a constant velocity device which can absorb and record maximum muscular forces through a complete range of motion. Ten repetitions of elbow flexions and extensions and knee-hip flexion/extensions at 765 milliradians per second allowed good determinations of the maximum forces and the fatigue decrement.

The loss of muscle function and mass of the Skylab first visit crewmen in 28 days was rather striking. Not only were there complaints of sore muscles and joints, and paresthesias (hypersensitivity) of the feet, but there were losses of leg extensor (muscles required in standing) forces of up to 30 percent, even in the Commander who performed reasonable amounts of exercise on the bicycle ergometer.

Two exercise devices that allowed reasonably good arm exercise and some increase in leg exercise were used on the second visit. Postflight examinations revealed good arm function preservation but, as expected, a large loss of leg function, though relatively less than on the Skylab first visit. Postflight joint and muscle complaints continued as well as some unsteadiness in walking.

A treadmill device capable of supplying necessary forces to maintain one-g muscle function was developed for the third visit and is described in appendix A. Metabolic measurements indicate that the treadmill required approximately a one-third maximum effort as determined by the bicycle ergometer. The third visit crew made the treadmill a part of their standard daily exercise protocol by walking for up to 10 minutes or jogging for several minutes. In addition, the crew devised other exercises such as leaps against bungee straps and toe rises against bungee shock cords.

The third visit crew had less obvious difficulty in walking, standing, and stability upon landing than the two previous crews, in spite of the longer stay. The complaints about sore joints and muscles were minimal and no paresthesias were noted. Quantitative testing confirms these findings and although final results have not been compiled, little or no decrement in leg muscle function is evident.

Summary of results.- This investigation produced the following two findings of fundamental importance. First, a brief time of weightlessness produces a rapid and serious decrement in muscle function particularly in the gravity opposing muscles of the leg. Second, these decrements can be avoided by relatively brief periods of properly designed exercise.

3.3.16 Anthropometry

Anthropometric studies were designed to follow changes in body shape, composition, and especially the shifts in body fluids under zero-g and one-g conditions. Studies designed to follow the changes consisted of the following interrelated measurements.

a. Direct measurements of height as well as a series of trunk girth measurements and arm and leg girth measurements were taken at 3 centimeter increments using calibrated tapes. These measurements allowed overall changes to be documented and, in addition, allowed documentation of changes in leg volume secondary to fluid shifts.

b. Center of gravity/mass measurements were made preflight, inflight and postflight to allow further confirmation of shifts of fluid and of other mass. Preflight and postflight center-of-gravity determinations were made by balancing each crewman on a teeter board. Inflight, the center of mass was measured directly by applying an accelerating force at right angles to the long body axis and finding the null point.

c. Photographs of the crewmen were taken at regular intervals during the visit. Front, side, and rear exposures were made with the crewmen in the standard anatomical position, and against the "floor" grid to allow further evaluation of body configuration changes. A companion series of front and side views of the crewmen floating freely in a relaxed position were made to document postural changes caused by weightlessness. An infrared-augmented color film was used to enhance the superficial venous pattern and to allow further documentation of fluid shifts.

d. Limited pre-exercise and post-exercise arm and leg girth measurements were made inflight to compare with the normally expected increase in muscle size with exercise.

Since all of the measurements were interrelated, the results are described collectively. Anthropometric measurements made on two crewmen on visit day 3 provided, for the first time, direct evidence of the probable cause of the majority of the significant cardiovascular changes that have been observed in space flight. This evidence is the very large shift of blood and tissue fluids from the legs into the upper portions of the body and this amounted to some 2 to 2.5 liters in each subject by the third day of the visit. Although continued body configuration changes were noted during the visit, the changes were insignificant when compared to the initial shift. Further documentation of the fluid shifts by the center of mass measurements was unfortunately delayed. However, when performed, the center of mass measurements confirmed two facts:

a. Making an accurate measurement, apparently to within a few millimeters, was easy and practical.

b. The expected fluid shift had, in fact, occurred.

Film processing is incomplete, but a cursory examination of some of the film shows that several technical difficulties exist. The first, inadequate resolution, was anticipated preflight when the 35-mm camera was substituted for the 70-mm camera. Further, there appears to have been exposure and lens or focus difficulties. In spite of the difficulties, puffiness and marked venous distension are evidence that the fluid and blood shifts resulted in a hypervolemic state for the upper veins and tissues.

Simple third visit measurements documented the changes in the body under weightlessness caused by the removal of one g from the cardiovascular system and on the gravity-opposing muscles for the first time. These changes might account for a number of the effects noted in space flight including head fullness, nasal stuffiness, injected conjunctive, decreased tolerance to negative pressure and g-loads, and reduced blood volume and red cell mass.

The probable explanation of the reduced blood volume and red blood cell mass (see sec. 3.3.8) during postflight measurements is the body's attempt to produce a blood volume/cell mass compatible with the effectively reduced vascular space. The reduced blood volume and resulting anemia may, in turn, explain the reduced work tolerance and orthostatic tolerance seen upon return to one g. Implications for the lower body negative pressure (see sec. 3.3.6) reduced tolerances seen in flight are also evident.

Other interesting but less significant changes were the increase in height and the reduction in abdominal and chest circumferences, both of which rapidly reversed upon return to one g. The latter, plus shifting blood volume, is a possible explanation for the reduced vital capacities (maximum breath volumes) seen with the metabolic experiment (see sec. 3.3.12).

Also of note are changes in posture caused by the unloading of various opposing muscle groups. Such changes in force result in hyperextension (bending backward) of head and neck, as well as a variety of other changes at the beginning of flight. A series of films were taken to document these changes, but are not yet available for analysis.

3.3.17 Muscular Electromechanical Activity

The duration of the Achilles (ankle) reflexes and associated gastrocnemius (calf) muscle electrical activity of the third visit crew was recorded preflight and postflight. Plantar movement was measured by means of a displacement transducer and the muscle electrical activity was recorded by means of surface electrodes. In addition, electromyographic records were obtained on the right gastrocnemius muscle during a right toe stand, first supporting the total body weight and then repeated while holding a 18.1 kilogram weight in the right hand. Postflight data were compared to the preflight baseline values.

The following table summarizes the postflight trends of the deep tendon reflexes on each of the third visit crewmen.

Postflight measurement	Duration, milliseconds		
	Commander	Scientist Pilot	Pilot
Recovery day	491	416	242
Recovery plus 1 day	483	464	214
Recovery plus 5 days	556	494	213
Recovery plus 11 days	538	437	325

Summary of results.- The observed trends are similar to those obtained from the second visit crew; however, the third visit Commander and Scientist Pilot returned to the preflight values earlier than the Pilot or any of the second visit crew.

The most plausible explanation now seems to be the altered reactivity of the autonomic system together with the imbalance of the gravity and antigravity muscular systems. Also, the effect of changes in the hormonal secretion pattern and calcium metabolism cannot be ruled out.

Electromyographic records are still to be analyzed for any postflight alteration of muscle electrical activity.

3.3.18 Taste and Aroma

Tests were initiated on the third visit to determine if taste and aroma thresholds are subject to change in zero gravity as a result of comments from the first two visit crews that the food tasted more bland than on earth. Figure 3-10 shows the packaging arrangement for the taste test and figure 3-11 shows the packaging used for the aroma test.

The results of the taste test reveal a shift in threshold levels for the detection of certain taste sensations. The shifts varied highly with each crewman. This variation in reaction is, perhaps, the most significant finding because it was unexpected. The results are presented in table 3-II. The results of the aroma tests, so far, give no evidence that there is any change in the ability of any crewmen to identify aromas. The results of the aroma tests are shown in table 3-III.

The Commander had no change in his threshold to the four basic flavors (sweet, sour, salt, and bitter). However, the Commander's ability to detect the aromatic orange flavor was significantly increased, but his threshold for the aromatic onion flavor remained unchanged. These data suggest that the Commander would experience no overall dramatic change in flavor response to foods when comparing inflight to preflight responses.

The Pilot exhibited an increased sensitivity to salt and a very diminished sensitivity to both of the aromatic flavors tested (orange and onion). The other flavors (bitter, sour, and sweet) remained essentially unchanged. These tests suggest that foods would taste differently to the Pilot during the inflight test as compared to the preflight results.

The Scientist Pilot showed a marked enhancement in the ability to detect sweet flavor and a concomitant loss in the ability to detect bitter flavor. This was coupled with an enhanced ability to detect orange flavor. Sensitivity to other flavors remained unchanged. These results suggest that foods might taste sweeter to the Scientist Pilot inflight as compared to the preflight test.

These findings support the requirement for inflight condiments so that individuals can season the food to their taste preferences.

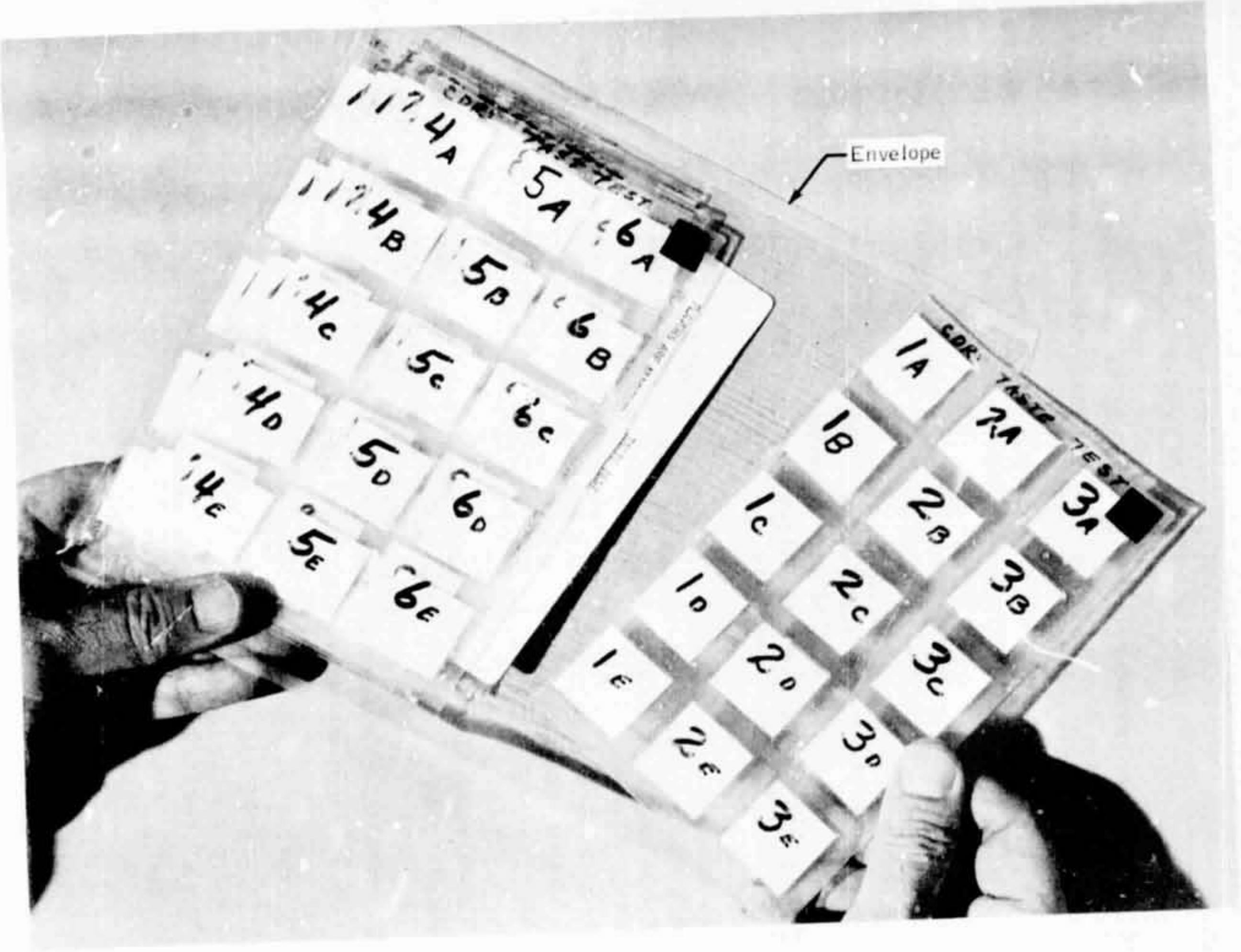
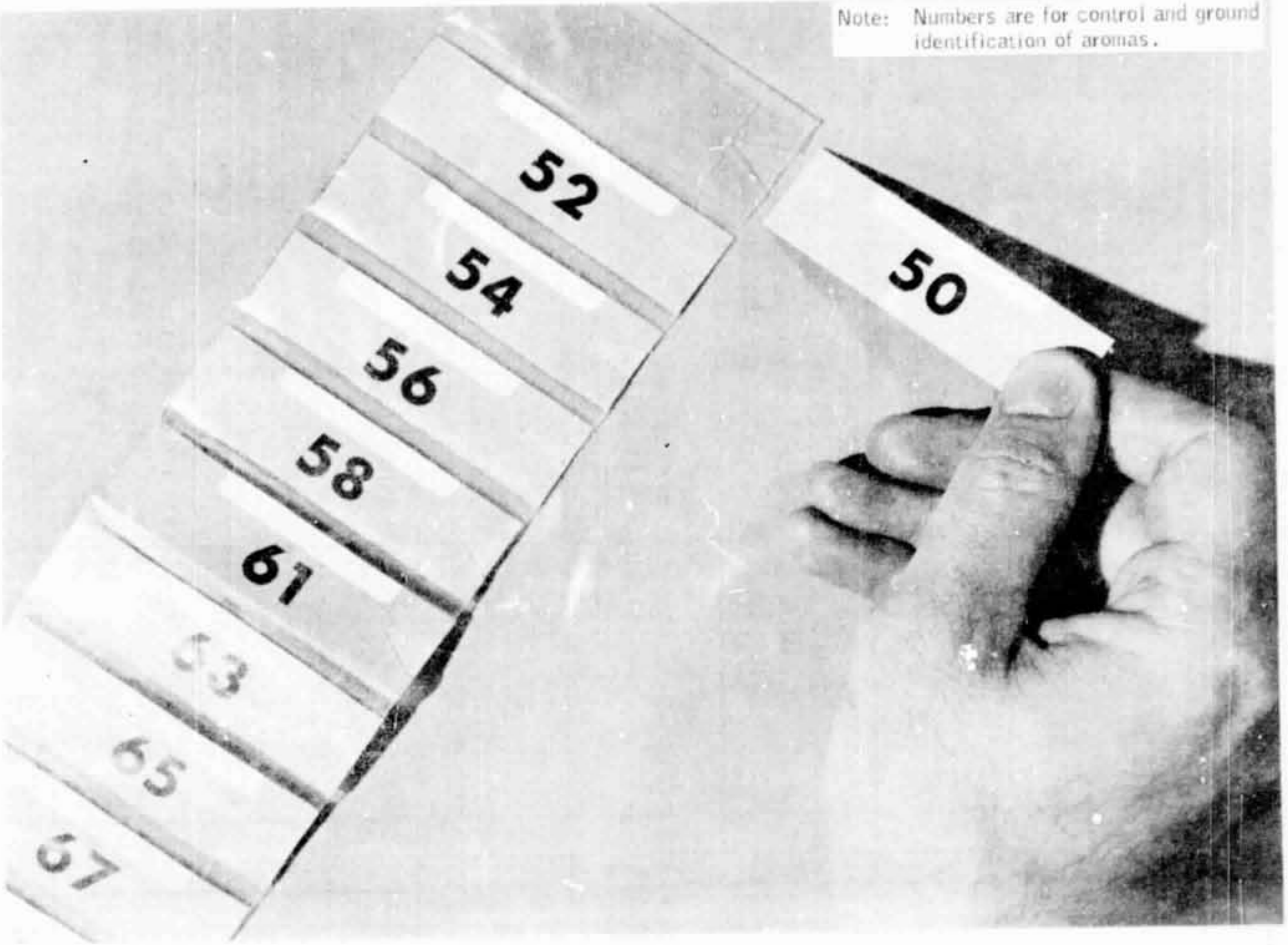


Figure 3-10.- Taste test flavors in flight packages.



Note: Numbers are for control and ground identification of aromas.

Figure 3-11.- Aroma test strips

TABLE 3-II.- SKYLAB TASTE THRESHOLD RESULTS

Taste	Taste level where first detected and confirmed[1]								
	Commander			Pilot			Scientist Pilot		
	Preflight	Inflight	Postflight	Preflight	Inflight	Postflight	Preflight	Inflight	Postflight
Bitter	C-D	B-C	D-E	C-D	C-D	B	[2]A-B	[2]NT[3]	[2]C-E
Sour	C-D	C-D	B-C	C-D	C-D	B-C	C-D	B-D	C-D
Salt	B-C	B-C	B-C	[2]D-E	[2]B-C	C-D	B-C	D-E	D-E
Sweet	B-D	B-C	B-C	D-E	[2]D-E	[2]NT[3]	[2]D-E	[2]B-C	[2]Bitter
Orange	[2]D-E	[2]B-C	[2]C-C	[2]B-C	[2]NT[3]	[2]C-D	[2]C-D	[2]B	[2]C-D
Onion	D-D	C-D	D-D	[2]D-E	[2]NT[3]	[2]NT[3]	C-D	[2]C	[2]D-E

[1] Each taste was offered at five levels of intensity (A,B,C,D,E), increasing in intensity from A through E. Tasters started with least intense level of one flavor and reported the letter (level) at which a taste was first detected and the identity of that taste. Tasters continued increasing intensity until the identity of the taste was confirmed and then reported the letter (level) at which taste identity confirmed. For example, "Bitter C-D" means bitter was first detected at intensity level C and confirmed at level D.

[2] Significant differences in which changes of more than two intensity levels were considered significant.

[3] No taste detected at highest (E) intensity level.

TABLE 3-III.- SKYLAB AROMA IDENTIFICATION RESULTS

Actual aroma	Aroma identified								
	Commander			Pilot			Scientist Pilot		
	Preflight	Inflight	Postflight	Preflight	Inflight	Postflight	Preflight	Inflight	Postflight
Chocolate	Pepper	Chicken[a]	Chocolate	Chocolate	Chocolate	Chocolate	Chocolate	Chocolate	Chocolate
Pepper	Chocolate	Pepper	Pepper	Pepper	Pepper	Chicken[a]	Pepper	Onion[a]	Pepper
Wintergreen	Wintergreen	Wintergreen	Wintergreen	Spearmint/ wintergreen	Cinnamon[a]	Wintergreen	Wintergreen	Wintergreen	Wintergreen
Cinnamon	Cinnamon	Cinnamon	Cinnamon	Cherry[a]	Not identified[a]	Lemon[a]	Cinnamon	Cinnamon	Cinnamon
Onion	Pork[a]	Onion	Onion	Onion	Chicken[a]	Onion	Onion	Pepper[a]	Pork[a]
Orange	Orange	Orange	Orange	Wintergreen[a]	Orange	Wintergreen[a]	Orange	Orange	Orange
Control	Control	Control	Control	Control	Control	Control	Control	Pork[a]	Onion[a]
Cherry	Cherry	Cherry	Cherry	Control[a]	Pepper[a]	Cherry	Cherry	Cherry	Cherry
Spearmint	Spearmint	Spearmint	Spearmint	Wintergreen/ spearmint	Cinnamon[a]	Spearmint	Spearmint	Spearmint	Spearmint
Chicken	Chicken	Pork	Chicken/ pork	Pork	Pork	Pork	Chicken	Chicken	Chicken
Lemon	Lemon	Lemon	Lemon	Control[a]	Cherry[a]	Cinnamon[a]	Lemon	Lemon	Lemon

[a] Significantly incorrect (pairs which are very difficult to distinguish have not been considered significantly incorrect - these pairs are. wintergreen/spearmint, chicken/pork; and pepper/chocolate.

3.3.19 Gypsy Moth Eggs Experiment

The primary purpose of the gypsy moth eggs experiment was to ascertain whether prolonged exposure to zero gravity would prematurely terminate the diapause of embryonated moth eggs. If successful, the results could lead to an improved laboratory technique in rearing large numbers of gypsy moths for application in the sterile male technique of aiding in the control of propagation of this insect.

Five hundred wild gypsy moth eggs were placed in one vial and 500 tame moth eggs in a second vial. The vials were then transferred from the command module to the Orbital Workshop as soon as possible after Workshop activation and were taped to the inflight medical support system locker at the wardroom entrance. The Scientist Pilot made daily observations of the egg demonstration vial assembly to ascertain if the eggs were hatching.

On visit day 30, five or six wild eggs had hatched. This number increased to a total of 10 to 12 by visit day 33. Again on visit day 55, two more wild eggs hatched for a total of 12 to 14 hatchings. In contrast to the reported numbers of hatched larvae, only seven empty wild egg shells were found in the vial. One parasite larva was also found in this group and identified as a tiny wasp. No evidence of hatching was observed in the tame gypsy moth eggs or in the ground-based controls. The preliminary results indicate that the weightless environment did cause an early termination of diapause in the gypsy moth eggs. The full significance of these results will not be known until the recovered eggs are fully incubated and the total numbers and time sequence of all of the hatchings are known.

3.4 EARTH OBSERVATIONS

Earth Resources Experiment Package data from the Skylab first and second manned visits as well as data generated during the third visit are being used by 137 principal investigators in 32 states and 19 foreign countries. The disciplines in which investigations are proceeding include: agriculture/range/forestry, geological applications, continental water studies, ocean studies, atmospheric studies, coastal zone/shoal/bay studies, regional planning and development, cartography, and remote sensing techniques development. The Earth Resources Experiment Package sensors gathered data over the 48 contiguous states of the United States and 41 foreign countries. Data were also gathered over key sections of the Atlantic and Pacific Oceans; the Bay of Biscay; the Gulfs of Aden, St. Lawrence, and Mexico; the Great Lakes; the Sea of Japan; and the Mediterranean and Caribbean Seas. Table 11-III and figure 11-1 in the trajectory section of this report provide additional information on the locations and times of the Earth Resources Experiment Package passes.

Most of the investigations will require from 1 to 2 years to complete because of the large amounts of data involved. Several years will be required for all of the scientific benefits of the Skylab earth resources program to be realized. However, some initial results have been identified by the Earth Resources Experiment Package investigators. A potential mineral deposit has been identified near Ely, Nevada; citrus fruitfly infestations have been identified on the Mexican side of the Rio Grande river; new urbanization patterns have been identified; the use of Earth Resources Experiment Package imagery for inventory of vegetation patterns has been demonstrated; silt and possible man-made pollution have been identified off the island of Puerto Rico; and studies of photographs of the Sullivan, Indiana, mining district have identified surface fractures associated with mine subsidence and suspected mine acid drainage. Earth Resources Experiment Package altimeter measurements over the Puerto Rico trench have confirmed a previously inferred depression of the ocean surface. The data show the depression to be approximately 20 meters below the mean sea level.

The performance of the Earth Resources Experiment Package hardware during the third manned visit is described in this report. Thirty-eight Earth Resources Experiment Package data passes using the complete instrument package were performed with the spacecraft in the Z-axis local vertical attitude and one pass was performed with the spacecraft in the solar inertial attitude. In addition, three lunar calibrations, three earth-limb passes, two experiment S191 (Visible and Infrared Spectrometer) calibrations, one special experiment S192 (Multispectral Scanner) solar inertial pass, and three solar inertial passes using only the experiment S190B earth terrain camera were performed. Though mostly concentrated over the United States, Mexico, and South America, data were also obtained over Europe, Africa, Asia, and Australia. The Earth Resources Experiment Package diagnostic downlink unit was used on eight occasions to provide telemetry data for real-time analysis and troubleshooting.

3.4.1 Experiment S190A - Multispectral Photographic Facility

The experiment S190A photography is being used by various principal investigators to perform land use inventories, studies of soil erosion, timberline location, snow extent and water equivalency, plankton production, fishing productivity, and African drouth areas. Oceanic circulation patterns and energy-momentum distributions are being determined from a study of the experiment S190A photographs. The photographs are also being used to identify soil types and to locate possible areas for future cultivation, and to determine the ecological effects of strip mining by assessing acid mine drainage, sediment loading of streams, and resulting sedimentation. The photographs are being used to aid in highway engineering and to locate potential land and forest reclamation areas. Existing maps of South and Central America, as well as the United States, will be updated with information obtained from these photographic data. In addition to the many uses described, the photographs will be used to map glacial features for the location and protection of ground water sources and for the mapping of geologic structure and active fault zones. The data will be used to provide a better understanding of the relationship of volcanoes and geothermal features to regional geologic structures and active faults. Two examples of black-and-white photographs from experiment S190A are the Mobile Bay area shown in figure 3-12 and the San Francisco Bay area shown in figure 3-13.

Approximately 2750 frames of photography were taken from each of the six Multispectral Photographic Facility cameras during the third visit for a resultant total of approximately 16 500 photographs. The color film image quality, in terms of resolution and acuity, was significantly better than that obtained with this film on the previous visits. However, the imagery from the black-and-white infrared, color infrared, and black-and-white panchromatic films does not appear to be as good as that of the two preceding visits. Five rolls of black-and-white infrared film had base fog with two of these being so severe as to make image identification extremely difficult. The increased base density was general throughout the rolls and did not appear to be related to camera functions. The experiment S190A performance was normal, except for several functional and procedural problems. The more significant problems are discussed in the following paragraphs.

The camera-station reseau-plate cleanliness was not as good as on the previous visits. The photographs from some stations showed the same particulate pattern for many Earth Resources Experiment Package passes; in some cases, for two or more sets of film. More frequent cleaning of the reseau plates would have removed much of this material.

During checkout of the Earth Resources Experiment Package, the experiment S190A facility would not respond to operate commands from the Earth Resources Experiment Package control and display panel when the mode switch was placed in auto-sequence position. However, the camera did respond to single exposure commands from the control and display panel. Subsequent camera checks indicated that the experiment was operating normally in local control and that the control and display panel mode switch was faulty. Repeated cycling of the mode switch restored normal operation. Section 16.2.1 contains a discussion of this anomaly.

The camera filters were not installed for the first ten Earth Resources Package passes because of crew oversight. The color film has been processed, but the film from the other five camera stations is being held in cold storage pending results of trial processing techniques for recovering the synoptic imagery. The degradation of the color imagery was slight because no color correction filter was required for this

Figure 3-12.- Silt and current flow in Mobile Bay area.

Figure 3-13.- Silt and current flow in San Francisco Bay area.

film; however, the film from five other cameras, where the filters were required for proper spectral response, is probably of little use.

Experiment S190A experienced a loss of power after exposing 4 of 54 frames scheduled for Earth Resources Experiment Package pass 10. Subsequent troubleshooting indicated that the experiment S190A circuit breakers on panel 202 (Airlock Module) were open, though these breakers appeared to be closed. Recycling of all three circuit breakers restored power to the camera. The crew also noted that during Earth Resources Experiment Package pass 46, the camera shutters slowed down on one occasion and then returned to a normal speed. Simultaneous with the slowing, malfunction lights for cameras 1, 4, and 5 illuminated; however, all cameras continued to operate. Inspection of the film for the period of slow operation showed that the film transport operation had stopped at all camera stations and that identical frames had been double exposed. This was indicative of a momentary drop in bus voltage, probably to less than 24 Vdc. The experiment again experienced a loss of power during Earth Resources Experiment Package pass 47. The following day, power was restored to the experiment by recycling the experiment S190A circuit breakers. The problems were most likely due to a defective circuit breaker.

The control and display panel malfunction light for the station 6 camera illuminated during preparation for Earth Resources Experiment Package pass 30. Malfunction procedures demonstrated that the station was advancing film and that the film motion sensing magnetic pickup in the magazine drive assembly, which is external to the magazine, was functioning normally. The conclusion, based on this troubleshooting, was that either the film end was detached from the spool core or that the mechanical linkage between the supply-spool spindle and the film-motion sensor was disengaged. The photography was in no way affected. This anomaly is discussed in section 16.2.5.

The station 6 camera advanced an extra frame of film on two occasions during the second visit. The film metering magnetic sensor in the film magazine drive assembly was probably the cause of the spurious film frame advances. The problem became worse during the third visit in that crew reports of the station 6 camera frame counter readings disclosed that this camera was using more film than the other cameras. The crew replaced the magazine drive assembly. Postflight inspection of the last set of film used before the magazine drive replacement showed that 26 extra (blank) frames had been advanced on the station 6 camera roll. The four sets of film used after the drive assembly replacement had no extra frames advanced.

3.4.2 Experiment S190B - Earth Terrain Camera

The experiment S190B (Earth Terrain Camera) photography is being used in conjunction with experiment S190A data and other sensor outputs in the various studies discussed for experiment S190A. Additional studies that are being performed with the experiment S190B photography include surface-drainage patterns and stream network analysis for improved flood prediction, fishing industry forecasts, and effects of heated discharges from power plants into inland seas and estuaries. Three experiment S190B solar-inertial attitude passes were accomplished over Paraguay. The photographs from these oblique passes can be coupled with those from the normal Z-axis local-vertical attitude passes to provide the convergent geometry needed to perform topographic mapping activities within Paraguay. Portions of Paraguay have just recently been mapped and data for these areas will provide a calibration for Earth Resources Experiment Package mapping capability. The Earth Resources Experiment Package data will have a mapping application for other areas where maps do not exist. The high-spatial-resolution photography provided by experiment S190B is particularly applicable to regional planning and land-use studies in urbanized areas. Photographs of the Baltimore-Washington area and 12 other cities are being used by the Department of the Interior to test the use of space imagery for updating the 1970 data on population patterns. Figure 3-14 shows the Mobile, Alabama, area as photographed by the S190B experiment.

To improve the accuracy of the time recorded on the photographic images, a new clock was installed in the camera prior to the first photographic pass of the third visit. At the same time, a new clock knob was installed because the original knob was lost during the second visit. On visit day 30, a new vacuum seal was installed on the spare magazine assembly to maintain proper vacuum integrity for film flattening.

The earth terrain camera performed very well throughout the third visit. A total of 2476 photographs was exposed, with no reported equipment anomalies or major problems. Because of the camera's high resolution capability, and ease of setup and operation, the camera was used for real-time photographic passes in addition to the standard Earth Resources Experiment Package requirements.

3.4.3 Experiment S191 - Visible and Infrared Spectrometer

Data obtained by the experiment S191 spectrometer are being used for many studies which include a study to improve stratospheric structure models that may be useful for improved weather forecasting. Also, data collected over jet-stream cirrus cloud formations are being used to evaluate the dynamics of upper air flow. Since the atmosphere attenuates and absorbs portions of the reflected and emitted earth radiation, a knowledge

Figure 3-14.- Experiment S190B picture of Mobile Bay.

of these effects is important for the effective use of the Earth Resources Experiment Package data. The spectrometer was aimed by its crew-operated viewfinder tracking system to locate small, individual, homogenous areas containing agriculture fields, forests, lakes, rock outcroppings, cultural features, et cetera. By comparing similar measurements obtained at or near ground levels with the Skylab measurements, the atmospheric attenuation effects can be determined.

Experiment S191 performance was normal throughout most of the third visit. The data reviewed were within expected limits and were in good agreement with data from the previous visits.

The long-wavelength detector temperature was high during the last Earth Resources Experiment Package pass. As a result, the long-wavelength detector data were degraded but are still usable.

Pictures obtained with the 16-mm data acquisition camera through the viewfinder tracking system were of lower quality than those from the second visit. Much of the imagery was underexposed; however, the quality is sufficient for performing the required target identification tasks. The camera was mounted at a right angle to the proper position for the first few passes, and several anomalous gimbal angle and Greenwich mean time displays were noted. However, these discrepancies have no effect on the usefulness of the film for target identification.

3.4.4 Experiment S192 - Multispectral Scanner

Imagery from experiment S192 is being used for mapping fault zones, determining snow cover, mapping of land use, studies of the African drouth area, and for geothermal, water, and mineral exploration. The data will also be used for studies of near-shore currents, sediment transport, thermal pollution, and for environmental studies of proposed dam sites in Illinois. In addition to these and many other studies, experiment S192 data will be used for improving stratospheric structural models necessary for improved weather forecasting, and for determining water color and thermal variations related to ocean current interfaces in support of improved forecasting of fish locations.

The performance of experiment S192 during the third visit was quite good. However, some of the data was lost during one Earth Resources Experiment Package pass because the experiment S192 alignment switch was inadvertently left on.

Near the end of the third visit, the detector assembly was replaced with a new assembly containing an improved thermal detector. Imagery from the new detector evidenced very little of the banding (low-frequency noise) that had previously degraded the thermal data (refs. 3 and 4). Resolution in terms of noise equivalent temperature difference is 0.8° K as compared with 2.0° K for the previous detector. Extensive analyses and ground tests subsequent to the first visit had shown the low-frequency noise to be the 1/f noise (noise amplitude inversely proportional to frequency) inherent in semi-conductor detectors. An extensive detector development program culminated in a modified thermal detector design which was incorporated into the detector assembly that was launched on the third visit. However, several changes of the new detector assembly were known to be inferior to those of the original assembly; consequently, the change-out was delayed until late in the third visit.

A new attenuator, designed to optimize dynamic range for spectral bands 4, 5, 7, and 8 and reduce high-frequency noise in these bands, was used throughout the third visit. Although the improvement in dynamic range was realized, the noise (approximately 20 kHz) was not significantly reduced.

3.4.5 Experiment S193 - Microwave Radiometer/Scatterometer and Altimeter

Experiment S193 data are being used for studies of means and methods to improve remote sensing techniques. Storm system studies and studies of the dynamics of upper air flow are being made to improve weather forecasting. Sea-state studies, wind-field studies, and determination of sea surface brightness temperatures are being conducted. The experiment data are being used to assist in snow moisture content studies. Cloud data taken offshore are being studied in an effort to improve land-based weather radar techniques and weather satellite interpretation. Near the end of the third visit, an "around-the-world" altimeter data pass was accomplished to provide heretofore unavailable data on the earth.

Except for an apparent reduction in radiated power and a partial loss of antenna roll control, the performance of the S193 experiment was similar to that of the previous visits. The radiometer portion of this experiment operated normally, with the radiometric data correlating closely with that from the previous visits. The performance of the scatterometer and altimeter portions of the experiment was degraded by the apparent reduction in radiated power and the roll gimbal problem. Except for mode 5, DAS-3 operation,* altimeter performance was normal over the oceans and areas of flat or rolling terrain, but was marginal over mountainous terrain. Altimeter aborts dominated the mode 5, DAS-3 operations; however, the pulse compression network used in altimeter mode 5 continued to perform properly during this visit. This network was inoperative during the first visit, but began working properly during the second visit.

*Mode 5 is the pulse-compression mode of the altimeter. DAS-3 is data-acquisition submode 3.

During the second visit, the antenna pitch potentiometer became shorted and all control of the experiment S193 antenna was lost. The pitch axis was disabled and pinned at zero pitch during the first extravehicular activity of the third visit. This action cleared the short, thus restoring roll axis operation so that radiometer and scatterometer data could be taken in the cross-track modes. Pinning of the antenna also permitted acquisition of altimeter data in three of the five altimeter modes.

The antenna ceased scanning in the positive roll direction (left of the spacecraft) during Earth Resources Experiment Package pass 24. The data indicate the roll-axis gimbal drive motor was not being provided with the proper current during the positive roll periods. As a result, the antenna scanned in the negative roll direction, but radiometer and scatterometer data could not be obtained at positive scan angles after Earth Resources Experiment Package pass 24. This anomaly is discussed in section 16.2.7.

The internal calibration data indicate that the electronic section of the experiment S193 transmitter and receiver operated properly. The received signal strength during radiometer operation was normal, but the received signal strength during scatterometer and altimeter operations was reduced by approximately 20 dB throughout the third visit. Since the data indicate proper transmitter output power, the 20 dB loss may be the result of a problem in the antenna or antenna feed assembly. The data from the third visit represent the first experiment S193 data that were acquired subsequent to the shorting of the pitch potentiometer during the second visit. The antenna or antenna feed assembly may have been damaged or misaligned when the antenna repeatedly slammed against the limit stops during the second visit. The loss in signal strength will degrade the dynamic range of the scatterometer to an extent that the data obtained at the maximum scan angles may not be usable. The apparent loss in radiated power explains the marginal altimeter operation over mountainous regions and the aborts in mode 5, DAS-3.

3.4.6 Experiment S194 - L-Band Radiometer

Experiment S194 data are being used for analysis of snowfields to improve radiation models and energy transfer processes. Data collected over the western United States are being used to determine soil and snowpack moisture content for use in crop planning and predicting the effects of snow melt. For several days, experiment S194 data were acquired over a North Atlantic storm which was the largest and most intense cyclonic storm not of tropical origin to occur in this area in over a decade. Such repetitive data collected over a wide range of wind fields and sea states will be of major importance in studying storm development and progression, in evaluating alternative numerical model configurations, and in analyzing sensor signal variations.

The L-band radiometer, which is a microwave receiver that senses the L-band electromagnetic energy being radiated by the Earth's surface, performed normally during the third visit and, as on the previous visits, good quality data were received. The electronics enclosure temperature was always several degrees cooler than the design temperature, requiring an adjustment to the scientific data during ground processing.

A high beta angle resulted in a higher heat input from the sun to the experiment S194 system during Earth Resources Experiment Package pass 29 (visit day 60). As a consequence, both of the cold reference sources were too warm to provide valid calibration data and the scientific data from this pass are not usable unless special processing techniques are employed to utilize a valid calibration from the preceding pass.

3.4.7 Tape Recorder

The Earth Resources Experiment Package tape recorder system consisted of two tape recorders. Tape recorder 1 (primary) was used for the first 31 Earth Resources Experiment Package passes and recorded 11 reels of tape. Recorder performance was normal during seven of the reels, but during four reels, occasional tape motion light flickering (indicative of erratic tape velocity) occurred for short intervals while recording at the fast tape speed (1.524 meters per second). To preclude the possible loss of Earth Resources Experiment Package data, tape recorder 2 (secondary) was used for the remainder of the visit and recorded three reels of tape. Tape recorder 2 performance was normal except for a few instances of tape motion light flickering, as had occurred on both previous visits.

The quality of the Earth Resources Experiment Package data processed from the tapes indicates that both recorders performed quite well during the third visit. Some data losses did occur, most of which coincided with reports of the flickering tape motion light. However, in all cases, the data were redundantly recorded on another track that experienced no problem at that time. The data on tracks 3 and 13 of tape recorder 2 were of marginal quality, as was the case during the previous visits, but track 3 data were noticeably improved.

Analyses of the tape recorder system and inspections of the tapes indicate that the brief data losses were caused by accumulations of sticky tape degradation products on the recorder heads. The observed signal losses were characteristic of a gradual buildup of tape debris on the heads followed by a sudden self-cleaning action. As these buildups of contamination became thicker, they resulted in recorded signal loss due to increased head-to-tape spacing. The heads had been cleaned after the completion of each Earth Resources Experiment Package pass and both the heads and the tape path had been cleaned after removing each reel.

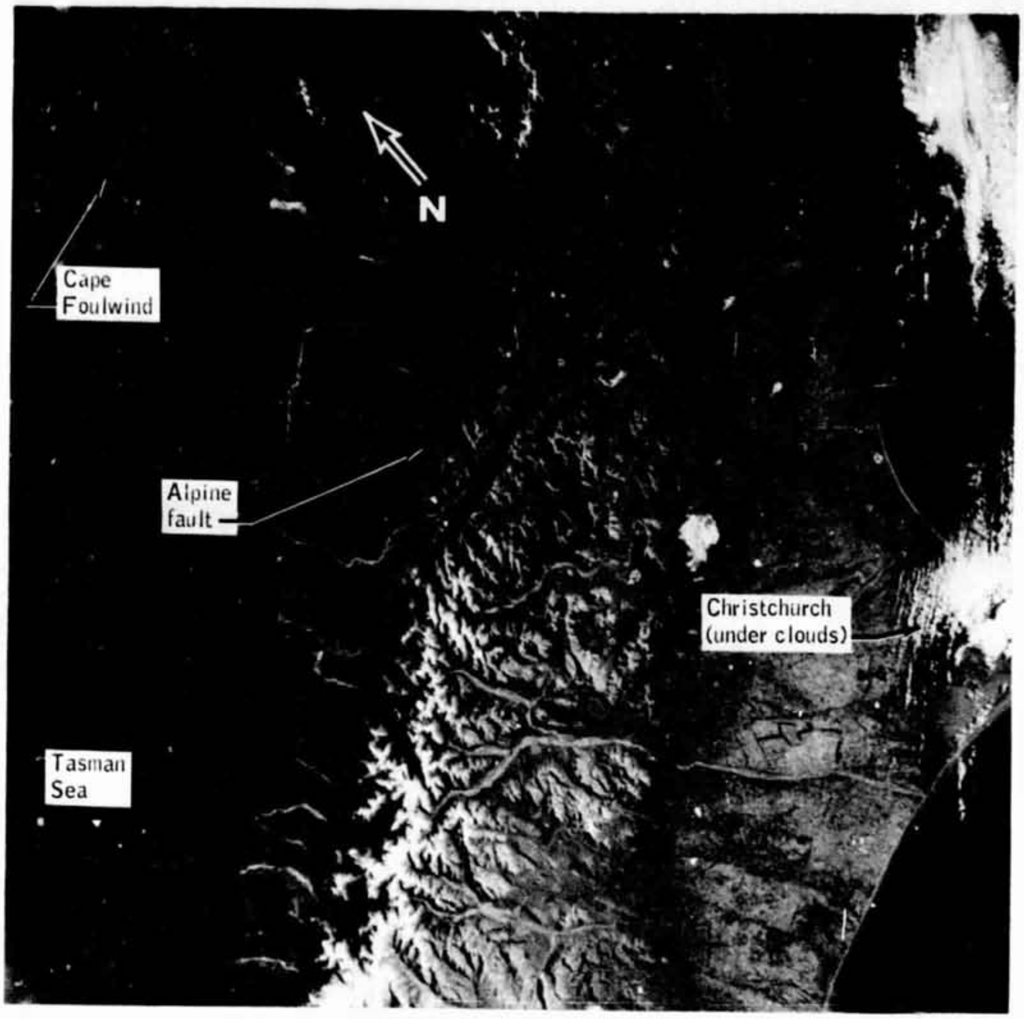
The flickering tape motion light occurrences on both tape recorders are indicative of erratic friction and drag in the tape path. One source of drag had been previously identified as sticky tape. Chemical, mechanical and functional tests performed on the turn-around idler removed from tape recorder 1 by the third visit crew show this idler to be another source of drag. The idler shaft at the upper jeweled bearing was found to be in an advanced stage of degradation. A combination of misalignment, excessive end play of the idler shaft, and loss of end jewel support was observed. The worsening idler condition observed in conjunction with sticky tape contaminants explains the onset of flickering motion light with tape recorder 1 used on the third visit. It is quite possible that a similar condition existed on tape recorder 2.

3.4.8 Visual Earth Observations Experiment

The visual earth observations experiment was conducted on the third visit and was designed to determine the tasks that man could visually perform from the Skylab space station in accomplishing scientific study of earth processes and phenomena. The data collected included crewmen observations and hand-held photographs obtained with the 70-mm and 35-mm cameras. More than 2000 photographs and about 850 observations were completed on the third visit.

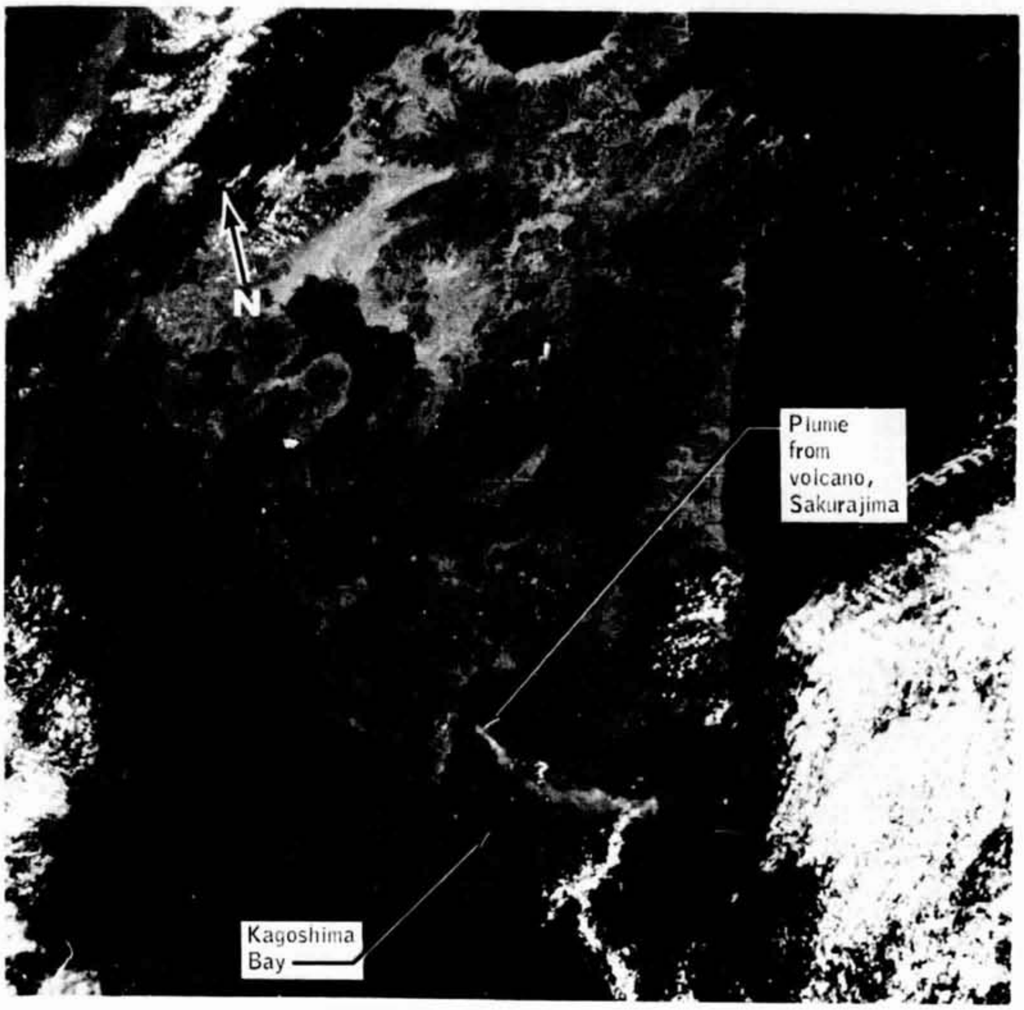
Observations of major geological fault systems indicate that low sun angles enhance tectonic structural features and that high sun angles enhance color differences. The Alpine Fault in New Zealand is shown in figure 3-15. Crew discussions of the extent and nature of the Alpine, Atacama, and Caucasus mountain fault systems indicate that the faults are more complex than had been recorded. Information obtained on the San Andreas, San Jacinto, and Agua Blanca fault systems identified areas that may provide new factors on the age and relative motion of the faults. Significant observations and photographs were obtained of the erupting volcano Sakurajima (Japan), shown in figure 3-16, and the relatively inaccessible volcanic fields of Bolivia, Argentina, and Chile. The Sakurajima information included the color, distribution, shape, and texture of the eruptive clouds and associated fume pattern. Specific new information was obtained on the star dunes in Algeria and on the Empty Quarter in Saudi Arabia.

Winter in the Northern Hemisphere allowed the crew to record areas of snow cover and snow melting on the Great Plains of the United States - conditions that are important to winter wheat production. Repetitive observations and photographs of the snow accumulation and melting phenomena of the mountainous regions of the western United States and the Great Plains have added appreciable information to the study of snow as a water resource. The snow melt rate progression, as related to cultural features, suggests that cities influence snow albedo and, therefore, snow



The Alpine fault line is marked by a scarp which is very distinct from orbital altitude. The left side of the fault has moved northeast (upward) relative to the right side; some stream offsets indicate the direction of relative movement. The distance from top to bottom is about 290 kilometers.

Figure 3-15.- South Island, New Zealand.



In repeated observations from Skylab, the plume of the volcano, Sakurajima, was seen to stream out to the south or southeast and became increasingly diffuse away from the volcano. The abundance and distribution of the plume gasses will be studied to help evaluate the effects and significance of man-made atmospheric pollutants.

Figure 3-16.- Island of Kyushu, Japan.

melt rates. Forest cover increases the difficulty in snow mapping and low sun angles facilitate the distinction of snow from clouds. Crew observations, relative to color tone between snow and snow-free areas aid directly in the interpretation of photographic data.

Croplands were determined to be the easiest vegetation environment for the crewmen to observe; primarily because of field color, and shape and linearity of field boundaries. In the Southern Hemisphere, harvesting and replanting of the cereal crops were recorded. Crop damage was not readily discernible; however, the crew could readily resolve the extent of flood conditions. Analysis has shown that visual observations from space are useful for assessing the rate and timing of plant development and these data may be applied to the development of a global crop inventory system. Haze conditions apparently do not impair crew observation capability to distinguish agricultural patterns although the haze reduces the color contrasts recorded in photographs. The best viewing time is mid-day, local time, and color is the principal factor used to distinguish type and maturity of crops, with light colors being the more readily discernible.

Color changes, indicative of vegetation growth, could be detected in regions of 50 percent vegetation cover but, in areas of sparse vegetation, the conditions of the forage could not be resolved. Numerous range fires were sighted in South America, Africa, and Australia; the crew could usually determine whether grass, shrub, forest, or croplands were burning. Fire scars were readily resolved; however, damage by disease and insects could not be determined. The recording of vegetation patterns and the variability within croplands could be accomplished through as much as 75-percent broken cloud cover.

The observation data, supported by many excellent photographs, have provided information on ice dynamics in the Great Lakes region and in the Gulf of St. Lawerence such as: rapid variability in ice features during very short time intervals, morphological change as new ice forms and old ice thickens, and the overall extent and character of the ice sheet from beginning to maximum coverage. The third Skylab visit provided visual information for determining the relationship of weather and the extent of ice, the thermodynamic studies of ice and water, and ship routing. Photographs of icebergs in the South Atlantic Ocean provide new and interesting time-sequence information on their distribution, size, shape, and occurrence. Further studies will aid in calculating their movements and their possible use as a source of fresh water in the desert areas of Chile.

Current boundaries were observed by color contrast and the presence of plankton bloom. Data obtained on the confluence of the Falkland-Brazil currents will provide new information on the growth and separation of meanders and current rings. The color differences showed that the currents do not mix, but travel side-by-side.

New data on red plankton bloom occurrence may aid biologists in the study of the spatial and temporal extent of the bloom. Crew confirmation of the occurrence of cold water eddies in the Yucatan current and their identification in other major ocean currents is an important new data source for study of ocean properties and ocean atmospheric energy exchange. Current-generated turbulent areas in the lee of islands was clearly visible and the crew could distinguish features which were not discernable in the photographs that they obtained. Also, detailed features of atolls, seamounts, and shoals that were not apparent in photographs were identified and described by the crew. The apparent absences of transported sediment far from the coastal sources, as reported by the crew, is an important data point in the study of ocean bottom sedimentation.

The cities of the western world stand out in sharp contrast to the surrounding cultivated regions and their characteristic photographic signature makes for ready identification. The cities in the Morocco-Algeria region, however, lack an abundance of industrial and commercial buildings. Therefore, these cities are in low contrast to the surrounding regions and are difficult to identify by visual observation and by image analysis.

Although analysis of the data obtained from this experiment will not be completed for several months, preliminary results indicate that visual observations have contributed to the knowledge of many earth phenomena.

4.0 ENGINEERING AND TECHNOLOGY EXPERIMENTS

4.1 ENGINEERING

4.1.1 Experiment M487 - Habitability and Crew Quarters

The third visit tended to confirm the conclusions drawn from the first and second visit results in the area of habitability. All scheduled objectives were accomplished. Supplemental tasks added to the original list of objectives toward the end of the visit were also completed. The only premission objective not accomplished was the evaluation of a new concept in foot restraints which could not be done because command module stowage became critical and items intended only for evaluation were removed from the stowage list in favor of additional consumables.

4.1.2 Experiment M509 - Astronaut Maneuvering Equipment

Five experiment M509 runs were completed with a total flying time of 5 hours and 23 minutes, although eight runs were planned. One of the Commander's runs and two of the Pilot's runs could not be scheduled in the flight plan. Consequently, some of the planned maneuvers, many of the exploratory maneuvers, and the suited evaluation of the hand-held maneuvering unit could not be performed.

There were no failures or new anomalies on the third manned visit. Data dropouts during about 10 to 15 percent of the flying time was the only continuing problem. Suited operations using the life support umbilical, which had been stripped to just the oxygen hose, were very satisfactory. Perturbations from the oxygen hose were barely noticeable by the crew, although the effects were observed in the rate data. Both crewmen had some difficulty in gripping the rotational hand controller when suited, causing long-duration yaw rotation commands to be very tiring. The Pilot also had some difficulty in connecting the propellant tank to the airlock recharge station during the Commander's suited run and this caused the tank and battery changeouts to be performed out of sequence. Consequently, the batteries were depleted before all of the planned maneuvers were completed on that run.

Overall accomplishments during the three visits include 11 experiment runs, flights by five different crewmen, and about 12 1/2 hours of flying time of which suits were worn for 3 hours. The automatically stabilized maneuvering unit modes were generally operated with the greatest precision. The specific tasks flown included point-to-point transfers, dogleg and curved trajectories, stationkeeping, attachment/assembly operations, docking, cargo transfer, rescue, free-floating object retrieval, tracking, and tumble recovery. Six degrees of control authority, automatic stabilization, proportional rate command, and conventional spacecraft piloting logic were verified as necessary design requirements for future extravehicular maneuvering units. The control moment gyro mode provided superior control performance, even in excess of the requirements for some tasks. The rate gyro mode performance was satisfactory for all tasks; however, the rate and displacement deadbands were not adequate for the limb motion and umbilical disturbances experienced. The direct mode performance was adequate, but required considerably more pilot attention than the stabilized modes. The hand-held maneuvering unit mode was usable when operating in the shirtsleeve configuration, but required excessive mental and physical activity when operating in the suited configuration. In view of the extensive training required for hand-held maneuvering unit operations, as well as the marginal control provided by this unit, further use of the hand-held maneuvering unit as an extravehicular tool is not planned.

4.1.3 Experiment M516 - Crew Activities Maintenance Study

The third visit supported the original hypothesis that man can accomplish any reasonable task assigned during weightless space flight provided the proper tools and environment are given. The third visit tasks were predominately servicing and troubleshooting, rather than repair. Nevertheless, the crew demonstrated many times the unique qualifications of man as a maintainer in devising solutions to nagging, if not major, difficulties which confronted the crew during the visit.

Not as much data were obtained for experiment M516 as was expected during the third visit because of scheduling difficulties associated with anticipating upcoming maintenance tasks and obtaining photographic coverage. Oftentimes, the problem was diagnosed and resolved by the crew before the proper protocols could be implemented on the ground to insure experiment coverage. Nevertheless, a wealth of data was compiled that will play a large part in assuring that maintainability is considered in future designs. Supplement 3 will contain additional information.

4.1.4 Skylab Parasol Material Evaluation

The Skylab parasol remained deployed throughout the third visit; however, the parasol did not provide any thermal protection because the twin-pole sun shield was deployed over the parasol. The remaining parasol material samples that were deployed on the first visit were returned for postflight analysis and for final validation of the laboratory environmental simulation techniques used in the evaluation of the parasol material.

The critical properties of the material chosen for fabrication of the parasol were evaluated. The parasol material consisted of orange nylon rip-stop cloth which was laminated to the Mylar side of an aluminized Mylar film. Ultraviolet radiation degradation of the laminate was evaluated in ground tests to determine the expected useful life of the parasol. The tests were conducted at several facilities with flux levels ranging from 1.2 to 5.4 suns, durations up to 1260 equivalent sun hours, and temperatures ranging from 311° K to 394° K. Following exposure to the ultraviolet radiation in a thermal/vacuum environment, a series of measurements including solar absorptance, total emittance, breaking strength, elongation, and tear strength were made on the parasol material and compared with similar measurements performed on control samples. Scanning electron microscope photomicrographs were taken of the material in the as-received condition and also after ultraviolet/vacuum exposure. The greatest degradations were a 68-percent loss in breaking strength and a 92-percent loss in elongation after 877 equivalent sun hours at twice the radiation intensity from the sun and an exposure temperature of 366.5° K. Tear strength results showed a 70 percent reduction after an exposure of 500 equivalent sun hours. No change was detected in total emittance after sample exposure, but, as expected, the solar absorptance increased moderately with ultraviolet exposure.

Additionally, two 30.5- by 30.5-centimeter specimens of the parasol material were deployed on the second extravehicular activity of the second visit and one sample was returned by the second visit crew after approximately 475 sun hours in the space environment. As before, solar absorptance, total emittance, breaking strength, elongation, etc., were measured on the returned sample. A 31-percent loss in breaking strength and a 40-percent loss in elongation compare favorably with the average ground-based data for a comparable exposure time. A second 30.5- by 30.5-centimeter specimen was returned by the third visit crew after the specimen had been exposed for approximately 1580 sun hours in the space environment. As expected, the solar absorptance increased to 0.58 (from 0.49 for the second visit sample), and breaking strength and elongation were further decreased (54 percent loss and 63 percent loss, respectively).

The results of the evaluation program have shown that exposure of the Skylab parasol material to ultraviolet radiation in a thermal/vacuum environment causes degradation of the parasol material. These effects were most pronounced in the mechanical properties and to a lesser degree in the optical properties; however, even with these degraded properties, the material was acceptable for use in the parasol because of the minimum loading the material received in service. The evaluation also showed that the laboratory tests adequately simulated the effects of exposure in the space environment.

4.1.5 Fire Extinguisher Discharge Test

A discharge test of one Orbital Workshop fire extinguisher was conducted to evaluate the effects of extended exposure of the extinguishing agent to zero gravity, and to assess the behavior of the extinguisher when discharged in a zero-g environment. The fire extinguisher is described in appendix A of this report.

Previous experience with this type of extinguisher has shown that the extinguishing agent will stratify during one-g storage, thus reducing the effective quantity and quality of the foam extinguishing agent when discharged. Stratification was not believed to occur in zero gravity, and discharge tests of returned fire extinguishers on the first and second visit spacecraft has indicated that stratification does not occur.

The test was conducted after the fire extinguisher had been exposed to zero-g conditions for 262 days. Complete discharge of the extinguisher into a plenum storage bag required 30 seconds. Based on the crew's comments, the extinguisher yielded between 0.1 and 0.14 cubic meter of foam. Only 0.07 cubic meter of foam was expected, indicating that storage in zero gravity does not adversly affect the extinguishing agent, and foam production may be enhanced in the zero-g environment.

4.2 TECHNOLOGY

4.2.1 Experiment T025 - Coronograph Contamination Measurement

The specially designed bracket, filter trays, and occulting disk performed very satisfactorily during all extravehicular operations on visit days 7, 40, 44, and 80.

During the first extravehicular activity on visit day 7, the 35-mm camera extravehicular activity viewfinder became loose. This prevented further use of the experiment at that time because the shutter-speed extension knob free-wheeled (see sec. 16.3.3). A total of five exposures had been completed when the problem occurred. Prior to the second extravehicular activity on visit day 40, the knob was repaired and all succeeding extravehicular activity operations for this experiment were satisfactory.

4.2.2 Experiment T053 - Skylab Earth Laser Beacon

Twenty-two passes with experiment T053 were performed during the third visit. Of the 22 passes, the beacon was successfully sighted 11 times and photographed by the crew. About 15 to 20 photographs were taken. All functional objectives were met.

The third visit showed that laser beacon stations can support operational spacecraft using existing technology, and that laser beacons are the brightest feature on the face of the earth.

The crew preferred the green/yellow colors over the blue colors for visual acquisition tracking. The nominal operational levels of 0.5 to 1 watt were adequate for man to sight the beacon from orbit. With power levels of 1 to 2 watts in the yellow, the laser beam remained visible to the spacecraft at slant ranges over 2592 kilometers. This corresponded to elevation angles of 170 to 340 milliradians relative to the beacon transmitter.

5.0 FOOD AND MEDICAL OPERATIONAL EQUIPMENT

5.1 FOOD

The extension of the third visit to 84 days required 66.4 kilograms of additional food to be launched to support the visit. Because of launch weight restrictions, the Skylab menus for the 28 additional days were modified to include new high-caloric-density foods and to make maximum use of the foods available in the Orbital Workshop. To provide a 10-day contingency rescue capability at the end of the visit, 9.8 kilograms of survival bars with a nutritional value of 60 000 kilocalories were also launched.

A resupply of salt was required because of the increased rate of consumption allowed on the first and second visits. For the resupply, crystal salt was packaged in modified Apollo beverage packages. The salt was rehydrated inflight, and syringes fitted with a special nozzle were used to dispense the liquid salt as required by the crew menus and by the mineral balance experiment. Powdered horseradish was provided in an Apollo rehydratable spoon bowl package.

As a result of crew experiences with conventional shaker and bottle-type condiment dispensers on the second visit, a squeeze dispenser was supplied for the third visit. The squeeze dispenser, containing a collapsed inner bag, was used for dispensing liquid pepper, Tabasco sauce, and liquid garlic. As the liquid was expelled from the dispenser, the collapsed inner bag inflated with air. This prevented air from becoming mixed with the liquid.

The Skylab food system and ancillary equipment presented minor problems; however, the problems did not prevent the use of any item.

The rehydratable packages presented several problems. A slight seepage occurred through the zipper closure of the spoon bowl package when kneading the package. When eating from a spoon bowl package, inadvertent closing of the bag caused food particles to be released into the atmosphere. One rehydration valve tube split because the water passage hole was either omitted or had been heat-sealed shut during manufacture.

The tension of the bellows (body) of the coffee container tended to expand the package and introduce gas into the beverage. Also, four black coffee items were mislabeled as coffee with sugar.

Lid seam failures were noted in one can of pineapple and one can of peanut butter. The salt dispenser nozzle became plugged with dried salt, causing one salt dispenser bag to split when force was applied in an attempt to remove the salt solution from the bag. The crew procedures were modified to prevent the splitting from recurring. Finally, surface tension caused the liquid pepper to cling to the outside of the dispenser nozzle instead of dispensing in a stream.

The crew commented that the chili was messy when eating. They also expressed a need for more ready-to-eat, quick-energy type foods. Comments concerning the condiments were that the liquid pepper could be used by dispensing the liquid on the back of a spoon and then spreading it on the food. Also, liquid condiments worked best when dispensed from a syringe-type device similar to the salt dispenser.

Summary of performance.- The food system performed reliably. Excluding the catsup package failures, which occurred in the first visit as a esult of the high temperature, the failure rate on all visits was less han 0.1 percent.

5.2 MEDICAL OPERATIONAL EQUIPMENT

5.2.1 Inflight Medical Support System

The inflight medical support system provided a source of drugs and medical equipment for miscellaneous problems. Several sets of resupply drugs were available aboard the Orbital Workshop. Several injectable drugs were resupplied because of potential degradation that was noted in concurrent ground-based testing which simulated the planned Workshop environment (except for zero gravity). Other resupplied injectable and noninjectable drugs included those with potential heavy use, or drugs which data had indicated may have incurred further degradation subsequent to the increased temperatures of the Workshop postlaunch phase. Special usage rules were added to the inflight medical support system checklist and these allowed access to the freshest of the many onboard drugs.

The preflight evaluation of the inflight medical support system equipment was generally satisfactory. The items of questionable efficacy included:

a. Tracheotome - Inadequate sharpness, somewhat time consuming to use.

b. Intravenous bags - Plastic tubing crushed in packaging.

c. Endotracheal tube - Crushed in packaging.

d. Injectables - Difficult to pull covers off needles.

e. 1 to 10 000 injectable Epinephrine (10 cc) - Glass container found broken on one sample.

f. Catheterization kit - Kit contained inadequately sized collection bags.

g Head mounted light source - Focus of the light was poor.

The diagnostic equipment that was used included the otoscope for the evaluation of the Pilot's left ear fullness (occurring from visit day 29 through visit day 32), the thermometer for several of the "congestion" episodes, and the hemoglobinometer and refractometer as part of routine checking by the crew.

Hemoglobin and specific gravity were checked at the time of the regular blood drawings during the second visit. This same plan was initially followed by the third visit crewmen, but to save time, the specific gravity measurements were deleted except for clinical necessity after visit day 38 and only four measurements were taken.

The hemoglobin check continued to be performed and, because of low readings starting about visit day 59, additional checks were made between the regularly scheduled blood drawings by using blood drawn by the fingerstick technique.

5.2.2 Operational Bioinstrumentation System

The operational bioinstrumentation was used during launch, extravehicular activities, experiment M509 suited runs, and entry with satisfactory electrocardiogram and impedance pneumograph data being obtained.

5.2.3 Exercisers

After the first Skylab visit, a need was recognized for some exercise device that was capable of supplying forces an order of magnitude greater than previously used to maintain one-g muscle function. In addition, the exerciser would require the coordination of walking or running as well as induce large energy workloads to minimize additional exercise time required for cardiovascular conditioning. In view of the critical stowage restrictions for the third visit command module, a treadmill was designed which required minimum stowage space and weighed only 1.6 kilograms. The treadmill is described in appendix A.

The treadmill did not exactly simulate normal walking, but did place heavy loads on calf musculature, in particular, and extensors, in general. High forces were placed on the extensor muscles, as was desired. No attempt was made to achieve aerobic exercise, which was provided by the bicycle ergometer. The exercisor required a reasonable degree of coordination. One measurement showed that oxygen uptake was approximately 50 percent maximum while using the device. It was typically used for 10 to 1[illegible] minutes per day with walking, jogging, and jumping-in-place exercises.

The Mark I, Mark II, and Mark III exercisers (ref. 3) and the bicycle ergometer (ref. 5) performed as anticipated, but the Mark I exerciser sustained three return-spring failures during the third visit. The first two, on visit days 19 and 74, were corrected by the crew through replacement of the return spring. The final spring failure, on visit day 80, was not repairable and usage of the unit was discontinued for the remaining 4 days of the visit.

5.3 ENVIRONMENTAL MONITORING

Three types of monitoring and sample techniques were used in the Orbital Workshop to assess the consumables and the livability of the environment. The atmosphere was monitored for toxicity and volatile content. The potable water was sampled to determine quality and the iodine content.

5.3.1 Atmospheric Toxicity Monitoring

The third visit was completed without any toxicological difficulty. Three carbon monoxide detector tubes were available for measuring carbon monoxide levels in the Orbital Workshop work space during the beginning, mid-portion, and final phases of the visit. No significant levels of carbon monoxide were detected at any period during the visit.

The Orbital Workshop wall insulation (polyurethane) caused some concern because of excessive heating conditions during certain spacecraft maneuvers required for Earth Resources Experiment Package data collection. Laboratory tests were conducted on insulation samples to determine if any toxicological problem could develop as a result of the heating of the spacecraft wall. The results indicated that a safe environment could be maintained as long as the wall was not heated beyond 435° K for a period not exceeding 8 hours. The Earth Resources Experiment Package maneuvers were completed without causing environmental difficulties.

5.3.2 Atmospheric Volatile Concentration

An atmospheric volatile concentration measurement device was used on the third visit for the first time. This device collected and trapped volatile organic molecules from the Workshop environment in small tubes. The tubes were subsequently capped and returned for quantitative analysis. Samples from the beginning, middle, and end of visit have been subjected to high-resolution gas-chromatographic analysis. The results indicate the presence of at least 150 organic volatile compounds, which are defined for this experiment as those chemicals that can be desorbed from the porous polymer in the sample tubes and can be chromatographed directly at 448° K. In essence, the compounds which are not gases under normal conditions are separated and assessed at the parts per billion level. These consist of chemicals (aldehydes, ketones, alcohols, and hydrocarbons) that range up to 200 in molecular weight. Mass spectrometric analysis is continuing to determine the concentration of these compounds.

5.3.3 Potable Water

Inflight potable water samples were taken to monitor the biocide concentration in the water storage tanks and to determine the amount of adjustment necessary to maintain an effective biocide level. Inflight samples were also returned for postflight verification of the chemical quality of the water. The postflight analysis was required so that an assessment could be made of the impact of potable water chemical constituents on the mineral balance and bioassay of body fluids experiments. Water usage for all phases of the third visit was 746.3 kilograms, which is about 72 percent of the preflight estimates.

Summary of performance.- The water system performed satisfactorily throughout all visits and no significant problems were experienced. Water usage throughout the three visits to the Orbital Workshop was 1763.4 kilograms, about 81 percent of the total planned usage.

6.0 COMMAND AND SERVICE MODULES

This section contains the performance evaluation of the command and service module systems for the third visit.

6.1 STRUCTURES AND MECHANICAL

The command and service module structural, mechanical, and earth landing systems performed satisfactorily, although two attempts were required for the initial docking because of low command and service module closure rates.

The third visit crew noticed a light brown film of contamination on the surfaces of all the command module windows upon reentering the spacecraft for earth return. The film remained intact during earth entry except for some flaking in local areas.

After recovery, the two rendezvous windows were removed and examined with a scanning electron microscope. The examination showed the film to consist of a top layer that was 0.4 micrometer thick, and a lower layer that was 1.3 micrometers thick. Dispersive X-ray analysis showed the presence of silicon in both layers. Infrared spectrochemical analyses showed the silicon to be present in the form of silicone chemical linkages. The mass of the contaminant film ranged from 0.25 to 0.28 milligrams per square centimeter.

Although no specific contaminant sources can be identified from these data, the top layer of contaminant was undoubtedly collected during entry from outgassing of tape adhesives and thermal control paints. The bottom layer is hypothesized to have been deposited in orbit due to outgassing of S-13G thermal control paint located on the bottom of the Orbital Workshop solar panels as well as other areas on the cluster. Predictions of deposition on window surfaces, primarily due to outgassing of S-13G, had been made through the contamination mathematical model prior to any flights. Further analyses is continuing to specifically identify the source of contaminants.

Summary of performance.- The spacecraft structural, mechanical, and earth landing systems performed satisfactorily during all three visits except that after the standup extravehicular activity during the first visit, eight attempts were required to achieve a hard docking with the Workshop. This condition is discussed in reference 3.

6.2 THERMAL

The third visit spacecraft temperatures were within acceptable limits. Table 6-I compares the service module reaction control system temperature limits to the flight data.

The command and service module thermal control system configuration of each Skylab spacecraft was changed to meet the normal variations in the thermal environment for each visit. The angle between the orbital path and the ecliptic plane determines the quantity of solar heat incident upon an orbiting spacecraft with a fixed orientation. This angle, termed the beta angle, was a function of the launch date and varied throughout each visit with a consequential variation in solar heating of the spacecraft. Therefore, each Skylab spacecraft thermal control system required a custom design.

The third visit command and service module thermal control system configuration was changed in that a different thermal control coating was applied to the surface of the service module covering the orbital batteries in bay I (fig. 6-1) to reduce the absorbed solar heat. The preferred maximum temperature of the batteries in a dormant condition was 302.6° K. Without a change in thermal coating, the temperature would have been about 315° K. With the coating change, the maximum temperature was 303° K. The change was necessitated by a prolonged solar heating period caused by adverse beta angles near the end of the visit, a condition peculiar only to the third visit.

The quad A propellant storage module flexible line bracket temperature, as a function of beta angle, changed for each Skylab visit. The effect of the beta angle changes is typical for all the temperature measurements; however, differences in the average visit temperatures are somewhat greater for this measurement than that of other components, because this measurement is the most sensitive and is exposed to the most severe thermal environment. The temperature at this sensor, as well as surrounding components, increased each time the spacecraft returned to the same beta angle. This resulted from degradation of the thermal control coating.

Photographs taken during the fourth extravehicular activity show that the major portion of the command and service module thermal coating changed color, that sections near quad A of the service module reaction control system had blistered and peeled, and that the coating just below quad A was charred. The general discoloration of the command and service module was thought to be caused by deposited contaminants (possibly outgassed material) and by solar ultraviolet irradiation. The blistering and charring was caused by the reaction control system engine plume heating. The effect of the thermal control coating degradation was to increase the solar-side component temperatures each time the spacecraft returned to the same beta angle.

TABLE 6-I.- THIRD VISIT REACTION CONTROL SYSTEM TEMPERATURE DATA

Category/name	Temperature, °K			
	Limit		Recorded	
	Maximum	Minimum	Maximum	Minimum
Quad A				
Engine package	394	286	378	314
Oxidizer line	352	267	325	283
Helium tank	333	267	325	292
Fuel tank	332	272	324	294
Quad B				
Engine package	394	286	373	312
Oxidizer line	352	267	299	277
Helium tank	333	267	292	279
Fuel Tank	332	272	295	284
Quad C				
Engine package	394	286	372	311
Oxidizer line	352	267	298	276
Helium tank	333	267	297	279
Fuel tank	332	272	297	280
Quad D				
Engine package	394	286	373	320
Oxidizer line	352	267	309	272
Helium tank	333	267	311	289
Fuel tank	332	272	306	286

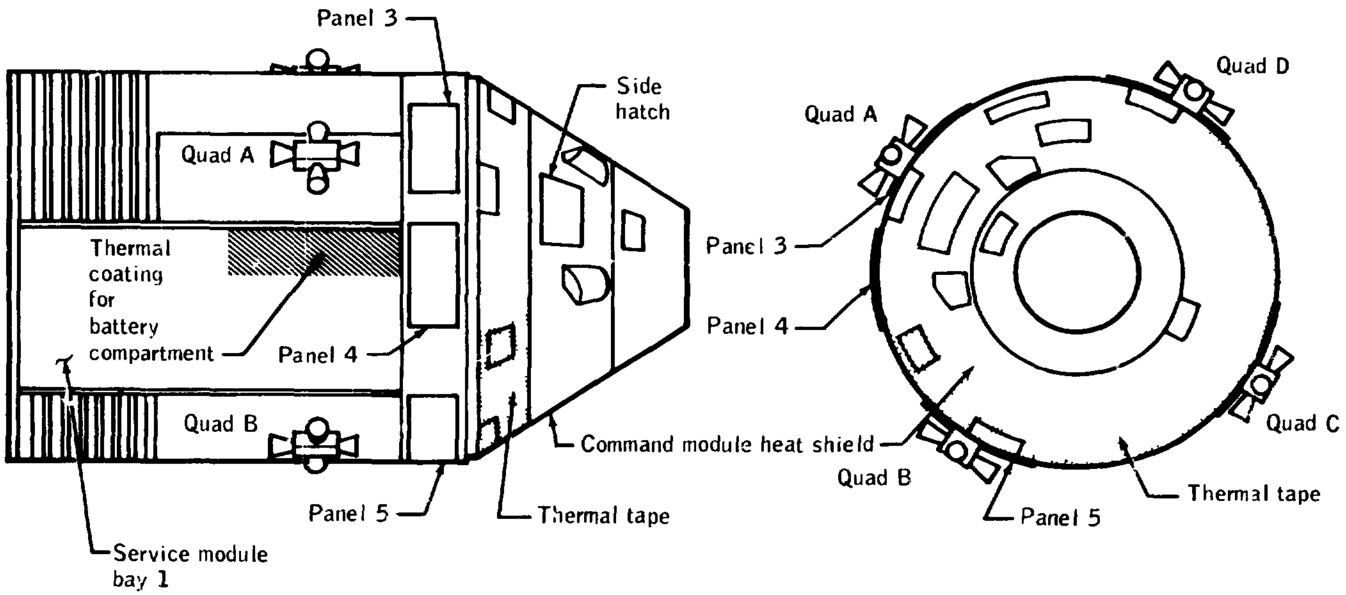


Figure 6-1.- Thermal modification to the third visit command and service module.

6.3 ELECTRICAL POWER, FUEL CELLS, BATTERIES, AND CRYOGENIC STORAGE

6.3.1 Electrical Power Distribution

The power distribution system performance was satisfactory. After docking, the command and service module was powered down to the planned quiescent power level. After depletion of fuel cell reactants, the command and service module received power from the Saturn Workshop power sources. All power transfers and power levels were normal with the exception that, during the entry minus 6 day checkout, no indication of voltage was present when entry battery A was switched onto battery bus A. Repeated cycling of the bus tie circuit breaker was required to place battery A on the bus. A discussion of this anomaly is contained in section 16.1.4.

6.3.2 Fuel Cells

Fuel cell performance was normal throughout the third visit. Radiator thermal taping was not required to maintain the proper condenser exit and radiator temperatures because the radiator area bypass valve was actuated. The valve bypasses three of the eight radiator panels, thus reducing the effective radiator area.

The average spacecraft electrical load during the docked quiescent operations was 43.7 amperes. The fuel cells were shut down when the hydrogen quantity approached zero percent, which occurred 19 days after lift-off.

The fuel cells provided 19 500 ampere-hours of energy at an average bus voltage of 29.8 volts.

6.3.3 Cryogenic Storage

The cryogenic hydrogen and oxygen storage system performance was normal. Oxygen tank 2 was deliberately offloaded to about 80 percent quantity to minimize the amount of inflight venting after fuel cell shutdown. After shutdown, the hydrogen vent was opened and the small amount of residual hydrogen was vented overboard through the nonpropulsive vent. The remaining oxygen was managed by flowing oxygen through the polychoke orifice into the command module. Oxygen was not vented overboard during the third visit, thereby precluding any thrusting that might disturb the Orbital Workshop attitude. Oxygen and hydrogen quantities are summarized in section 6.10.3 of this report.

Summary of performance.- Cryogenic storage system performance was normal for all three visits. Minor problems were experienced during the first two visits; however, these were quickly remedied and did not adversely impact mission opertions.

6.3.4 Batteries

The entry and postlanding batteries, pyrotechnic batteries, and descent batteries supported spacecraft operations normally.

Entry batteries A and B were each charged once on the launch complex and once after docking with the Orbital Workshop at the beginning of the third visit.

Battery A could not be placed on the bus during the entry minus 6 day checkout because of a circuit breaker problem. (Sec. 16.1.4 contains a discussion of this anomaly.) As a result of this problem, more energy was used than planned from batteries B and C (approximately 10 ampere-hours each) during this check. Consequently, both batteries were recharged to full capacity prior to undocking.

Pyrotechnic battery A was placed on main bus A for a momentary period during the troubleshooting of the circuit breaker problem to assure that a backup capability to entry battery A existed. This application of a pyrotechnic battery was the first usage in this type of situation.

The service module descent batteries, during the period from spacecraft powerup to command module/service module separation, provided 715 ampere-hours of energy for all spacecraft operations as compared with the planned usage of 830 ampere-hours. Battery 1 delivered 375 ampere-hours and experienced a temperature rise from 290° K to 372° K during this period while battery 3 delivered 340 ampere-hours and an attendant temperature rise from 284° K to 328° K. Battery 2 was not used.

Entry battery A provided 12 ampere-hours during entry, while entry battery B provided 15 ampere-hours, and entry battery C provided 13 ampere-hours, for a total usage of 40 of the 120 ampere-hours available.

Summary of performance.- Battery performance throughout all three Skylab visits was normal with the batteries supporting all spacecraft power requirements and, in many instances, exceeding the specification operational requirements.

The entry and pyrotechnic batteries from the spacecraft used on the first two visits received a residual capacity discharge test about 2 months after the second visit spacecraft had landed. All 10 batteries tested delivered, as a minimum, the specification capacity of 40 ampere-hours, even after extended periods of storage.

6.4 COMMUNICATIONS AND TELEVISION

6.4.1 Communications

The communications system satisfactorily supported the third visit operations.

During the previous two visits, considerable effort was required to keep the volume controls on the speaker intercom assemblies, located throughout the Saturn Workshop, adjusted to prevent feedback squeal. A command and service module audio-center adapter was carried on the third visit to reduce the level of the audio signal as it was processed in the command and service module system. The adapter was installed after Workshop activation and was very effective in alleviating the feedback problem.

A condition occurred at landing which was identical to one which had occurred on the second visit. Salt water collected in the docking tunnel connectors, shorting the keying function and causing the very-high-frequency transmitter to key continuously. The system was reconfigured in accordance with corrective procedures established after the second visit problem, and two-way communications with the recovery forces were established.

Summary of performance.- Except for two unrelated updata link failures during the first and second visits and a hand-held microphone shield problem, the system hardware provided relatively trouble-free reliable communications for the entire Skylab program.

6.4.2 Color Television Camera

One color television camera was resupplied for the third visit, thus providing two cameras for use during the visit. The color television system performed as expected except for the following two problems.

a. Spots appeared on transmitted images from at least one of the cameras. Similar spots were observed on previous visits and were, thus, somewhat expected. They did not adversely affect the video operation other than for the obvious cosmetic degradation.

b. The crew noticed a small object apparently floating inside the tube of one of the mini-monitors. The monitor continued to operate normally throughout the visit and its use was not impaired.

Summary of performance.- During the entire Skylab program, the color television camera system performed all required functions. Certain problems occurred including a camera failure (due to severe overheating during an extravehicular activity), cable failures, and spots on some of the video transmissions. However, backup units and the resupply capability on the second and third visits provided the necessary equipment to accomplish all of the required color television objectives.

6.5 INSTRUMENTATION AND DISPLAYS

All command and service module instrumentation hardware performed satisfactorily with the exception of a resistance thermometer and a differential pressure transducer. The displays performed satisfactorily throughout the third visit.

A resistance thermometer that measured the surface temperature of a service propulsion system oxidizer tank indicated off-scale low on visit day 5. This anomaly is discussed in detail in section 16.1.1.

The differential pressure transducer which indicated flow rate in the primary water/glycol line showed large perturbations in the indicated flow rates, pressures, and temperatures of the primary loop when the weekly test procedure was performed on visit day 29. After the procedure was conducted, the primary loop water/glycol flow rate indication was approximately 4 percent higher than it had been before the procedure was performed; however, the actual flow rate, as calculated from the indicated pump pressure, was unchanged.

An 8-percent increase above the normal flow rate value was indicated after the weekly test was conducted on visit day [illegible]. The procedure was again conducted on visit days 45 and 50 and, in each instance, the indicated water/glycol flow rate was reduced about 4 percent, thus indicating the normal value after visit day 50. Subsequent weekly tests resulted in erratic indications, both higher and lower, of flow rates of about the same order of magnitude. The correct flow rate was indicated after the procedure was conducted for the last time on visit day 78.

The most probable cause of the erratic indication was stiction in a pivot bearing of one of the movable components in the transducer. Physical analysis of the transducer is not planned because the flow rate can be satisfactorily determined from the accumulator quantity and the pump pressure indications, should the erratic behavior reappear during another mission.

6.6 GUIDANCE, NAVIGATION, AND CONTROL SYSTEMS

The performance of the guidance, navigation, and control system was normal. At the completion of the launch phase, the onboard computer indicated that an orbit of 153.7 by 223.5 kilometers had been achieved. Analysis of launch data indicates insertion errors of 0.53, -0.95, and 0.54 meter per second in spacecraft X, Y, and Z axes, respectively. These compare favorably with previous visits and indicate normal performance of the inertial instruments during the launch phase.

The tracker light on the spacecraft display console illuminated approximately 34 minutes after lift-off. This alerted the crew to a fail condition in the optical coupling data unit. Attempts to reset the warning indication were unsuccessful and the fail condition persisted for approximately 35 minutes before it cleared itself. A data review while the fail condition was present verified that the coupling data unit was operating normally and the cause of the fail condition was probably an intermittent failure within the failure detection circuit. This failure would have had no effect upon mission operations. The optics operated normally before and after the time period when the failure condition existed. A segment within the optical coupling data unit is used to route steering commands to the service propulsion system engine, and a verification was made that this segment would not be affected by this failure. At no time during the remainder of the visit did the failure indication reappear.

Table 6-II summarizes the platform alignments and table 6-III summarizes the maneuvers performed using the service propulsion system engine.

The guidance, navigation and control systems operations during entry were normal. Adequate control authority was available using only one ring of the reaction control system. The second ring was disabled because of the helium leak discussed in section 16.1.3.

An attitude control problem was experienced during the command module/service module separation sequence. A procedural error resulted in four circuit breakers being opened which removed 28 volts from the automatic coils of the pitch and yaw control engines. Consequently, the crew had to use the emergency direct coils to maintain manual attitude control in pitch and yaw. The roll automatic coils were configured properly and the digital autopilot controlled the spacecraft roll attitude through entry

TABLE 6-II.- PLATFORM ALIGNMENT SUMMARY

Time, Day:hr:min:sec	Program option	Star	Gyro torquing angle, rad			Star angle difference, rad	Gyro drift, meru		
			X	Y	Z		X	Y	Z
320:14:50:49	3	04 Achernar, 14 Canopus	0.646	0.000	-3.683	0.0	-2.93	0.00	-17.07
320:14:57:37	2	02 Diphda, 04 Achernar	7.365	-5.062	0.471	0.0	-	-	-
320:16:10:11	3	02 Diphda, 04 Achernar	0.785	-0.489	-0.262	0.0	-2.47	1.53	-0.80
320:17:49:24	3	02 Diphda, 04 Achernar	0.681	-0.733	-0.599	0.0	-1.53	1.67	-1.27
320:22:24:24	3	02 Diphda, 04 Achernar	0.593	-2.025	-1.379	0.0	-0.47	1.67	-1.13
322:21:05:30	3	12 Rigel, 14 Canopus	3.543	-23.091	-14.644	0.0	-0.29	1.93	-1.22
322:21:30:00	3	12 Rigel, 14 Canopus	-0.052	-0.209	0.0	0.0	0.49	1.95	0.0
33:13:00:30	1	22 Regulus, 24 Gienah	-	-	-	-	-	-	-
33:16:04:40	3	22 Regulus, 26 Spica	3.158	-5.898	-3.839	0.0	-3.87	7.33	-4.73
38:12:25:30	-	22 Regulus, 31 Arcturus	1.064	0.034	1.745	0.0	-	-	-
38.17:02:00	-	26 Spica, 31 Arcturus	3.141	-7.172	-2.792	0.0	-2.60	5.93	-2.27
39:03:11:10	3	26 Spica, -	-6.736	16.422	-6.422	0.0	2.53	-6.27	-2.40
39:08:24:24	3	22 Regulus, 24 Gienah	-0.069	0.917	-0.017	-	0.00	0.00	0.00
39:13:00:00	3	15 Sirius, 31 Arcturus	-0.094	0.855	1.082	0.0	0.73	-0.67	0.87

TABLE 6-III.- MANEUVER SUMMARY

Parameter	First phasing	Second phasing	Corrective combination	Coelliptic	Terminal phase initiation	Shaping	Deorbit
[a]Time							
Ignition, G.m.t.	320:16:23:21.62	320:18:36:19.62	320:19:21:27.24	320:19:58:27.24	320:20:49:00.26	39:11:32:54.00	39:14:35:59.00
Cutoff, G.m.t.	320:16.23:23.31	320:18:36:27.05	320:19:21:37.11	320:19:58:28.35	320:20.49:01.07	39:11:33:06.14	39:14:36:06.97
Duration, sec	1.69	7.43	9.87	1.11	0.81	12.14	7.97
Velocity, meters/sec							
X-axis	10.36	46.70	63.73	7.22	5.79	-82.33	-54.65
Y-axis	0.00	0.00	-2.74	2.19	0.21	0.00	0.00
Z-axis	-4.88	0.76	2.29	1.49	-2.62	21.37	13.93
[b]Residuals, meters/sec (before trim)							
X-axis	0.06 (0.2)	-0.06 (-0.2)	-0.06 (-0.2)	0.00 (0.0)	0.12 (0.4)	0.03 (0.1)	-0.21 (-0.7)
Y-axis	0.06 (0.2)	0.03 (0.1)	0.00 (0.0)	0.00 (0.0)	-0.03 (-0.1)	0.09 (0.3)	0.21 (0.7)
Z-axis	-0.03 (-0.1)	-0.03 (-0.1)	-0.09 (-0.3)	-0.06 (-0.2)	-0.03 (-0.1)	0.21 (0.7)	0.18 (0.6)
[b]Residuals, meters/sec (after trim)							
X-axis	No trim	No trim	-0.03 (-0.1)	0.00 (0.0)	-0.03 (-0.1)	-0.03 (-0.1)	-0.03 (-0.1)
Y-axis			0.03 (0.1)	0.00 (0.0)	-0.03 (-0.1)	0.03 (0.1)	0.06 (0.2)
Z-axis			-0.03 (-0.1)	0.00 (0.0)	-0.03 (-0.1)	0.03 (0.1)	0.00 (0.0)

[a] Greenwich mean time is shown in day-of-the-year, hours, minutes and seconds.

[b] Residuals shown in parentheses are in feet per second, as displayed to the crew.

and the vehicle was guided to a landing at latitude 31 degrees 18 minutes 36 seconds north, longitude 119 degrees 46 minutes 12 seconds west, as indicated by the onboard computer. The landing was about 3.5 kilometers from the recovery ship.

6.7 PROPULSION

6.7.1 Service Propulsion System

The service propulsion system operations were normal throughout the visit. Seven maneuvers were accomplished with a total firing duration of 41 seconds. Propellant usage data are shown in section 6.10.1.

During the docked period, system parameters were normal. On visit day 3, the oxidizer tank outboard temperature indication decayed to a reading of zero and remained there throughout the remainder of the visit. The redundant measurement, oxidizer tank inboard temperature, was used to monitor this area. Section 16.1.1 discusses this anomaly in detail.

After undocking and prior to the shaping and deorbit maneuvers, the propellant tank pressures were equalized by manually activating the helium isolation valves. Firing times for the shaping and deorbit maneuvers were approximately 12.1 seconds and 8 seconds, respectively.

Photographs were taken during the fourth extravehicular activity showing the command and service module between quads A and D (fig. 6-2). Analysis of these photographs showed some surface distortions on the engine nozzle extension in the area of the columbium/titanium interface and intermediate stiffener ring (fig. 6-3). The coated columbium/titanium configuration is subject to this type of distortion as a result of the thermal shock that is caused by the short-duration firing characteristic of the Skylab mission. Similar deflections and wrinkles occurred during the altitude chamber tests early in the development program of the engine. The nozzle extension design and the physical properties of the alloys allowed for such distortion without rupture. Consequently, the engine performance was not affected by the surface distortion.

Summary of performance.- The service propulsion system performed normally during all three visits. The basic finding during the missions was the fact that the modifications made to the Apollo service propulsion system to withstand the effects of long-duration exposure to the propellants were successful.

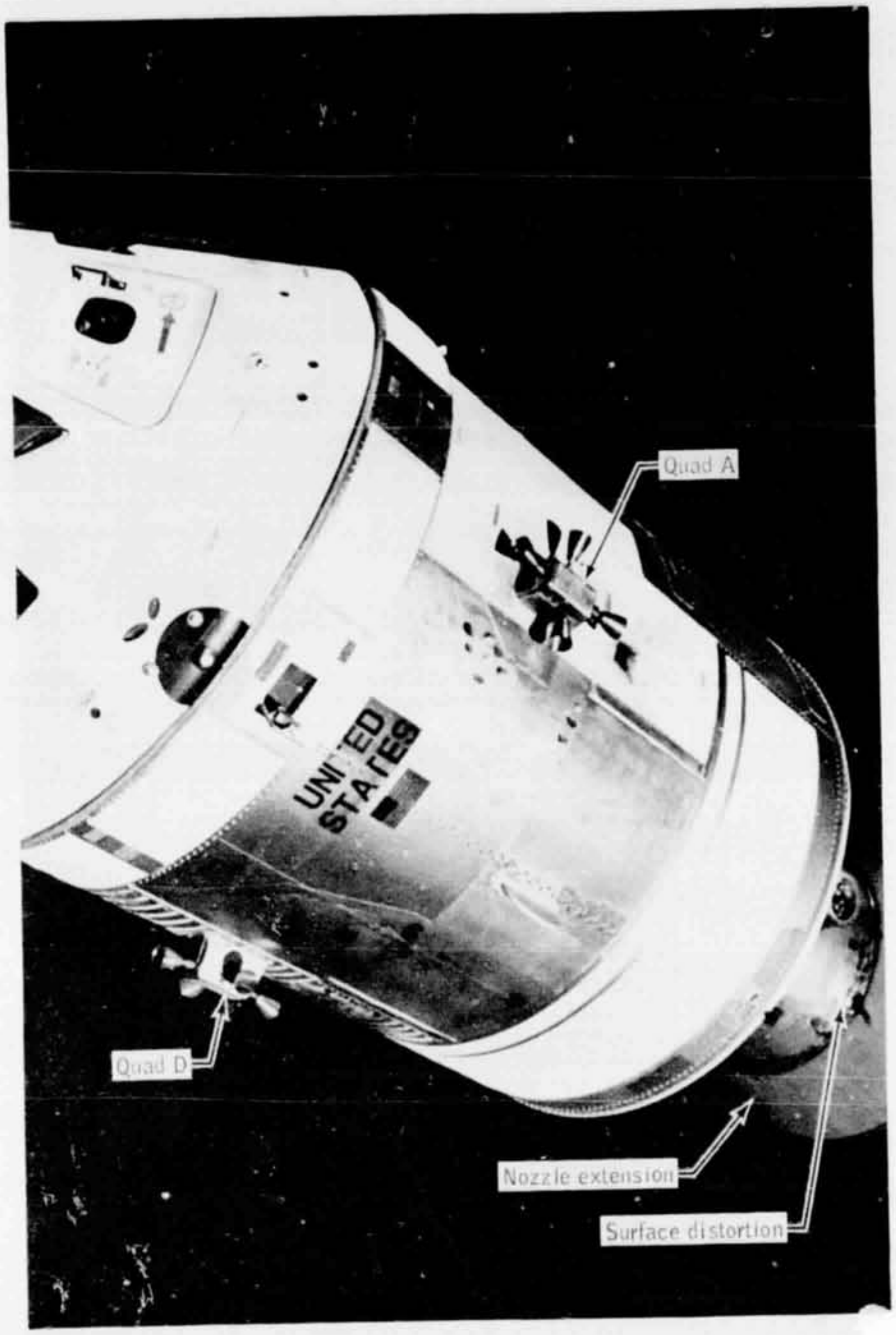
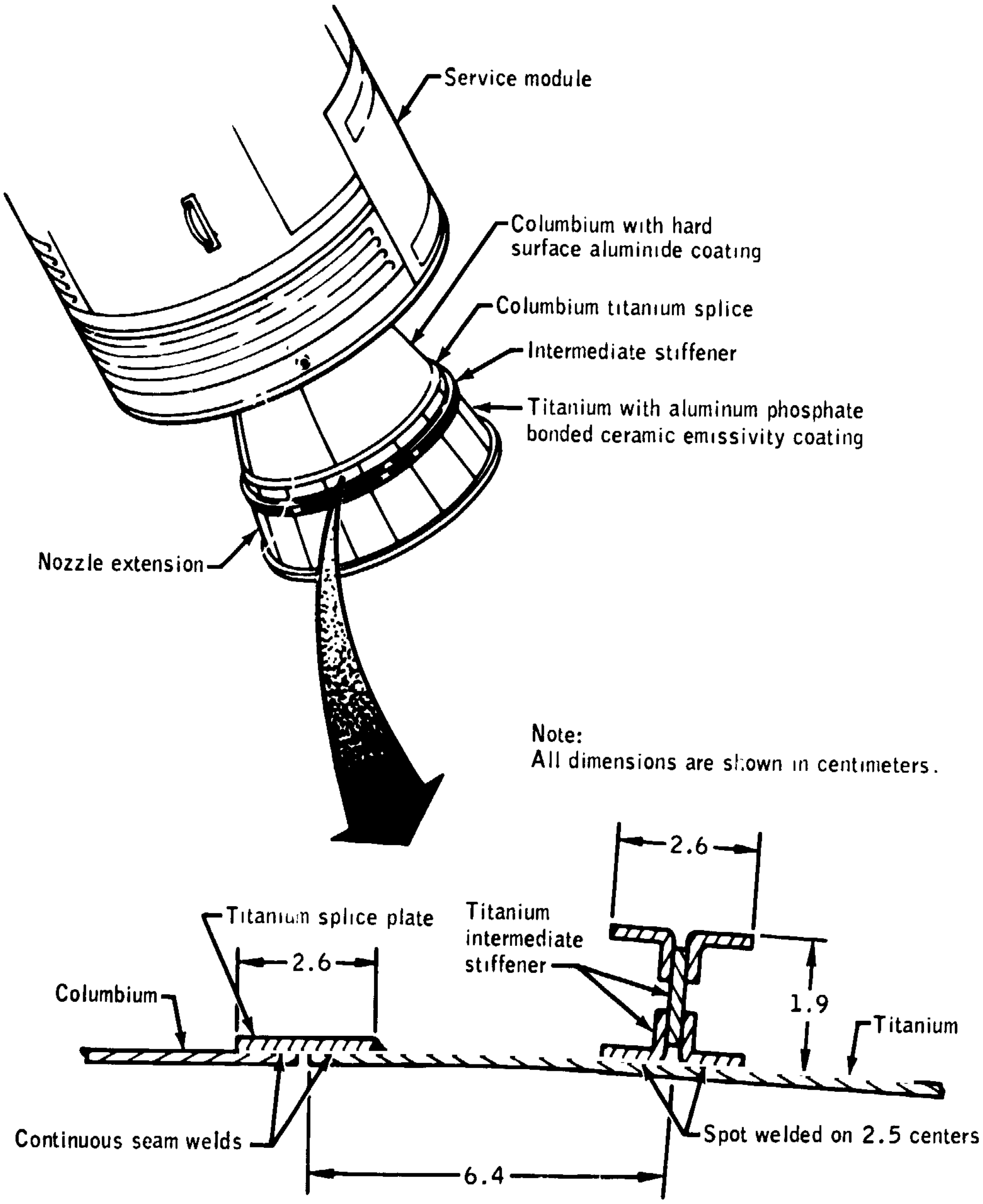


Figure 6-2.- Command and service module, including service propulsion system engine nozzle extension.



Note:
All dimensions are shown in centimeters.

Note: All dimensions are shown in centimeters

Figure 6-3.- Service propulsion system engine nozzle extension.

6.7.2 Service Module Reaction Control System

The service module reaction control system performed normally from first usage through the docking phase and after the valve reconfiguration for the quiescent period. Propellant from the quad tanks was used first to increase the ullage volumes in the tanks. After about 23 kilograms of propellant per quad had been used, the system was configured to supply propellants from the propellant storage module tanks. When not in use, the propellant supplies were isolated from the manifold system. Propellant usage data are given in section 6.10.2.

Data received after docking, particularly during the Saturn Workshop trim maneuvers, showed that the propellant storage module fuel manifold and the quad B fuel manifold pressures were tracking each other even though the quad B fuel isolation valves were closed. The valves were cycled open and then closed, but the data continued to indicate that at least one of the quad B fuel isolation valves was leaking. This anomaly is discussed in section 16.1.2.

During the high beta angle phase of the visit, propellant temperatures and pressures approaching the system high redline constraints occurred in quads A and D. The pressures were relieved by temporarily interconnecting either quad A or quad D with the propellant storage module.

Summary of performance.- Overall reaction control system performance was generally comparable to its performance during the Apollo program. The most significant differences were in thermal management and operation during the second visit following two system leaks. Excessive system temperatures, and therefore pressures, were prevented during Apollo flights by periodically rolling the vehicle. High pressures during the high beta angle phases of the first and third visits were relieved by transferring propellant from a quad with high pressures to the propellant storage module where the pressure was lower. System leakage in quads B and D during the second visit required that these quads be used only in an emergency situation. The use of these two leaking quads was not required during the remainder of the visit. Trim maneuvers to adjust the ground track were postponed until the third visit.

6.7.3 Command Module Reaction Control System

The performance of the command module reaction control system was normal throughout the quiescent portion of the visit. Immediately following command module reaction control system activation, the system 2 helium source pressure began dropping, indicating a leak. Further details of this anomaly are given in section 16.1.3. A normal single-ring entry was accomplished using system 1. Propellant usage data are given in section 6.10.2. All postflight activities relative to safing and decontaminating the command module reaction control system were accomplished normally.

Summary of performance.- Overall reaction control system performance was comparable to that during the Apollo program except for the pressure leakage during the third visit. A significant demonstration by both the command module and service module reaction control system was the long-term propellant compatibility.

6.8 ENVIRONMENTAL CONTROL SYSTEM

The environmental control system performed satisfactorily during the command and service module active and quiescent phases of the third visit. Only minor operational discrepancies were noted and these had no significant impact on third visit operations.

The secondary coolant loop evaporator steam pressure decreased from full-scale high to the lower limit of the measurement during the launch phase. Since the secondary coolant loop was inactive during this phase, the pressure should have remained at the upper measurement limit with the evaporator back pressure valve in the normally closed position. Attempts by the crew after orbital insertion to obtain satisfactory secondary evaporator operation were unsuccessful. However, 10 hours later, another attempt to activate the evaporator using the standard procedures resulted in a slow recovery to normal system operation. This sequence of events indicates that the secondary evaporator back pressure valve was inadvertently left in the open position during the performance of the prelaunch switch configuration checklist, causing evaporator freezing which resulted in irregular system operation.

The primary water/glycol flow measurement indicated an increased flow rate after the fourth and fifth 7-day checks of the command and service module systems. A comparison of the pump differential pressure data during these periods with the ground test data indicated normal system operation and erroneous flow measurement operation. This discrepancy is discussed in section 6.5.

During the quiescent phase of the visit, when the water tanks were pressurized only by cabin pressure, the indicated waste water quantity showed a very gradual decrease of about 6 percent. Infrequent higher and lower excursions also were observed during this time period. These types of variations have been noted on both the waste and potable water quantity transducers during ground tests and previous flights. The erratic operation of these transducers was attributed to film-like deposits between the wiper and the cermet core element of the potentiometer. Complete loss of the measurement would have had no impact on this visit. Transducer operation after repressurization of the tanks during the pre-entry operations appeared satisfactory.

The suit return flapper valve in the Commander's suit flow control valve stuck closed during activation for entry. For this visit, the suit hose interconnects were deleted for weight savings, thus requiring the valves to be left closed during the quiescent period to prevent dry-out of the suit heat exchanger wicks and to prevent entry of debris. This configuration caused the elastomer on the flapper to stick to the seat, a problem that has been encountered during ground operations after long periods with the valve seated. Sufficient differential pressure was obtained to open the flapper by performing a backup procedure and using both suit compressors. The valve operated normally after the flapper was unstuck.

Evaporator water reservicing prior to undocking was interrupted to solve the sticking suit flow control valve discussed in the previous paragraph. As a result of the interruption, the primary evaporator water flow valve remained on for about 30 minutes rather than the planned 3-minute period. Data indicate that approximately 4.5 kilograms of water were supplied to the primary evaporator, considerably more than the normal servicing requirement of about 0.5 kilogram. Primary and secondary evaporator activation after undocking appeared erratic with both the evaporator steam pressures and outlet temperatures above normal. Additionally, the steam duct temperature dropped to a lower than usual level of about 280° K, which indicates free water carry-over into the steam duct and freezing, as would be expected. This sequence also could account for the ice particles observed by the crew during this period. Erratic secondary evaporator operation was still noted about 40 minutes later (primary evaporator was in non-boiling temperature regime), but data after 1 hour showed satisfactory evaporative control in both loops.

Summary of performance.- The command and service module environmental control system operated successfully throughout the manned Skylab visits. The components used in the environmental control system for the first time in the Skylab program performed satisfactorily. Adequate thermal control was maintained for all orbital attitudes, beta angles, and command module heat loads. Most environmental control system problems were the result of instrumentation malfunctions, minor leakages, and procedural errors. All of these problems were minor in nature and had no overall effect on visit operations.

6.9 SPECIAL STOWAGE

Special command module stowage was required to: reservice and replace equipment; replace items with improved designs; provide for the extended visit duration; provide for changes in planned activities; replenish supplies being depleted because the usage rates were greater than anticipated; replace lost items; provide items for crew comfort; and provide for improvements in communications, television transmission, and photography. Also, there were some items that were originally scheduled for the first and second visit stowage lists that were held over for the third visit because of stowage priorities. Command module weight and center of gravity for launch, and weight during descent and landing are shown in the following table.

Item	Actual	Limit
Earth launch weight, kg	6103.72	6123.50
Launch escape vehicle Z-axis center of gravity, cm	19.45	8.94
High altitude abort burnout X-axis center of gravity, cm	2847.09	--
Descent on main parachute weight, kg	5872.71	5896.70
Landing weight, kg	5633.80	--

All available third visit command module stowage locker space was used for the items discussed in the previous paragraph. In addition to the use of this normal stowage space, the following items were stowed on top of the aft bulkhead lockers: supplementary food for the extended visit, experiment T025 extravehicular activity bracket, experiment S193 tool kit, experiment S054 film, and coolant accessories. The launch stowage configuration is shown in figure 6-4 and the return stowage configuration is shown in figure 6-5. The launch and entry couch stroking envelopes resulting from a worst-case landing are shown in figures 6-6 and 6-7.

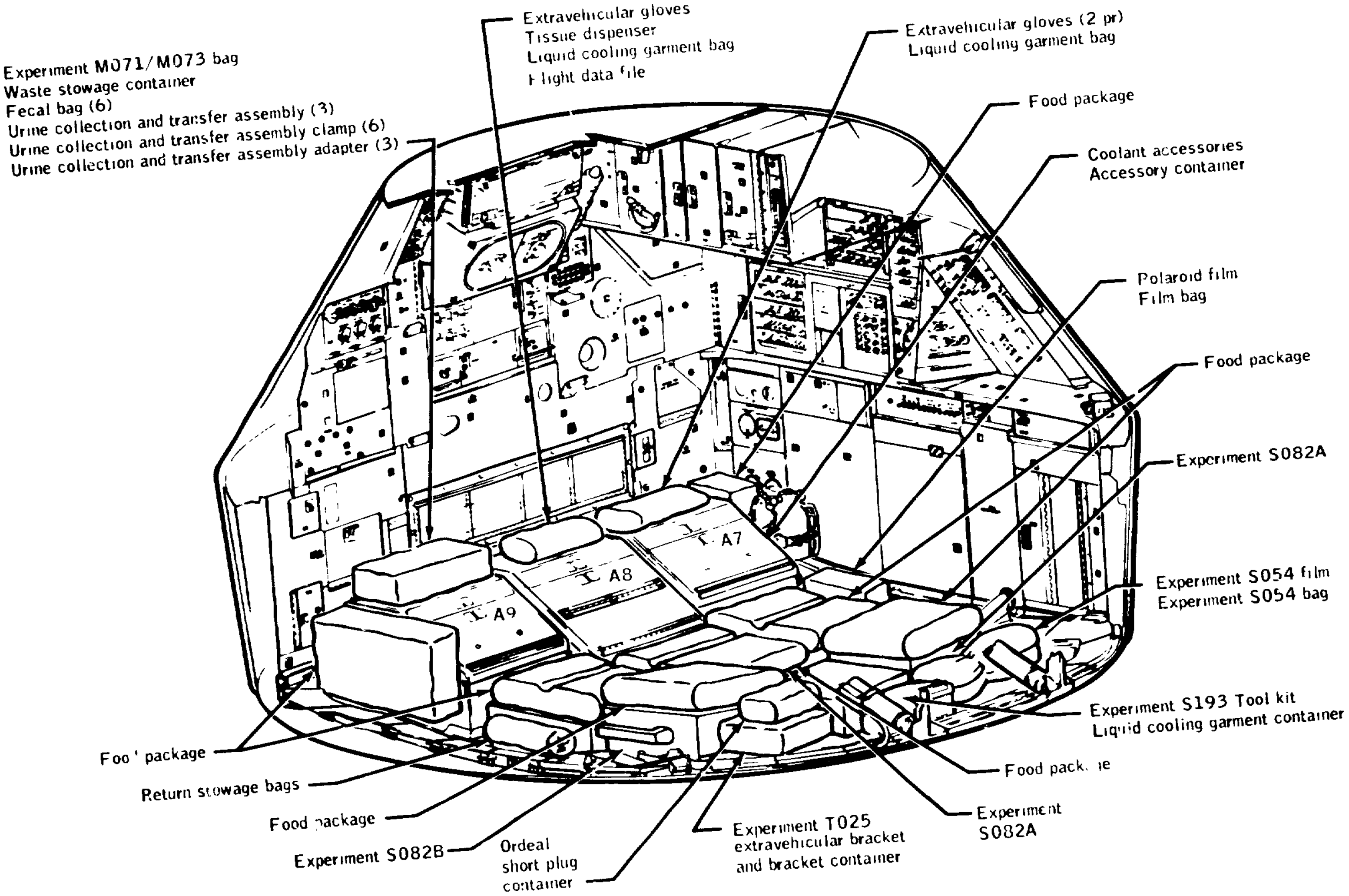


Figure 6-4.- Command module launch stowage configuration.

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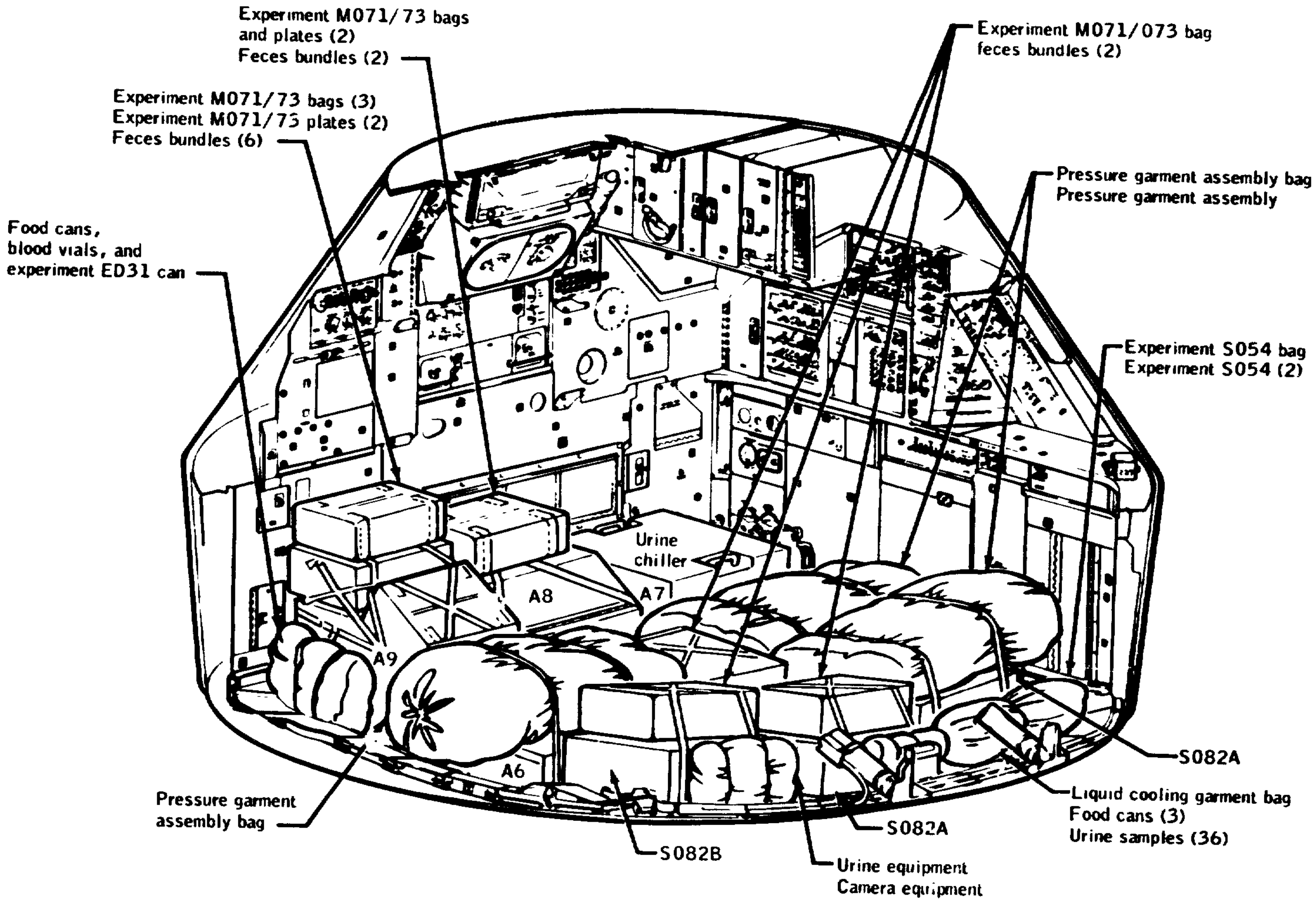


Figure 6-5.- Command module return stowage configuration.

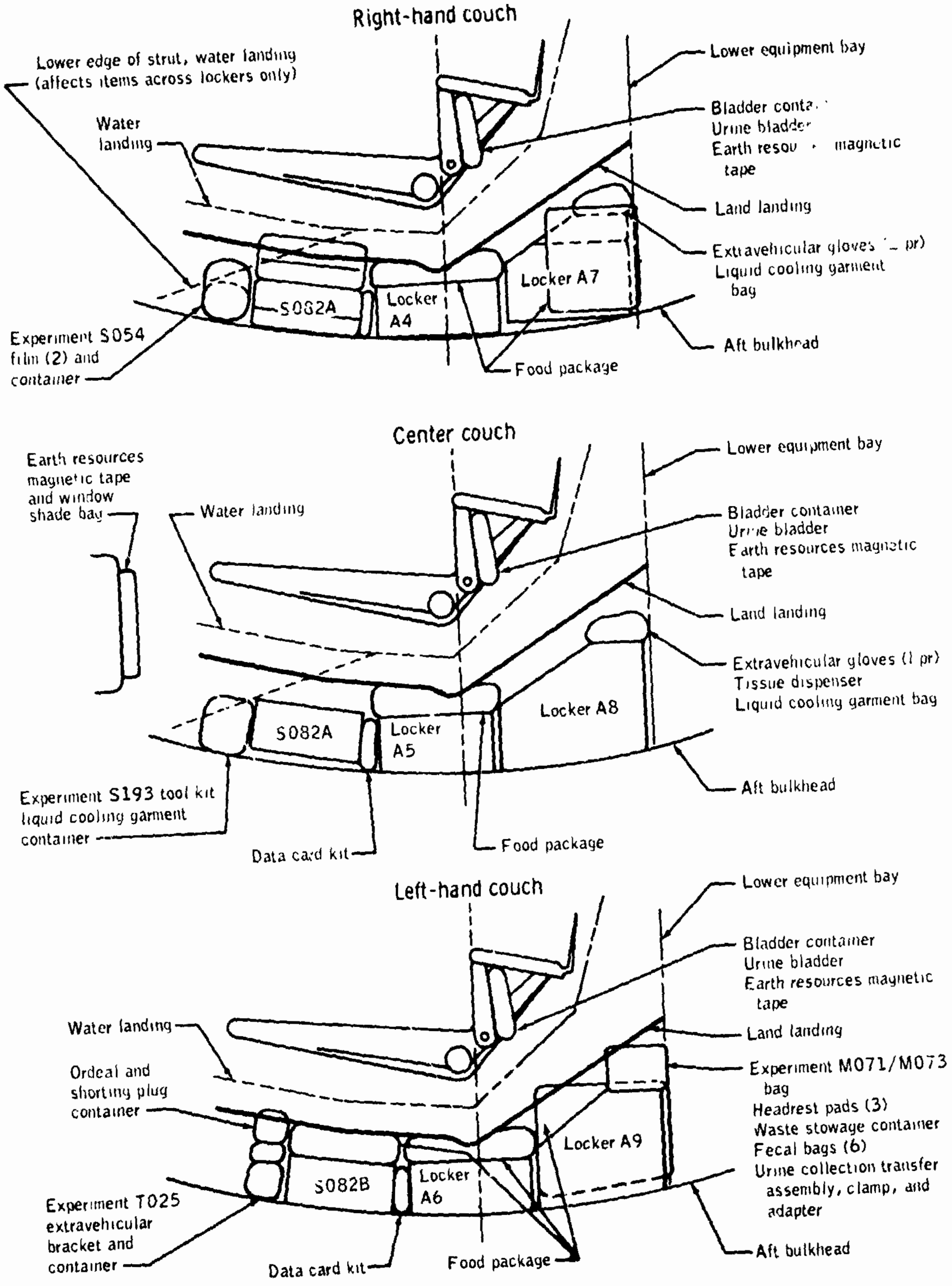


Figure 6-6.- Launch couch stroking envelopes.

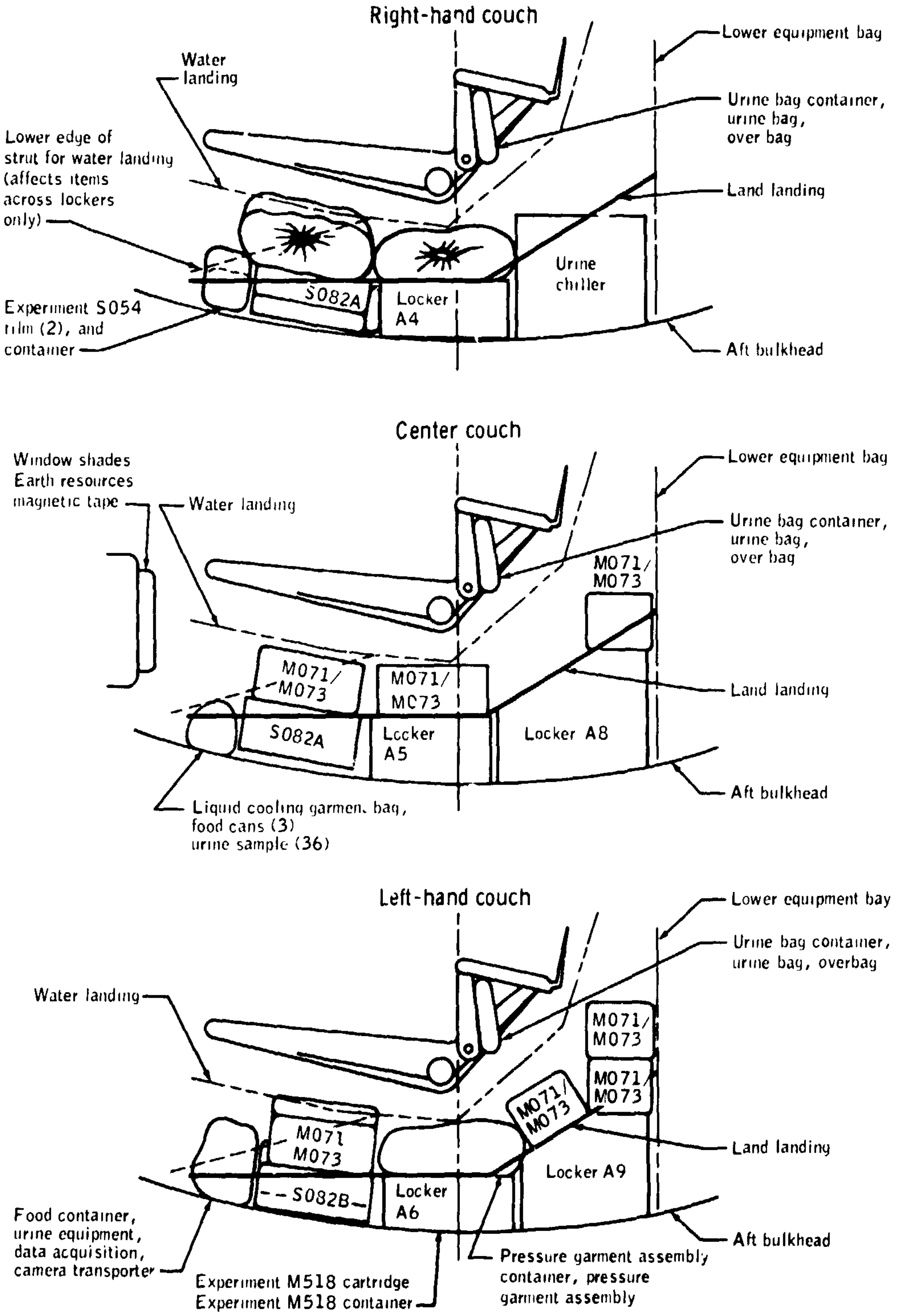


Figure 6-7.- Entry couch stroking envelope.

6.9.1 Launch Stowage Relocations

Deviations from the planned stowage caused many command module stowage items to be relocated. The crew was aware of all changes as the items were repositioned as well as being given a final bench review prior to final stowage. Training hardware was used to demonstrate the packaging feasibility of the new stowage configuration and photographs were taken to record the stowage for use during final packing. The following table includes the functional areas from which the launch stowage configuration changes emanated.

Area	Weight, kilograms	$\bar{X}$ axis, centimeters	$\bar{Y}$ axis, centimeters	$\bar{Z}$ axis, centimeters
Baseline stowage	652.47	2612.31	6.07	1.88
Operational additions	200.33	2592.10	7.65	14.61
Science additions	241.45	2593 [illegible]	-5.49	6.71
Operational deletions	-211.51	2584.73	20.68	-11.66
Science deletions	-3.23	2608.53	55.30	-53.19
Actual launch stowage	879.51	2604.87	0.89	3.73

6.9.2 Return Stowage

The majority of the return stowage additions were items returned for postflight analysis. Nine delivered items were deleted from the return stowage list. The following table includes the functional areas from which the return stowage changes emanated.

Area	Weight, kilograms	$\bar{X}$ axis, centimeters	$\bar{Y}$ axis, centimeters	$\bar{Z}$ axis, centimeters
Baseline stowage	754.71	2598.45	3.07	3.48
Operational additions	24.17	2600.96	-12.62	-41.43
Science additions	3.13	2566.42	-56.64	-5.03
Science deletions	-2.66	2579.12	0.00	42.67
Actual return stowage	779.35	2598.95	1.04	2.77

6.9.3 Stowage Differences

The third visit launch and return stowage differences from the baseline configuration are listed in appendix B.

6.10 CONSUMABLES

The command and service module consumable usage during the third visit was maintained well within the redline limits. Specific system usage is discussed in the following paragraphs.

6.10.1 Service Propulsion System

The service propulsion system propellant and helium loadings and consumption values are listed in the following table. The loadings were calculated from gaging system readings and measured densities prior to lift-off.

Condition	Propellant, kilograms		
	Fuel	Oxidizer	Total
Loaded	1203	1934	3137
Consumed	475	757	1232
Remaining	728	1177	1905

Condition	Helium, kilograms	
	Storage bottles	Propellant tanks
Loaded	19.9	14.2
Used	2.3	-2.3
Remaining	17.6	16.5

6.10.2 Reaction Control System Propellant

Service module.- The propellant utilization and loading data for the service module reaction control system were as shown in the following table. Consumption was calculated from telemetered helium tank pressure histories and was based on pressure, volume, and temperature relationships.

Condition	Propellant, kilograms		
	Fuel	Oxidizer	Total
Loaded			
Quad A	50	102	152
Quad B	50	102	152
Quad C	50	102	152
Quad D	50	102	152
Propellant storage module	228	458	686
Total	428	866	1294
[a]Usable loaded			1188
Consumed			520
Remaining at command module/service module separation			668

[a] Usable propellant is the amount loaded minus the amount trapped with corrections made for gaging system errors.

Command module.- The loading of command module reaction control system propellant was as follows:

Condition	Propellant, kilograms		
	Fuel	Oxidizer	Total
Loaded			
System 1	20	41	61
System 2	19	41	60
Total	39	82	121
[a]Consumed	5	8	13

[a]Based on amount of propellant off loaded.

6.10.3 Cryogenic Storage System

The total cyrogenic hydrogen and oxygen quantities available at lift-off and consumed during the third visit are as follows. Consumption values were based on quantity data transmitted by telemetry.

Condition	Hydrogen, kilograms	Oxygen, kilograms
Available at lift-off		
Tank 1	11.7	144
Tank 2	11.9	112
Total	23.6	256
Consumed		
Tank 1	11.7	92.9
Tank 2	11.9	98.2
Total	23.6	191.1
Remaining at fuel cell shutdown		
Tank 1	0	51.1
Tank 2	0	13.8
Total	0	64.9

6.10.4 Water

The water quantities loaded, produced, and expelled during the third visit are shown in the following table.

Condition	Quantity, kilograms
Loaded (at lift-off)	
Potable tank	2
Waste tank	3[a]
Produced in-flight	
Fuel cells	204
Lithium hydroxide canister	2
Metabolic activity	2
Total loaded and produced	213
Stored in Orbital Workshop	0
Lost as urine	7
Evaporator usage	15
Remaining at command module/ service module separation	
Service module tank	161
Potable tank	16
Waste tank	10
Total expelled and remaining	209
Balance	4[b]

[a] Calculated from fuel cell and metabolic production.

[b] Discrepancy attributed to data system inaccuracies.

7.0 CREW EQUIPMENT

7.1 EXTRAVEHICULAR MOBILITY UNIT

The extravehicular mobility units performed satisfactorily throughout the third visit. Water leaks were observed during two of the extravehicular activities at the pressure control unit/life support umbilical composite disconnects; however, these leaks did not affect successful completion of the extravehicular activities. The extravehicular mobility units, in whole or in part, were used in the following activities:

a. Launch and boost phase - visit day 1

b. First extravehicular activity - visit day 7

c. Second extravehicular activity - visit day 40

d. Third extravehicular activity - visit day 44

e. Experiment M509 (suited test) - visit day 63

f. Experiment M509 (suited test) - visit day 66

g. Fourth extravehicular activity - visit day 80

h. Undocking preparations - visit day 85

The Airlock Module primary coolant system was reserviced early in the third visit, thus enabling liquid cooling garment water cooling to be used for all extravehicular and intravehicular suited activities on this visit. All three crewmen were connected to the suit umbilical system 1 water loop during all four extravehicular activities, and both Airlock Module primary coolant loop pumps were operated to provide a greater heat removal capability.

Some mildew was discovered on the liquid cooling garments during the preparations for the first extravehicular activity and the garments were cleaned with Zephiran chloride and Betadine wipes and air-dried before being used. No sign of deterioration or functional degradation of the liquid cooling garments was noted during the visit as a result of the mildew, cleaning, or normal operations. Samples of mildew were collected and returned for analysis.

Water was delivered to the liquid cooling garments at temperatures between 286° K and 288.8° K during the 6-hour and 34-minute first extravehicular activity, until the crewmen started working at the experiment S193 (Microwave Radiometer/Scatterometer and Altimeter) antenna. The work location and longer lengths of exposed umbilicals resulted in the water delivery temperatures dropping to 282.4° K. The average calculated heat load rates during the first extravehicular activity were 291 watts for the Pilot and 330 watts for the Scientist Pilot. The extravehicular mobility unit pressures were maintained at 2.48 newtons per square centimeter for the Pilot and 2.43 newtons per square centimeter for the Scientist Pilot. The Pilot reported cuff gage reading of 2.52 newtons per square centimeter and the Scientist Pilot reported a reading of 2.48 newtons per square centimeter during the status checks.

Water was delivered to the liquid cooling garments at temperatures between 284° K to 286° K during the 6-hour and 54-minute second extravehicular activity, until a water leak developed in the Commander's pressure control unit/life support umbilical composite disconnect, and the cooling induced by freezing and sublimation of the leaking water reduced the indicated water inlet temperature slightly. (This anomaly is discussed in sec. 16.3.1.) The average calculated heat load rates during the second extravehicular activity were 327 watts for the Pilot and 204 watts for the Commander. The extravehicular mobility unit pressures were maintained at 2.43 newtons per square centimeter for the Pilot and 2.48 newtons per square centimeter for the Commander. The Pilot reported a cuff gage reading of 2.48 newtons per square centimeter and the Commander reported 2.52 newtons per square centimeter during status checks. An evaluation after the extravehicular activity showed that the suit umbilical system 1 water reservoir was empty as a result of the leak, and the reservoir was later reserviced. The Commander's pressure control unit and life support umbilical were replaced with spare units prior to the next extravehicular activity because the pressure control unit/life support umbilical composite disconnect part that was leaking could not be determined.

The 3-hour and 29-minute third extravehicular activity was completed satisfactorily. Water was delivered to the liquid cooling garments at temperatures between 284.9° K to 286° K. The average calculated heat load rates during the extravehicular activity were 301 watts for the Scientist Pilot and 256 watts for the Commander. The extravehicular mobility unit pressures were maintained throughout the extravehicular activity at 2.43 newtons per square centimeter for the Scientist Pilot and 2.52 newtons per square centimeter for the Commander. The Scientist Pilot and Commander reported cuff gage readings of 2.48 newtons per square centimeter during status checks.

The extravehicular mobility unit performance was normal during the suited experiment M509 (Astronaut Maneuvering Equipment) activity conducted with the Commander as the subject. The modified life support umbilical which consisted of only the oxygen hose was used, thus precluding telemetry performance data from being received. The maneuvering time while operating on the life support umbilical was 57 minutes. An additional 17 minutes of maneuvering time was obtained without the umbilical during which time life support oxygen was supplied from the secondary oxygen pack. The secondary oxygen pack was used to depletion.

The extravehicular mobility unit performance was also normal during the suited experiment M509 (Astronaut Maneuvering Equipment) activity conducted with the Pilot as the subject. A secondary oxygen pack was worn for ballast, but the pack was not actively used. All maneuvers were performed using the modified life support umbilical containing only the oxygen hose. The total maneuvering time was about 1 hour and 48 minutes.

During the 5-hour and 19-minute fourth extravehicular activity, water was delivered to the liquid cooling garments at temperatures from 284° K to 286° K until a water leak developed in the Scientist Pilot's pressure control unit/life support umbilical composite disconnect. (This anomaly is discussed in sec. 16.3.1.) As in the second extravehicular activity, the cooling resulting from the leak caused a slight reduction in the indicated water inlet temperatures. The Scientist Pilot decreased the water diverter valve setting to obtain minimum flow through the liquid cooling garment and this decreased the leak rate. The Scientist Pilot then increased the pressure control unit oxygen flow control to high flow for maximum gas cooling. The suit umbilical system 2 pump was started in preparation for possible use; however, sufficient water remained in the suit umbilical system 1 loop for the extravehicular activity to be successfully completed. The average calculated heat load rates during the extravehicular activity were 291 watts for the Scientist Pilot and 266 watts for the Commander. The extravehicular mobility unit pressures were maintained at 2.43 newtons per square centimeter until the Scientist Pilot switched to the high gas flow after the leak was noted. The pressure then dropped to 2.41 newtons per square centimeter. The Commander's pressure was maintained at 2.52 newtons per square centimeter throughout the extravehicular activity. The Scientist Pilot reported cuff gage readings of 2.50 newtons per square centimeter and the Commander reported 2.55 newtons per square centimeter during status checks. No cuff gage readings were given after the Scientist Pilot switched to high gas flow.

Summary of results.- The extravehicular activities performed during the three Skylab visits required extravehicular mobility unit operation under normal modes and also under many of the contingency modes for which the unit was designed and developed. The extravehicular mobility unit successfully fulfilled all performance objectives for all extravehicular and intravehicular activities.

7.2 CREW PROVISIONS

The crew found their garments to be satisfactory in terms of fit, warmth, and comfort, but the crew suggested that colors in addition to brown should be considered to relieve the monotony of a single color. Other crew comments about clothing included preference to change underwear and socks every day rather than every other day. The crew would have preferred to have some plain handkerchiefs rather than using tissues all the time. Another suggestion was that all zippers should have extensions on the zipper pull-tabs.

The socks that were removed from the lower half of an underwear-type garment were found to be better than the regular socks when using the treadmill. These socks were cotton, which made them more absorbent than the regular socks, and they were less inclined to stick on the treadmill when the crewmens' feet became hot and sweaty.

The crew used the tape recorder, the binoculars, and a few books from their off-duty activities equipment kit. The crew commented that the most relaxing and enjoyable off-duty activity was looking out the window with a pair of binoculars. Also, the crew reported that the tape recorders should be more sturdily constructed because the door that closes over the top of the cassette broke on two of the three recorders.

8.0 BIOMEDICAL

8.1 INTRODUCTION

Each of the crewmen logged 2017 hours and 16 minutes of space flight. This section discusses the relative medical stability of the three men in their 84 days of weightlessness, and also shows that much has been learned on optimizing patterns for such basic activities as working/resting, eating and exercising for long-duration missions.

8.2 FLIGHT CREW HEALTH STABILIZATION

The flight crew health stabilization program for the third visit was to be initiated 21 days prior to the planned launch on September 24, 1973; however, after the launch date was delayed to November, the program eventually was maintained for 27 days prior to the launch date. Approximately 650 crew-primary-contact personnel were given physical examinations. The number of primary contacts was reduced to approximately 250 persons 21 days after the third visit launch, and consisted only of those persons required for recovery operations.

Primary contacts reported seventeen illnesses to the clinic during the 2-week period just prior to the start of crew isolation. An additional 63 illnesses were reported to the clinic after the start of isolation and during the visit. Approximately 50 medical disqualifications were necessary because of the infectious nature of the illnesses, which were principally upper respiratory in nature.

8.3 CREW MEDICAL TRAINING

The basic review of the inflight medical support system protocol was conducted at Sheppard Air Force Base, Texas. Each specialty area was discussed by the appropriate consultant and emphasis was placed on learning basic diagnostic techniques and gaining familiarity with the medical hardware as well as the medical terminology. Additional training was obtained at Lackland Air Force Base, Texas, where the crew actually participated in dental extractions as part of their instruction on the use of the dental kit.

Practical exposure was also obtained under the personal guidance of five Houston physicians and emergency procedures were observed at Ben Taub Hospital. Actual procedures which were practiced in a dog laboratory at the Houston Medical Center were the introduction of intravenous fluids, placing of sutures, and performance of a tracheotomy and an intracardiac injection. Examples of observed cases included: serous otitis, tonsillitis, perforated ear drum, maxillary sinusitis, right tonsillar abscess, pericardial rub, pleural rub, rales (various), and palpation of premature atrial contractions and premature ventricular contractions.

Additionally, "medical letters" were given to the crew on an as-required basis to summarize items of medical importance. Topics covered in this fashion included first and second visit medical data, and reviews of motion sickness in prior crews and potential remedies which could be used.

Blood drawing was an example of crew-requested training. Although largely established to train in the technique, blood drawing was further utilized to demonstrate the variability of cholesterol and triglyceride in response to time of day and general diet pattern.

8.4 ENVIRONMENT

No problems were encountered in maintaining the allowable limits of pressure, oxygen, and carbon dioxide within the Saturn Workshop environment. Other parameters, such as temperature and relative humidity, were more flexible. These parameters became of significant concern about visit day 60 when the high beta angles resulted in the internal temperatures rising above 300° K, concurrent with the onset of crew discomfort and potential problems from possible outgassing of the heated spacecraft wall. The inflight medical support system was not exposed to any significant temperature elevation. During visit days 63 through 67, the Scientist Pilot slept in the Airlock Module to be comfortable; otherwise, a reasonable temperature was maintained in the sleep compartments.

Ground test experience and subjective comments from the Skylab crewmen indicated that the crewmen felt uncomfortably warm at 297° and 298° K and had trouble sleeping in a 300° K environment. Temperatures from 300° to 303° K could be expected to interfere with work performance, sleep, and morale. Above 303° K, crew performance could be expected to be seriously affected. Flight planning guidelines allowed tasks to be deleted or modified if temperatures above 300° K were reached.

The effect of the dew point is relatively unimportant in the comfort temperature range, but becomes more important as thermal stress is applied. The relatively dry state of the Workshop was beneficial during the higher temperature periods, but lower humidity during the visit tended to hasten drying of the skin. The Scientist Pilot also commented on how rapidly the blood dried when using the finger-stick hemoglobin technique.

Other environmental observations included general satisfaction with lighting and noise levels. Specific noise irritants did exist, and two examples were: the exercisers (principally the ergometer) and the lack of noise insulation in the crew sleeping areas, which allowed noise to enter from other compartments and from the rest of the Orbital Workshop. The Multiple Docking Adapter also had high ambient noise levels.

There were no chronic smell problems, but selected sites generally associated with urine handling such as the trash airlock were malodorous. Clothes also gave off odors because of the prolonged wearing required; showers could not be taken as often as desired because of time constraints.

The crew commented that there were no obviously dirty areas in the Saturn Workshop. Details of the inflight microbiology are discussed more fully in section 9.8. Maintaining clean surroundings was generally feasible, but food spills were difficult to clean up in view of the nonremovable grating.

8.5 CREW HEALTH

8.5.1 Preflight Period

One of the earliest crew evaluations included a full pressure-suit donning and, while exposed to vacuum, performing controlled amounts of work by stepping onto and off of a step at a predetermined rate. All three crewmen executed successful checkouts at 352 watts, 469 watts, and 586 watts.

The prime crew performed a full-day checkout of the command and service module in August, 1973. This successful test was made with the astronauts in pressurized suits in an environment varying between 0 and 3.45 newtons per square centimeter. These tests were conducted with the crewmen fully instrumented.

Selection tests conducted in 1965 and 1966 showed that the Commander and Pilot were free of any arrhythmias, and that the Scientist Pilot had sporadic premature atrial contractions during the centrifuge test, treadmill exercise, the double Master's test, and while on the tilt table.

Subsequent annual electrocardiographs of the crew did not show any abnormal rhythms, nor were any observed during tests conducted in June, 1973, with controlled workloads and pressurized suits. The Commander showed no premature atrial contractions and no premature ventricular contractions, the Scientist Pilot showed three premature atrial contractions and one premature ventricular contraction, and the Pilot showed three premature atrial contractions and two premature ventricular contractions in the command and service module checkout in August 1973.

The responses of the crew to 62 drugs (including 20 topicals) in the inflight medical support system were determined by drug history reviews and by actual administration of many of these drugs. There were no unique intolerances noted in the prime crew.

The first comprehensive prime crew health evaluation was performed 35 days prior to launch. Components of this physical examination included drawing of blood, part of which was used for the scheduled requirements 21 days before launch. Venous pressure was determined as a part of the blood drawing. Dental salivary and multiple site microbiological samples were taken. Major experiments performed at this time included M078, M092 with closeup photographs, and M171 with tilt ergometry as well as arm and trunk measurements, and stereophotographs. A refraction was completed and an audiometry test was conducted on each crewman. Muscle strength testing, center of gravity determinations, and a complete general physical examination completed the testing and the crewmen were cleared for flight.

The level of oral health of the third visit crew was excellent. Clinical and laboratory findings of the prime and backup crews were all within normal limits with the exception of the total protein values in the saliva which were subnormal for all the crewmen except for the backup Pilot. No reason could be given for this finding, but it was not considered to be a threat to oral health or general health. There were no dental findings to indicate a potential problem in an 84-day visit.

The next comprehensive preflight examinations occurred at 21 days before launch. During these examinations, the crew participated as operators of the lower body negative pressure and metabolic activity experiments to gain experience. Additional tests at this time included the lower limb blood flow, electromyography, and skinfold measurements. The final comprehensive evaluations were made 10 and 5 days prior to flight. During these evaluations, the first preflight pulmonary function and electronystagmography baselines were obtained. The crew continued to be cleared for flight.

On the day before launch, as well as the day of launch, a "quick-look" physical showed the crew to be in good health. No preflight enemas were required; all crewmen took sleeping medication the night before launch. On the day of launch, the crew was adequately rested, the final microbiology samples were taken, and the crew was suited for launch.

Results of the preflight series of examinations showed the crew to be in excellent physical and psychological health. The preflight examinations and history reviews revealed nothing of permanent significance to the planned operational aspects of the visit. Daily medical surveillance was maintained including the use of a private mobile clinic during the flight crew health stabilization period.

8.5.2 Inflight Phase

Maximum heart rates during launch were below 125 beats per minute for all crewmembers. Once in flight, the crew had no formal scheduled medical examinations. Data from experiments and medical evaluations performed as necessary provided the required monitoring of health status; the basic lower body negative pressure/metabolic activity/vectorcardiogram experiment package protocols were performed on 3- or 4-day centers.

The absence of any major illness or injury was significant; however, there were numerous symptomatic events that required variable amounts of medication.

The initial medication used by the crew was the prescribed anti-motion-sickness medication on visit day 1. The second major recurring use of medication was lip balm and an emollient skin cream to prevent drying of the lips and skin. In addition, each of the crewmen used nasally and orally administered decongestants several times, especially before and after the extravehicular activities. From visit day 65 to visit day 80, the Pilot complained of increasing congestion (nasal and paranasal, largely frontal) and was treated with the decongestants pseudoephedrine, pseudoephedrine-triprolidine, and oxymetazoline. Each of the crewmen used a soporific of choice on visit days 83 and 84 when the shift in circadian rhythm was being effected. The Commander used his sleep medication before one other sleep period during the visit, whereas the Scientist Pilot used his sleep medication before eight other sleep periods and the Pilot took his sleep medication before six other sleep periods. The sleep medications of choice for the crewmen were as follows:

a. Commander - Chloral hydrate

b. Scientist Pilot - Promethazine/ephedrine and flurazepam

c. Pilot - Secobarbital

Twice during the 84-day visit, the Scientist Pilot took aspirin for a transient headache. Both the Scientist Pilot and Pilot developed mild dermatological problems which cleared up promptly with minimal treatment.

Vials containing the anti-motion-sickness medications scopolamine/dextroamphetamine and promethazine/ephedrine were placed in each crewman's pressure garment in addition to 10 chloral hydrate capsules for the Commander and five Ornade capsules for the Pilot as readily available supplements to onboard drug supplies. The first anti-motion-sickness medication was taken by the Commander after the rendezvous first phasing maneuver, and by the Scientist Pilot and Pilot at orbital insertion. All three took their second prescribed dose at docking. Because of symptoms, the Pilot took a third medication a short time later. All crewmen remained in a good subjective state until docking, at which time the Pilot had a sudden onset of nausea and vomiting. The Scientist Pilot did not take the mandated medication between insertion and docking, but, nonetheless, had no problems.

All crewmen had head fullness and a headache shortly after insertion; this was fullness one could see and feel. The Commander described it as feeling like a cold; the neck was quite distended. By visit day 3, the head fullness, red face, blood-shot eyes, and distended neck veins began to decrease; there was never any difficulty clearing the ears. Exercise was noted to clear some of the these symptoms. Head fullness, however, was an intermittent recurring symptom throughout the visit and, in conjunction with this, the veins also remained prominent at all times.

The Pilot ate poorly on visit day 1, but the Commander and Scientist Pilot were able to eat most of their alloted food; however, the crew found that their onboard activities made it impossible to eat at the prescribed lunch time and they were rushed in eating. On visit day 2, the Scientist Pilot was eating everything on his menu and had no stomach problems. The Commander and Pilot continued to have a feeling of "stomach awareness" through visit day 3 which resulted in a slightly decreased food intake. The food was consumed in several small meals instead of three main meals. By visit day 4, all crewmen were free of gastrointestinal symptoms and they reported that, subjectively, the other symptoms were also better.

Eating was an important event for the third visit crewmen because they complained of quick fatigue if they did not eat on time. The taste of food was somewhat altered but, in general, what was liked on the ground was still enjoyed onboard the Workshop. Eating high density food every 3 days did not impose unique problems, although the crew commented on feeling hungry on those days. They had a pool of extra supplementary foods which could be used with minimal restriction; such supplementation became very prominent after the mid-point of the visit. A full stomach seemed to excessively push into the chest, especially if exercise was attempted soon after eating.

Bodily waste functions were normal; there was no constipation or diarrhea, but excess flatus was noted. Urinary frequency remained normal with any increased water intake reflected in increased output, just as in a one-g environment.

As with the first and second Skylab visits, the private medical conference offered the benefit of allowing systematic reviews of body symptoms and a clarification of crew comments and problems. Besides the private communication conducted by the crew surgeons, the single most comprehensive guide was the daily health status summary form that was maintained in the Mission Control Center. This form contained all pertinent medical and physical data concerning the crew and provided an easy means for readily determining the current crew health status.

The first inflight exercise was initiated on visit day 3 and the first treadmill exercise was performed by the Commander and Pilot on visit day 8. The following exercise capability was available to this crew: the bicycle ergometer, the Mark I exerciser, the Mark II exerciser, the Mark III exerciser, the treadmill; and isometrics exercises. The requirement for exercise was 1-1/2 hours per day per man. The crew required about 3 weeks to stabilize their individual exercise protocols. Table 8-I shows a comparison of the quantifiable exercise levels of the three Skylab crews.

Determination of the acceptable daily workload for a very long duration mission was a key problem of this visit. Comments from the crew during the early portion of the visit indicated that the main difficulties were a lack of free time in the evening to relax before bedtime, and having to perform time-critical events scheduled too close to one another. Iterations were made in the flight planning guidelines and experiment goals during the first month of the visit and an acceptable balance was finally achieved. An operational conference at mid-visit was also successful in refining flight planning for the last half of the visit. Further discussion of these flight planning problems appears in section 14.1.

The impact of stress on satisfactory crew rest was seen in the number of times sleep medications were taken, although the actual number taken did not indicate a concern for habituation. Minor disruptions of sleep to attend to early-morning earth resources program activities and occasional late-day Comet Kohoutek or rocket observations were generally dispersed throughout the visit and compensatory sleep time was made available.

A shift to central daylight time was made on January 1, 1974. The required 10-hour circadian shift was implemented at the end of the visit after much discussion between ground control and the crewmen. A short

TABLE 8-I.- COMPARISON OF CREW EXERCISE LEVELS ON THE BICYCLE ERGOMETER

Visit/crewman	Watt-minutes/kilogram of body weight/day			
	Visit day 1 to 28	Visit day 29 to 59	Visit day 60 to 84	Average per visit
First visit				
Commander	47	--	--	47
Scientist Pilot	21	--	--	21
Pilot	26	--	--	26
Second visit				
Commander	41	74	--	58
Scientist Pilot	49	73	--	62
Pilot	54	96	--	75
Third visit				
Commander	57	65	60	61
Scientist Pilot	88	73	77	79
Pilot	62	85	73	74

forward shift of the sleep period was made on visit day 83, and mid-day sleep was allowed on visit day 84. There was no inordinate fatigue on recovery day.

The overall psychological status of the crew was good; it was fortified by regular family calls. The crew also commented that window viewing and hand-held photography were exceptionally interesting and pleasant. There was no significant intra-crew disharmony under the Commander's fairly democratic control.

The third visit deactivation varied from previous deactivations in that many of the housekeeping procedures were omitted. The deactivation tasks were arranged to allow two full 8-hour sleep periods on visit days 83 and 84.

During the final 2 to 3 days of the visit, monitored data from experiments M071, M073, and M172 (see sec. 3.3) showed the crew to be eating well, maintaining weight, and not exhibiting any alarming signs of excessive or scanty urination. There was no pattern of continued degradation of tolerance to the lower body negative pressure experiment; likewise, fatigue and the varied congestion phenomena were not problems during the deactivation phase. These findings reinforced the ground-based evaluation that the crew was in good physical and mental health.

Entry preparation included a meal about 3 hours before landing and the mandatory intake of anti-motion-sickness medication (scopolamine/dextroamphetamine) approximately 2 hours before landing. Actual sleep during the last sleep period was: Commander, 5-1/2 hours; Scientist Pilot, 5 hours; and Pilot, 3-1/2 hours. The crew was estimated to have been awake for 13-1/2 hours prior to the landing.

The crew inflated their orthostatic countermeasure garments for the deorbit firing and reinflated the garments after entry to compensate for the increasing atmospheric pressure.

8.5.3 Entry and Postflight Phase

The day of recovery was very clear and the sea was very still. No untoward physiological responses were mentioned in the parachute descent phase. The landing was followed by a stable II command module attitude for about 5 minutes before the vehicle returned to an upright attitude. Other than some pulling of the neck muscles, the landing was well tolerated by the crew.

The initial on-water pulse rates, taken between 5 and 10 minutes after landing, were: Commander, 70 beats per minute; Scientist Pilot, 80 beats per minute; and Pilot, 80 beats per minute.

The initial vital signs were obtained with the crew inside the command module after it had been placed aboard the *U.S.S. New Orleans*. The first heart rate/blood pressure was determined on the Scientist Pilot about 1 minute after hatch opening and the last heart rate/blood pressure reading was completed on the Pilot about 15 minutes later. The readings obtained during this period are shown in the following table.

Crewman	Supine, suit inflated		Sitting, suit deflated		Sitting, suit inflated	
	Heart rate, bpm	Blood pressure, mm hg	Heart rate, bpm	Blood pressure, mm hg	Heart rate, bpm	Blood pressure, mm hg
Commander	84	155/82	112	158/105	88	135/110
Scientist Pilot	76	146/78	96	Not available	96	128/100
Pilot	68	162/78	64	138/90	72	138/84

The crew moved around remarkably well and easily assumed the sitting (semi-standing) posture inside the narrow space of the command module. The command module was relatively warm and all three crewmen were sweaty. (The postlanding ventilation valve was left closed and the fan was off as a precaution against possibly exposing the crew to reaction control system propellant leakage during the postlanding phase.) All were noticeably unstable when egressing from the command module; the prime problem was difficulty in coordinating movements, especially of the lower extremities, and in applying just the correct amount of force and movement to accomplish the desired task. The extremities felt as if they were being subjected to 1-1/2 to 2 g's.

The Scientist Pilot egressed the command module first, and the Commander last; all three uneventfully took their places on the chairs that were mounted on a platform on a fork-lift. The Skylab mobile laboratories were entered and the medical protocol began about 30 minutes after the command module was aboard the recovery ship.

All three crewmen were hungry and thirsty on arriving in the Skylab mobile laboratories, and none was in any acute distress. Although head motion was minimized, no one was incapacitated by vertigo when moving the head. Vertigo without nausea was largely occasioned by forward/backward head motion. The vertigo experienced by the Commander and Pilot subsided over the 2 weeks following recovery; there was no dizziness; most of the subsidence occurred in about 2 days. The Commander was free of all vertigo 10 days after recovery. The Pilot still felt a trace of vertigo with rapid anterior/posterior head movement through 14 days after recovery. The Scientist Pilot said he had no vertigo about 7 hours after landing.

The crew had no particular skin problems but there was minimal thickness of the skin of the distal finger tips. A couple of contusions and pinch points stemming from the deactivation were noted.

The Commander had a transient headache during entry, but it was not noted after landing. The Pilot complained of left ear fullness; however, the postlanding physical examination disclosed no inflammation; a single Ornade was given on the afternoon after the medical protocol and the symptoms completely resolved. No crewman had any of the inflight head fullness.

No important difficulty was experienced with the initial urination; the Pilot and Scientist Pilot gave the first sample while still in the Operations Laboratory, but the Commander required about 4 hours before he could produce a sample.

The cranial nerves were intact. The neurological evaluation confirmed absence of nystagmus (except for end positional), either spontaneous or provoked by rapid lateral-medial eye motion. Speech was normal. There was no loss of vibration, light-touch, or pain sensation, or proprioception by the standard testing techniques. The one exception was a transient overshoot of the nose in a very early finger-to-nose test of the Scientist Pilot (eyes open). Walking was wide-based and ataxic early after recovery; it was more nearly normal 3 to 4 hours later. Heel walking and toe walking were also performed well at this time. An unmodified Romberg test was easily accomplished, but standing on one leg was impossible.

There was no marked tone or flaccidity of the muscle and no intention or resting tremor. Deep tendon reflexes were more hyperactive than they were preflight for the Scientist Pilot, moderately so for the Commander, and not apparently so for the Pilot. The same ranking of most-to-least reflexivity was maintained as preflight (i.e., Scientist Pilot, Commander, Pilot). The Pilot retained his hyperactive abdominal reflexes. The hyperactivity of the deep tendon reflexes was most prominent in the lower extremities.

On recovery day, the crewmembers all continued to wear their orthostatic countermeasure garments until such time as they actually accomplished the lower body negative pressure experiment which was performed first on the Commander, then on the Scientist Pilot, and finally the Pilot. The continued wearing of the suits was based on the required medical protocol as opposed to the prevention of orthostatic hypotension.

During these first few hours prior to crew entry into the lower body negative pressure vessel, the rule was to inflate the suit when upright; this was not accomplished consistently because inflation required constant pumping of the suit to adjust for changing leg size. A noteworthy item is that the suit was not essential for the prevention of orthostatic hypotension as early as 1-1/2 to 2 hours after the onset of the medical protocol. During the first 1-1/2 to 2 hours, the crew rested in a basically supine position and did not require the suit.

The basic recovery day protocol included traditional blood work and physical examinations, but was the first to be completed with echocardiography and the metabolic activity experiment emphasizing reduced workloads and tilt ergometry. Major deviations from the planned protocol on recovery day were as follows.

a. The Commander's pulmonary function testing was terminated early because of a vagal response triggered by forced expiration.

b. The Pilot's lower body negative pressure protocol was terminated early because of a drop in blood pressure.

c. The Pilot's cardiac X-ray was repeated because of technical difficulties (all X-rays were taken with the countermeasure garment deflated).

d. The remote electrocardiogram sensoring had to be deleted because of unpredictable vagaries in the system.

The day following recovery was a long day of experiments. During the evening of recovery day, as well as the day following, the crewmembers were noted to have petechiae in the lower legs. Those of the Scientist Pilot and Commander were largely perifollicular and were noted first on recovery day, while those of the Pilot were more in patch-like distribution and were noted first on the day after recovery. Pressure from the countermeasure garment or the gravity dependence of the blood may have caused the condition. By 3 days after recovery, the petechiae were nearly cleared. The neurological status was unchanged except walking was nearly normal. Walking was already remarkably normal on recovery day when, after supper, the crew returned to examine the command module. Mild stiffness and soreness were noted on the day after landing as follows.

a. Commander - Lower back and left abdominal muscles.

b. Scientist Pilot - Mid-back and neck muscles.

c. Pilot - Neck and lower back, and some soreness over the coccyx.

Major deviations included less than full three-step workloads on the metabolic activity experiment.

The protocol for 2 days after landing was completed rapidly and in a timely fashion. Each of the crewmen completed his lower body negative pressure and metabolic activity in a full three-step protocol, with the Scientist Pilot's third work level being slightly reduced from the norm.

The third visit crew had no dental complaints. The postflight clinical evaluation revealed increases of gingival inflammation and dental calculus to be almost double that seen in the preflight evaluation. There was a decrease in salivary protein. Secretory IgA began rising shortly before the third visit and remained at a high level at the first postflight sampling 4 days after landing. These preliminary results are consistent with the changes observed in oral samplings from the first and second visit crews. The significance of the noted changes and the interpretation of these changes will be further evaluated when analyses are complete. While significant changes have been observed, clinical oral health remains acceptable.

No significant audiometry changes were noted during the postflight tests.

The subjectively decreased near vision of the Commander and the Pilot that had been noted inflight was normal by 5 days after landing. The Commander and Pilot also manifested decreased far vision and depth perception on recovery day. Both conditions returned to normal for the Pilot by 5 days after landing, while remaining variable for the Commander, probably because of a non-flight-related astigmatism. The Commander's intraocular pressure was still decreased on the fifth day after landing and was normal by 14 days after recovery. No significant visual field changes were noted in any of the crew.

No unmanageable medical events were experienced during the postflight period. Variable joint and muscle soreness, located largely in the lower back and knees, was caused by the resumption of exercise. For about 2 weeks after landing, the crew experienced earlier fatiguing than was noted preflight; no arrythmias of concern were noted during the postflight period. The only postflight medication used was Ornade taken by the Pilot on recovery day.

The third visit crew was clinically equal to or better than the other two crews on all parameters. Formal medical clearance for flying status was granted 21 days after recovery. Subtle postflight changes were followed by routine examinations through 68 days after landing.

8.6 METABOLIC RATES

Four extravehicular studies were conducted having a total duration of 22 hours and 16 minutes. Metabolic rates were calculated for each of the extravehicular activities using the two correlations of metabolic rate to heart rate and astronaut life support assembly parameters. The extravehicular activity durations, maximum and minimum heart rates, and metabolic rates are presented in table 8-II. The metabolic rates were at or below the predicted levels based on extravehicular activities from previous missions.

The crew experienced no apparent medical difficulties during the extravehicular activities. During the last 60 minutes of the fourth extravehicular activity, the Scientist Pilot lost the use of his water cooling system, but completed the extravehicular activity without incident. The use of gas cooling for that limited time period and at the metabolic rates experienced was not a problem and did not limit the extravehicular activity.

8.7 RADIATION

Radiation doses to the third visit crewmen were proportional to the time in orbit and to extravehicular exposure; consequently they were higher than those experienced by the previous Skylab crewmen. Preliminary values for the doses to the third visit crewmen have been derived from postflight analysis of thermoluminescent materials in the passive dosimeters continuously worn by the crew. The preliminary analysis indicates dose values from 14.3 to 17.1 rem at skin depth, from 9.5 to 12.2 rem at lens-of-eye depth, and from 5.4 to 6.9 rem at a tissue depth equivalent to blood-forming organs. These doses are compared in table 8-III with doses received by the first and second visit crewmembers.

A significant fraction of the dose to the skin of the third visit crewmen originated during extravehicular activities on visit days 7, 40, 44, and 80. The extravehicular activity dose is mainly from the Van Allen Belt electrons. These electrons can penetrate the thin space suit, but do not pass through the spacecraft walls in significant numbers as do the more penetrating Van Allen Belt protons. The doses listed in table 8-III include both electron and proton doses. Extravehicular activity skin dose comparisons (electron contributions) for the three Skylab visits are shown in table 8-IV.

Spacecraft radiation levels were monitored throughout the third visit with an electron-proton spectrometer mounted outside the spacecraft, by a Van Allen Belt dosimeter mounted inside the spacecraft, and by three personal radiation dosimeters which were worn by the crewmen during extravehicular activities and were mounted in specific locations within the Workshop at other times during the visit.

TABLE 8-II.- METABOLIC RATES DURING THIRD VISIT EXTRAVEHICULAR ACTIVITIES

Extravehicular activity/crewman	Duration, hr:min	Heart rate, beats/min		Average metabolic rate, watts
		Maximum	Minimum	
First	6:34			
Scientist Pilot		140	48	288
Pilot		150	45	270
Second	6:54			
Commander		165	46	182
Pilot		170	44	238
Third	3:29			
Commander		121	45	169
Scientist Pilot		130	53	275
Fourth	5:19			
Commander		185	55	259
Scientist Pilot		132	66	214

TABLE 8-III.- FIRST, SECOND, AND THIRD VISIT RADIATION DOSE COMPARISONS

Crewman/body area	First visit, rem	Second visit, rem	Third visit, rem
Commander			
Skin	4.39	7.01	14.30
Eye	2.43	5.14	12.20
Blood forming organs	1.06	2.90	6.95
Scientist Pilot			
Skin	3.98	9.78	17.10
Eye	2.39	6.65	10.30
Blood forming organs	1.05	3.75	5.89
Pilot			
Skin	3.07	7.47	15.40
Eye	2.34	5.89	9.52
Blood forming organs	1.00	3.33	5.44

TABLE 8-IV.- FIRST, SECOND, AND THIRD VISIT EXTRAVEHICULAR ACTIVITY SKIN DOSE COMPARISONS

Crewman	First visit, rem	Second visit, rem	Third visit, rem
Commander	1.07	1.50	1.34
Scientist Pilot	0.82	2.65	6.07
Pilot	0.25	1.15	5.22

The electron-proton spectrometer and Van Allen Belt dosimeter provided detailed telemetered radiation spectra and dose rate information which confirmed that a stable radiation environment existed throughout the third visit. In fact, this environment remained extremely stable for the complete period of the three visits. The personal radiation dosimeters integrate radiation dose in 10 millirad integrals, and readings were reported to the ground at daily intervals throughout the visit. The third visit personal radiation dosimeter locations were: (1) sleep compartment, (2) experiment compartment, and (3) solar scientific airlock. Mean dose rates ranged from 0.070 rad per day in the experiment compartment to 0.126 rad per day at the solar scientific airlock. Converted to dose equivalent (rem), the rad values represent a range of from 0.085 rem per day to 0.177 rem per day to the lens of the eye. Table 8-V compares mean dose rates obtained for various areas during the first, second, and third visits.

TABLE 8-V.- MEAN DAILY DOSE RATES DURING FIRST, SECOND, AND THIRD VISITS

Location	First visit, rad/day	Second visit, rad/day	Third visit, rad/day
Sleep compartment	0.088	0.082	0.091
Experiment compartment	0.055	0.047	0.070
Solar scientific airlock	--	--	0.126
Anti-solar scientific airlock	0.075	0.110	--

Doses to the third visit crewmen were greater than doses to prior Skylab crews because of the longer visit, longer duration of extravehicular activity, and a slight increase in dose rates as the use of food, water, and other expendables reduced the overall radiation shielding of the habitation areas. Dose rates in the sleep compartment remained relatively more stable than the other locations, largely because stowage in and about the compartment was minimal; thus, shielding variations were reduced.

Although the third visit radiation doses are the highest obtained during a manned mission, all doses were less than 25 percent of the third visit guidelines. These levels are well below the threshold for production of detectable medical effects.

8.8 MICROBIOLOGY

Microbiological studies of the crew were conducted on fecal specimens, gargle and urine aliquots, and swab samples obtained from eight body surface areas of all three crewmembers. Eight different sample sets were obtained throughout the preflight and postflight period (87, 35, 21, and 10 days before launch, launch day, recovery day, and 11 and 17 days aft [illegible] anding).

[illegible] complement the preflight and postflight testing, inflight environ- [illegible] microbiological samples were collected on visit day 69 and visit [illegible] 1. Crew samples were also collected on visit day 69. No medically important micro-organisms have been isolated from environmental or crew samples collected on visit day 69. *Pseudomonas aeruginosa, Klebsiella pneumoniae*, and *Serratia marcescens* were isolated from the debris screen in the waste management compartment on visit day 81. Each of these micro-organisms is frequently isolated in cases of urinary tract and respiratory tract infections. *Serratia marcescens* was isolated in high numbers from all four air samples collected on visit day 81. Table 8-VI shows a comparison of the total environmental isolations from each visit and the average concentration in the areas tested.

Postflight, seven different species of medically important microbes were recovered from the recovery day crew specimens. Although this number was within the preflight range, these species were recovered more often and were distributed over a significantly larger number of sampled areas, indicating a spread of these micro-organisms over the body. The most notable buildup observed was of *Klebsiella pneumoniae,* which was never recovered more than twice from any preflight sample set, but was recovered seven times from the recovery day sample set. *Serratia marcescens* was recovered from all three crewmembers on recovery day, but was never recovered preflight. This is especially notable because this species was also shown to inhabit the Workshop, apparently being introduced with the third visit crew. Preliminary data on distribution of fungi, and certain other bacterial contaminants, indicate that the visit will provide valuable information about the manner in which microbial populations on the crew and in the Workshop reciprocally affect one another.

Microbiologically, increases in specific oral anaerobic components and *Streptococcus mutans* from gingival sulcus fluid were observed.

Mycological samples were collected postflight from each pressure garment assembly and the one liquid cooling garment that was returned for analysis. Visible fungal growth was observed on the liquid cooling garment at the time of postflight sampling.

TABLE 8-VI.- MICROORGANISMS ISOLATED FROM SKYLAB ENVIRONMENTAL SAMPLES

Microorganism	Pre-flight	First visit		Second visit		Third visit	
		Mid visit	End of visit	Mid visit	End of visit	Mid visit	End of visit
Bacillus pantothenicus	1	0	0	0	0	0	0
Bacillus sp.	0	0	0	3	2	1	2
Corynebacterium sp.	0	0	0	1	0	0	1
Evans group A	0	1	0	0	0	0	0
Evans group B	0	0	0	1	0	0	0
Evans group D	2	0	0	0	0	0	0
Evans group E	0	0	0	0	0	0	1
Evans group G	0	0	0	1	0	1	2
Eubacterium pentum	0	0	0	0	1	0	0
Herellea vaginicola	1	0	0	0	0	0	0
Klebsiella pneumoniae	0	0	0	0	0	0	1
Micrococcus sp.	0	1	0	1	0	0	0
Subgroup 1	0	0	0	3	1	2	3
Subgroup 2	0	0	1	1	2	1	2
Subgroup 3	0	0	0	0	4	2	2
Subgroup 5	0	0	0	1	[illegible]	0	0
Subgroup 7	2	0	0	0	3	2	4
Mima polymorpha	0	0	0	0	0	1	0
Moraxella sp.	0	0	0	0	0	1	0
Peptococcus marvillarum	0	0	1	0	0	0	0
Proprionobacterium acnes	1	3	0	2	7	0	2
Peptococcus magnum	0	0	1	0	0	0	0
Peptococcus saccharolyticus	0	0	0	1	0	0	0
Pseudomonas aeruginosa	0	0	0	1	0	0	1
Serratia marcescens	0	0	0	0	0	0	1
Staphylococcus aureus	1	0	2	3	5	0	0
Staphylococcus epidermidis	0	1	0	1	0	2	0
Subgroup II	5	1	5	3	4	2	4
Subgroup III	0	0	0	0	0	0	1
Subgroup IV	2	1	0	1	1	0	1
Subgroup V	0	1	1	2	2	1	1
Subgroup VI	0	0	1	1	1	1	0
Streptococcus faecalis	0	0	0	0	1	0	0
Streptococcus mitis	0	0	1	0	2	0	0
Unidentified (gram pos. cocci)						0	1
Unidentified (gram neg. rod)						1	0
Total isolations	15	9	13	27	37	18	30
Average concentration, organisms per square centimeter	8	13	[illegible]	170	880	26	143

Skylab third visit crew
Commander Gerald P. Carr, Scientist Pilot
Edward G. Gibson, and Pilot William R. Pogue

9.0 PILOT'S REPORT

This section contains a discussion of the third Skylab visit as related by the crew. The major divisions of the report correspond with the major mission events with nominal events omitted. The command module portions of the mission are treated in a sequential manner, and the orbital activities are essentially divided into disciplines. The thoughts, comments, recommendations, and suggestions presented for this report must be weighed with the reports and comments of the crewmen from the first and second visits to permit an integrated overall assessment of the Skylab program. Supplement 4 will evaluate Skylab crew reports.

9.1 LAUNCH THROUGH DOCKING

Training for the launch through docking phase of the mission was considered to be adequate. The training received in the moving-base simulator was exceptionally good, and the inflight stationkeeping and flyaround inspections were much easier to perform than was expected from training. The physiological sensations experienced during actual flight was the only area in which the crew could not be fully trained. The crew believes that probably the most valuable trainer available for that particular aspect of the flight was the dynamic crew procedures simulator, which is a moving-base simulator that was designed for launch/abort training.

Part-task training proved to be a very economical method of training a crew in the initial phases of procedures development. This type of training was used to acquaint the crew with procedures and to smooth out procedures before involving them with more sophisticated trainers such as the command module simulator. The part-task training that was received in two areas was especially valuable. First, the dynamic crew procedures simulator provided an early opportunity for the crew to become familiar with nominal launch procedures and launch abort procedures. Second, the command module procedures simulator provided a tool for the crew to become familiar with procedures used during the rendezvous and docking phases.

After the crew had reached a reasonable level of proficiency with command and service module procedures, the command module simulator training was valuable in that it integrated the critical timeline events with systems problems. The capability of adding malfunctions into the simulator training was a valuable asset. An additional advantage of the command module simulator was that it allowed suited tests to be incorporated into the training. This was of particular value in familiarizing the crew with the physical restrictions and the physiological limitations of the launch phase while suited. A deficiency of the command module simulator was that the visual presentation was poor and it was difficult for the crewmen to develop a good feel for relative motion between the vehicles.

Rendezvous techniques and the rendezvous phase have matured to the point that the third visit rendezvous can best be described as being rather routine. However, the intermittent station coverage or discontinuous communications between the ground and the spacecraft caused excessive voice traffic during the infrequent ground station passes.

Experience with the hand-held computer indicates that they should be used for future backup rendezvous computations. The versatility and rapid growth in capability of these computers is especially significant with the recent introduction of special-purpose-program cards which can be inserted into the computer.

Finally, the initial docking attempt was unsuccessful mainly due to very low closure rates. After the command and service module was backed off, the capture latches recocked, and closing reinitiated (using a good closure rate of 1/4 to 1/3 meters/sec), docking was effected.

9.2 UNDOCKING THROUGH LANDING

The crew was proficient in operating the command and service module early in the visit but, after 84 days of flight, the proficiency level had decreased considerably. Consequently, the crew was probably much less prepared to handle problems at the terminal phase of the visit than at the start of the visit. Again, as in the rendezvous phase, intermittent communications with the ground stations caused problems with control continuity. Figure 9-1 shows the configuration of the Saturn Workshop after separation of the command and service module.

Physiological cues of the entry phase of flight were not covered during training. However, the entry conditions were not really too wild. (The g-load axis was virtually purely "eyeballs in.") A dynamic crew procedures simulator would have helped the crew experience the feeling of service propulsion system ignition. The crew was disconcerted by being off the couch and floating in zero gravity at one moment and then being pushed hard into the couch at service propulsion system ignition.

The horizon check made prior to the shaping maneuver was about 140 milliradians from the expected position; however, the crew was convinced that the guidance and navigation attitude positioning was good because the inertial measurement unit check was within tolerance (check against a star). Therefore, the guidance and navigation attitude was selected.

Figure 9-1.- Photograph of Saturn Workshop showing the twin-boom sunshade deployed over the Skylab Parasol.

The guidance and navigation check at 0.05g minus 1 minute was impossible to perform because the ionization cloud had already begun to form around the spacecraft obscuring the horizon. However, as the time for 0.05g approached, the crew could intuitively see that the horizon was moving toward the correct position.

An unsuited entry established a comfortable spacecraft environment before undocking and made the undocking through landing phase an easier task.

Based on the crew report of seeing "snow" (particulate matter) outside of the spacecraft window, Mission Control advised that the command module reaction control system ring 2 (with an indicated decay in helium pressure) should not be used for entry. The ground personnel believed that there was a good probability that the observed particles were caused by propellant leakage. They did not realize that the crew had seen the particles before activating ring 2 and that the particles were more likely the result of water evaporator overservicing. Again, this indicates the need for continuous communications with the ground.

After the first maneuver the crew noticed water on the aft bulkhead (as did all of the Apollo crews). In future systems, areas in which condensation can form should be protected or should be crew-accessible to allow removal of water accumulations.

Circuit breakers were incorrectly opened prior to entry, removing power from the solenoid valves of the command module pitch and yaw reaction control system thrusters. This was a procedural error and the problem occurred because the crew had not operated most of the command module systems for 84 days. The reason for disabling the breakers in the first place was to protect against a potential electrical short circuit which might occur at separation when guillotines severed lines and electrical cables connecting the command module to the service module. A major component malfunction was assumed to be possible, so it was deemed necessary to back it up with a procedural step which could lead, as it did, to a procedural trap.

The procedure that required main parachute release circuit breaker activation before main parachute release switch actuation was difficult to perform. The crew totally agrees with the philosophy of preventing inadvertent application of power to the parachute release circuit prior to landing. The objectionable part is having to operate circuit breakers which are awkward to reach from a flat-on-the-back position in the couch.

9.3 ORBITAL OPERATIONS

9.3.1 Activation and Deactivation

Workshop activation and deactivation phases of the orbital operations are essentially sequential in nature. Some of the steps were time-critical because of the requirement for ground monitoring and were, therefore, tied to ground station acquisition times.

Training for activation was based upon sequential flow of the tasks but, during the flight, the time element was not given the attention it required. Consequently, the crew had difficulties in maintaining continuity between tasks. Causes of the difficulties were the delay while awaiting signal acquisition; interruptions for troubleshooting during ground contact periods; and the requirement to perform special medical detailed test objectives, such as anthropomorphic measurements, in which little prior training had been received and for which insufficient flight time was allowed. In summary, better planning and training for realistic situations is essential, particularly to maintain high human reliability.

As also experienced on the second visit, the crew found that there were many tasks in the activation sequence that could well have been delayed until a less critical time. When planning the first activities in orbit, emphasis should be given to setting up for living and the non-essential elements should be eliminated.

The most significant problem encountered by the crew was the physical adaptation to zero gravity and the Workshop atmospheric pressure of 3.45 newtons per square centimeter. The flight planning aspects of adaptation are discussed in section 9.3.2 and the physical aspects are discussed in section 9.3.3.

The crew found that the activation workday was much too long and the activity level too high. Lack of physical stamina and the lack of proficiency in handling materials, as well as in body positioning, caused a considerable reduction in efficiency. The crew quickly fell behind schedule, and in an effort to keep up the pace, only aggravated the situation. The scheduled daily activities for the first week of flight should have been severely limited. A workday ending at a time of about 1500 or 1600 hours would have been more appropriate, along with a "shopping list" of optional tasks. The crew day-off that had been planned for visit day 4, which was cancelled a month before launch, should have been retained to allow a time buffer for crew rest and adjustment.

The deactivation phase was conducted on a much more relaxed timeline which made use of the shopping list concept, and involved only those tasks necessary to getting the systems deactivated and the crew out of the Workshop.

9.3.2 Flight Planning

After activation, the crew continued to find themselves overscheduled because, in their opinion, a basic error in flight planning was made well before the start of the visit. A decision was made, with tacit crew concurrence, that approximately 24 science man-hours would be scheduled per day and, after visit day 18, the science man-hours would be increased to 28 (which was the level being scheduled during the latter half of the second Skylab visit). All parties involved should have realized that even 24 science hours was an overly ambitious goal. After activation, when it became apparent that the crew was behind schedule and was making entirely too many mistakes because of haste and distractions, no one, either on the ground or in orbit, made the necessary prompt move to significantly readjust the workload to compensate for these problems. On visit day 24 the science man-hours were reduced back to 24. The reluctance to speak forthrightly over the air-to-ground communications loop was the primary reason for the failure to promptly resolve the problem.

As previously mentioned, the cancellation of the day-off on visit day 4 eliminated the crew's best opportunity to consolidate their position and organize themselves for the remainder of the visit. The crew felt that they were never in a position in which one day's scheduled work could be completed with ease, for approximately the first 30 days of the visit.

Also, as noted in the activation discussion, the medical detailed test objectives took their toll in time and efficiency, mainly because of insufficient schedule time. The medical objectives included anthropomorphic measurements, limb blood flow measurements, leg blood presssure measurements, infrared facial and full-body photographs, stereoscopic photographs, and sweat samples, all of which the crew agreed were significant and worthwhile. However, it was apparent that no one really knew how much time was necessary for their accomplishment. Further, when the necessity for adjustments became evident, the flight plan usually did not reflect the adjustments until about 2 days later. The time delay was not unexpected because it was a characteristic of the flight planning cycle that was known before the visit began.

A prelaunch agreement was made that a 50-percent time-cushion would be scheduled for the first inflight performance of tasks for which the crew was adequately trained. The crew still believes that this guideline is valid as long as the time allowed is based on observation of training and that the observation was made in the context of a full day's activities (e.g., with other tasks before and after the one considered and with realistic allowances for transfer from one task to another). In performing tasks for which little or no training was received, it is the crew's opinion that flight planning criteria should be on the order of 2 to 2-1/2 times the normal time expected to complete the task.

A shopping list would be a good vehicle to apprise the crew of tasks which can be performed at a crew selected time but must be accomplished or they will appear as timeline scheduled items on a future flight plan. This methodology presents a pretty strong case for the concept of onboard flight planning in future missions wherein the ground blocks out only time-critical items and the major goals for the day that are constrained by trajectory considerations, leaving the more routine tasks to be managed by the crew.

The diversity of tasks which a particular crew member must undertake is another factor which must be considered in flight planning. A man who begins his first days in orbit with only a limited range of jobs will "come up to speed" much faster than will one whose workday involves a wide variety of tasks involving the development of many different techniques.

9.3.3 Medical

There is very definitely an adjustment period at the beginning of orbital operations. This crew is of the opinion that it is analagous to the required period of adaptation one experiences when he moves from a sea-level environment to a high-altitude environment (or vice versa), except that the physiological changes involved are accentuated when going from one g to zero g. There is a definite degradation in one's personal physical reserves or stamina while the body readjusts to the new environment. On this flight, 10 to 14 days were required to reach the point where the crew felt that they had some reserve stamina. The crew experienced somewhat the same situation when they returned to the earth's gravitational field and atmospheric pressure. They felt that they were without reserves and that their stamina was limited. About the same 10 to 14 days were required to become readapted to the earth environment and begin to build stamina reserves.

Exercise is essential during space flight and the 1-1/2 hours per day of scheduled exercise kept the crewmen in excellent physical condition. This conditioning was the primary reason that the crew experienced very little muscular discomfort during the postflight adaptation period. The crew is also of the opinion that it was essential for them to keep their cardiovascular systems in good condition and to maintain their one-g muscle tone to the greatest extent possible. All crewmen discovered that they invariably felt better after heavy exercise. Though somewhat fatigued after exercising, they found that the reduced fluid pressure in their heads was a welcome change. The exercise seemed to "purge" the system physiologically as well as afford a new psychological outlook.

The exercise can be divided into three major categories according to the device used. The bicycle ergometer was exceptionally good for cardiovascular, pulmonary, and large leg-muscle conditioning. The Mark I ex-exerciser was used for stressing the overall skeletal structure and conditioning the upper body muscles (e.g., the upper torso and arms). A treadmill device proved to be exceptionally beneficial for conditioning the calves and putting a heavy compression load on the total skeleton, particularly the spine, feet, ankles, and knee joints. Walking, running, and toe-rise exercises served also to maintain the smaller muscle groups necessary for balance.

The inflight medical support system training was adequate considering the amount of time available for training and the crew's background. The training provided good emergency insurance and the crew believed that they could have handled most of the emergencies that would have been encountered on board.

The Workshop did not have a designated medical emergency locker stocked with all the proper equipment and with a design feature for quick-and-easy deployment. However, the crew improvised by placing a selection of equipment in locker W700.

No displays were provided which would allow the inflight observer to clinically assess the reaction of the subject. As an example, the lower body negative pressure and the ergometer experiment provided no electrocardiogram for the observer to monitor such things as premature auricular and ventricular contractions, or general changes in the electrical activity of the heart. A means for displaying trend data so that a crewman could compare his performance of a particular day with his performance of the previous week or month would have been useful, particularly for selecting an exercise routine. The Scientist Pilot had a large number of charts for plotting of data, but comparison of one set of data with another was not convenient or straightforward, and data plotting was very time consuming.

Biosensor attachment was a high-overhead item in the medical experiment timelines. The biosensors were inconvenient to attach and, on some crewmen, the proper operation was not always assured. Impedance checks were consistently long from day to day, and the crew could do little to improve the checkout time. A great deal of time was consumed troubleshooting.

9.3.4 Solar and Comet Kohoutek Observations

Apollo Telescope Mount.- The most significant observations made with the Apollo Telescope Mount were of a coronal transient; a solar flare, including its early rise; and Comet Kohoutek. The coronal transient, which occurred on January 17, 1974 (visit day 63), was unusual in that an exceptionally large quantity of dense gas was ejected from the sun. Ground personnel first detected the transient as an eruptive prominence and notified the crew. The inflight observations began in a matter of minutes thereafter. The observations of the flare were unique in that data were obtained on the short, explosive phase of a flare for the first time. This was of primary importance for understanding the cause and mechanism of these unpredictable events. The comet observations were very successful in an operational sense. Although the Apollo Telescope Mount instruments were optimized for solar observations and the comet was far less bright than anticipated, useful data were obtained. Also, in spite of the loss of one of the three control moment gyros, the crew maneuvered the Workshop extensively to perform the comet observations. Figure 9-2 shows the Scientist Pilot at the Apollo Telescope Mount control panel.

a. Solar observations: The Apollo Telescope Mount was an exceptionally complex but versatile set of observing instruments. The manner in which the observing programs were organized and also the manner in which ground planning was carried out provided a very challenging and interesting task for the crewman who operated the Apollo Telescope Mount.

The required observations were specified to a high degree of detail so that an acceptable level of data was always returned. The Apollo Telescope Mount also provided the opportunity for the onboard observer to exercise his judgement in obtaining additional data, or in a different manner than specified, thereby significantly enhancing the overall quality of data return. The crew's strong recommendation is that this type of flexibility and potential for data enhancement, by using crew judgement, should always be a part of an experiment system.

The more training a crewman receives and the more extensive his background in the basic sciences, the more opportunity he has for enhancing the quality of the data by using his judgement. Each observer tended to become more proficient in operating the Apollo Telescope Mount as the flight progressed; to move away from the rigid structure of the joint observing programs; and to a degree which varied in the case of different crewmen, to use his own judgement of how, when, and where to operate the instruments. In many instances, the Scientist Pilot eliminated the joint observing program and building blocks, which were essentially middle men, and the data were gathered by first assessing the physically important phenomena on the sun and then directly matching the instrument operations to those phenomena.

The ground interaction for the Apollo Telescope Mount operations was excellent. First, a daily morning discussion was held with the ground on the observing objectives of that day. This permitted a two-way exchange

Figure 9-2.- Scientist Pilot manning the Apollo Telescope Mount controls.

of information pertinent to the operation of the experiments on a continuing basis. Second, the response time of the ground personnel to phenomena which they or the crew observed was rapid and alterations to the flight plan were quickly made. Rapid response time was exemplified by the coronal transient, figure 9-3, which was first detected by a ground observatory. Information was transmitted to the crew and the Apollo Telescope Mount instruments were observing the transient within a matter of minutes. The Apollo Telescope Mount experimenters had obviously spent much premission time in organizing their ground team and their observing programs so as to have a short response time to obtain maximum data from the acquisition opportunities.

Another strong point of the Apollo Telescope Mount operations was the potential for growth on the part of the observer. As the visit progressed, a crewman was able to become significantly more proficient in both the operational and the scientific aspects. Because of the growth factor, the long duration mission was a continual challenge and one never felt that he had reached the point of saturation. One knew that he could operate the Apollo Telescope Mount significantlv better on the 80th day than he could on the 30th day, not only by improving the mechanical skills, but mainly by improving the interpretive and subjective skills. For any phenomena which is not predictable in time or space, observations should be made in such a way that a crewman can make judgements on how, where, and when to take data.

Another very good feature exhibited by the Apollo Telescope Mount was the capability for near-real-time data analysis. Data, down-linked on telemetry, was analyzed in a matter of days and the significant results were transmitted to the crew so that future observations could be improved.

Because of the nature of the joint observing programs, the Apollo Telescope Mount instruments were used in a combined way that allowed the study of specific features as opposed to experiments wherein each instrument had to be operated independently. This joint approach to observing allowed one crewman to effectively control many instruments simultaneously.

The length of time that could be spent operating the Apollo Telescope Mount on the sun side of an orbit was constrained by the attitude and pointing control system. Approximately one-third of an orbit was allotted for momentum dumping of the control moment gyros. Thus, the Apollo Telescope Mount observations could not be made all the way through the high beta angle daylight cycles because of spacecraft motions induced by the momentum dump. The motion of the spacecraft during momentum dumping also precluded observations with other experiments on the night side. A second pointing problem was that of uncorrectable misalignments between instruments. The capability to make vernier-type adjustments to align the instruments would have simplified data taking.

Figure 9-3.- White light coronagraph picture of the solar disc.

The Apollo Telescope Mount operations demonstrated that, had the crew the capability of repairing and replacing critical optical elements and film canisters, better performances would have been obtained from the instruments.

b. Comet Kohoutek observations: Proper pointing of the Apollo Telescope Mount instruments at the comet was uncertain because the comet could not be seen at the time the instruments were actually pointed toward it. The procedure used was to point the vehicle about 18 milliradians away from the comet, calculate the maneuver that had to be made to center the instruments, and then proceed with the centering. This involved uncertainties in three different areas: finding the center of the instruments relative to the center of the display, positioning an overlay on the display accurately, and reading the overlay accurately (because of parallax). Each step introduced a potential error in pointing the Apollo Telescope Mount within the desired 0.6 of a milliradian of the comet. A closed-loop or a visual feedback system would have eliminated these errors.

In terms of controls, the crew had to perform a number of small vehicle maneuvers while looking for the comet and adjusting the Apollo Telescope Mount instruments at various points around the comet. Twenty key strokes were required for each adjustment and, many times, these adjustments had to be made every 1 to 2 minutes as the crew tried to account for drift or the motion of the comet.

A major consideration in assessing how well the cluster was used for comet operations is that only two control moment gyros were available (since one had failed). An excellent job of reprogramming was provided for two-gyro operation by the ground personnel to accomplish all of the comet viewing as well as reprogramming for other experiments that required special vehicle orientation. The crew was not able to desaturate the control moment gyros while maintaining observation attitudes. This was a special limitation at all times when making long-duration (30-minute) exposures on the comet.

Comet Kohoutek photography.- Experiment S233 (35-mm photography of the comet Kohoutek) was strictly an ad-lib operation using a hand-held camera. Time exposures ranging from 60 to 180 seconds were required, but there were no facilities anywhere in the Orbital Assembly to adequately mount and point the camera. The crew had to make extensive use of universal camera mounts, gray tape, and cardboard to mount the camera in a window steadily enough to obtain the photographs.

Any potential observation point inside a spacecraft should have some kind of indexing station which could receive universal mounts so that the ground could provide reference angles for pointing. An example of an inadequate pointing description that the crew was obtaining toward the end of the visit was an instruction to look at the Apollo Telescope Mount truss in a certain way and then point the camera toward the command and service module.

Visual observations of the comet were made just prior to and just after perihelion. Crew sketches (fig. 9-4) were drawn to record the visual impressions and were shown on telecasts to earth.

9.3.5 Earth Resources Experiment Package

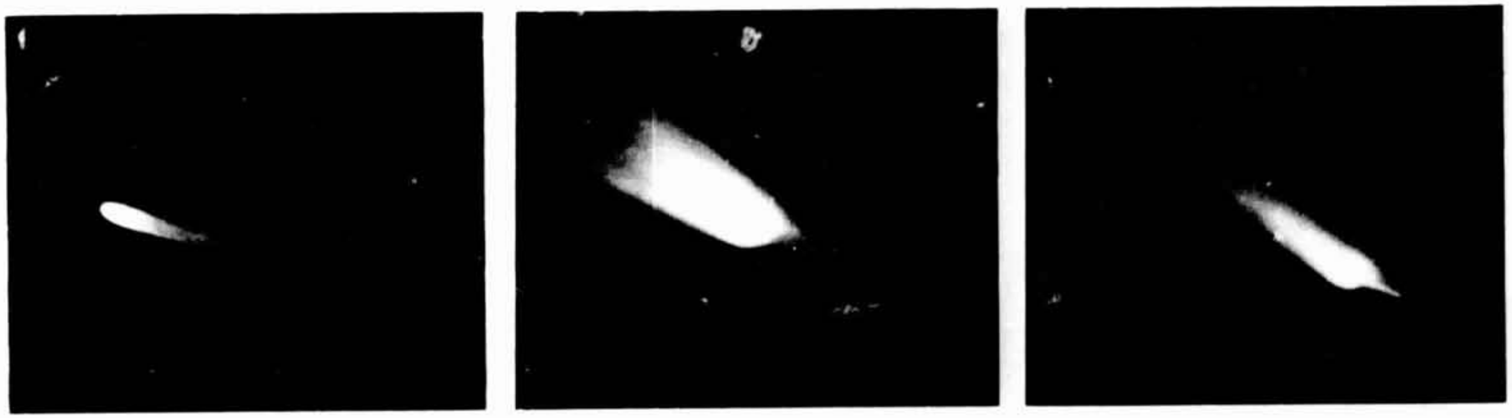
The Earth Resources Experiment Package yielded exceptionally useful data and, in this sense, the experiment was rewarding to operate. However, the value of the observations would be greatly enhanced if the crewman's ability to make judgements was used to the same degree as it was with the Apollo Telescope Mount. The right kind of equipment was provided in the Earth Resources Experiment Package, but provisions were not made for operator flexibility and judgement. Not until late in the visit was the Scientist Pilot allowed to exercise his judgement as to whether or not to operate the S190B earth terrain camera if the selected site was cloud covered. The visual earth observations experiment (sec. 9.3.6) brought all sorts of crew flexibility and judgement into play.

Some minor problems were encountered which were inherent in the design of the earth resources equipment. A loss of focus was experienced with the viewfinder tracking system optics when adjusting the zoom, and no manual recovery of the focus was possible. This was a detriment to the capability for site acquisition and tracking. The alignment of the S192 multispectral scanner was entirely too complicated. A simple and straightforward procedure is necessary for accurate alignment. With the exception of S190A and S190B experiments, all Earth Resources Package data were recorded on magnetic tape for return at the end of the visit.

The number of successive Earth Resources Experiment Package operational passes and the capability for making valuable nighttime observations was constrained by the requirement for momentum dumps. Also, the passes with the space vehicle in the solar-inertial attitude were good for acquiring earth resources data, and the use of this time frame for acquiring such data was not fully explored.

9.3.6 Visual Earth Observations

The visual earth observations effort was a very interesting and satisfying task for the crew. Much of its appeal rested in the fact that judgement could be exercised as to the suitability of sites and as to the type of data to be taken at a particular time; for example, photography or verbal description. The program had enough flexibility that observations could be fitted into whatever time was available during the workday. Approximately 30 training hours were spent in preparation for the earth observations activities. This training was extremely valuable in preparing the crew to make ad-lib descriptions of targets of opportunity. There



Perihelion - 10 days
December 18, 1973

Perihelion + 1 day
December 29, 1973

Perihelion + 2 days
December 30, 1973

Perihelion + 3 days
December 31, 1973

Perihelion + 5 days
January 2, 1974

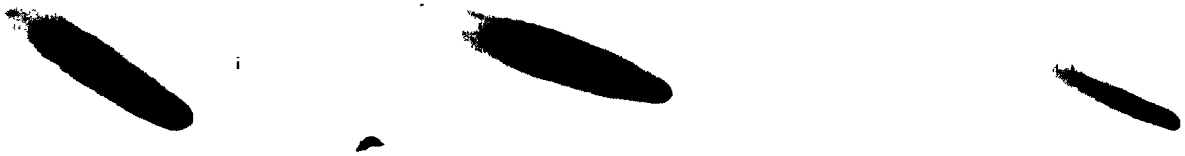
Perihelion + 8 days
January 5, 1974

Figure 9-4.- Artist's enhancement of Comet Kohoutek sketches made by crew.

Perihelion - 10 days
December 18, 1973

Perihelion + 1 day
December 29, 1973

Perihelion + 2 days
December 30, 1973



Perihelion + 3 days
December 31, 1973

Perihelion + 5 days
January 2, 1974

Perihelion + 8 days
January 5, 1974

Figure 9-4.- Artist's enhancement of Comet Kohoutek sketches made by crew.

is no substitute for properly trained human observers for the job of gathering data when its value is dependent upon such unpredictables as weather (clouds and wind), color (depth and contrast), sun glint and other lighting effects. In cases where the necessary detail could not be captured by photography, the crew was prepared to supplement the photography with verbal comments. See figures 9-5 through 9-7 as examples. Apparently these on-the-spot comments have greatly increased the value of many of the photographs taken. Several equipment deficiencies and suggestions for improvement of future earth observation programs are discussed in the following paragraphs.

The camera equipment used for hand-held photography was not optimum. The lenses and the dynamic range of the film were not adequate to gather the data that were available. Also, the crew believes that there was insufficient equipment flexibility to allow for photography of areas of interest with several types of film, filters, and lenses. Cameras should be designed for quick magazine changes. The turret lens concept could possibly be utilized with still cameras to attain the necessary quick-change capability.

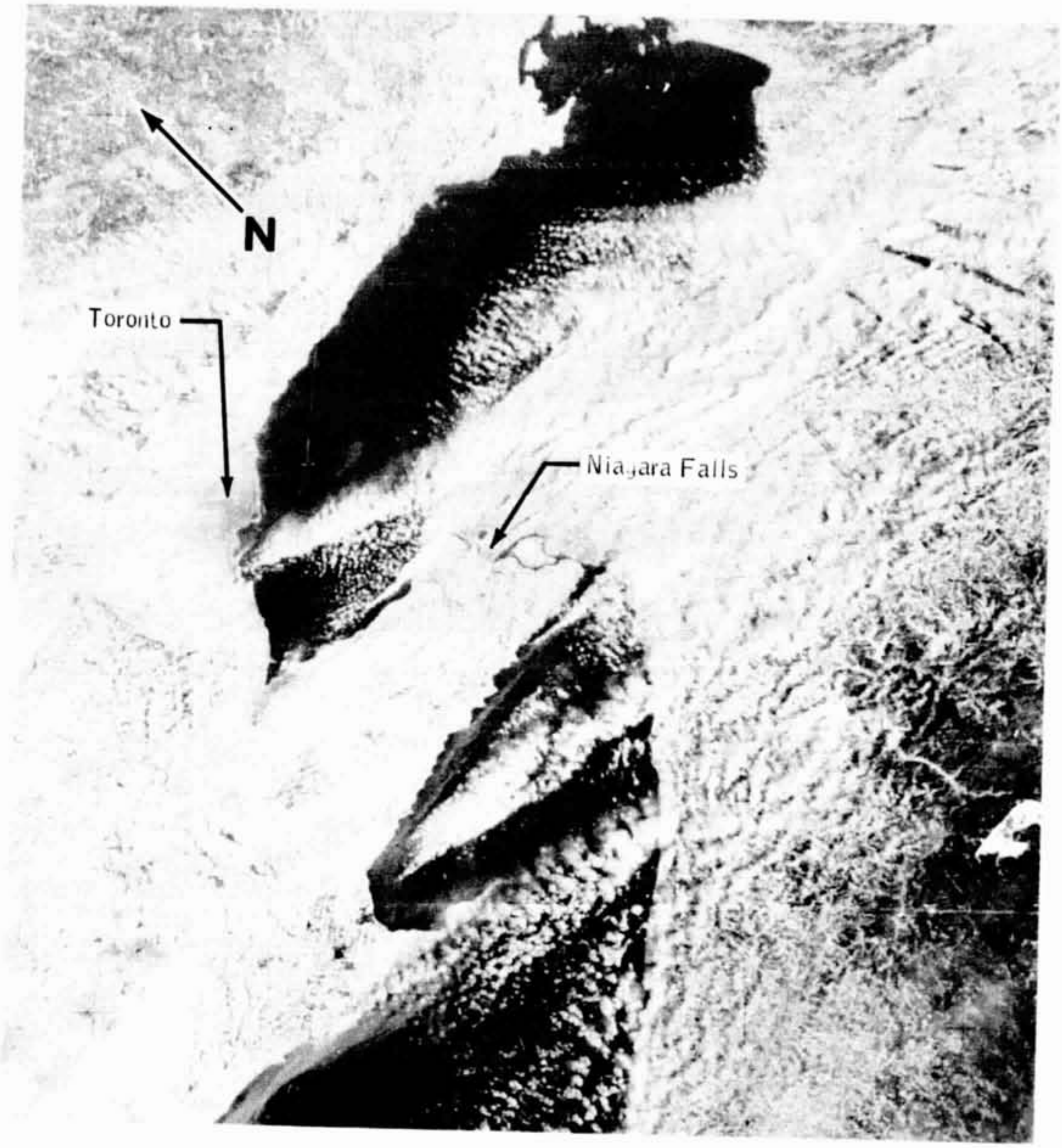
The crew experienced some difficulty in recognizing earth terrain features early in the visit, and the slider map proved to be an invaluable aid. As the crew gained experience in making earth observations, recognition of features became considerably easier, but the slider map continued to be the prime tool for determining geographic position at a given time.

The crew believes that, for future missions, a means should be provided for quickly and easily determining geographic position; and that up-to-the-minute information should be available on the most important sites being approached. This would appear to be most critical on short-duration missions where flight time limits the attainment of crew proficiency and, particularly, when crew preflight training is limited. Having an orbital position display at every crew station from which earth observations can be accomplished could provide the crewmen with the "present" geographic position and with the projected ground track in much the same way that it is presented in the Mission Operations Control Room. Ground personnel access to such a display would permit the highlighting of important sites as well as providing a means to update a presentation of communications configuration and network coverage.

Camera equipment stowage and mounting provisions were non-existent at the wardroom window and at the Structural Transition Section windows. Operations could have been considerably streamlined had the Workshop design included organized stowage and data recording facilities at the observation locations.

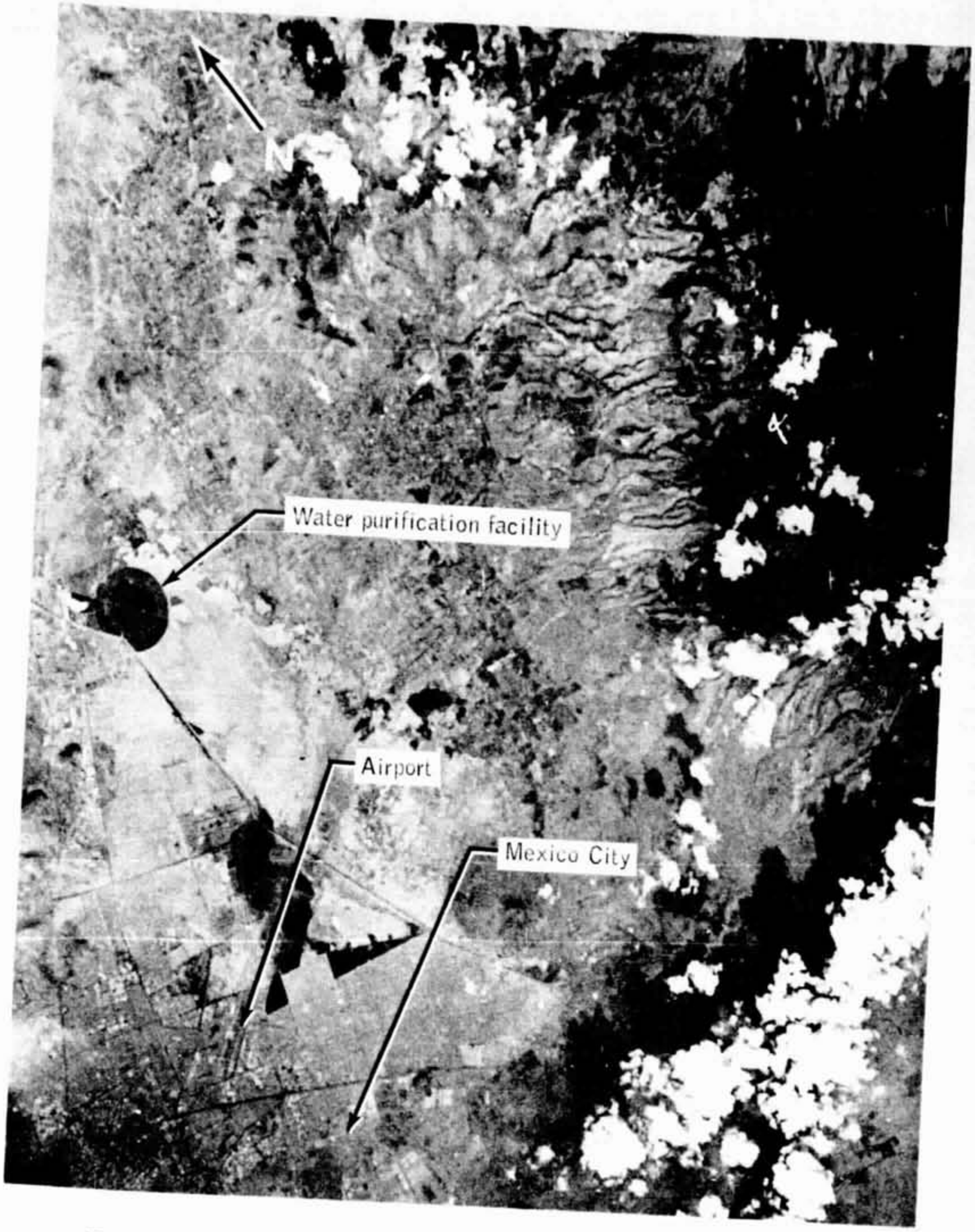
The snow blanketed Pennsylvania, New Jersey, New York, and Connecticut area is shown under light-to-heavy cloud cover. Long Island is clearly seen under light scud clouds.

Figure 9-5.- Northeastern United States.



A point source for cloud formation is located south of the city of Toronto. Dry air passing over Lake Erie and Lake Ontario requires some distance before attaining enough moisture to promote cloud formation.

Figure 9-6.- Niagara Falls area.



The water purification facility near the outskirts of Mexico City was an outstanding landmark and created much discussion between the crew and ground personnel.

Figure 9-7.- Mexico City and northeastern vicinity.

An important item to be considered in future earth observations programs is the cleanliness of optical surfaces (windows as well as lenses). A film of contamination was deposited on all spacecraft windows and this undoubtedly influenced the quality of photography.

Man can make valuable observations from space if he is properly trained and equipped. The crew strongly urges that the earth observations effort be given more stature on future missions, and that design criteria be established for an "earth observatory" in much the same manner as for solar and stellar observatories. The observatory should permit the operator to have control over a number of instruments that could acquire data in the most advantageous wavelengths for viewing the earth. Included in these are the visible, of course, which can be broken down by filters into several ranges; the infrared; the microwave; and other regions which may prove to be useful to supplement the Earth Resources Experiment Package and Earth Resources Technology Satellite data. The observer should be trained to know which wavelength ranges are the most significant for studying the various phenomena that he can perceive from orbit. He should have the capability of pointing the total instrument package in much the same way the Apollo Telescope Mount was pointed at several locations on the sun. The capability here, however, should be to point the package toward sites ranging from zero to right angles from the nadir. The sensor arrays should be arranged and aligned in the same way as was recommended for the Apollo Telescope Mount (e.g., they should be individually alignable in order to maintain co-alignment in flight).

The various wavelengths should be displayed to the crew. Those wavelengths not in the visible range should be converted to a visible image — particularly the infrared range. The visual display should be designed so that the observer does not have to remove his eye from the eyepiece, but can use hand controls to change the presentation or the wavelengths that are to be sampled. Split-image techniques could be used to great advantage for site acquisition and data sampling, and image motion compensation is a must for adequate tracking. As with the Apollo Telescope Mount, the film in the earth observatory instruments should be radiation shielded in the operational location. (A great deal of Skylab flight time was lost in moving camera equipment to and from the Orbital Workshop film vault.) On future missions the observer should be required to verbally debrief only the features of immediate interest. All other data such as f-stop, Greenwich mean time, and information pertinent to the instruments should be automatically recorded on film or magnetic tape or should be down-linked in real time.

A dedicated voice channel for science could be very useful in improving the quality of the data and reducing response time. Such a channel would allow free and continuous exchange of information between the onboard observer and the ground support team. Further, it would be highly desirable that crew specialists be assigned for operation of the earth observatory in much the same manner as for the Apollo Telescope Mount.

Future systems should also provide a capability for observing the night side of the earth as well as the day side. A wealth of valuable information for such disciplines as land use, cartography, pollution control, and meteorology could be gathered at night.

9.3.7 Corollary and Student Experiments

The equipment provided for corollary experiments varied considerably in quality. Some equipment lacked rigidity which made alignments and manual adjustments uncertain. The more rigid equipment worked as expected.

In training, the crew saw the whole spectrum of equipment, from good to bad. The training hardware for corollary experiments, in general, was very good, but dynamic simulators were not available. A dynamic simulator provides the best training aid for experiments which require tracking of the horizon and/or other objects, or the time critical manipulation of related hardware.

Timeline training in conjunction with corollary experiments is very important, and leads immediately to consideration of overhead time allowances. Corollary experiments were pretty much characterized as being high-overhead experiments. That is, a great deal of time was required to prepare the experiments for operation. In particular, experiments that went into the scientific airlock required unproductive time spent in unstowage, assembly, installation, removal, disassembly, and restowage. The crew handled the hardware excessively and, consequently, some of the hardware began to wear out toward the end of the visit. The aforementioned problems led to the crew conclusion that all corollary experiments should have shared a common facility (like a turret) that, by design, would minimize equipment handling and attendant overhead time.

Another characteristic of the corollary experiments is that they did not take advantage of crew initiative and judgement. These experiments should be designed with thought toward flexibility, versatility, and growth potential. The same sort of criteria should be applied to the corollary experiments as have already been applied to the Apollo Telescope Mount experiments, the visual earth observations, and, to a lesser extent, the Earth Resources Experiment Package. If operation of an experiment can be programmed and judgement is not required, the experiment hardware should be designed for automatic sequencing. Flight time is too valuable to have crewmen performing strictly routine mechanical functions that are repeated many times.

In regard to the student experiments, it is well to involve young people in experiments, but the student experiments were introduced into the Skylab program a bit late and, therefore, did not receive the attention that was given to the other experiments. This concept should be retained for the next generation of spacecraft and more attention should be given toward insuring equipment reliabliity and good design. The same operational criteria should be applied as indicated for the corollary experiments.

9.3.8 Extravehicular Activities

The training for the extravehicular activities and the facilities that were made available for extravehicular activity training were excellent. The one-g trainer at the Johnson Space Center was a good mockup and provided a good trial of the flight equipment. Of greater value, of course, was the neutral-buoyancy facility at the Marshall Space Flight Center. That particular facility and the people who worked there were extremely valuable in the crew training for extravehicular activity. The neutral-buoyancy facility provided the crew with the opportunity to experience the same sort of problems that they were going to have to cope with in performing a zero-g extravehicular activity. The crew was trained to the point where the actual transfer of film, both to and from the Apollo Telescope Mount, became very routine. Because the normal procedures became routine, the crew was in a position to give full attention to special operations such as repair of the experiment S193 antenna. Using the one-g trainer, the crew had the opportunity to look at the backup antenna and to handle and develop the tools and procedures needed in flight to do the work; then the equipment was moved to the neutral-buoyancy facility where a reasonable amount of time was spent underwater working the problems. The other extreme of special extravehicular activity procedures was the experiment S054 filter wheel positioning, where there was no premission training.

Neutral-buoyancy training is certainly the key to successful extravehicular activity. The importance of being able to develop the extravehicular activity and practice every procedure in the tank cannot be overemphasized. Equally important is the fact that one has to learn how to work in a suit, pace the task sequence and, in general, feel comfortable and knowledgable in the extravehicular environment. This pays dividends when encountering non-nominal situations, which did occur on each of the third visit extravehicular activities. The neutral-buoyancy facility and the one-g walk-through facility are both essential to proper extravehicular activity training.

A major problem that consistently occurred during extravehicular activity was the requirement for greater manual dexterity. If any one element of the suit could be improved, it should be the dexterity capability of the hands and fingers. All crewmen experienced very sore fingers after an extravehicular activity, and the experiment S193 antenna repair was barely accomplishable because of the restricted manual dexterity and the required work with many small parts. Figure 9-8 shows the method of suit donning employed by the Pilot.

The relative order of preference for use of the boom and the clotheslines for transferring film from one part of the spacecraft to another, was in the order listed. The boom was, by far, the best of the two methods. It was the easiest to use, required the least amount of crew overhead time, and was the least complicated method. The clothesline was a good backup method, but the price of a certain amount of time lost must be paid in managing the clotheslines (keeping them from tangling, getting twisted up, and encumbering the crewman).

As a general principle for extravehicular activity, the crew should have the capability of unrestricted access to every exterior part of the vehicle. This is a point which proved itself to be valid over and over again during the extravehicular activities on the third visit as well as on previous visits. The first item of importance is to make sure that it is safe to go to any external location of any working component. Secondly, hand-holds should be provided along likely translation paths and/or located at various points on the vehicle where one might possibly work. Since it may not be possible to predict beforehand exactly how a vehicle will have to be maintained and repaired in flight (as evidenced by the large number of unexpected extravehicular repairs in Skylab), it would be best to take the extra precaution of providing extravehicular access capability to all external working components.

The concept that all external areas are candidates for extravehicular activity implies that adequate lighting should be provided in all areas; otherwise, the extravehicular activity equipment should provide the lighting. All of the tools used in Skylab extravehicular activities were special-purpose tools. Such tools would not necessarily have to be special insofar as their work interface with the vehicle is concerned, but the grips or ends handled by an extravehicular crewman deserve special attention. A tool should be designed so that it can be gripped and held with a pressure suit glove. The common screwdriver is a good example of a tool that is not suitable. The blade does not have to be changed, but the handle does.

The astronaut maneuvering unit (fig. 9-9) was evaluated as a corollary experiment and, with its stabilization and attitude control system, appeared to be a safe unit to operate outside the vehicle. A light tether of some kind would probably be a desirable feature but, for the most part, the astronaut maneuvering unit is an effective way to move around on the outside of a spacecraft.

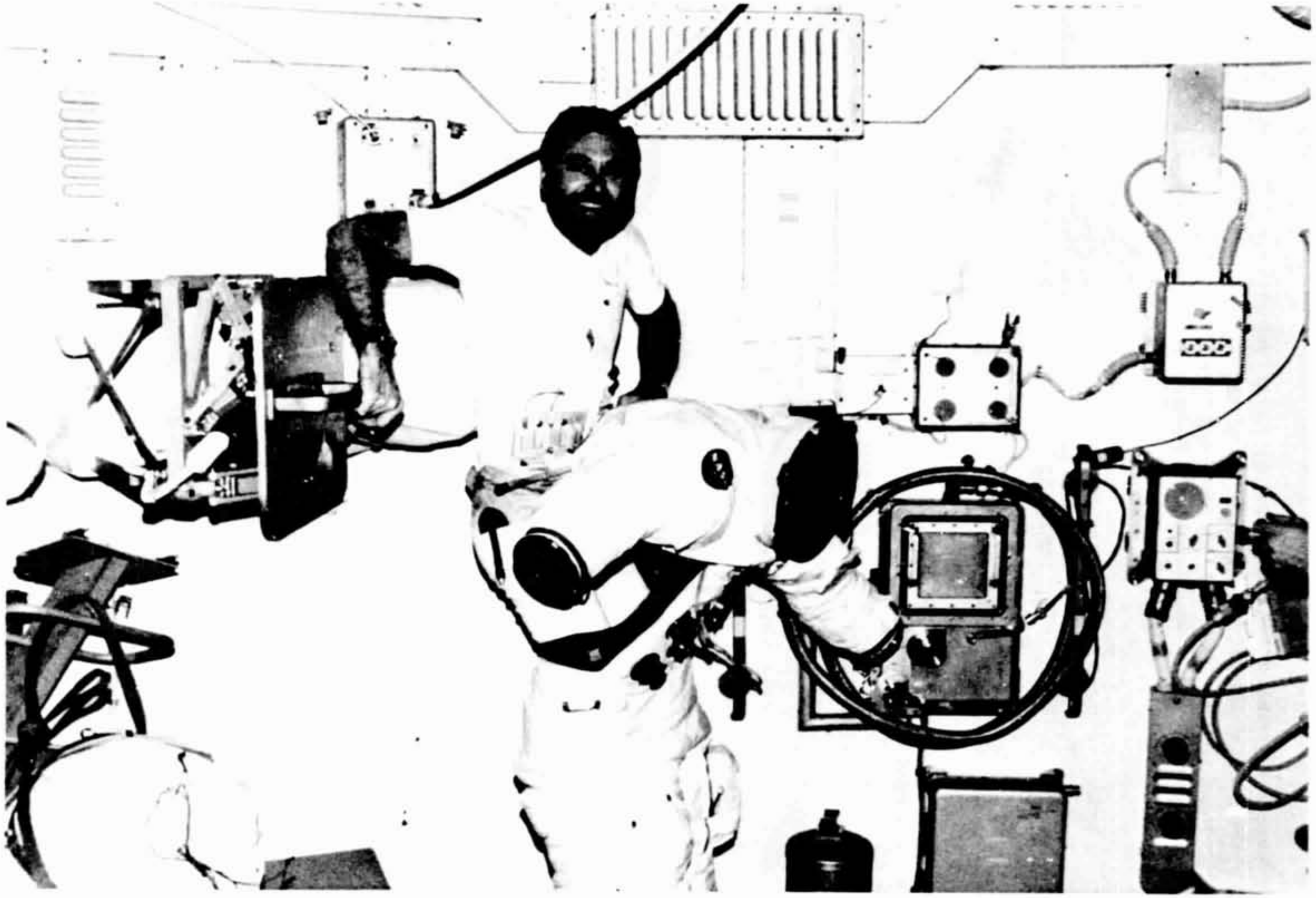


Figure 9-8.- Pilot preparing to don pressure garment.

Figure 9-9.- Commander operating the hand-held maneuvering unit.

The preplanned extravehicular activities were completed without major difficulty because the responsible NASA organizations have learned how to design and train for them and the necessary facilities are available. One final point relative to training for extravehicular activity is the assumption that the vehicle configuration is accurately known. Problems occurred during the execution of the experiment S193 antenna repair because the orbital vehicle was different from the training installation. The precise configuration of this area of the actual Workshop was not known.

9.3.9 Architecture and Human Engineering

Layout and arrangement.- For any particular work station, a preferential up-down and left-right orientation should be referenced to the orientation sensed by the crewman as he is restrained in his work position. For example, when working at the Skylab scientific airlock, all control and display panels, decals, labels, et cetera, should be referenced to the up-down and left-right orientation that appears to the crewman as he is facing the airlock in his normal work station posture.

Wall space appeared to be incompletely or randomly utilized. There were large portions of the wall, particularly the dome area, where work stations or equipment could have been located or to which equipment could have been transferred during the course of the program to provide additional work stations.

The space/volume efficiency in the Multiple Docking Adapter was really quite high, with almost the total peripheral (wall) area being used. The difficulties encountered with working in the Multiple Docking Adapter were all problems that resulted from the lack of handholds and foot restraints.

Locational scheme.- The crew had extreme difficulty in locating some items in the Multiple Docking Adapter/Structural Transition Section. The scheme that was used was ambiguous and led to confusion because a number assigned to a control and display panel was sometimes the same as one given to a stowage or equipment area location. In many cases, distinguishing a control and display panel number versus a location number was difficult. Although a stowage location number was always preceeded by the letter "M" and the panels were indicated by an arabic number or numeral in the documentation, most of the difficulty arose in actually finding the location. Several minutes could be wasted trying to find the "location" or "panel." Future spacecraft design should incorporate a master locational scheme for the location of all items within the vehicle. A three dimension coordinate system could be used or a clocking index system could be used, if more appropriate. In either instance, the system selected should be cross indexed by part name, number, and coded location to quickly direct the crew to the desired equipment or spacecraft area.

Restraints at heavy-use work locations.- A crewman at work in any given location requires the capability to stow pieces of equipment, pieces of paper, himself, and a multiplicity of other items. There were no provisions at the anti-solar airlock for such requirements, and this was also true of almost all of the work stations throughout the vehicle. There should be provisions for stowing and temporarily restraining a large number of items of different sizes, densities, and make-up, varying from small pieces of paper to large, bulky and massive pieces of hardware.

The triangular grid surfaces used throughout the vehicle were of great use and convenience. The triangular shoes were excellent but could only be used in the Workshop area and at the Apollo Telescope Mount, Earth Resources Experiment Package, and the materials processing facility locations in the Multiple Docking Adapter. Aside from the above locations, the Multiple Docking Adapter/Structural Transition Section had inadequate crew restraints.

The crew restraint system in the waste management compartment was also unsatisfactory in that a great deal of time was wasted trying to maintain body positions.

Crew traffic and procedural considerations.- The location of the wardroom window was non-optimal because the comfortable body orientation for stabilized posture when looking out the window was limited to the Workshop one-g orientation (i.e., with the long axis of the body parallel to the long axis of the vehicle). The only other possible position was with the legs protruding through the access port to the forward compartment so that one looked out of the wardroom window "upside down." For a window station that is to be used for viewing the earth or any outside object, the total work station should be capable of being freely swiveled or should be designed in such a way that the left-to-right horizon of view can be varied by moving the body through a complete rotation while facing the window.

Posture should also be considered in the positioning of crew restraints near control panels and work areas. The most comfortable monitoring or performing arrangement was when the center of attention or manipulation was located at chest height with the body in an erect or semi-erect posture. The erect posture is the relaxed position of the body in zero gravity; hence, foot restraints should be located to provide a visual working envelope at chest height for an erect crewman. Work or activity areas that required a crouched posture for proper work completion were: the Apollo Telescope Mount, the food tray in the wardroom, the solar airlock, and the water tanks. Foot restraints were provided in all these areas but the general arrangement was not optimum because the major work activity areas were at waist level.

The Scientist Pilot did not have easy access to his food drawers in the pantry area when the other crewmen were eating. To reach the drawers he had to go around and behind either the Pilot or the Commander or go over the top of the table.

Viewing and visibility considerations.- Although the wardroom window was the best viewing window available, the view of the earth was greatly restricted at any given time. A possible solution would be a hemispherical bubble on the earth-facing side of the spacecraft to optimize visibility of the sunlit earth during a daylight pass.

The facilities that were available for storing photographic and documentation equipment (cameras, pencils, books, tape recorders, etc.) were limited. This was a distinct disadvantage in recording observations, narrative descriptions, or technical data.

Optical surfaces.- All optical surfaces that interfaced directly with the crew got dirty very quickly as a result of human activity around them, and the external optical surfaces were degraded by contamination from vents and thruster firings. The crew should have the capability to clean all optical surfaces (inside and outside surfaces, where applicable). A good example is the scientific airlock windows that could actually be removed and taken inside for cleaning. The Earth Resources Experiment Package maintenance kit provided for optical cleaning of the experiment package itself, but the quantities of the consumables were not sufficient for use elsewhere.

Extravehicular activity facility.- During preparation for extravehicular activity, a significant traffic bottleneck was caused by extravehicular equipment being located in a high-traffic area. Also, since the Skylab airlock compartment (egress area) was located in the central part of the Workshop, depressurization of the airlock resulted in separating the Workshop into two isolated areas, one of which was inaccessible to the crewman remaining inside during an extravehicular acitivity. All extravehicular equipment and tools should be stowed near the airlock to reduce the extravehicular activity preparation time.

Display and control panel utility.- A properly designed panel containing a functional line drawing or layout can provide an operator with visibility into the operational status of a system. An example of good panel design was panel 225, while a poor example was the scattered and poorly arranged controls and valves for the molecular seives. Also, panel 217 (which provided access for servicing and maintaining the liquid gas separator) was poorly designed and was always causing cuts and scratches.

9.3.10 Maintenance and Repair

Skylab systems were, for the most part, not designed with inflight maintenance and repair in mind. However, as in a one-g environment, if the proper tools and working surface are available, a job involving several small pieces can be easily accomplished. Examples in support of this argument are the second visit crew's tape recorder repairs and the third visit crew's repair of experiments S183 and S009, the Mark I exerciser, and the reservicing of the primary coolant loop. Inflight maintenance and repair is a completely feasible and practical mode of operation.

9.3.11 Hygiene and Housekeeping

Personal cleanliness was much easier to maintain than was expected. A shower was welcome when sufficient time was available to take one. Normally, a shower required between 45 minutes and 1 hour. The sponge bath was much quicker to accomplish (15 to 20 minutes) and was taken once a day.

The task of handling teleprinter pads and checklist changes was time-consuming and bothersome. Handling the many small pieces of paper indicated the need for some sort of zero-g desk designed to simplify the management of changes to daily flight plans and procedures.

Most of the trash was generated by the food system. The wardroom was the largest single source of trash, the waste management compartment was the next largest trash generator, while little trash was generated in the rest of the Workshop. There were very few trash disposal facilities in some areas, most noticeably in the Multiple Docking Adapter. It was necessary to dedicate one garment pocket as a trash receptacle when working in the areas devoid of trash disposal facilities. Only urine disposal bags and trash bags with a membrane were available for trash disposal during the third visit. Trash bags with a membrane were adequate, although it was sometimes difficult to seal the membrane for disposal. For the most part, the trash bag was superior to the urine disposal bag for small items because the membrane prevented them from floating back out of the bag. Small items such as the little green tags and strips on the fecal bags, the small sticky rings off of the biocide sensors, and the electrolite sponges had more of a tendency to float out of the urine disposal bags than out of the trash bags. A small overlap on the trash bag membrane would have significantly improved the containment of small items.

Considerable difficulty was encountered midway through the visit in ejecting the urine disposal bags. When the pressure was reduced in the trash airlock, the bags appeared to swell and jam inside the airlock chamber, making it difficult to eject the bags. The crew resorted to daily dumping of the urine bags through the urine dump system, then rolling and taping the used urine bags before placing them in a urine disposal bag. Figure 9-10 shows the method employed for inserting trash bags in the trash airlock.

The waste management equipment that was provided for Skylab was certainly a step forward from the equipment that was available for use in the Gemini and Apollo programs. The only major waste management problem area was the overhead time required to process the waste products; that is, the filling out of the data tags, the weighing of the waste matter, and the processing of the material in the ovens. Urine sampling was also a time-consuming process which required an average of 20 minutes per man per day to sample the 24-hour collection of urine and dispose of the remainder. The odor control was very effective in the waste management compartment, and the airflow technique of entrapping both urine and feces was an effective way of moving waste away from the body.

In summary, time overhead was the major problem encountered in the hygiene and housekeeping functions. By the third visit, the schedules indicated that the flight planners had a good handle on the periodic intervals required for housekeeping tasks such as cleaning with biocide, vacuuming, and washing with water. The time required for each task was well understood, but excessive.

9.3.12 Communications

As previously mentioned, Skylab operations were sometimes delayed or were inefficient because of the available opportunities for air-to-ground voice communication and teleprinter transmission. Continuous earth-orbit communications is highly desirable, not only for voice communications, but for any type of information flow required for the task at hand.

A tremendous advantage can be gained by having the capability for a two-way data flow, including the capability to record data aboard the spacecraft as well as on the ground. For example, if channels and time were limited and a down-link television transmission took precedence over a voice communication from the ground, a desirable feature would be the ability to record the up-linked voice transmission so that it could be listened to at a convenient time and replayed to insure understanding. Many times, extensive verbal information was transmitted at a very rapid rate with the transmission ending as loss-of-signal was occurring. Thus, the ground was giving what appeared to be operationally important data, but there was no onboard capability to confirm the transmission or to record it. The crew was required to write down the transmission, which, in many cases, was done hurriedly with the potential for error.

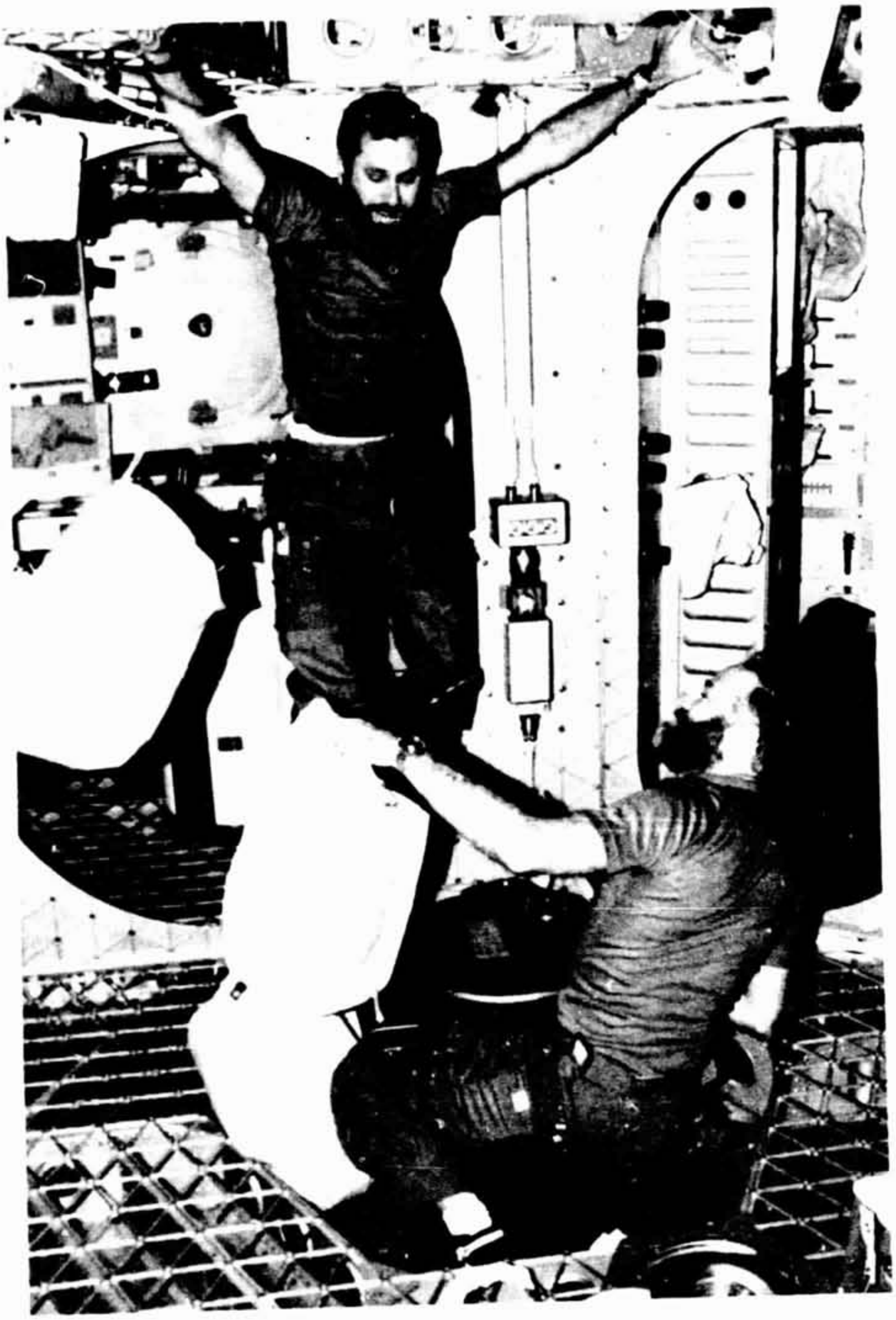


Figure 9-10.- Pilot preparing to force trash bag into airlock when Commander opens cover.

One of the advantages of up-linked television is that it could significantly reduce the preflight training load. For example, certain contingency operations could be video-recorded (as actually performed on training hardware) on cassettes and be available in an onboard tape library for use as required. This would be particularly useful and helpful if a long period of time (greater than 2 months, for instance) had elapsed since a crewman had trained for a certain task. He might even have a video tape of himself performing the task. He could then review the activity at his convenience prior to performing the inflight task with the actual hardware. The experiment S054 repair accomplished on the third visit required extensive verbage and tied up the communications loop for quite a period of time during the briefing. That entire transmission could have been handled by a very brief up-link of a television recording.

The communications system of the command and service module is somewhat complex, and, when connected with the communications system of the Workshop, the total communications system was extremely complicated. Although the combined system was also flexible, the crew often lost track of the configuration and this resulted in a configuration that was not anticipated or desired. The communications system should be as simple as possible. The crew encountered the situation in which they thought they had been recording data for some period of time, and actually had not been putting anything on the recorder. This could be avoided with a simple modulation talkback system such as found on most home-type tape recorders.

As previously stated, a separate science channel should be made available that could be used by the crewmen to discuss strictly scientific matters with ground personnel without affecting concurrent operational communications on the primary controller channel.

9.3.13 Psychological Factors and Human Behavior

Liberally applying 20-20 hindsight, the crew believes that the workload and complexity of tasks required early in a mission should start out at a low level and gradually increase. Planners should assure that the crew can easily attain each day's short-term goals with time to spare. "Shopping lists" of non-time-critical tasks should be provided to fill the spare time if it really exists. This approach would allow each crewman to work to his full capacity each day and most certainly would insure a positive frame of mind.

Another psychological aspect that should be considered for long duration flight is that the workday should be structured to be compatible with the sort of a workday routine that a man has before a mission. That is, when he arises in the morning, a reasonable amount of time should be allowed for personal hygiene and eating breakfast in a rather relaxed manner.

Meals should be rather regular. The crew also believes that, at the end of a workday, there should be time available prior to bedtime for the crew to unwind or relax and compose themselves for sleep.

The living environment became boring because of the lack of color variety. The only source of color variety was the out-the-window view of the earth. The paucity of color variety was rather dramatically illustrated when the crew attempted to decorate the Christmas tree. There were not many colorful things available in the Skylab Workshop. Color variety could become an important consideration for long-duration flights. Color television can be used as a dioramic type of art. Without stretching the point, anything from a mural, to a painting, to cartoons can be exhibited on a color television set, and this can provide a relief from monotony.

The diversions that were utilized on the third visit were taped music, books, and out-the-window sightseeing. A dart game, several balls and decks of cards were available but were seldom used. This crew found that making out-the-window observations was the most enjoyable form of diversion. Probably, the second most satisfying diversion was music. A television system would be a good means of entertainment, and materials for hobbies such as electronics kits, leathercraft kits, or whatever other manual hobbies are preferred, should be available for long-duration flights. More flexibility will be necessary in the design and selection of entertainment equipment, food, personal hygiene provisions, and other such items to allow for differing tastes. For long flights, the manner in which the daily routine is conducted will need to allow for change to avoid boredom. Such individual preferences as soap and lotions should be given consideration.

In pointing out the strong and weak points of certain experiments, the crew has touched on a strong psychological factor that must be given careful consideration on future long-duration missions. Man must be stimulated by his work; he must grow and learn with the tasks he performs and he must feel that he is productive or he will lose interest.

9.3.14 Food

The crew found the food to be very good. It was of high quality and was generally good tasting, but slightly bland. Although the use of condiments greatly enhanced the food, an undesirable situation which can be attributed to experiment M073 was that the crew could not use the condiments to the extent desired. For instance, they could not use as much salt as they desired because they were held within certain daily constraints. Also, the quantity and type of food which was consumed was rigidly controlled. This was undesirable from both a psychological and pysiological standpoint.

The crew made observations on the order of preference of the types of food. The first preference was the frozen food. The second preference was the thermostabilized food, particularly items such as the fruits and tomatoes. One thermostabilized item that was not well liked was the turkey-and-gravy. The third preference was the rehydratable foods, and individual preferences varied greatly in that area as to which rehydratables were preferred over others.

The stowage of food was not too efficient on the Skylab mission. Also, considerable waste bulk was associated with eating. Some foods could have been packaged together like TV-dinners. The individual drink cartons, or drink bags, had to be handled a minimum of two times — once when they were removed from the overcans and herring bones and placed into the pantry, and again when they were removed for use. One complete cycle of this effort could have been eliminated if the herring bones themselves could have been placed in the pantry so that they would be available for withdrawal at the time of use.

The drink dispensers or the drink packaging was very good. In contrast, the spoon-bowl type of packaging was a bother. The thickness and the viscosity of the food could be depended upon to keep food in the conical pack. Any food package which had elasticity caused problems when in contact with fluids. By elasticity, the inference is something that will snap and, if such a snapped surface had a blob of food on it, the food would be catapulted from the container. This includes the very thin cellophane-like membranes over the filet, some of the fruits, and other foods. When the membrane was cut and removed, specks of food were thrown into the surrounding areas.

Constraining the crew to the M071/M072 diet had operational overtones in that the full enjoyment of meals was not attained. A pantry-type food selection would have been good. In flight, the crew should be allowed to vary the menu as personal taste varies with time.

One cannot go as long without eating in zero gravity as compared to the earth environment, particularly during the early part of a mission. One becomes hungry faster and feels the effects of hunger quicker (i.e., fatigue, irritability, and overall inefficiency). This directly impacts the food system. Thus, a great deal of flexibility is required in designing the snacks, whether they be candy bars, peanuts, or other between-meal food items. Three meals a day are fine, but one should have the ability to vary the frequency and times of eating.

10.0 GENERAL PHOTOGRAPHY AND CAMERA SYSTEMS

10.1 SUMMARY

The general photographic systems performed satisfactorily throughout all three Skylab visits with few problems and none of significance occurring on the first and second visits. However, an increase in film jams and numerous 16-mm camera problems were noted during the third visit. In addition, postflight processing of the 35-mm film showed that one of the 35-mm cameras had an out-of-focus condition while much of the film was being exposed. The increase in problems on the third visit is attributed primarily to deteriorated film and camera wearout. The onboard data acquisition camera (16-mm) spares were substituted for the failed hardware.

The general photographic systems were used to meet many new requirements. This was possible because of the flexibility of these systems plus the ability to supplement the basic system with special lenses, filters, and support hardware.

10.2 DATA ACQUISITION CAMERA (16-mm) SYSTEM

The 16-mm data acquisition camera system was used to record the exterior and interior of the Saturn Workshop, the extravehicular and intravehicular crew activities, and in support of many experiments.

Table 10-I lists the 16-mm camera usage for this visit. Essentially all of the planned Workshop photography was accomplished. Two of the three magazines were used as planned in the command module. Approximately 4000 meters of film were used in documenting crew operations and experiment activities.

Overall equipment performance was acceptable. A number of film jams were reported, and all but one were cleared using onboard procedures. Two cameras had failures which rendered then unusable; however, preplanned spares were provided onboard, preventing the loss of data. Section 16.3.2 contains an analysis of the 16-mm camera and film transporter failures that occurred on the third visit.

Seven of the nine onboard cameras operated for approximately 36 hours. Thirty 122-meter film cassettes were used and ten 47-meter magazines were used. One unused roll of 122-meter film was returned for analyses by the film manufacturer for effects of the extended exposure of the film to the Orbital Workshop thermal environment.

TABLE 10-I.- 16-mm CAMERA USAGE

Experiment/ activity	Experiment/activity title
ED63	Cytoplasmic streaming
ED72	Capillary studies
M092	Lower body negative pressure
M093	Vectorcardiogram
M110	Blood sampling
M131	Human vestibular function
M151	Time and motion study
M171	Metabolic activity
M479	Zero-gravity flammability
M487	Habitability/crew quarters
M509	Astronaut maneuvering equipment
M512	Materials processing in space
M516	Crew activities/maintenance study
S054	X-ray spectrographic telescope
S183	Ultraviolet panorama
S190B	Earth terrain camera operation
S191	Infrared spectrometer operation
S192	Multispectral scanner operation
T053	Laser beam tracking
T020	Foot-controlled maneuvering unit
EVA	Extravehicular activity
Operational	Flyaround activity, vehicle inspection, and interior crew activities
Documentary	Documentary photography of all aspects of Skylab operations

10.3 35-mm CAMERA SYSTEM

The 35-mm camera system was used as planned to record data for experiments S063 (Ultraviolet Airglow Horizon Photography), T025 (Coronograph Contamination Measurement), S073 (Gegenschein/Zodiacal Light), T053 (Earth Laser Beacon Assessment), S232 (Barium Cloud), S233K (Comet Kohoutek Photometric Photography), and M509 (Astronaut Maneuvering Equipment). In addition, the camera system was used for documenting various medical detailed test objectives (crew profile and stereoscopic photographs), several student experiments, science demonstrations, closeout operations, and other operational aspects of the visit. Table 10-II lists the 35-mm photography taken on the third visit.

A 135-mm lens was added on the third visit to photograph the Saturn Workshop prior to docking and to use as a medium telephoto lens for targets of interest. Two additional manual camera bodies were added to enhance film logistics. A long-eye-relief viewfinder was added to the system to support the extravehicular activity requirements of experiment T025 and to provide documentary photographs of the final extravehicular activity. A thermal blanket was also added for the electric camera body and lens to support the extravehicular activity. Several filters, adapter rings, and a shutter release cable were also added on the third visit to support the Comet Kohoutek photographic requirements for experiments S063 and T025. As in the first and second visits, the crew used the 300-mm lens for air-to-ground photography of targets of interest. A description of the equipment added for the third visit is contained in appendix A.

Only minor problems such as the long-eye-relief viewfinder becoming disengaged from the camera body and the inadvertent depletion of the exposure-timer batteries became apparent during flight. Both problems were easily resolved with little or no effect on the visit. However, after the flight film used with camera NK02 was processed, only the photographs taken with the first roll of film were in focus. Section 16.3.3 discusses this anomaly in detail.

The remaining film indicates that all other cameras and components functioned satisfactorily. The electronic flash greatly enhanced the interior photography. Figure 10-1 is a typical picture of the interior operational documentary photography obtained using the electronic flash unit. The 135-mm and 300-mm lenses on the 35-mm camera contributed significantly to the air-to-ground photography of targets of opportunity. Figure 10-2 is a typical 35-mm photograph of the Denver, Colorado, area.

TABLE 10-II.- FILM UTILIZATION WITH 35-mm CAMERA

Magazine[a]	Film type	Frames used	Activity
CI110	S0168	61	General interior
CI111	S0168	62	Student experiment (ED31), medical stereo, and gypsy moth experiment
CI112	S0168	62	Student experiment ED61/62
CI113	S0168	64	Student experiment ED61/62 and medical stereo
CI114	S0168	28	Closeout
CI115	S0168	71	Student experiment ED61/62 and medical stereo
CI116	S0168		Not used, left in Orbital Workshop
CI117	S0168	47	General interior
CI118	S0168		Not used, left in revisit bag
CX19	S0368	64	Terrain photography
CX20	S0368	64	Terrain photography
CX36	S0368	41	Terrain photography and medical stereo
CX37	S0368	56	Terrain photography
CX38	S0368	54	Terrain and cloud photography
CX39	S0368	45	Terrain and cloud photography
CX40	S0368	60	Terrain photography and twilight airglow
CX41	S0368	64	Terrain photography
CX42	S0368	58	Terrain
CX43	S0368		Film had no exposures
CX44	S0368	64	Terrain photography
CX49	S0368	47	Terrain and medical stereo
CX53	S0368	63	Terrain photography
CX54	S0368	63	Terrain and cloud photography
CX55	S0368	61	Initial docking with Orbital Workshop
CX56	S0368	64	Extravehicular activity
CX57	S0368	64	Terrain photography
CX58	S0368	64	Terrain photography
CX59	S0368	64	Terrain photography

TABLE 10-II.- FILM UTILIZATION WITH 35-mm CAMERA - Continued

Magazine[a]	Film type	Frames used	Activity
CX60	S0368	64	Terrain photography and twilight airglow
CX61	S0368	64	Terrain photography
CX62	S0368		Not used, left in revisit bag
CX63	S0368	23	Cloud and terrain photography
BE03	2403	5	Experiment T025
BE04	2403	41	Experiment T025
BE05	2403	42	Experiments T025 and S063
BE08	2403	38	Experiment S063
BE09	2403	41	Experiments S063 and T025
BE10	2403	41	Experiment S063
BE11	2403	32	Experiment S063
BE12	2403		Not used, left in Orbital Workshop
BE13	2403		Not used, left in Orbital Workshop
BE14	2403		Not used, left in Orbital Workshop
BE15	2403		Not used, left in Orbital Workshop
BE16	2403	38	Experiments T025 and S063
BV22	2485	41	Experiment S063
BV26	2485	36	Experiment S063
BV27	2485	41	Experiment S063
BV28	2485	30	Experiment S063
BV29	2485	40	Experiment S063
BV40	2485	23	Operational
BV41	2485	30	Operational
BV42	2485	44	Operational
BV43	2485	43	Operational
BV44	2485	40	Experiment S073
BV45	2485		Calibration roll, no mission photographs
BV46	2485		Not returned, left in Orbital Workshop
BV47	2485	28	Experiment S232
BV48	2485	20	Experiment S073

TABLE 10-II.- FILM UTILIZATION WITH 35-mm CAMERA - Concluded

Magazine[a]	Film type	Frames used	Activity
BV49	2485	46	Experiment S073
BV50	2485	36	Experiment S073
BV51	2485		Not used, left in Orbital Workshop
BV52	2485		Not used, left in Orbital Workshop
BW04	3400		Not used, left in Orbital Workshop
BW05	3400		Not used, left in revisit bag
BW07	3400		No mission photographs, returned for evaluation
BH03	3401	59	Experiment S233
BH04	3401	59	Experiment S233
BH05	3401	50	Experiment S233
BH06	3401	52	Experiment S233
IR07	2443	43	Medical profile
IR08	2443	52	Medical profile
IR09	2443	12	Medical profile
IR10	2443	43	Medical profile
IR11	2443	33	Medical profile
IR12	2443	43	Medical profile
IR13	2443	43	Medical profile
IR14	2443	27	Experiment S063

[a] The magazine prefix CI indicates interior color film with an ASA rating of 500, CX indicates exterior film with an ASA rating of 64, BE indicates black and white film with an ASA rating of 500, BV indicates high-speed black and white film with an ASA rating of 4000, BW indicates black and white film with an ASA rating of 80, BH indicates black and white film with an ASA rating of 160, and IR indicates color infrared film with an ASA rating of 64.

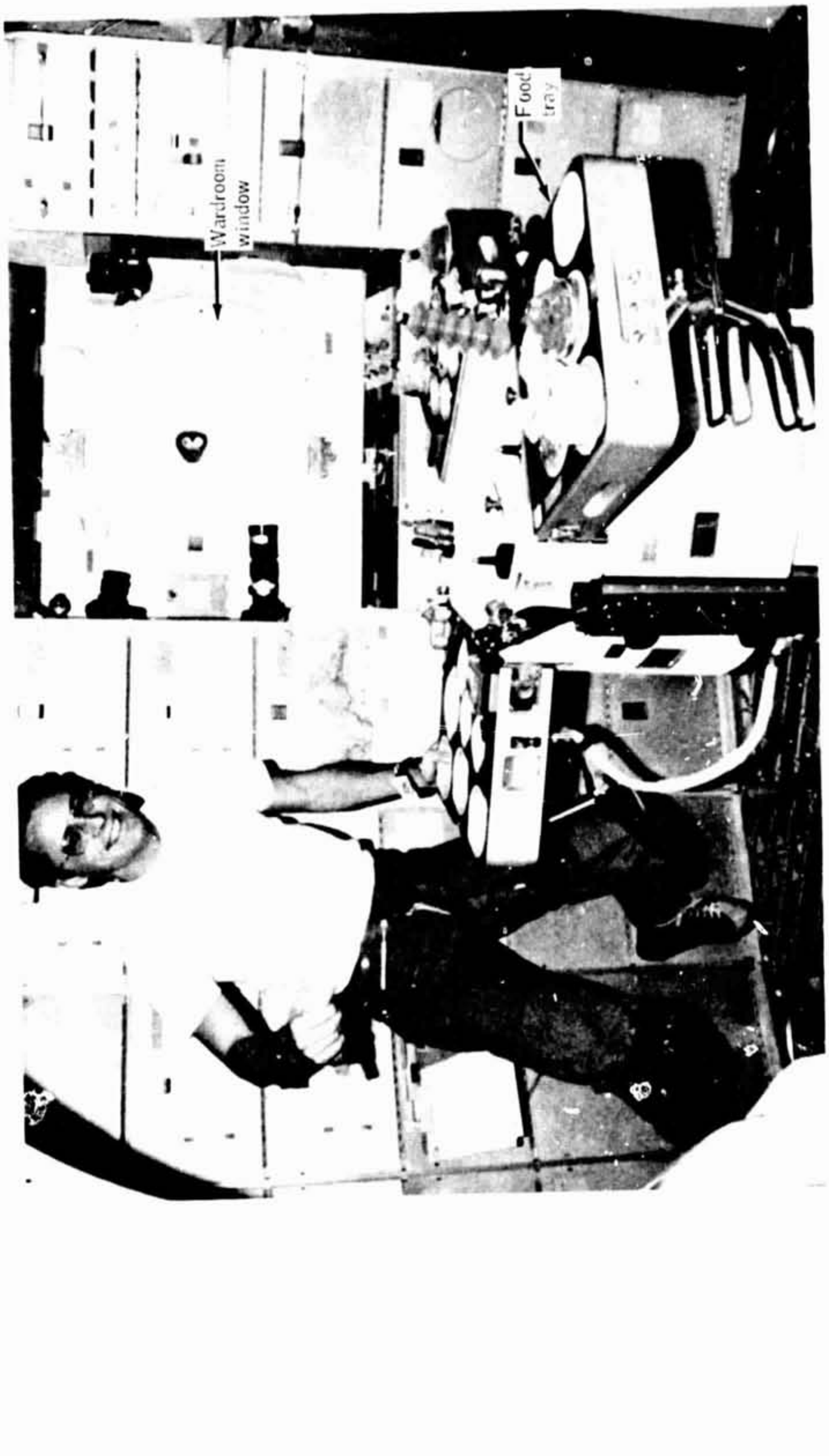


Figure 10-1.- Scientist Pilot in the wardroom.

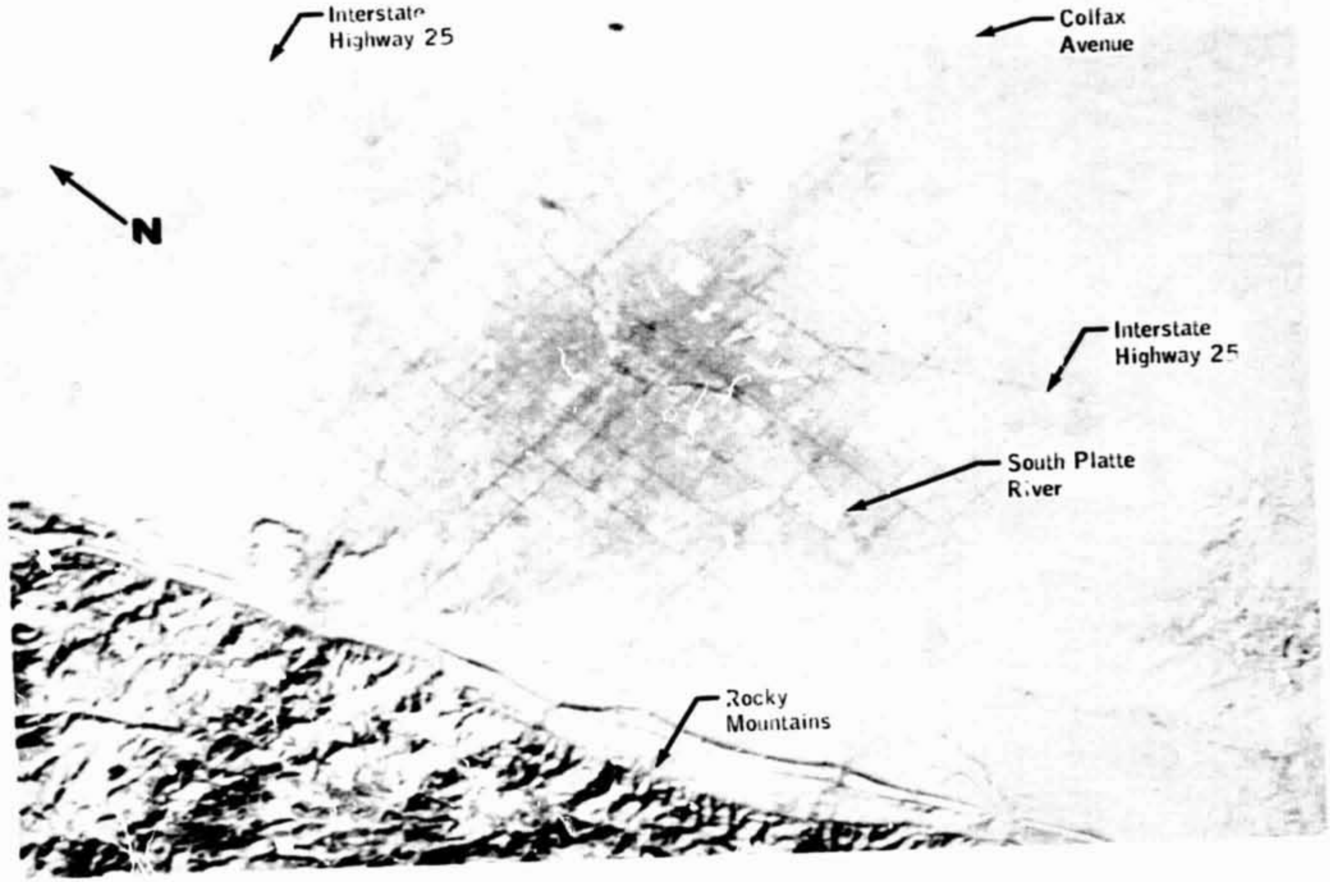


Figure 10-2.- Snow covered Denver, Colorado.

10.4 70-mm DATA CAMERA SYSTEM

The 70-mm data camera system operated satisfactorily and provided documentation photography of the Saturn Workshop during approach, docking, undocking, and the flyaround inspection. General and scientific interest photographs were also taken of cloud formations, cloud features, earthquake fault areas, tropical storm activity, South America, Central America, Japan, and Africa.

Eight film magazines of exterior color film were used on the third visit. The Orbital Workshop data camera with the 100-mm lens was used for all 70-mm photography on this visit.

Summary of performance.- The 70-mm data camera systems performed exceptionally well throughout all three Skylab visits with approximately 700 pictures being taken. The majority of these photographs were of selected ground sites assigned to the crew on the basis of scientific interest.

11.0 TRAJECTORY

Lift-off of the third Skylab visit occurred at 14:01:23 G.m.t. (09:01:23 a.m. e.s.t.) on November 16, 1973, from Launch Complex 39B with earth orbital insertion occurring 9 minutes and 47 seconds later. The rendezvous was conducted very smoothly with no unexpected problems. The maneuver solution sources agreed well within the comparison limits and the midcourse corrections were smaller than experienced on the previous Skylab visits. The prelaunch rendezvous plan was based on a launch time of 14:01:23 G.m.t. The planned and actual rendezvous maneuver profiles are compared in table 11-I.

The trajectory parameters at orbital insertion were 227.08 by 150.10 kilometers. These parameters were established by adjusting the preliminary estimate of the insertion conditions to fit orbital tracking data obtained during the first three revolutions. At first, a large out-of-plane error was indicated; however, this was resolved as a reference matrix definition problem.

The first phasing maneuver solution was based on the ground track and was somewhat different from the prelaunch and instrument unit post-insertion solutions. No plane change maneuver was needed since the predicted yaw gimbal angles for the corrective combination and coelliptic maneuvers were small. The ground solutions were executed for the second phasing maneuver and the residuals were trimmed to -0.06, 0.03, and -0.21 meter per second for the X, Y, and Z axes, respectively.

The final command module computer and ground solutions for the corrective combination and coelliptic maneuvers agreed well within the comparison limits of 0.45, 1.5, and 4.5 meters per second for X, Y, and Z axes, respectively; and the command module computer solution, which was based on over 30 sextant marks taken after the second phasing maneuver was executed.

The command module computer solution was also used for terminal phase initiation. An interesting note on the terminal phase initiation maneuver was that, while the command module computer and ground solution differential velocities agreed almost perfectly, the ignition times did not agree. In fact, the times were separated by 85 seconds which was the result of a downtrack error of approximately 2435 meters. The final terminal phase initiation time was approximately 90 seconds earlier than the premission nominal time.

Two small midcourse corrections were executed. The first maneuver solution was confirmed by a comparable chart solution, while no chart solution was obtained for the second maneuver. The magnitude of the second maneuver was approximately 1.22 meters per second. No problems were encountered during the braking and the rendezvous phases.

TABLE 11-I.- RENDEZVOUS MANEUVER SUMMARY

Maneuver	Preflight profile			Real time profile		
	G.m.t., hr:min:sec	Elapsed time, hr:min:sec	Differential velocity meters/sec	G.m.t., hr:min:sec	Elapsed time, hr:min:sec	Differential velocity meters/sec
First phasing	16:21:58	2:21:58	11.85	16:23:21.62	2:23:21.62	11.45
Second phasing	18:35:00	4:35:00	47.49	18:36:19.62	4:36:19.62	46.70
Corrective combination	19:20:08	5:20:08	62.61	19:21:27.24	5:21:27.24	63.83
Coelliptic	19:57:08	5:57:08	7.28	19:58:28.24	5:58:28.24	7.69
Terminal phase initiation	20:49:00	6:49:00	6.79	20:49:00.26	6:49:00.26	6.35
Terminal phase finalization	21:22:37	7:22:37	8.94	--	--	--

The second visit final orbital trim maneuver was designed to establish the initial conditions for the first trim maneuver on the third visit. The first trim maneuver was calculated to stop the easterly drift of the ground track and to reverse the drift such that a second maneuver could establish the nominal 5-day repeating ground track that was achieved on the second visit. Calculations showed that a maneuver would be required about every 20 days to maintain the desirable track. The resulting orbital trim maneuvers are presented in table 11-II.

The repeating ground track concept was included in the Skylab program to enhance the Earth Resources Experiment Package data collection. This concept provided the Earth Resources Experiment Package planners with a valuable tool for long-range planning when the same task-sites were covered every 5 days (approximately 2 hours earlier on each repeat). The Earth Resources Experiment Package passes for the third visit are given in table 11-III. The location of these passes on a world map are shown in figure 11-1.

The undocking, deorbit maneuvers, and entry sequence were constrained by the requirements to make a flyaround inspection and obtain photographs, and to recover the crew and spacecraft in daylight with adequate recovery support. These requirements resulted in a descending west-coast entry with a landing at longitude 119 degrees 48 minutes 12 seconds west, and latitude 31 degrees 18 minutes 12 seconds north. The sequence of events from undocking to landing are shown in table 11-IV.

TABLE 11-II.- ORBITAL TRIM MANEUVERS

Maneuver	G.m.t. days:hr:min:sec	Differential velocity, meters/sec	Firing time, sec
First trim	329:02:22:30	1.77	88
Second trim	346:17:04:54	0.34	17
Third trim	21:13:12:00	0.21	10
Boost	37:20:48:00	3.66	180

TABLE 11-III.- REAL-TIME EARTH RESOURCES EXPERIMENT PACKAGE PASS SUMMARY

Pass	Track (a)	Revolution	Day-of-year	Data taking time, min	Longitude, deg	
					Start	Stop
1		Cancelled				
2		Cancelled				
3	6/7D	2875	333	23	109W	46W
4	19/20D	2888	334	23	101W	37W
5	34/35D	2903	335	23	107W	48W
6	48D/49D	2917	336	11	108W	75W
7	49D	2918	336	13	132W	94W
8	62D/63D	2931	337	15	114W	67W
9	63D	2932	337	13	139W	96W
10	6D	2946	338	17	151W	89W
11[b]	20D/21D	2960	339	15	111W	72W
12	48A	2988/2989	341	10	169E	138W
				19		
13		Cancelled				
Special[c]	69D	3009	343	24	--	-
14	70D	3010	342	19	82E	128E
15[b]	13D	3095	348/349	19	103E	152E
Special[d]	21D	3103	349	3	64W	55W
16	57A/58D	3140	352	22	76W	29E
17	63/64D	3145	352	21	147W	81W
Special[d]	55A	3208	356	2	64W	59W
Special[d]	41A	3265	360	2	63W	58W
18	53A/54A	3348	001	36	91W	19E
19	10A	3376	003	12	23E	53E
20	29A/30D	3395	004	25	108W	01E
21	57A/58D	3423	006	26	106W	01E
Special[c]	69D	3435	007	25	--	--
22	71A/1D	3437/3438	007	24	100W	02E
Special[e]	5D	3442/3443	008	11	--	--
23[b]	14A/15D	3451/3452	008	29	103W	10E
				24		
24	28A/29	3465/3466	009	23	91W	02W
25	49A	3436	011	30	76E	164E

[a] The A and D in parentheses following the track number indicate an ascending or descending pass, respectively.

[b] Earth limb data also taken on this pass.

[c] Lunar calibration data taken this pass.

[d] Passes are conducted with only the earth terrain camera and the vehicle in solar inertial attitude.

[e] Pass for experiment S191 calibration.

[f] Pass for experiment S192 earth resources data downlink unit transmission in solar inertial attitude.

[g] Specific starting and stopping times are not known, nor are the longitude and latitude. Data shown reflects the recommended times given to the crew.

TABLE 11-III.- REAL-TIME EARTH RESOURCES EXPERIMENT PACKAGE PASS SUMMARY (Concluded)

Pass	Track (a)	Revolution	Day-of-year	Data taking time, min	Longitude, deg	
					Start	Stop
26	58A/59D	3495	011	25	119W	08W
27	1A/2D	3509/3510	012	24	113W	05W
28		Cancelled				
29	29A/30D	3537	014	23	103W	0
		3358	014	10	119W	97W
Special[f]	60A	3568	016	7	138W	105W
30	19/20D	3598/3599	018	20	112W	62W
31		Cancelled (weather)				
32	47/48D	3626/3627	020	15	129W	63W
33,34		Cancelled				
35	62D/63D	3641/3642	021	27	128W	45W
36		Cancelled				
37	5D/6D	3655/3656	022	26	115W	39W
38,39		Cancelled				
40	33A,D/34D	3683/3684	024	26	151W	49W
41	47A/48D	3697/3698	025	30	154W	39W
42	63/64D	3713/3714	026	30	132W	48W
43		Cancelled				
44	2A/3D	3723/3724	027	43	146W	10E
45	6/7D	3727/3728	027	30	130W	43W
46	20D/21D	3741/3742	028	32	128W	36W
47	34D/[illegible]	3755	029	34	158W	46W
48	48/49D	3769	030	33	150W	42W
49	62D,A/63D	3783/3784	031	94	[illegible]7W	60W
50	6/7D	3798/3799	032	28	171W	72W
Special[c]	7	3799	032	2	—	—
Special[e]	—	—	032	12	—	—

[a] The A and D in parentheses following the track number indicate an ascending or descending pass, respectively.

[b] Earth limb data also taken on this pass.

[c] Lunar calibration data taken this pass.

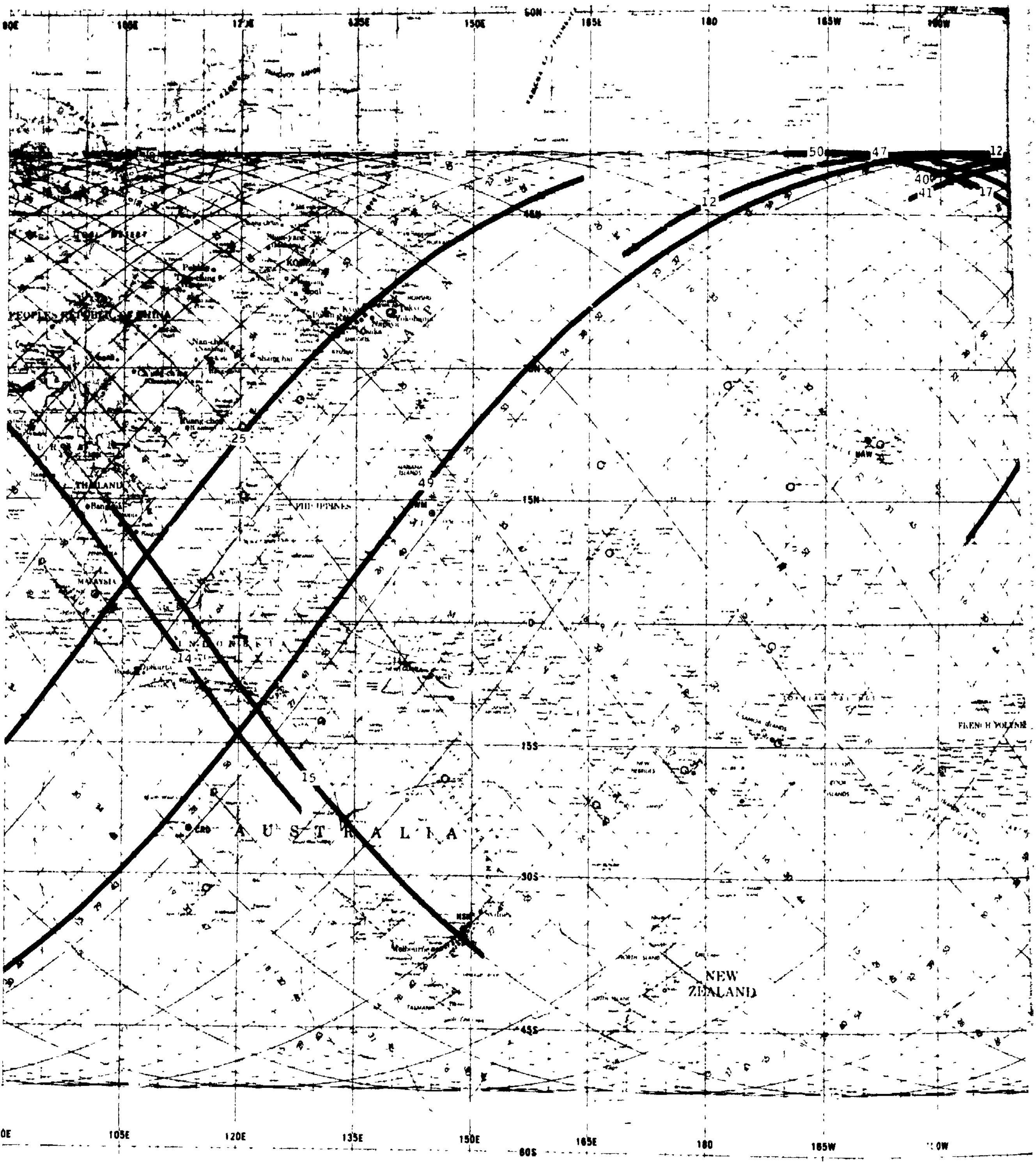
[d] Passes are conducted with only the earth terrain camera and the vehicle in solar inertial attitude.

[e] Pass for experiment S191 calibration.

[f] Pass for experiment S192 earth resources data downlink unit transmission in solar inertial attitude.

[g] Specific starting and stopping times are not known, nor are the longitude and latitude. Data shown reflects the recommended times given to the crew.

FOLDOUT FRAME



FOLDOUT FRAME 2

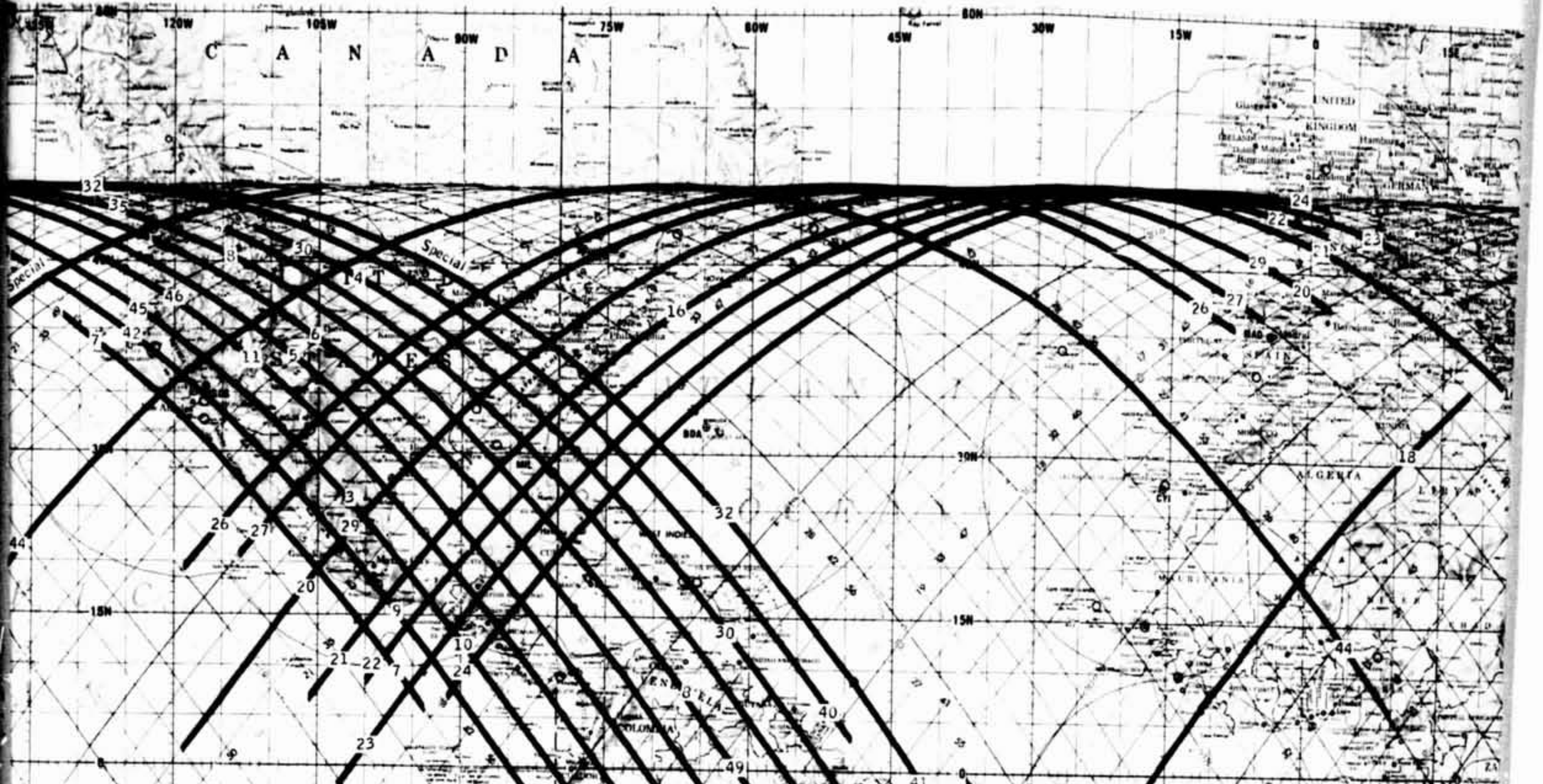
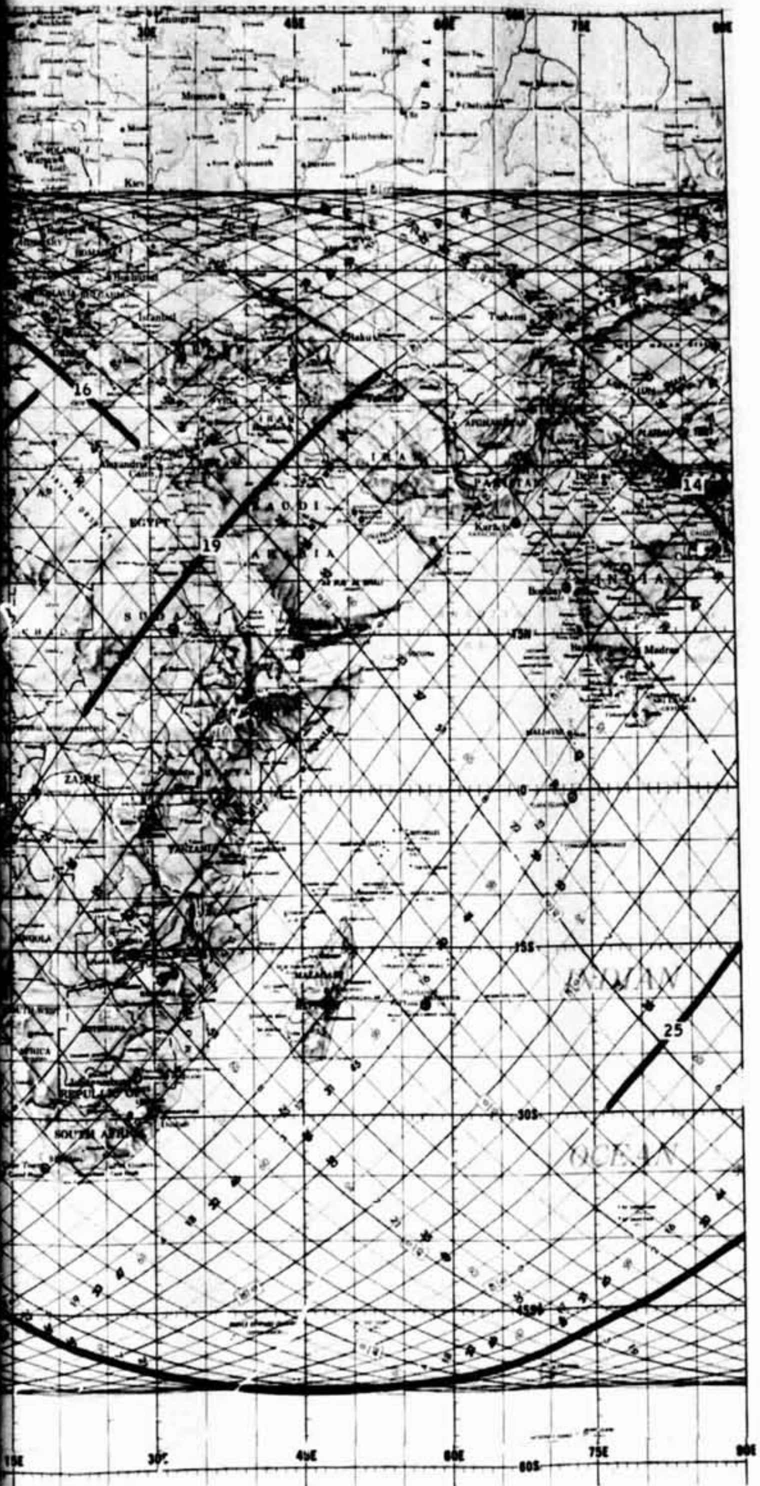


Figure 11-1. - Earl

1

FOLDOUT FRAME 3



-1. - Earth Resources Experiment Package passes during third visit.

1

12.0 MISSION SUPPORT

12.1 FLIGHT CONTROL

Mission preparations for the third visit launch resembled the period between the Saturn Workshop launch and the first visit launch in that a great many planning changes were made for the visit activities and requirements. The more significant changes were:

a. Extension to an 84-day duration.

b. Addition of the Comet Kohoutek observations.

c. Expansion of the medical experiments.

The incorporation of these changes resulted in a visit plan that was very ambitious; but attainable. The visit results have demonstrated the feasibility of this approach; however, many problems were encountered in completing the visit objectives. There were many areas of endeavor with which the crew had limited familiarity because time constraints inhibited thorough training. The overall effect of this apparent lack of training was that more time was required for the first few preparations and executions of a given experiment. As with previous crews, the third visit crew's learning curve was very pronounced, and as time passed, the crew became more proficient.

The crew time may have been scheduled too heavily in the beginning as a natural result of trying to reduce the scheduling level from that of the second visit, but not reducing the level far enough. After the operations conferences were initiated and an in-depth comparison of the work levels across the visits was made, the comparison showed almost identical accomplishments for the comparison points of 7, 15, 20, and 25 days. The operations conferences should have been initiated as soon as the problems surfaced and scheduling constraints began being levied by both the crew and flight control. The week following the first operations conference was marked by a free exchange of information between the crew and flight control and this produced a much improved environment and more effective flight planning and execution functions. The average science man-hours per day increased from 24 to 27, and many of the previous constraints were deleted.

Prelaunch, launch, and rendezvous were essentially normal. The best measure of how well these operations were performed is the reaction control system propellant consumption which was much closer to the planned amount than experienced on the previous visits. The only item of any consequence was the lack of achieving a soft-dock condition because of low closure rates.

As in the second visit, Saturn Workshop activation required a little more time than planned because of the crew discomfort in the new environment. The prescribed medication may have helped, but the rescheduling of time with new medical and other detailed test objectives resulted in more tasks than the crew could complete in the time alloted.

The Workshop deactivation activity was completed about as planned, primarily because of the learning curve of the ground personnel. Flight planning became much more rigid in that unscheduled tasks not associated with deactivation were not allowed to creep into the flight plan. This rigidness, combined with the crew's competence, resulted in a very relaxed timeline which allowed a good response to the few problems which occurred during the deactivation and command and service module powerup operations.

Circadian rhythm shifting to prepare for the end-of-visit activities was conducted in two 8-hour rest periods separated by a 9-hour work day. This resulted in the crew obtaining limited sleep before the entry sequence, even though they took sleep medication.

Approximately 24 hours of Saturn Workshop remote testing was executed after command module landing. These tests, for the most part, produced no surprises and confirmed that control moment gyro 1 had failed.

As noted from previous visits, the teleprinter was absolutely mandatory for this type of mission. The flight control and flight planning functions would have been severely restricted without it

The various "criteria" documents again proved to be essential as a means of providing consistency across the flight control teams. The "quick update" capability of this supplement to the [illegible] rules is a necessary part of a Skylab-type mission.

The position of Program Scientist again proved to be a necessary part of the ground support team. The long-range planning and real-time trades across all of the science disciplines were effectively accomplished. The area of planning for experiment operations would have been a major problem, had it been necessary for the on-console flight control team to make trade-offs in addition to flight plan execution and vehicle management.

The third visit had many new problems added to those of the first two visits. Several are worthy of mention because of their impact. Probably the most dramatic anomaly was the loss of control moment gyro 1. Because of this problem, an inordinate amount of time and effort was required in:

a. Managing momentum dumps and the attitude control system thruster activity to minimize propellant expenditure.

b. Defining, redefining, and refining control moment gyro performance limits after control moment gyro 2 began showing abnormal operational characteristics.

c. Defining and refining thruster attitude control system redlines.

d. Developing Apollo Telescope Mount digital computer and command module computer software for another possible control moment gyro loss.

e. Developing crew procedures for monitoring and managing the attitude and pointing control system.

f. Managing control moment gyro bearing temperatures.

For the most part, the preceding activities were accomplished in a timely fashion.

The Airlock Module coolant loops functioned well during the third visit. The primary loop was reserviced and both loops performed adequately. Coolant loop reservicing and repair of the experiment S054 (X-Ray Spectrographic Telescope) filter wheel were two more justifications for manned flight and inflight maintenance.

The Apollo Telescope Mount control and display loop was erratic for most of the visit. Much effort was expended in managing this system and in servicing the system using the water/gas separator. The system functioned adequately, but never normally once erratic operation began.

The crew reported that a "klunking" noise was heard twice during the visit when the command module was manned. The first occurrence was noted to be near the time that the Apollo Telescope Mount orbital locks were hung in the up/down axis, and the second occurrence was near the time that the Apollo Telescope Mount caged. Both occurrences were examined as possible causes, but no relationship can be established that would satisfy all the conditions. No other explanation has been found that would indicate the origin of the noise.

The star tracker failed and the average Z-axis error was about 0.0051 radian after the failure. This failure may complicate the postflight reduction of pointing data for experiments in the Apollo Telescope Mount, Earth Resources Experiment Package, and scientific airlock.

The cameras were a continuing source of problems on the third visit. The data acquisition cameras, transporters, and 35-mm cameras experienced many problems. Sections 16.3.2 and 16.3.3 discuss the camera problems.

The experiment S183 (Ultraviolet Panoramic Camera) carrousel magazines were a continuing source of trouble. In the case of one of the carrousel magazines, these problems could have begun with the second visit when the instrument was not reset after the last operation. This may have caused the broken slide that occurred on the first operation during the third visit. Carrousel operation was marginal throughout the third visit.

There were also several problems which were not mechanical in nature. The following were among those experienced.

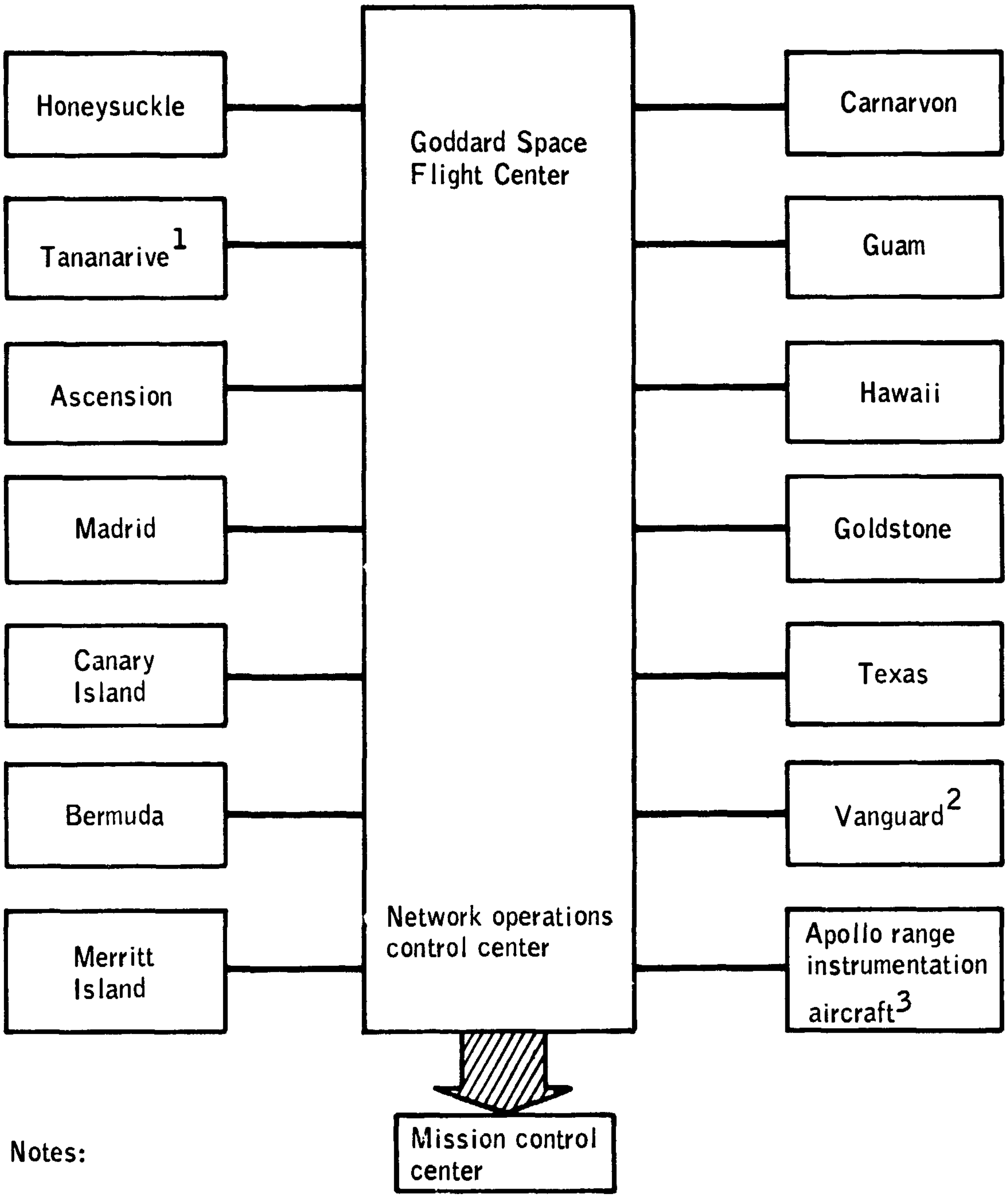
a. Crew movement resulted in a relatively large disturbance source to the vehicle. Consequently, crew movement was constrained during very sensitive data acquisition periods. The constraint varied from no body motion during some activities to no ergometer operations during others.

b. The increased solar heating on the vehicle, resulting from long exposure and a high beta angle, caused high Orbital Workshop internal temperatures for a 1-week period. Several actions such as minimizing the time out of the solar inertial attitude, reducing the number of lights, and running both Airlock Module coolant loops helped reduce the problem. The Scientist Pilot slept several nights in the Multiple Docking Adapter because his compartment was uncomfortably warm.

12.2 NETWORK

12.2.1 Third Visit

The Spaceflight Tracking and Data Network for the third visit consisted of the stations shown in figure 12-1. The capabilities provided were the same as for the second visit with two minor exceptions; a second Apollo range instrumentation aircraft was used on entry day to provide coverage of the deorbit maneuver in addition to the previous post-blackout support, and the Tananarive station was modified to provide S-band voice for orbital support.



Notes:

1 C-band radar and S-band voice
2 Located at 38° 02' south
and 57° 32' west
3 With Apollo capabilities

Figure 12-1.- Spaceflight Tracking and Data Network.

The performance of hardware and software was very good for the third visit. The problems resulting in data delays experienced during the first two visits had been resolved and were not experienced during this visit. Operating procedures and constraints utilized and refined during the first two visits were utilized for this third visit with minimal changes.

12.2.2 Summary of Performance

The network supported spacecraft control and operations throughout all three manned visits with only minor problems. No significant loss of support occurred during any of the manned or unmanned periods during which the network was supporting flight control operations.

12.3 RECOVERY OPERATIONS

The Department of Defense provided recovery support as requested by the National Aeronautics and Space Administration. The recovery force deployment is outlined in table 12-I.

12.3.1 Prelaunch Through Orbital Insertion

On visit day 1, weather in all launch abort areas was acceptable. After orbital insertion, the recovery forces were released or placed on alert, as appropriate.

12.3.2 Orbital Operations

From orbital insertion through visit day 58, the primary recovery support consisted of inflight refuelable helicopters and an HC-130 aircraft at Hickam AFB, Hawaii, and a duty salvage ship on call at Pearl Harbor, Hawaii. This support posture was the same as for the first two visits.

To support the weekly medical go/no-go decision points commencing on visit day 59, the primary recovery ship, *U.S.S. New Orleans*, sailed from San Diego, California, on visit day 50 with a contingent of National Aeronautics and Space Administration recovery, biomedical, and public affairs personnel. The shipboard personnel trained while en route and arrived in Pearl Harbor, Hawaii, on visit day 58. The Skylab mobile laboratory and experiment containers/experiment handling equipment/command module depressurization equipment were flown to Hickam AFB, Hawaii, on a C-5 aircraft and a C-141 aircraft, respectively, and were loaded aboard the primary recovery ship immediately after it arrived in port.

TABLE 12-I.- Third VISIT RECOVERY FORCE SUPPORT

Type ship/ type aircraft	Number	Ship name/aircraft staging base	Responsibility
ARS	1^a	*U.S.S. Escape*	Launch site recovery ship.
ATF	1^b	*U.S.S. Beaufort*	Duty salvage ship providing secondary landing area support until primary recovery ship active.
ATF	1^b	*U.S.S. Tawakoni*	
ARS	1^b	*U.S.S. Bolster*	
LPH	1^a	*U.S.S. New Orleans*	Primary recovery ship.
HH-53C	1^a	Patrick Air Force Base	Launch site area. Short access time to early launch aborts.
HC-130	2^a 1^c	Pease Air Force Base	Support for launch aborts (a) and orbital contingency deorbit (c) west and Mid-Atlantic areas.
HH-3E	1^c	Loring Air Force Base	Minimum crew retrieval time in West Atlantic area for launch aborts.
HH-3E	1^c	Gander International Newfoundland	Minimum crew retrieval time in West and Mid-Atlantic areas for launch aborts.
HC-130	1^a 1^c	RAF Woodbridge, England	Launch abort support (a) and contingency deorbit support (c) in East and Mid-Atlantic areas.
HH-53C	1^c	RAF Woodbridge, England	Minimum crew retrieval times for East Atlantic area for launch aborts.
HC-130	1^c	Hickam Air Force Base	Secondary landing area support and primary recovery ship support.
HH-53C	2^c	Hickam Air Force Base	Support from orbital insertion until primary recovery ship active.
HC-130	1^c 2^a	McClellan Air Force Base	Support for contingency deorbits (c) and for landing uprange or downrange of end-of-visit landing point (a).
HC-130	1^c	Eglin Air Force Base	Contingency support in West Atlantic area.
HC-130	1^c	Kadena Air Force Base	Contingency support in West Pacific area.
HC-130	1^c	Clark Air Force Base	Contingency support in West Pacific area.
SH-3G	5^a	*U.S.S. New Orleans*	Primary landing area and end-of-visit support.

[a] Active.

[b] One of three ships active at all times.

[c] On Air Rescue and Recovery Service alert.

On visit day 59, additional recovery and biomedical personnel boarded the *U.S.S. New Orleans* and the ship sailed for San Diego with the intention of supporting daily target points during its transit across the Pacific Ocean. The ship was to have arrived at San Diego on visit day 72 to embark the remaining civilian recovery team complement. However, the concern over the control moment gyro problems, which were becoming more frequent and severe, forced a decision on visit day 68 to provide for an earlier full-team recovery readiness, even though a full-duration visit was still expected. Consequently, the primary recovery ship docked at San Diego on visit day 69. The remaining National Aeronautics and Space Administration biomedical personnel were flown to San Diego, and all command module depressurization and news media personnel/equipment were aboard the primary recovery ship on visit day 71, ready to sail to support a landing on visit day 73, should it become necessary.

In addition to the support described, air rescue units of various air rescue bases around the world were prepared to provide support should a contingency landing occur.

12.3.3 End-Of-Visit Support

Recovery support for the primary landing area off the west coast of the United States was provided by the *U.S.S. New Orleans* (fig. 12-2). Air support consisted of five SH-3G helicopters from the primary recovery ship and two HC-130 rescue aircraft staged from McClellan Air Force Base, California. Three of the helicopters carried underwater demolition team personnel. The first, designated "Recovery," also carried the flight surgeon and was used for command module retrieval operations. The second helicopter, designated "Swim," served as backup to "Recovery" and aided in the retrieval of the forward heat shield. The third helicopter designated "ELS" (Earth Landing System), aided in the retrieval of two of the main parachutes. The fourth helicopter, designated "Photo," served as a photographic platform for motion-picture photography. The fifth helicopter, designated "Relay," served as a communications relay aircraft. The HC-130 aircraft, designated "McClellan Rescue 1" and "McClellan Rescue 2," were positioned to track the command module after it exited from S-band blackout, as well as to provide pararescue capability and to optimize the capability for locating the command module had it landed uprange or downrange of the target point. Figure 12-2 shows the relative positions of the recovery ship, its aircraft, and the HC-130 aircraft prior to landing; as well as the target point, the crew readout of the computer landing point (while on main parachutes), and the estimated target point.

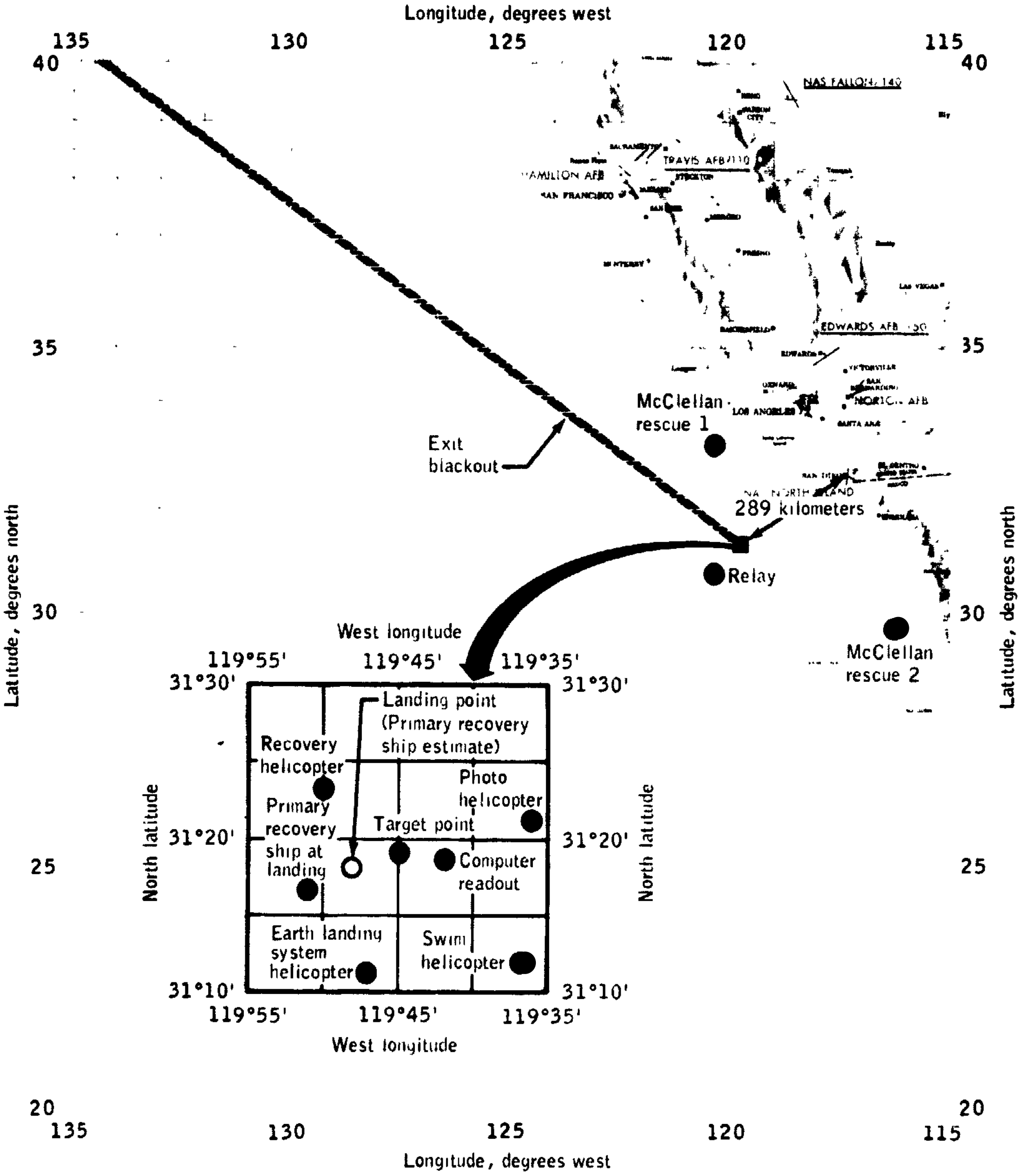


Figure 12-2.- Recovery force deployment at end of visit.

12.3.4 Command Module Location and Retrieval

At approximately 3 hours prior to landing, recovery forces were notified of a possible reaction control system propellant leak. The appropriate alternate procedures were initiated. Details of the recovery timeline are shown in table 12-II.

Weather at the end-of-visit area on recovery day was good. At landing, the only cloud coverage was a thin broken cirroform layer at about 9150 meters; winds were 8.2 meters per second from 60 degrees true. There were 0.6-meter wind waves (2-second intervals) on top of 0.9-meter swells (7-second intervals), and the water temperature was 287.5° K.

The command module landed at 15:16:54 G.m.t. Based upon navigation satellite (SRN-9) fixes obtained at 13:00 and 14:46 G.m.t., and long range navigation and omega fixes obtained every 15 minutes between 13:00 and 16:00 G.m.t., the *U.S.S. New Orleans'* position at the time of landing was calculated as latitude 31 degrees 16 minutes 42 seconds north, and longitude 119 degrees 51 minutes 6 seconds west. Using the ship position, plus visual bearings and radar ranges, the landing point coordinates of the third visit command module were determined to be latitude 31 degrees 18 minutes 12 seconds north, and longitude 119 degrees 48 minutes 12 seconds west.

Upon landing, the command module went to the stable II attitude. After the uprighting bags inflated, the command module uprighted to a stable I position. The swimmers were deployed to the command module and the flotation collar was installed and inflated at 15:31 G.m.t. The flight crew remained inside the command module while it was retrieved by the *U.S.S. New Orleans.* The crew egressed from the command module at 16:29 G.m.t. and sat on chairs on a mobile platform. The platform was moved to a position next to the Skylab mobile laboratory, and the crew walked into the laboratory.

The flight crew remained aboard the *U.S.S. New Orleans* until completion of the recovery-plus-2-day medical examinations. The crew departed the ship at North Island Naval Air Station, San Diego, California, at 20:50 G.m.t. on February 10, 1974, and were flown to Ellington Air Force Base, Texas, where they arrived at 23:30 G.m.t. on February 10, 1974.

The command module was off-loaded at North Island Naval Air Station, San Diego, California, on February 9, 1974. The spacecraft was deactivated and delivered to the contractor's facility on February 13, 1974.

TABLE 12-II.- RECOVERY EVENT TIMELINE

Event	Time, G.m.t.	Time relative to landing day:hr:min
	February 8, 1974 (visit day 85)	
Radar contact by *U.S.S. New Orleans*	15:07	-0:00:10
Visual contact by *U.S.S. New Orleans*	15:12	-0:00:05
VHF voice contact	15:13	0:00:04
Command module landing	15:17	0:00:00
Command module in stable I attitude	15:22	0:00:05
Flotation collar inflated	15:32	0:00:15
Flight crew/command module aboard *U.S.S. New Orleans*	15:57	0:00:40
Hatch open	16:04	0:00:47
Flight crew in Skylab mobile laboratory	16:29	0:01:12
	February 9, 1974 (recovery plus 1 day)	
Time critical experiment removal completed/hatch closed	0:01	0:08:44
Reaction control system depressurization started	0:01	0:08:44
Reaction control system depressurization complete	2:45	0:11:28
Hatch reopened	3:00	0:11:43
Destowage complete/hatch closed	6:00	0:14:43
Hatch reopened/begin interior inspection	15:00	0:23:43
U.S.S. New Orleans arrived North Island	16:20	1:01:03
Command module hatch secured	18:00	1:02:43
Command module offloaded from *U.S.S. New Orleans*	19:30	1:04:13
Command module in hangar at North Island Naval Air Station	19:50	1:04:33
Begin offloading experiments from *U.S.S. New Orleans*	20:40	1:05:23
Experiments arrived at North Island Naval Air Station	22:00	1:06:43
Experiments departed North Island Naval Air Station	23:31	1:08:14

TABLE 12-II.- RECOVERY EVENT TIMELINE - Concluded

Event	Time, G.m.t.	Time relative to landing day:hr:min
	February 10, 1974 (recovery plus 2 days)	
Experiments arrived at Ellington Air Force Base, Texas	2:18	1:11:01
Experiments delivered to Johnson Space Center	3:45	1:12:28
Flight crew departed primary recovery ship in limousine	20:50	2:05:33
Flight crew departed North Island Naval Air Station by aircraft	21:00	2:05:43
Skylab mobile laboratory offloading from primary recovery ship begun	21:00	2:05:43
Skylab mobile laboratory arrived North Island Naval Air Station	22:30	2:06:13
Flight crew arrived at Ellington Air Force Base, Texas	23:30	2:07:13
	February 11, 1974 (recovery plus 3 days)	
Skylab mobile laboratory departed North Island Naval Air Station	1:43	2:10:26
Skylab mobile laboratory arrived at Ellington Air Force Base, Texas	4:20	2:13:03
Skylab mobile laboratory in place at Johnson Space Center	16:00	3:00:43
	February 13, 1974 (recovery plus 5 days)	
Command module deactivation completed	3:00	4:11:43
Command module departed deactivation site	16:20	5:01:03
Command module arrived at contractor facility	22:30	5:07:13

12.3.5 Summary of Skylab Recovery Operations

Recovery operations went well for each of the manned Skylab visits and all spacecraft were recovered on board the primary recovery ship in less than 45 minutes. In addition to the ships and operational aircraft support outlined in table 12-I of this report and references 3 and 4, the Department of Defense also provided logistics support aircraft for each of the three manned Skylab missions. This support is outlined in table 12-III.

TABLE 12-III.- LOGISTICS SUPPORT AIRCRAFT

Type aircraft	Number active each visit	Aircraft staging base	Area of responsibility
C-5A[a]	1	Travis Air Force Base	Transport the Skylab mobile laboratory and passengers from Ellington Air Force Base to Hickam Air Force Base.
C-141[a]	1	Travis Air Force Base	Transport NASA experiment handling/command module depressurization equipment and passengers from Ellington Air Force Base to Hickam Air Force Base.
C-141[b]	1	Norton Air Force Base	Transport NASA recovery and medical personnel from Ellington Air Force Base to North Island Naval Air Station
C-130[c,d]	1	Hamilton Air Force Base[d] McClellan Air Force Base[c]	Transport and air drop medical isotopes to the primary recovery ship on recovery minus 2 days.
SH-3[b]	2	North Island Naval Air Station	Transport medical equipment/isotopes and very important personages from North Island Naval Air Station to the primary recovery ship on recovery minus 1 day.
SH-3[a]	2	*U.S.S. Ticonderoga*[d] *U.S.S. New Orleans*[b,c]	Transport public affairs film[a], television pool video tapes[b], very important personages[b] from the primary recovery ship to San Diego after landing on recovery day.
C-135[c,d] (ARIA)	1	Patrick Air Force Base	Transport public affairs film from North Island Naval Air Station to Ellington Air Force Base on recovery day.
T-39[b]	1	Patrick Air Force Base	Transport public affairs film from North Island Naval Air Station to Patrick Air Force Base on recovery day.
SH-3[d]	2	*U.S.S. Ticonderoga*	Transport flight crew from primary recovery ship to Western White House and back to primary recovery ship on recovery plus 1 day.
C-141[a]	1	Travis Air Force Base	Transport experimental data and film[a], experiment handling equipment[a], passengers[a], and the flight crew[d] from North Island Naval Air Station to Ellington Air Force Base on recovery plus 2 days.
VC-140[c]	1	Andrews Air Force Base	Transport Skylab flight crew plus 5 passengers from North Island Naval Air Station to Ellington Air Force Base on recovery plus 2 days.
C-5A[a]	1	Travis Air Force Base	Transport Skylab mobile laboratory plus 15 passengers from North Island Naval Air Station to Ellington Air Force Base on recovery plus 2 days.

[a] All manned visits.

[b] Third manned visit.

[c] Second manned visit

[d] First Manned visit.

13.0 MISSION OBJECTIVES

The Skylab mission included a series of three manned visits whose major objectives were to achieve long-duration space flights of men and systems and perform scientific investigations in earth orbit. All primary mission objectives of the third visit were accomplished. The specific mission objectives were:

a. Perform unmanned Saturn Workshop operations.

1. Obtain data for evaluating the performance of the unmanned Saturn Workshop.

2. Obtain solar astronomy data by unmanned Apollo Telescope Mount observations.

b. Reactivate the Skylab Orbital Assembly in earth orbit.

1. Operate the Orbital Assembly (Saturn Workshop plus command and service module) as a habitable space structure for a nominal period of 56 days, with the option of extending to 84 days after the third visit launch.

2. Obtain data for evaluating the performance of the Orbital Assembly.

3. Obtain data for evaluating crew mobility and work capability in both intravehicular and extravehicular activity.

c. Obtain medical data on the crew for use in extending the duration of manned space flights.

1. Obtain medical data for determining the effects on the crew which result from a nominal space flight duration of 56 days, with the option of extending to 84 days.

2. Obtain medical data for determining if a subsequent manned space flight mission of greater duration than the duration of the Skylab third manned visit is feasible and advisable.

d. Perform inflight experiments.

1. Obtain Apollo Telescope Mount solar astronomy data for continuing and extending solar studies beyond the limits of earth-based observations.

2. Obtain earth resources data for continuing and extending multisensor observation of the earth from the low-earth orbit.

3. Perform the assigned scientific, engineering, technology, and Department of Defense experiments.

4. Obtain Comet Kohoutek data for continuing and extending studies of comets beyond the limits of earth-based observations.

Tables 13-I through 13-VIII list the experiments, student investigations, system/operational detailed test objectives, and science demonstrations assigned to the third visit and show the degree of completion of each objective. Since the data analyses are not completed, the tables indicate only the number of planned activities that were completed.

Although not a primary mission objective, a requirement to obtain documentary motion picture photography of scenes to present the human story of Skylab was considered to be of paramount importance. Approximately 95 percent of the desired crew activity scenes were filmed.

The planned requirements were not only met, but were exceeded for almost all experiments. Also noteworthy were the large number of candidate experiments that were performed.

There were 70 telecasts performed during the third v[illegible]able 13-IX). Premission planning for this visit made provisio[illegible] the development of telecast requirements which would be timely [illegible]ould not be a repeat of subjects covered during the earlier two vis[illegible]. This planning included three flight-data-file "TV Numbers" which were for television of a variety of subjects. These numbers were TV-77, general purpose intravehicular activity telecast; TV-78, earth surface features; and TV-81 optional crew day-off activities.

TABLE 13-I.- MEDICAL EXPERIMENTS

Experiment		Number performed		Remarks
Number	Title/subject	Planned	Actual	
M071	Mineral balance	84		
	Food tracking	84	84	
	Urine measurement	84	75	
	Urine samples	84	77	
	Fecal/vomitus	84	84	
	Body weight	84	83	
M073	Bioassay of body fluids	84	77	
M074	Specimen mass measurement	3	3	
M092	Lower body negative pressure			Included facial photographs and blood flow test
	Commander	26	22	
	Scientist Pilot	26	22	
	Pilot	26	23	
M093	Vectorcardiogram			
	Commander	26	21	
	Scientist Pilot	26	21	
	Pilot	26	21	
M110	Blood study series	8	8	An additional hemoglobin test was also conducted on each crewman
M131	Vestibular function			
	Spatial location			
	Commander	3	3	
	Scientist Pilot	3	3	
	Pilot	3	3	
	Oculogyral illusion/motion sensitivity			
	Commander	7	6/6	
	Scientist Pilot	7	6/5	
	Pilot	7	6/5	
M133	Sleep monitoring	8	18	Ten performances were added during the visit

TABLE 13-I.- MEDICAL EXPERIMENTS - Concluded

Experiment		Number performed		Remarks
Number	Title/subject	Planned	Actual	
M151	Time and motion study			
	Experiments M092/093 or M092/171	12	16[a]	
	Experiments S190B or S183	7[a]	7	
	Pressure garment assembly donning and doffing	3	3	
	Maintenance activities on experiment M509	4	3	
M171	Metabolic activity			
	Commander	12	12	
	Scientist Pilot	12	12	
	Pilot	12	12	
M172	Body mass measurement	3	3	

[a] Three experiment S183 photography sessions were deleted. Four experiment M092/M093/M171 sessions were added.

TABLE 13-II.- EARTH RESOURCES EXPERIMENT PACKAGE DATA COLLECTION FOR THIRD VISIT

Discipline	Task-site requirements[a]		Task-sites completed		Task-sites partially completed
	Total	Third visit	Mandatory requirements met	Mandatory and desired requirements met	
Agriculture/range/forestry	89	22	4	7	4
Geology	169	55	4	9	13
Continental water resources	84	27	0	10	4
Ocean investigations	117	37	4	9	10
Atmospheric investigations	162	44	2	16	14
Coastal zones, shoals and bays	56	17	4	1	4
Remote sensing techniques development	246	21 43[b]	6 10[b]	2 10[b]	5 15[b]
Regional planning and development	263	80	13	15	21
Cartography	113	38	8	3	17
User agency tasks	261	85	--	16	14
Total	1560	469	55	98	121

[a] The Mission Requirements Document (Revision C) contained only the third visit requirements and did not reflect requirements for all three visits. The totals shown reflect the addition of the requirements shown in the first and second visit mission reports plus the requirements for the third visit.

[b] Coverage for sensor performance anlaysis only.

TABLE 13-III.- COROLLARY EXPERIMENTS

Experiment		Number performed		Remarks
Number	Title	Planned	Actual	
D024	Thermal control coatings	2	2	
M479	Zero gravity flammability	5	5	
M487	Habitability/crew quarters	21[a]	21	
M509	Astronaut maneuvering unit	8	5	
M516	Crew activities/ maintenance	7	3	
M556	Vapor growth of IV-VI compounds	1	1	
M557	Immiscible alloy compositions	1	1	
M560	Growth of spherical crystals	1	1	
M561	Whisker-reinforced compositions	1	1	
M562	Indium antimonide crystals	1	1	
M563	Mixed III-V crystal growth	1	1	
M566	Silver grids melted in space	1	1	
S009	Nuclear emulsion	1	1	
S019	Ultraviolet stellar astronomy	14 28[b]	13+	Partial performance of functional objective 14
S020	X-ray ultraviolet solar photography	1	3	More than the one planned performance is highly desirable, but not planned
S063	Ultraviolet airglow horizon	7	7	Only four of five parts of functional objective 5 completed
S073	Gegenschein zodiacal light	36	15	Includes partial completion of functional objectives 7 and 16
S149	Particle collection	1	1	(c)
S183	Ultraviolet panorama	23	18	

[a] Two original functional objectives were deleted. Subsequently two other requirements were added.

[b] Non-interference basis.

[c] One set of cassettes also deployed for retrieval during possible revisit.

TABLE 13-III.- COROLLARY EXPERIMENTS - Concluded

Experiment		Number performed		Remarks
Number	Title	Planned	Actual	
S201	Extreme ultraviolet electrongraphic camera	12	10	All film used
S228	Trans-Uranic cosmic rays	3	3	Detector module deployed[d]
S230	Magnetospheric particle collection	2	2	
S232	Barium plasma observation	2	1	Completed with the single observation
T002	Manual navigation sightings	34[b]	16	
T003	Aerosol analysis	26	30	Four additional readings taken by crew during experiment T020 operations
T020	Foot-controlled maneuvering unit	3	2	Two unsuited runs were performed
T025	Coronograph contamination measurement	1	1	Photography terminated after five exposures on first extravehicular activity because of camera malfunction. Subsequent photography was successful
T053	Earth laser beacon assessment	46	22	

[a] Two original functional objectives were deleted. Subsequently, two other requirements were added.

[b] Non-interference basis.

[c] One set of cassettes also deployed for retrieval during possible revisit.

[d] Sample deployed on experiment S009 bracket for retrieval during possible revisit.

TABLE 13-IV.- MANNED APOLLO TELESCOPE MOUNT OPERATION

Observation/Operation	Time, hr:min	
	Planned	Actual
[a]Observation	339:00	337:58
[b]Solar	—	308:52
Comet Kohoutek	—	29:06
[c]Total man-hours of operation	564:00	518:49
Solar	509:00	466:21
Comet Kohoutek	55:00	52:28

[a] Data-taking while the line of sight from the Apollo Telescope Mount to the sun was at a minimum height of 400 kilometers above the earth's surface.

[b] Stellar observations (Joint Observing Program 13) are included in the solar time.

[c] Includes non-observing time at console.

TABLE 13-V.- SUBSYSTEMS/OPERATIONAL DETAILED TEST OBJECTIVES

Detailed test objective		Number performed		Remarks
Number	Title	Planned	Actual	
20.10	Environmental microbiology	5	4	
20.11	Radiation measurement	89	86	Includes unmanned data between second and third visit
20.14	Orbital assembly contamination	10	1	Does not include completion of functional objectives 7 and 8
20.16	Water sample	1	3	Two added
20.17	Iodine monitoring	7	6	
20.18	Carbon monoxide monitoring	3	3	
20.20	Parasol and sail material	2	2	
20.21	Taste and aroma evaluation	2	2	
20.22	Food package (return)	1	-	Deleted
20.23	Atmospheric volatile concentrator	3	3	
20.25[a]	Girth measurement and crew profile photographs	17	16[b]	
20.27[a]	Collection of sweat samples	9	5	Deleted
20.28[a]	Blood limb flow	10	7	Functional objective 7 on Scientist Pilot not obtained
20.29[a]	Stereophotogrammetry	3	2	
20.30[a]	Gypsy moth	4	4	
20.31	Visual light flash phenomenum	1	2	
20.32	Fire extinguisher discharge test	1	1	
20.33	Heat pipe performance evaluation	1	0	
20.34	Thermal curtain sample	0	1	
20.35	Return of molecular sieve charcoal filters	0	5	
20.36	Zero-gravity cover return	0	1	

[a] These special detailed test objectives were performed on a non-interference basis only.

[b] Two performances of insensible water loss measurements and performance of girth measurement were added inflight and accomplished.

TABLE 13-VI.- COMET KOHOUTEK EXPERIMENTS[a]

Experiment[b]		Number performed	
Number	Title	Planned	Actual
Corollary Experiments			
S019K	Ultraviolet stellar astronomy	20	13
S063K	Ultraviolet airglow horizon photography	22	14[c]
S183K	Ultraviolet panorama	13	6
S201K	Extreme ultraviolet electronographic camera	15	14
S233K	Comet Kohoutek photometric photography	84	74
T025K	Coronograph contamination measurements	2	2
Apollo Telescope Mount Observations			
S052K	White light coronograph	15	13
S-54K	X-ray spectrographic telescope	15	13
S055A-K	Ultraviolet scanning polychromator - spectroheliometer	15	13
S056K	Extreme ultraviolet and X-ray telescope	15	13
S082A-K	Coronal extreme ultraviolet spectroheliograph	1	1
S082B-K	Chromospheric extreme ultraviolet spectrograph	15	13

[a] The preflight-assigned experiment titles are used in this table. Titles which are more descriptive of the actual comet observations are used in section 4.2.

[b] One unplanned observational pass was completed with experiment S073K while spacecraft was in the plane of the comet.

[c] Five additional hand-held photography sessions were accomplished on targets of opportunity.

TABLE 13-VII.- STUDENT INVESTIGATIONS

Investigation		Number performed		Remarks
Number	Title	Planned	Actual	
ED11	Atmospheric absorption of heat[a]		1	Partially completed
ED12	Volcanic studies[a]		1	Partially completed
ED21	Libration clouds[b]		1	
ED22	Objects within Mercury's orbit[b]		18	Initiated during unmanned Apollo Telescope Mount observations (data obtained daily)
ED24	X-ray stellar classes[b]		0	
ED25	X-rays from Jupiter	1	0	
ED31	Bacteria and spores	2	2	
ED41	Motor sensory performance	3	3	
ED61/62	Plant growth/plant phototropism	2	2+	
ED63	Cytoplasmic streaming	3	2	Plants died and experiment was terminated
ED72	Capillary study	3	1	
ED76	Neutron analysis	2	2	

[a] Uses Earth Resources Experiment Package data.

[b] Uses Apollo Telescope Mount data.

TABLE 13-VIII.- SCIENCE DEMONSTRATIONS[a]

Demonstration		Number performed
Number	Title	
SD4	Momentum effects	
SD5	Energy loss and angular momentum	
SD6	Bead chain	
SD7	Wave transmission/reflection	
SD8	Wilberforce pendulum	
SD9	Fluid mechanics series	2
SD12	Electrostatic and magnetic effects	
SD15	Diffusion in liquids	
SD16	Ice melting	
SD17	Ice formation	
SD18	Effervescence	
SD19	Immiscible liquids	1
SD20	Liquid floating zone	1
SD21	Deposition of silver crystals	1
SD22	Liquid films	1
SD23	Lens formation	
SD24	Acoustic positioning	
SD25	Aerodynamics (curve ball effect)	
SD26	Human body momentum	1
SD28	Gyroscope	6
SD29	Cloud formation	
SD30	Orbital mechanics	1
SD32	Perfect gas law	
SD33	Rochelle salt growth	1
SD34	Neutron environment	1
SD35	Charged particle mobility	1

[a] Demonstrations were conducted on a time-available basis.

TABLE 13-IX.- THIRD VISIT TELEVISION SUMMARY

Number	Title	Remarks
TV-3	Eating	
TV-3A	Eating	
TV-4	Experiment M110 (Blood Sampling)	
TV-6	Experiment M092 (Lower Body Negative Pressure Device)	
TV-16	Personal hygiene demonstration	
TV-23	Experiment S183 (Ultraviolet Panorama)	Comet observations
TV-27	Professor Kohoutek conference (live)	
TV-27	Press conference (live)	
TV-27	Press conference (live)	
TV-28	Scientist Pilot highlights	Discussion of Apollo Telescope Mount procedures and techniques
TV-29	Viewfinder tracking system (earth observation)	Views of South America
TV-33	Water sampling	
TV-36	Experiment M509 (Astronaut Maneuvering Unit)	Shirtsleeves with Commander as subject
TV-36	Experiment M509 (Astronaut Maneuvering Unit)	Suited with Commander as subject
TV-36	Experiment M509 (Astronaut Maneuvering Unit)	Suited with Pilot as subject
TV-47	Experiment S019 (Ultraviolet Stellar Astronomy)	
TV-57	Experiment T020 (Foot-Controlled Maneuvering Unit)	
TV-57	Experiment T020 (Foot-Controlled Maneuvering Unit)	
TV-64	Activation in Multiple Docking Adapter area	

TABLE 13-IX.- THIRD VISIT TELEVISION SUMMARY - Continued

Number	Title	Remarks
TV-66	Experiment M479 (Zero-Gravity Flammability)	
TV-67	Experiment ED41 (Motor Sensory Performance)	Student experiment
TV-68	Experiment ED61/62 (Plant Growth/Plant Phototropism) preparations	Student experiment
TV-69	Experiment ED61/62 (Plant Growth/Plant Phototropism) preparations	Student experiment
TV-72	Coolant servicing	
TV-77	General purpose intravehicular activity telecast	Pilot exercising on treadmill
TV-77	General purpose intravehicular activity telecast	Comet Kohoutek instrument tour (part I)
TV-77	General purpose intravehicular activity telecast	Comet Kohoutek instrument tour (part II)
TV-77	General purpose intravehicular activity telecast	Comet Kohoutek instrument tour (part III)
TV-77	General purpose intravehicular activity telecast	Comet Kohoutek sketches
TV-77	General purpose intravehicular activity telecast	Comet Kohoutek sketches
TV-77	General purpose intravehicular activity telecast	Earth Resources Experiment Package instrument discussion
TV-78-1	Earth surface features	Falkland currents
TV-78-2	Earth surface features	Falkland/south equitorial currents
TV-78-3	Earth surface features	Aleutian Islands
TV-78-4	Earth surface features	California and Baja
TV-78-5	Earth surface features	Japan and Alaska
TV-78-6	Earth surface features	Aleutian Islands

TABLE 13-IX.- THIRD VISIT TELEVISION SUMMARY - Continued

Number	Title	Remarks
TV-78-7	Earth surface features	California and Baja
TV-78-8	Earth surface features	Galapagos Islands
TV-78-9	Earth surface features	Mouth of the Amazon
TV-78-10	Earth surface features	California and Baja
TV-78-11	Earth surface features	Andes and Santiago, Chile
TV-81	Crew day-off activities	Air swimming and Pilot taking shower
TV-81	Crew day-off activities	Demonstration of donning of spacesuits
TV-81	Crew day-off activities	Removing foot restraints at wardroom table
TV-81	Crew day-off activities	Christmas special
TV-81	Crew day-off activities	Spacesuit with the name S. Claus
TV-81	Crew day-off activities	Comet Kohoutek sketches
TV-81	Crew day-off activities	Comet Kohoutek sketches
TV-81	Crew day-off activities	Discussion of water blob
TV-81	Crew day-off activities	Completion of TV-87 science demonstration
TV-83	Experiment S192 alignment	
TV-87	Science demonstration	Human body momentum
TV-101-1	Liquid floating zone	
TV-101-2	Liquid floating zone	
TV-101-3	Liquid floating zone	
TV-101-4	Liquid floating zone	
TV-101-5	Liquid floating zone	

TABLE 13-IX.- THIRD VISIT TELEVISION SUMMARY - Concluded

Number	Title	Remarks
TV-103	Liquid films	
TV-104	Gyroscope	
TV-104	Gyroscope	Repeat for different view angle
TV-107-1	Fluid mechanics series	
TV-107-2	Fluid mechanics series	
TV-107-3	Fluid mechanics series	
TV-107-4	Fluid mechanics series	
TV-107-5	Fluid mechanics series	
TV-110	Orbital mechanics	
TV-120	Gypsy moth	Hatched larvae
TV-XX	Experiment S054 film canister reloading	

14.0 FLIGHT PLANNING

14.1 SUMMARY

Flight planning for the third manned visit continued along the lines developed during the first and second visits. Daily flight plans were produced 24 hours in advance of their execution in the manner described in reference 3. The loss of one of the control moment gyros early into the third manned visit placed additional constraints on maneuvers and the momentum dump inhibits required by a number of experiments. These restrictions resulted in less flight planning flexibility than for the previous visits and the daily flight plans required more analysis and scrutiny by the Workshop systems experts before being certified as acceptable.

Despite the complications discussed in the previous paragraph, the accomplishments during the third manned visit were nearly as planned in all areas. An assessment of these accomplishments is discussed in section 14.2. A discussion of certain "lessons learned" in the flight planning area of Skylab appears in section 14.3.

14.2 THIRD VISIT ASSESSMENT

Visit accomplishments in terms of particular experiments and test objectives are discussed in section 13.0. The actual distribution of crew time compared to the premission allocation is shown in table 14-I. Both of these sources reflect that the level of accomplishment was about 15 percent, on an average, below the premission plan. The reasons for some of this loss are discussed in the following paragraphs.

The premission estimate of 1969 man-hours being available for experiments was derived using basically the same planning constraints as the second visit; that is, time was alloted for eating periods, exercise, pre- and post-sleep, housekeeping, etc. The results from the second visit indicated that, after an initial period of adjustment and learning, the crew devoted about 29 to 30 man-hours per day to experiment operations out of the total 48 man-hours available. On their days off, the second visit crew also devoted about one-half the normal amount of time to experiment activities. Thus, using figures of 28 man-hours for normal days (22 man-hours for the first 2 weeks) and 16 man-hours on days off, and accounting for activation, deactivation, and extravehicular activity requirements, an estimated 1969 manhours would be available for conducting experiments. This total time was divided between the various experiment disciplines as shown in table 14-I and these figures represented the third visit experiment goals.

TABLE 14-I.- COMPARISON OF ACTUAL CREW TIME ALLOCATION WITH THE PREFLIGHT PLAN

Category	Allocation, manhours		
	Previsit	Adjusted as of visit day 28	Actual
Medical	476	422	397
Apollo Telescope Mount (solar)	509	417	466
Earth Resources Experiment Package	295	242	275
Corollary	297	245	235
Comet Kohoutek	282	231	204
Miscellaneous	110	58	96
Total	1969	1615	1673

Two factors which were later learned proved these goals to be excessive by about 20 percent. First, shortly before the visit began, the crew established that they planned to devote 1-1/2 hours per day per man to exercise rather than the 1 hour of the second visit crew. This meant that about 5 percent less time would be available for experiment activities. Second, it became apparent during the early part of the third visit that the crew was being over-scheduled relative to the pace to which the crew felt attuned for their longer-duration visit. (Ground personnel later learned that the crew had always intended to work at a somewhat reduced pace, but this fact had not been sufficiently communicated to all concerned.) By the time the first one-third of the visit was over, the ground planners had achieved a better understanding of the desired pace, and adjustments were made to reflect more realistic goals. These reductions were apportioned among the experiment disciplines on the basis of priority and other considerations, and are shown in the middle column of table 14-I. On an average, the reductions amounted to an additional 15 percent of the previsit goals. Actual end-of-visit results have shown the visit-day-28 projection to be slightly under the achieved capability so that the overall level of accomplishment was only about 15 percent below the previsit plan instead of the 20 percent discussed previously.

The loss of one of the control moment gyros early in the third visit placed new constraints on maneuvers and momentum dump inhibits and significantly restricted the ground controller's flexibility in experiment scheduling. Considerably more attention in the daily flight planning to the spacing of maneuvers and inhibits was required and computer simulations were required on each day's flight plan before certifying the plan as acceptable. Innovations in momentum management techniques by the flight controllers were effective in limiting the impact of the control moment gyro failure, so that the overall experiment accomplishments were still mainly limited by the man-hours available and not by the momentum constraints. As a result, the stellar astronomy and comet observations suffered less than anticipated from the control moment gyro failure. In the Earth Resources Experiment Package area, however, the control moment gyro failure was a significant factor in the decreased data return since maneuver constraints precluded multiple data passes on the days when exceptionally good weather conditions existed over the ground tracks of prime interest.

14.3 SKYLAB MISSION ASSESSMENT

Based on experience from the Skylab program, certain flight planning lessons became apparent. These items are discussed as follows:

a. A clear and conscious understanding is required between all parties involved in a mission, namely the crew, the Mission Control Center, and program management on the general planning and execution of the mission, not just an assumption that the crew is training to perform the experiments and systems in the same way that the other groups are planning the mission. During the planning for the third visit, the general assumption by the program management was that scheduling for experiment performance would follow a pattern similar to the second visit. Crew planning, however, was directed toward a different goal of establishing a "nominal pace" that would be appropriate for a longer visit. This resulted in a conflict since more requirements were established than could be met.

During training before the third visit, the crew made a number of inputs concerning operating procedures, particularly in the area of the Apollo Telescope Mount, which were not widely recognized until these problems arose during the visit.

Semi-isolation of the crew in quarantine and the short turn-around time between visits may have contributed to the problem, but very probably were not the main factors.

b. A single point of contact is extremely useful (e.g., Program Scientist) between the Flight Director and the various experiment areas on issues concerning science policy. On multi-discipline missions such as Skylab, single points of contact between the individual disciplines and the Program Scientist would also be very useful. Such a procedure was followed during Skylab and found to produce a well-organized and smoothly flowing communications channel. Because of the lack of a single spokesman for the corollary experiments, a disproportionately large amount of time was required by the Program Scientist in resolving scheduling conflicts between individual corollary experiments.

c. Provisions for carrying extra experiment consumables (film, tapes, etc.) in excess of premission requirements and providing inflight spares for experiments to the extent permitted by stowage and weight limitations is a desirable feature. Extra experiment consumables permit increasing a given experiment's time allocation to take advantage of situations where:

1. More time becomes available for all experiments than was anticipated.

2. More time becomes available for some experiments because of the failure of other experiments.

3. More emphasis may be desired on a given experiment because of unanticipated scientific phenomena (e.g., sun more active than expected.)

The availability of inflight spares to repair a failed experiment is an obvious advantage and the provision of spares need not be limited to the entire instrument level. On both the second and third visits, the spare film canister on experiment S019 permitted continuation of this experiment after one canister had jammed. Other examples during Skylab include use of Earth Resources Experiment Package tapes and experiment S082 film at earlier times than anticipated by mortgaging against the supplies which were onboard for later missions and replacing these on subsequent launches. In addition, the resupply permitted by multiple visits to the Workshop was an important capability in maximizing the scientific return by making available more data recording media such as film and tape, and also allowing for modifications in film loads based on experience during the visits.

d. For long-duration missions, the flight planning system for experiments should provide the flexibility to update the premission plan on a day-by-day basis. Based on Skylab experience, it appears unrealistic to expect that a premission plan could be followed to the letter on a long-duration mission. Science planning was conducted on a weekly basis at the level of assigning blocks of time, but because of the "domino effect," both within a day and extending from day to day, even a small number of changes meant that each day's summary flight plan could be more efficiently optimized by starting from scratch. Factors which lead to this conclusion and which determine the extent of deviation from premission plans include the following:

1. Inflight hardware problems which result in new constraints.

2. Inflight experience which results in the discovery of unanticipated constraints.

3. Unpredictability of weather affecting many of the earth-looking experiments.

4. Changes in scientific emphasis during the visit for a variety of reasons.

5. Late requirements.

On Skylab, the premission plan was a necessary step in determining the feasibility of accomplishing the objectives and provided visibility into potential scheduling problems. However, because of hardware problems (both experiments and spacecraft), adhering to the premission plan became impractical. Fortunately, the planning system had been set up to provide for day-by-day replanning during the visit, so this resulted in no great problem.

e. Depending on the nature of the decisions required during the day (execute) shift, a Program Scientist may or may not be required beyond the night (summary) shift. During Skylab, the role of the Program Scientist as the arbiter between all the experiment areas on matters of planning was filled only during the summary shift because almost all issues that arose during the day pertaining to advance planning were left for the summary shift to resolve. Experiment operation problems that arose during the day were generally settled by direct interface between the Flight Director, the experiment controller, and the experiment representative and, generally, the problems did not involve conflicts between experiments. There are, however, missions where a large amount of short-term planning and interaction between various experiments and disciplines would require a Program Scientist's evaluation and participation during the execute period as well as planning phases (e.g., lunar surface activity during Apollo).

f. Regularly scheduled meetings between the various individuals involved in experiments planning provides an effective means of obtaining inputs for the day-to-day flight planning of experiments. On the second and third visits, such meetings were held on a twice-a-week basis and were called science planning meetings. The meetings were chaired by the Program Scientist and participation included, primarily, the experimenters (principal investigators or their representatives) and also some operations personnel and flight planners. Attendance was open to all other interested parties. These meetings provided a forum to:

1. Obtain near-term inputs in an organized fashion from the experimenters.

2. Provide near-term forecasts to the experimenters.

3. Communicate any new experiments/flight planning constraints from the operations personnel.

4. Keep the Program Scientist advised in an organized fashion about areas of concern pertaining to various experiments.

Even though summary flight plans were put together on a day-to-day basis, the inputs from these meetings allowed the Program Scientist to plan ahead for several days. Minutes of these meetings documented the inputs, derived plans, and provided the basis for experiment planning during the next week.

An additional important advantage of the science planning meetings was that they provided the experimenters with an across-the-board understanding of the operational limitations imposed by the visit and an appreciation of other problems which, hopefully, led them to the conclusion that they were being dealt with fairly when all things were considered. (Such meetings had not been a part of the first visit operations and there were indications that some uninformed experimenters thought they were being singled out unfairly for reductions in their experiments.)

g. The creation of Mission Operations Control Room positions representing the major experiment areas is an effective way of handling the operational aspects of each of the experiments and also providing daily inputs to the experiments flight planning.

During Skylab, such experiment flight controllers who had a good understanding of requirements, hardware constraints, and operational limitations contributed significantly to the successful operation of the experiments. These experiment flight controllers manned their positions in the Mission Operations Control Room on a three-shift basis as regular members of the flight control teams with ready access to the Flight Director.

h. An extremely useful situation is to have experiments available that do not have any priority for scheduling, but that can be used as "fillers" when time is available that cannot be used by any of the "regular" experiments. In building the daily flight plan during Skylab, it was not always possible, for a variety of reasons, to fill the time available with the preplanned experiments. In such cases, a reservoir of activities which could be used to fill this otherwise open time was useful. Ideally, such activities should be one-man tasks of a non-time-critical nature and not too time consuming. On Skylab, such tasks included a series of science demonstrations, low priority experiments, and detailed test objectives which had been approved premission on the basis that they would be accomplished if time was available. Also included in this category were non-time-critical experiment or systems test activities generated during the visit. This procedure helped increase the efficiency in the use of crew time by providing worthwhile activities in otherwise empty time.

i. Except for the most routine and passive experiments, the principal investigator, or someone who can speak authoritatively for the experiment, should be present during the mission. There were many occasions during both experiment operations and planning meetings when questions arose that could only be satisfactorily answered by an authoritative spokesman for an experiment. To provide realistic inputs into the scheduling of experiment activities during a mission, the experimenters should maintain an up-to-date knowledge of the mission situation, including the overall constraints and limitations which influence individual experiment accomplishments. The best method of obtaining such knowledge and insuring the inclusion of their inputs is to be on the scene continually during the visit. When the spokesmen were available in the experiment support rooms or at the meetings, this worked well. On occasions when the spokesmen were not available, use of the telephone was sometimes, but not always, effective and some reduced efficiency in experiment achievement was perceptible. The lack of an experiment representative on the scene placed an additional and unwarranted responsibility on the experiment flight controllers.

j. Planners should consider the scheduling of crew activities on a 24-hour-a-day basis for future missions (e.g., with four men scheduled, two on and two off during each 12-hour period). Because of constraints (both experiment-to-system and experiment-to-experiment), the scheduling of experiments on the basis of two people available over an entire 24-hour period is more efficient than on the basis of four people on duty simultaneously for 12 hours of the 24-hour period. One example of this is the scheduling of momentum dump inhibits on Skylab. On the third visit, these inhibits became a very precious commodity and yet a number of possible dumps were lost each night because of crew sleep.

Because of the inflexibility of crew sleep, as planned in the Skylab schedules, early morning and late night operations were severely restricted. Had the schedule been formulated on a 24-hour basis, then the crew could have modified their schedules at their pleasure without affecting operations and ground planning; for example, if someone wanted to sleep in, the other crewmen could cover for him. However, implicit in this concept are the assumptions that the crewmen will be cross-trained so that at least two of them can perform any task and that the sleeping quarters will be such that half the crew can get good sleep while the other half of the crew is working.

k. The acceptance of hard requirements for performance of low-priority experiments very early in a visit (first week) should be avoided on missions which require substantial amounts of activation. During each Skylab visit, the first week was extremely busy and time was at a premium. Requirements for early observations for low-priority experiments resulted in either undue interference with the performance of high-priority experiments or failure to meet the requirements for the low-priority experiments.

15.0 LAUNCH PHASE SUMMARY

15.1 LAUNCH WEATHER CONDITIONS

At launch time, the axis of a weak, surface, high-pressure ridge lay across south-central Florida, while a weak cold front extended southwestward from a low-pressure area. The low-pressure area was centered in Connecticut, and passed through Florida in the vicinity of Tallahassee.

Skies over the launch area were cloud free, although scattered clouds were observed along the horizon in the northeastern, southeastern, and southwestern quadrants. Visibility was 18.5 kilometers and the surface temperature was 295.4° K. A light southwest wind at the surface gave way to mostly westerly winds at 1520 meters and these winds prevailed up through the troposphere. Wind speeds ranged from 5.1 meters per second in the surface layer to in excess of 25.7 meters per second in the layer from 9 to 15 kilometers. The maximum wind occurred at an altitude of 12.5 kilometers and was from west-southwest at 43.2 meters per second.

15.2 LAUNCH VEHICLE OPERATIONS

The space vehicle was launched on November 16, 1973, from Launch Complex 39B of Kennedy Space Center. The performance of ground systems supporting the countdown and launch was satisfactory. The launch was rescheduled from November 10, 1973, to replace all eight fins on the S-IB stage after postcountdown demonstration test inspections revealed cracks in the fin attachment fittings.

The vehicle was launched on an azimuth of 90 degrees east of north. A roll maneuver was initiated approximately 10 seconds after launch and placed the vehicle on a flight azimuth of 53.781 degrees east of north. The actual flight trajectory was very close to the nominal trajectory. The S-IB stage outboard engine cutoff was 0.31 second later than nominal, and the total space-fixed velocity at cutoff was 0.82 meter per second greater than nominal. The S-IB stage propulsion system performance was satisfactory. Stage specific impulse was within 0.04 percent of predicted. Inboard engine cutoff occurred at 137.82 seconds (0.16 second earlier than predicted) and outboard engine cutoff occurred 3.47 seconds after inboard engine cutoff at 141.29 seconds.

The S-IVB stage firing terminated with the guidance cutoff signal and was followed by parking orbit insertion. The orbital insertion parameters were 227.08 by 150.10 kilometers. An excess velocity of 0.73

meter per second at insertion resulted in an apogee 2.84 kilometers higher than nominal. The parking orbit portion of the trajectory from spacecraft insertion to command and service module/S-IVB stage separation was close to nominal. The S-IVB propulsion system performed satisfactorily throughout the operational firing phase and had normal start and cutoff transients. S-IVB stage firing time was 432.22 seconds, 2.46 seconds shorter than predicted for the actual flight azimuth of 53.8 degrees. The engine control system performed within expected limits. However, a helium leak was evidenced by greater than expected helium usage during mainstage operations. The S-IVB stage engine cutoff was initiated by the launch vehicle digital computer at 577.18 seconds. The S-IVB residuals at engine cutoff were near nominal.

During orbital coast, the liquid oxygen tank pressure increased more rapidly than predicted and went above the predicted limits. This was probably a result of the greater-than-expected liquid oxygen boiloff indicated by reconstruction of the orbital coast phase and the liquid oxygen dump.

Throughout the flight, the auxiliary propulsion system module 1 performed normally, and module 2 functioned normally except for the pitch engine. The pitch engine thrust was approximately 30 percent of nominal. The lower thrust level resulted in longer pitch-engine-on time to provide the required attitude control system total impulse. This reduced performance has been attributed to a partial blockage in the oxidizer injector area.

The structural loads experienced during the flight were well below design values. The maximum ground wind experienced during the prelaunch period was 10.8 meters per second and during launch was 5.1 meters per second. Both values were well below the allowable limits. There was no flight evidence of any compromise of structural integrity due to either the prelaunch propellant tank bulkhead reversal or the stress corrosion incidents associated with the S-IB E-beam, S-IB fin rear spar fitting, and S-IB/S-IVB interstage reaction beam. Total vehicle mass, determined from postflight analysis, was within 1.47 percent of predicted from ground ignition through S-IVB/spacecraft separation. Hardware weights, propellant loads, and propellant utilization were close to predicted values during flight.

The stabilized platform and the guidance computer successfully supported the accomplishment of the launch vehicle mission objective. The electrical systems and emergency detection system of the launch vehicle performed satisfactorily during the flight. Battery performance (including voltages, currents, and temperatures) was satisfactory and remained within acceptable limits. Operation of all power supplies, inverters, exploding bridge wire firing units, and switch selectors were normal.

The vehicle data systems performed satisfactorily except for a problem with one of the instrument unit telemetry links. This problem resulted in the loss of some instrument unit and S-IVB stage data, but sufficient data were recovered to reconstruct all important flight information and to provide real-time mission support.

The impulse derived from the liquid oxygen and fuel dumps was sufficient to satisfactorily deorbit the S-IVB/instrument unit. The total impulse provided, 297 629 newton-seconds, was in good agreement with the real-time nominal predicted value of 313 360 newton-seconds. The auxiliary propulsion system satisfied control system demands throughout the deorbit sequence. Propellant tank safing after the fuel dump was satisfactory.

All aspects of the S-IVB/instrument unit deorbit were accomplished successfully. The propellant dump was performed as planned with S-IVB stage impact occurring in the primary disposal area. Although vehicle breakup occurred after loss of signal at Kwajalein, the deorbit was confirmed from other sources.

16.0 ANOMALY SUMMARY

16.1 COMMAND AND SERVICE MODULE ANOMALIES

16.1.1 Oxidizer Sump Tank Measurement Indicated a Temperature Drop

On visit day 4, the service propulsion oxidizer aft dome sump tank temperature (outboard side) measurement properly indicated 290° K at the Vanguard tracking station loss of signal. On acquisition of signal 69 minutes later at the Goldstone station, the measurement indicated 255° K. The two other oxidizer sump tank temperatures had remained constant during this period, indicating that the problem was in the temperature instrumentation. One of the other two measurements that had remained constant was redundant to the failed measurement and indicated temperature on the inboard side of the tank aft dome. The redundant measurement was used for the remainder of the visit to determine the performance of the oxidizer sump tank heater. The hardware consists of a temperature sensor connected by cable to a signal conditioner that provides a 0- to 5-Vdc signal, representing a temperature range of 255° to 339° K.

The history of the measurement hardware shows that the probable cause of failure was in the signal conditioner operational amplifier, which is an integrated circuit. Circuit chips such as the one used in this application have a history of surface defects between conductor strips, as well as failed transistor and diode elements. These defects and failures result in the bipolar output of the amplifier being clamped to either the positive or the negative supply voltage. This, in turn, causes the signal conditioner output to be clamped at the upper or lower limit. As a result, the temperature indication is clamped at either 339° or 255° K.

Records show that the integrated circuit was an unscreened commercial device. The circuit had been subjected to an X-ray inspection and nonoperating temperature cycling, but neither of these tests would detect the surface defects that may result in circuit failure. A scanning electron microscope metallic inspection appears to be the only inspection method that would expose these surface defects that are the potential causes of failures.

Five of these integrated circuits are installed in service module signal conditioners on the Apollo/Soyuz Test Project command and service module (CSM-111). However, the five temperature measurements using these circuits are not mandatory for crew safety or mission success, and no corrective action is required.

This anomaly is closed.

16.1.2 Service Module Reaction Control System Fuel Isolation Valve Internal Leak

Data from the service module reaction control system on visit days 2 and 9 showed that one or both of the quad B fuel isolation valves were leaking in both directions. The leak was again verified on visit day 24 during a trim maneuver.

As shown in figure 16-1, four fuel tanks in the propellant storage module are manifolded to two parallel manifold isolation valves. The fuel manifold then branches out through four parallel propellant storage module propellant isolation valves to feed quads A, B, C, and D.

The quad B fuel system has a primary and a secondary fuel tank, both pressurized by helium gas. The two fuel tanks feed the fuel manifold through independent isolation valves. The manifold has an accumulator to limit and to damp the fuel pressure fluctuations. Fuel from either of the quad B fuel tanks and the propellant storage module fuel tanks, or just from the propellant storage module fuel tanks may supply the quad B engine cluster.

The crew closed the propellant storage module quad B fuel isolation valve on visit day 28 to eliminate the necessity of real-time isolation of quad B in the event that a fuel leak developed in quads A, C, or D, or in the propellant storage module manifold (fig. 16-1). An additional fuel leak would have drained the quad B fuel tanks through the leaking quad B fuel isolation valves.

Actuation of a switch to open or to close propellant isolation valves actuates both the fuel and oxidizer isolation valves of a corresponding set. Therefore, when the crew closed the propellant storage module quad B fuel isolation valve, the propellant storage module quad B oxidizer isolation valve was also closed. This action trapped oxidizer between the propellant storage module quad B oxidizer isolation valve and the two oxidizer isolation valves of the quad B panel assembly.

Any adverse sun-angle change had the potential of driving the pressure in the manifold to an unacceptably high value through thermal expansion of the trapped oxidizer. The oxidizer manifold pressure will rise 3.7 newtons per square centimeter for each degree K increase, and, if the oxidizer manifold's accumulator fails, 155 newtons per square centimeter per degree K increase. Therefore, on visit day 30, the crew opened the quad B propellant isolation valves to preclude the possibility of unacceptable pressure in the oxidizer manifold. The fuel manifold had no such problem because the quad B isolation valve leak allowed the quad B fuel tanks to act as an accumulator.

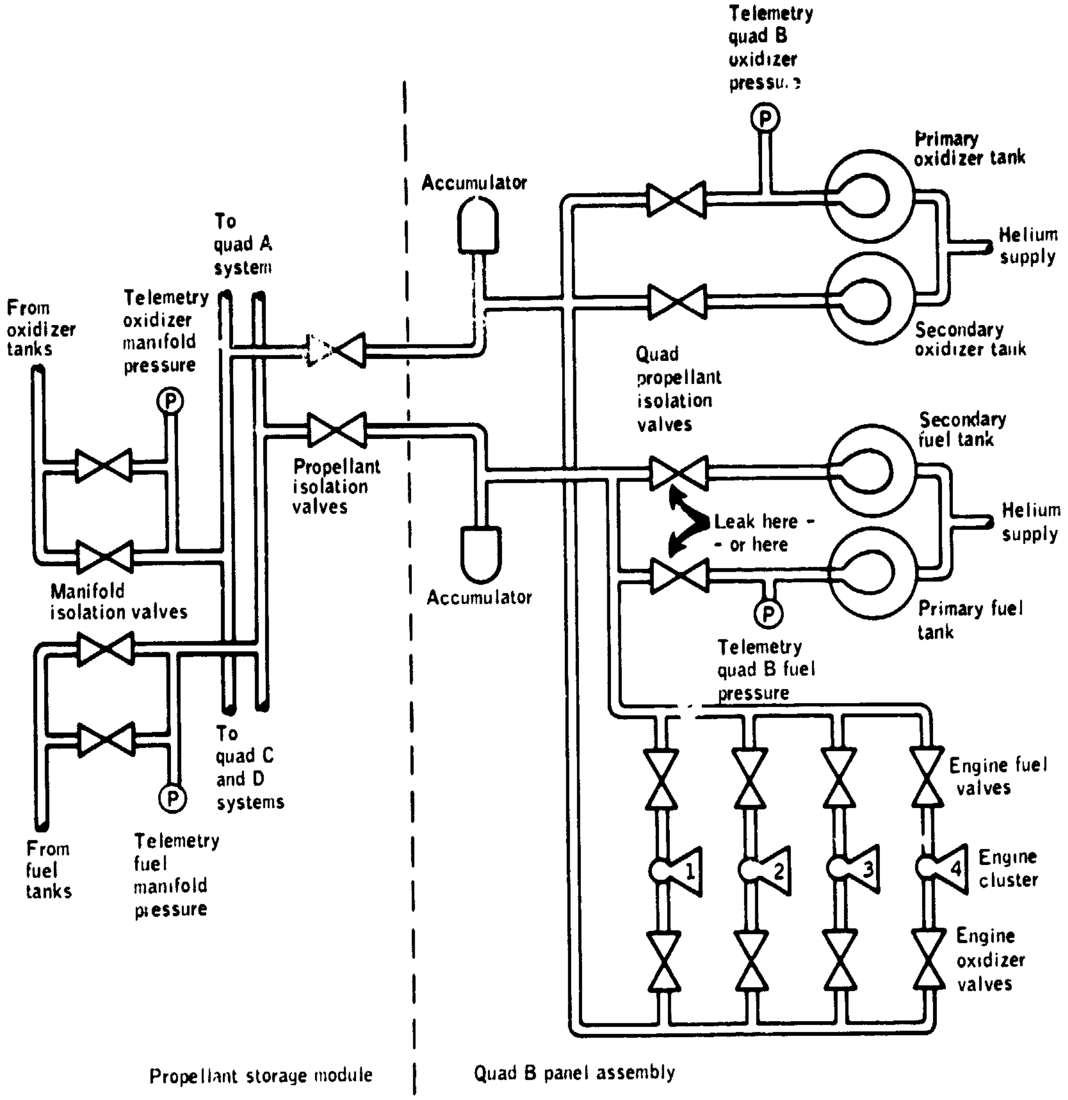


Figure 16-1.- Simplified quad B propellant schematic.

The preflight failure history of the two quad B fuel isolation valves showed six cases of internal leakage. One valve leaked twice because of contamination and once because of a porous Teflon seat that was subsequently replaced. The cause of an additional leak was unknown. The other valve leaked twice. One leak was due to contamination and one was due to an unknown cause.

The most probable cause of the inflight leakage was contamination in one of the two quad B fuel isolation valves. Since quad B can be isolated by the propellant storage module quad isolation valves, no corrective action is required.

This anomaly is closed.

16.1.3 Command Module Reaction Control System Helium Pressure Decay

The command module reaction control system 2 helium source pressure began to rapidly decay just prior to the deorbit maneuver. Figure 16-2 shows the pressure decay.

The crew disabled system 2 and continued normal system 1 single reaction control system entry. About 13.6 kilograms of system 1 propellants were used during the entry maneuvers. The system 2 source pressure continued to decay and was indicating 414 newtons per square centimeter 11 hours after spacecraft recovery.

Postflight checks showed a high-pressure helium leak at the outlet side of one of the system 2 squib-actuated helium isolation valves (fig. 16-3). The leak was through an external braze joint of the valve outlet filter (fig. 16-4). The braze joint was sectioned and a crack was revealed (fig. 16-5). In addition, corrosion was revealed at the braze interface, extending underneath the braze area and into the valve body.

The corrosion could have been caused by contamination of the valve before the assembly and brazing operations.

During manufacture, the valve body was passivated by immersion in a water solution of nitric acid and sodium dichromate. The body was then rinsed in water, vapor-degreased, assembled, and brazed. Incomplete water rinsing could have left sodium dichromate deposits on the valve interior that would cause the observed corrosion.

The valve was leak tested at component level in 1968, but no vehicle-level valve leak tests were performed. Braze joints in the helium system of the Apollo/Soyuz command and service module will be leak tested and dye-penetrant inspected at the launch site before systems servicing.

This anomaly is closed.

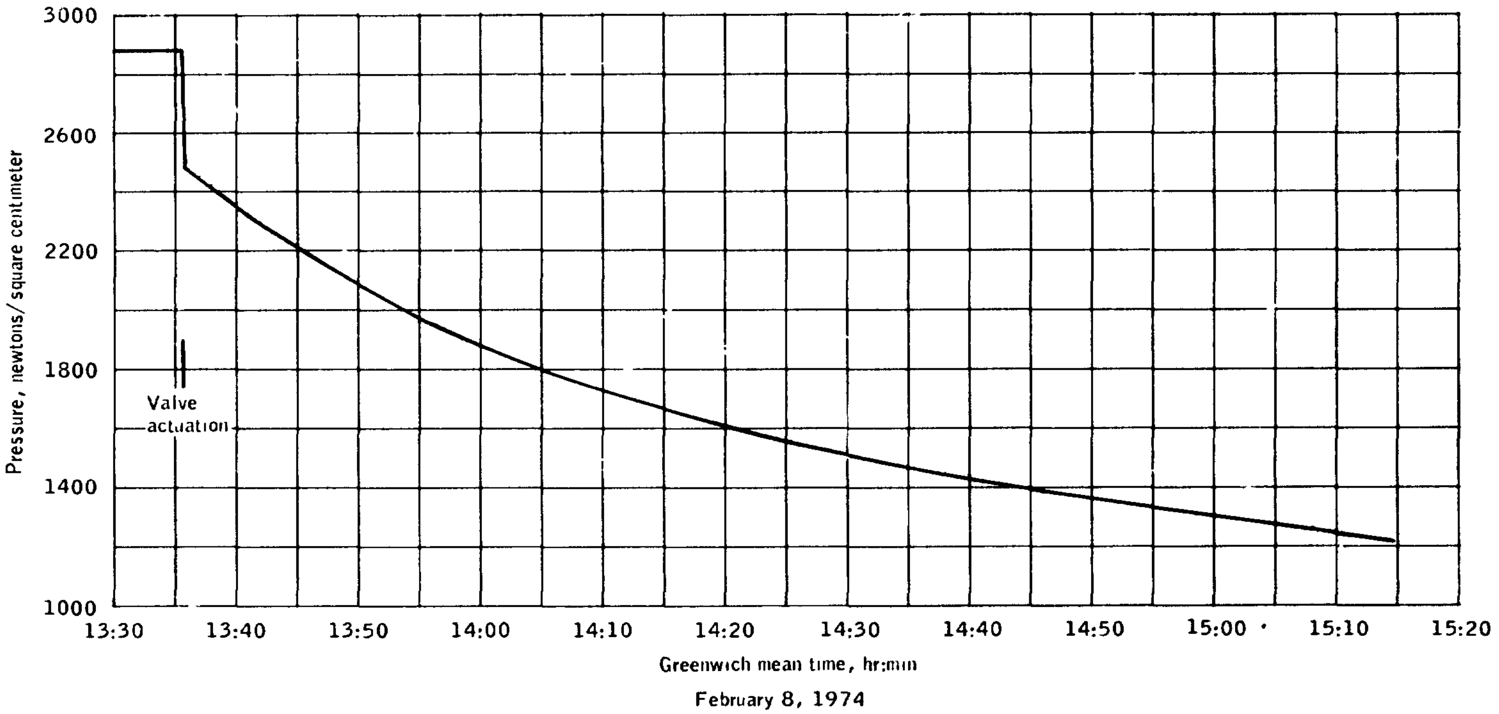


Figure 16-2.- Reaction control system B helium source pressure history.

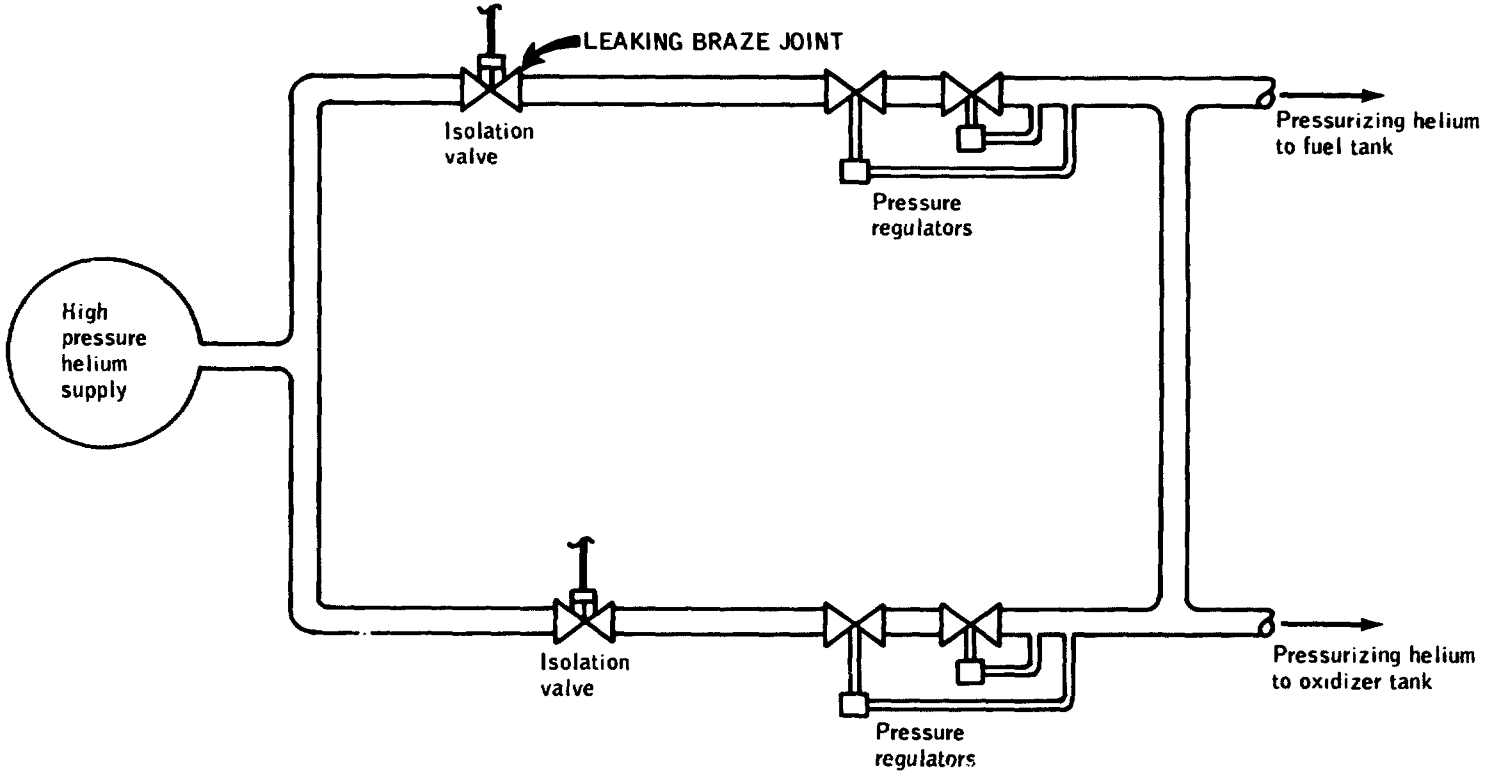


Figure 16-3.- Reaction control system 2 helium supply.

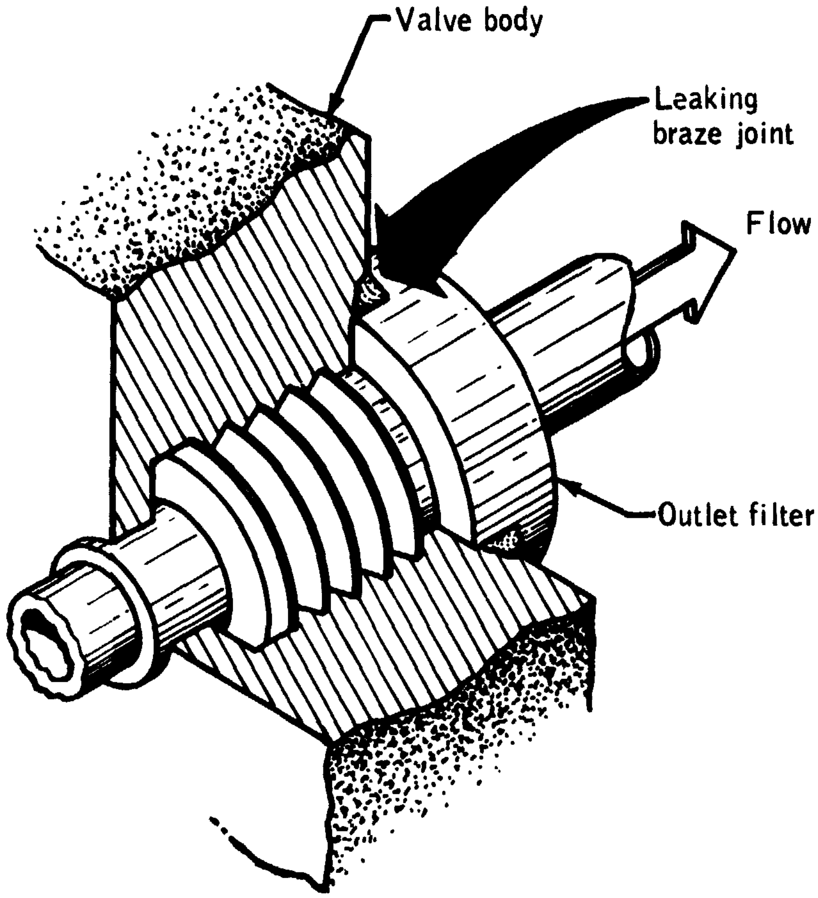
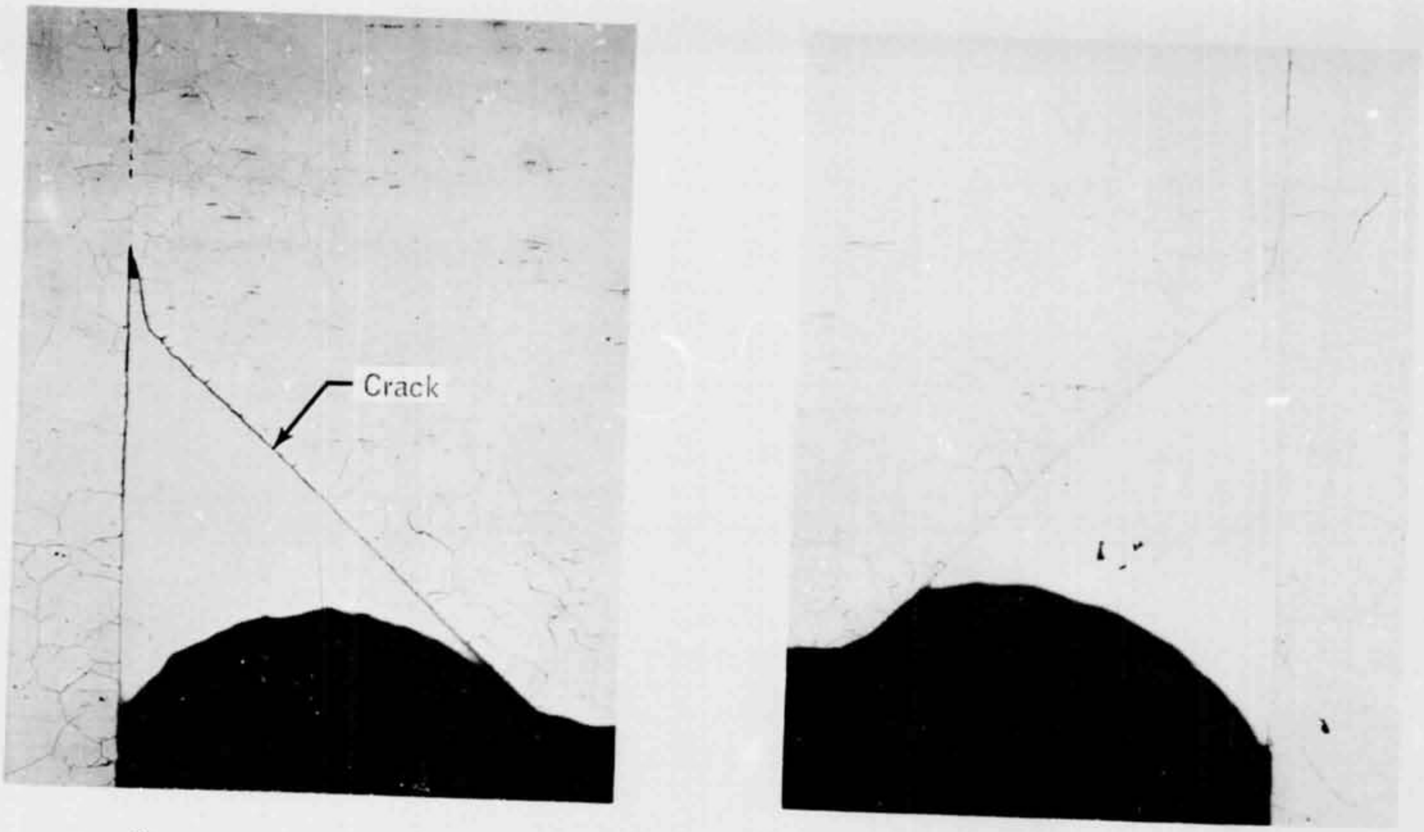


Figure 16-4.- Squib actuated helium isolation valve.



Braze joint in leaking valve

Normal braze joint, for comparison

Figure 16-5.- Photomicrograph (75X) of the cracked joint and a normal joint.

16.1.4 Intermittent Circuit Breaker

The battery A to battery bus A circuit breaker was closed on visit day 79 for the service propulsion system checkout. Circuit breaker operation was intermittent, and a good connection could be obtained only by pressing hard on the circuit breaker plunger. The circuit breaker was cycled, resulting in a good voltage reading. Battery bus A was then connected to main bus A (fig. 16-6) and it supplied 5 to 6 amperes momentarily before the battery bus A current and voltage dropped to zero. Later, a good contact was finally achieved by repeatedly cycling the defective circuit breaker while an electrical load was on the circuit.

The circuit breaker contacts are designed to roll slightly when the circuit breaker is closed. This action is needed to roll the point of contact to an unpitted surface after initial contact, assuring a good, low resistance contact.

Postflight X-ray photographs (fig. 16-7) showed that one of the defective circuit breaker fixed contacts was tilted, preventing the desired contact rolling. The two contact pairs shown in the X-ray photograph are connected in series. Since one of the two series contact pairs did not roll, and since contact always occurs at the same point, arcing at that point ultimately prevented the contact from making good electrical connection.

The defective circuit breaker was manufactured with the contact in the tilted position. Circuit breaker component X-rays were not taken because failure of any one command module circuit breaker will not affect crew safety or mission success.

This anomaly is closed.

16.2 EXPERIMENT ANOMALIES

16.2.1 Experiment S190A Failed in Automatic Sequence Mode

Experiment S190A (Multispectral Photographic Facility) failed to actuate when the mode switch was in the AUTO SEQ position. Subsequent cycling of the mode switch restored normal operation.

Figure 16-8 shows the circuitry associated with the mode switch. The three positions of the switch are AUTO SEQ, OFF, AND SINGLE. The single position of the switch is spring loaded for momentary actuation. The automatic sequencing is commanded by grounding the automatic sequence input

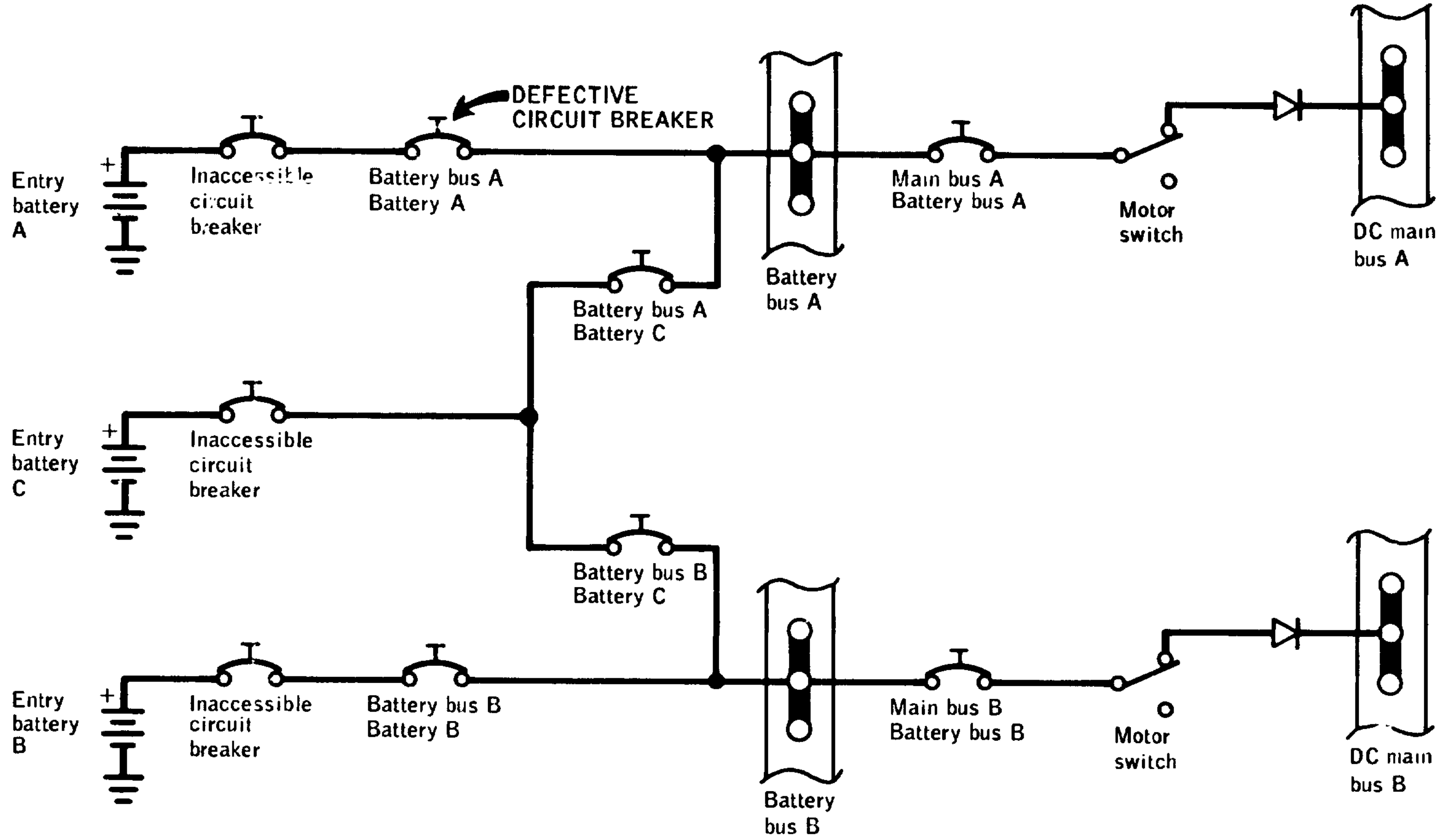
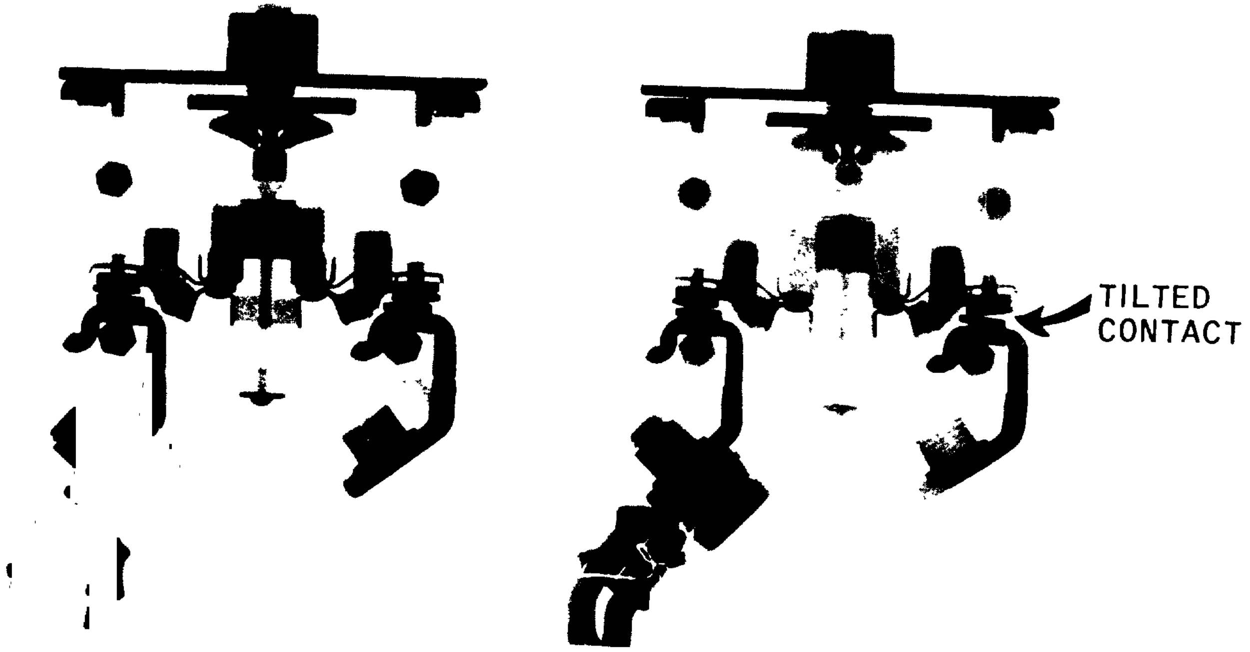


Figure 16-6.- Simplified dc power distribution schematic.



Good circuit breaker

Defective circuit breaker

Figure 16-7.- Circuit breaker X-ray photographs.

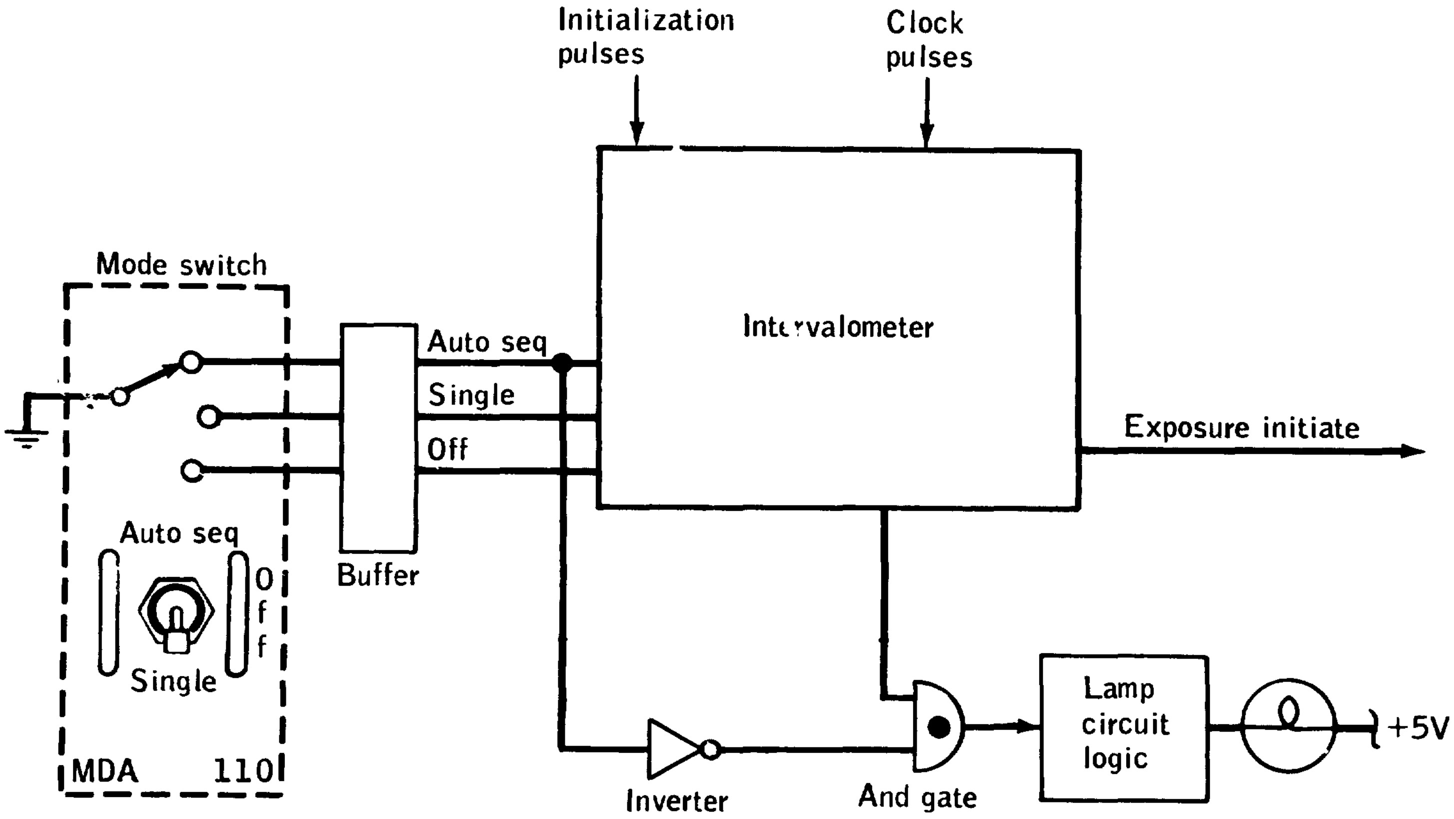


Figure 16-8.- Mode switch operation.

line to the buffer amplifier which also inverts the signal. The signal is then reinverted as it passes through the inverter (high to low). A low input to the AND gate coupled with a low input from the intervalometer results in illumination of the ready light. The low input also enables the intervalometer function generator. The intervalometer automatic sequence input is always low when the intervalometer is not operating.

During preparations for the Earth Resources Experiment Package pass on visit day 11, a ready light was not obtained and the camera array did not actuate. None of the malfunction lights were illuminated during preparation. After the crew cycled the mode switch several times, a ready light was obtained with the mode switch in the AUTO SEQ position. The anomaly did not recur during any subsequent cycling of the switch.

The switch is a self-cleaning type and the contacts are wiped each time the toggle position is changed. Cycling of the mode switch was the only switching change made to restore normal operation. Switch contact contamination could have caused the problem. The self-wiping action would then have cleared the contamination, restoring normal operation. No further experiment operations are planned; therefore, no corrective action will be taken.

This anomaly is closed.

16.2.2 Intermittent Operation of Experiment M133

Experiment M133 (Sleep Monitoring) malfunctioned twice during the third visit. The first occurrence was on visit day 24 when all six electrode impedance indicator lights operated intermittently. The second occurrence was on visit day 50 when the telemetry measurement of the stage of sleep was lost.

Experiment M133 (fig. 16-9) measures electro-encephalograph voltages, left-eye movement, and head acceleration of the subject and records the data on an onboard tape recorder. Logic circuits also use the data to determine the stage of sleep the subject is experiencing. The circuitry then provides a dc voltage output which is routed to a speaker intercommunications station for transmission to the ground. The output voltage assumes one of seven values corresponding to the seven sleep stages identified by the logic. The experiment electronics also contains test circuits that measure the impedance of each of the sensors attached to the subject and, if the electrode impedance is proper, illuminates the corresponding electrode impedance light.

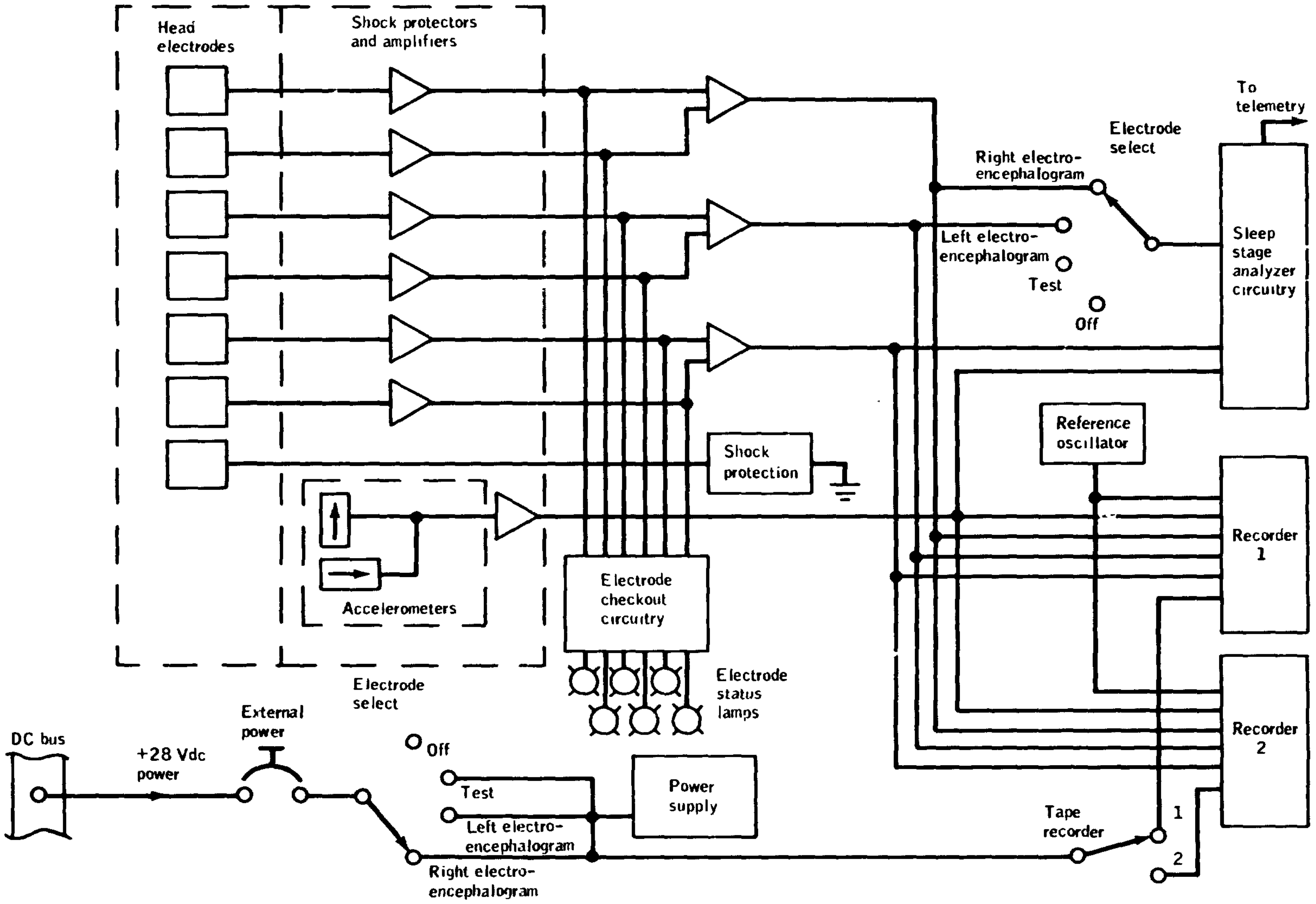


Figure 16-9.- Sleep monitoring experiment functional block diagram.

The head electrodes, as well as the associated accelerometers and preamplifiers, are mounted on a soft cap (fig. 16-10) that is worn by the subject during sleep. An electrical cable connects the soft cap electronics to the experiment electronics. Separate cables also connect the electronics to the speaker intercommunications station and to the utility outlet that supplies experiment power.

On visit day 24, the six electrode impedance indicator lights operated erratically during experiment checkout. The crewman flexed the electrode cap cable near the electronics package connector and determined that the problem was an intermittent condition in the cable. The cable was replaced with a spare cable and the problem was corrected.

On visit day 50, the ground telemetry measurement went to zero volts about 2 hours after the crewman went to sleep and remained at this level for the remainder of the sleep period. The following morning, the crew turned the experiment off, rechecked all cable connections and again turned the experiment on. At that time, the telemetry measurement returned to the proper level where it remained.

The zero-volt reading could have been caused by an interruption of experiment power, an intermittent condition in the logic electronics, or an open circuit in the cable between the electronics package and the speaker intercommunications station. Since the experiment cables are subjected to flexure at the beginning and at the end of each monitored sleep period, and cable failures were anticipated, spare cables were provided. Consequently, the crew replaced the speaker intercommunications station cable and no further problems were experienced with the experiment.

This anomaly is closed.

16.2.3 Experiment S019 Film Canisters Jammed

Film canister 002 of experiment S019 (Ultraviolet Spectrometer) jammed during attempts to transfer film slide assembly frame 58 on visit day 39, and film canister 003 jammed during attempts to transfer film slide assembly frame 83 on visit day 53.

Postflight examination of film canister 002 showed that film slide assembly frame 58 was tilted and jammed hard in the front transfer guides of the supply side (fig. 16-11). The spring pickup claws were riding on the outside of the nylon slide frame, and one of the claws was badly bent. The slide was jammed in a position that blocked the extension and retraction of the carriage.

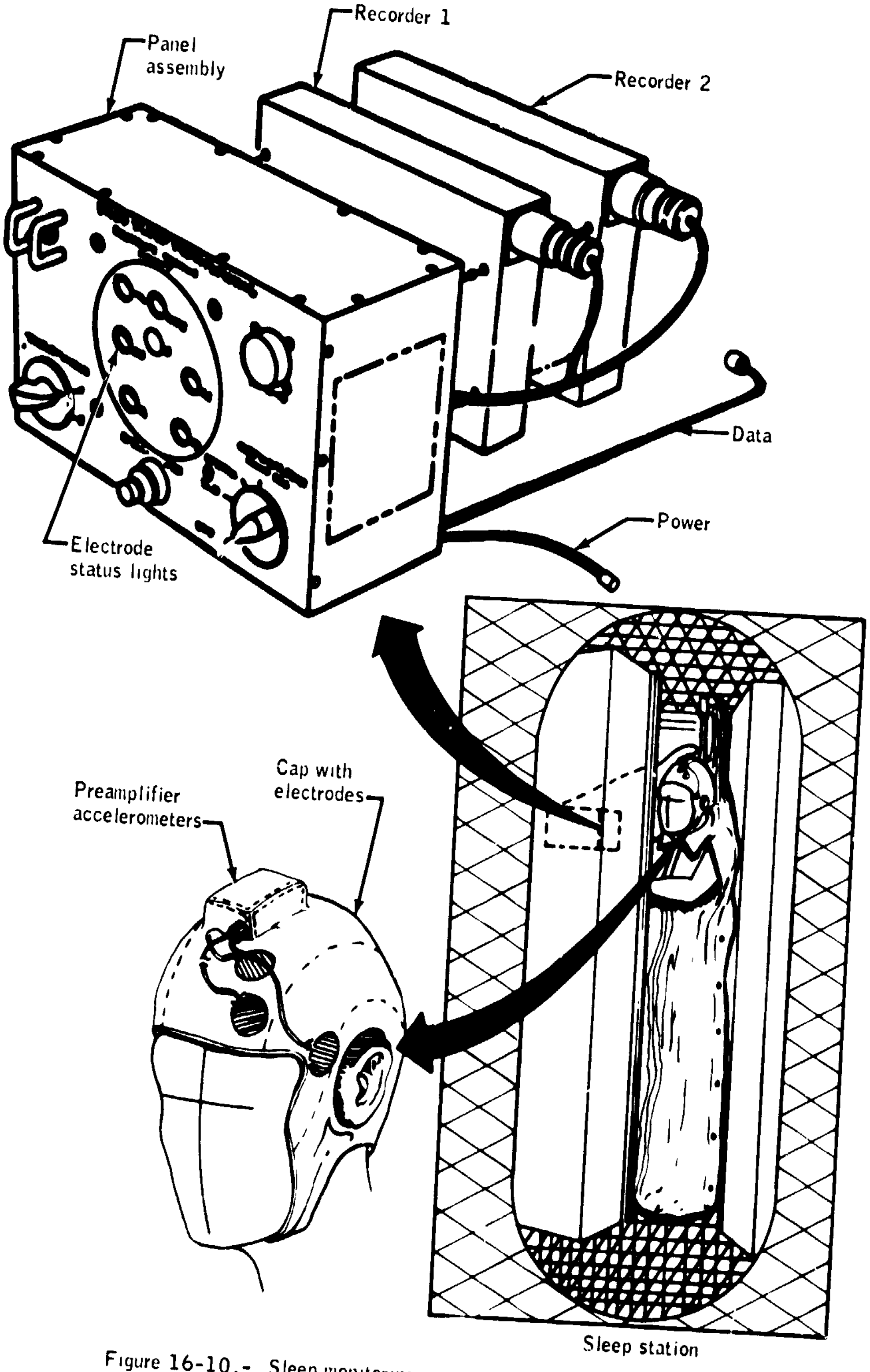


Figure 16-10.- Sleep monitoring experiment equipment.

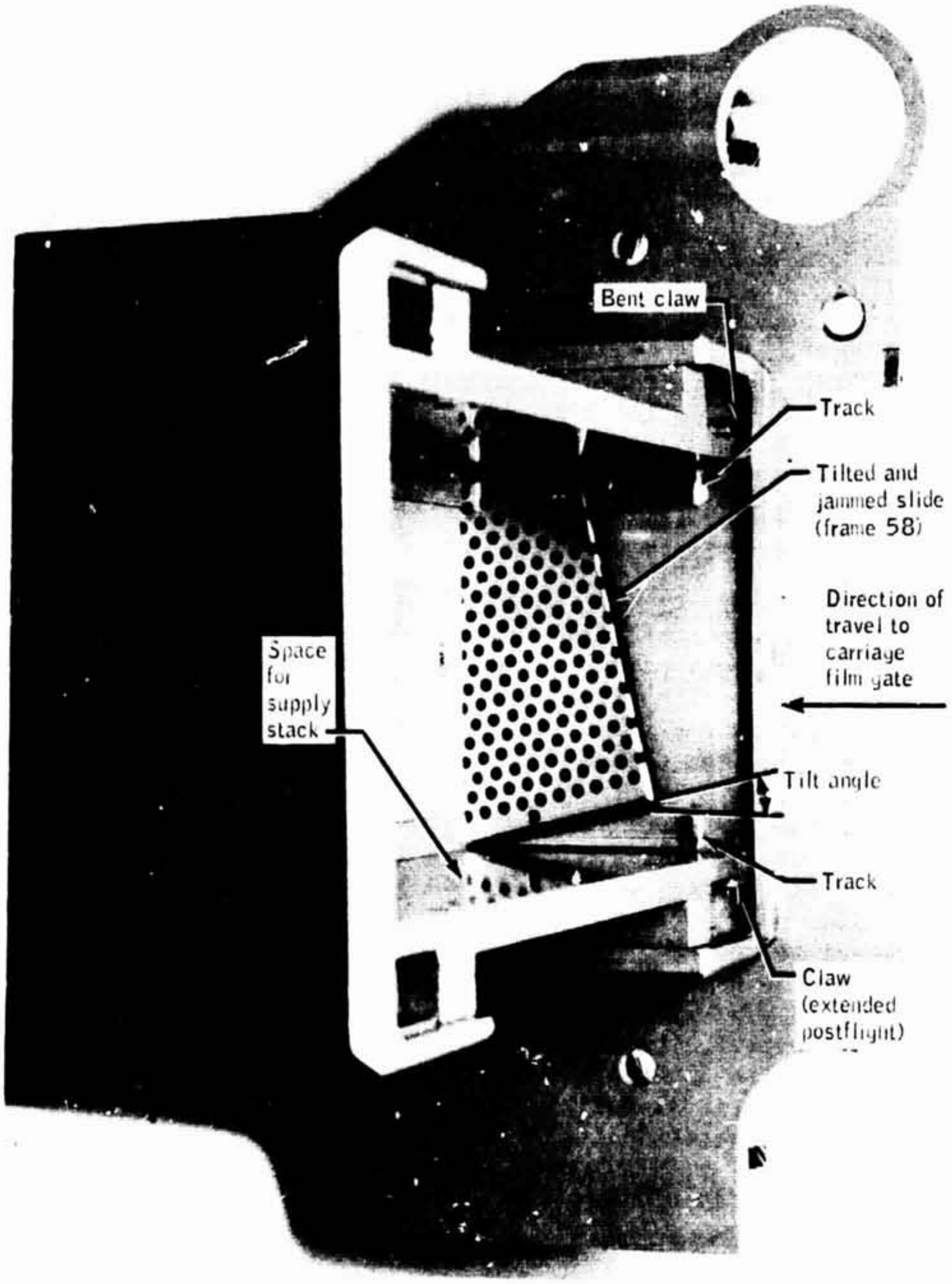


Figure 16-11.- View of jammed frame 58 in canister 002 with remainder of supply stack removed.

When a slide sticks during lateral transfer, but does not become tilted, the claw spring arms allow the slide to spring aside without being damaged. However, clearance space to allow the claws to spring aside no longer existed when the slide was tilted as shown in figure 16-11, and one claw was badly bent.

Normally, film slides are mounted in the film canister in two equal stacks, 81 slides in the supply stack and 81 slides in the takeup stack. Postflight examination of canister 002 disclosed a total of 83 slides in the supply stack. The greater-than-normal number of slides indicates that the front claws were sliding over frame 58 and that the rear claws transferred two frames from the takeup stack and wedged them into the rear of the supply stack until no more could be inserted. Subsequent cycling sequences caused the control crank clutch to slip because no more slides could be transferred. The carriage could neither extend nor retract.

Canister 002 was a refurbished qualification and trainer unit. A possible misalignment of one of the front claws could have caused the claw to slip off of the slide assembly and initiate the tilting of the slide as the other claw continued the transfer motion.

Postflight examination of film canister 003 showed that film slide assembly frame 83 was partly disassembled and jammed in the carriage film gate (fig. 16-12). The slide assembly had almost completed normal slide positioning within the film gate when the leading edge of the film slide assembly metal platen stopped against a square edge in the gate, causing the slide assembly nylon frame to spring aside. This resulted in approximately 0.1 centimeter of the platen extending outside of the gate on the supply side, and prevented extension and retraction of the carriage. During postflight testing, a light finger pressure against the faces of the two separated parts snapped the platen and frame together, and operation was restored to normal.

Disassembly of film slide assemblies during slide transfer occurred preflight. However, the mode of disassembly within the carriage film gate was different from any previously experienced. Additional care in refurbishment and functional verification of each canister had reduced the frequency of inadvertent disassemblies.

This anomaly is closed.

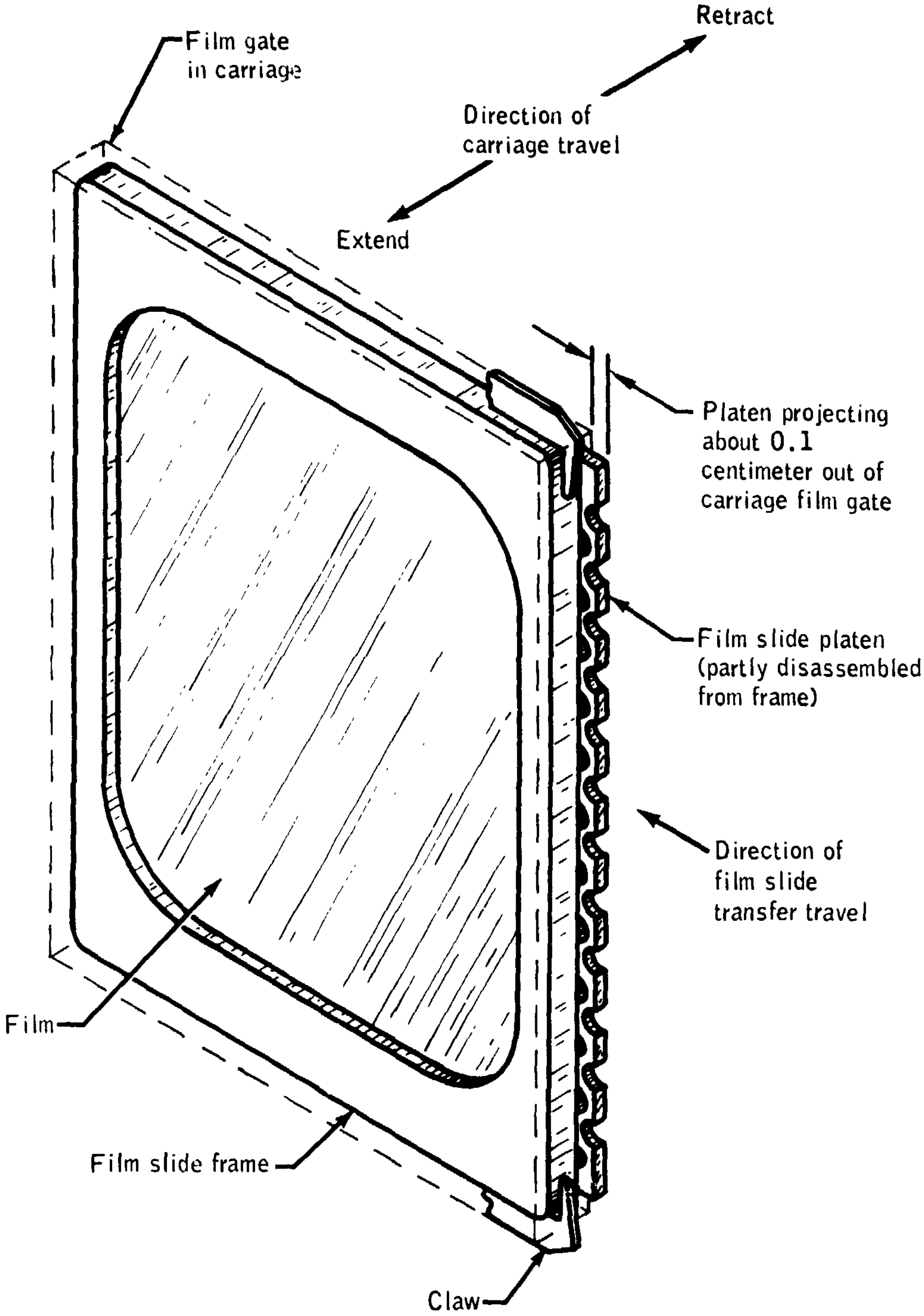


Figure 16-12.- Partial disassembly of frame 83 in canister 003.

16.2.4 Experiment S019 Articulated Mirror System Rotation Problems

The tens and hundreds digits in the rotation counter stopped indexing on visit day 48. As the mirror rotation hand wheel was turned, the tenths and units wheels continued to rotate normally, but the belt on which the tens and hundreds digits were mounted no longer moved.

An alternate procedure was implemented for the remainder of the visit to determine the mirror rotation position in terms of the number of clockwise turns of the rotation hand wheel from a sighting of a visual reference (viewing the discone antennas) together with the units and tenths reading on the rotation counter.

A shift of about 2 units in the units wheel of the rotation reading occurred on visit day 60 as indicated by changes in the visual reference alignments. Additional shifts of a similar nature occurred randomly during some subsequent operations.

The rotation counter indicated the angle of rotation of the mirror from 0 to 360 degrees in tenths of a degree increments. The counter was an off-the-shelf counter that had been modified for this application. A gear train from the mirror rotation drive assembly drove the drive shaft of the counter (fig. 16-13). The counter wheels for the units and tenths and the sprocket wheel which drove the belt for the tens and hundreds digits were mounted on the same drive shaft. Only the tenths wheel was pinned to the shaft. With each rotation of the tenths wheel, a pin projecting from the left face of the wheel indexed the units wheel one digit by driving it with a geneva wheel and a transfer pinion gear. The tens and hundreds belt and sprocket wheel was indexed one pair of digits in a similar way through a transfer tooth on the left side of the units wheel and a half-tooth/full-tooth pinion (fig. 16-14). The wheels and gears were made of Delrin material.

The engraved numbers on the counter wheels were filled with a luminescent material (promethium phosphor and epoxy) to make the numbers visible in subdued light with no additional lighting source. Prior to the third visit, the luminescent material had flaked off the units wheel. The flaked-off material contaminated the interior of the sealed counter housing. The qualification model demonstrated that the binding caused by such contamination could result in the failure of a pinion gear tooth in the counter.

The crew reported than an object, which appeared to be a piece of a gear tooth, was floating inside the counter. This could have been part of a tooth from the pinion gear between the units wheel and the sprocket wheel (fig. 16-14). The belt would not index with part of the tooth missing.

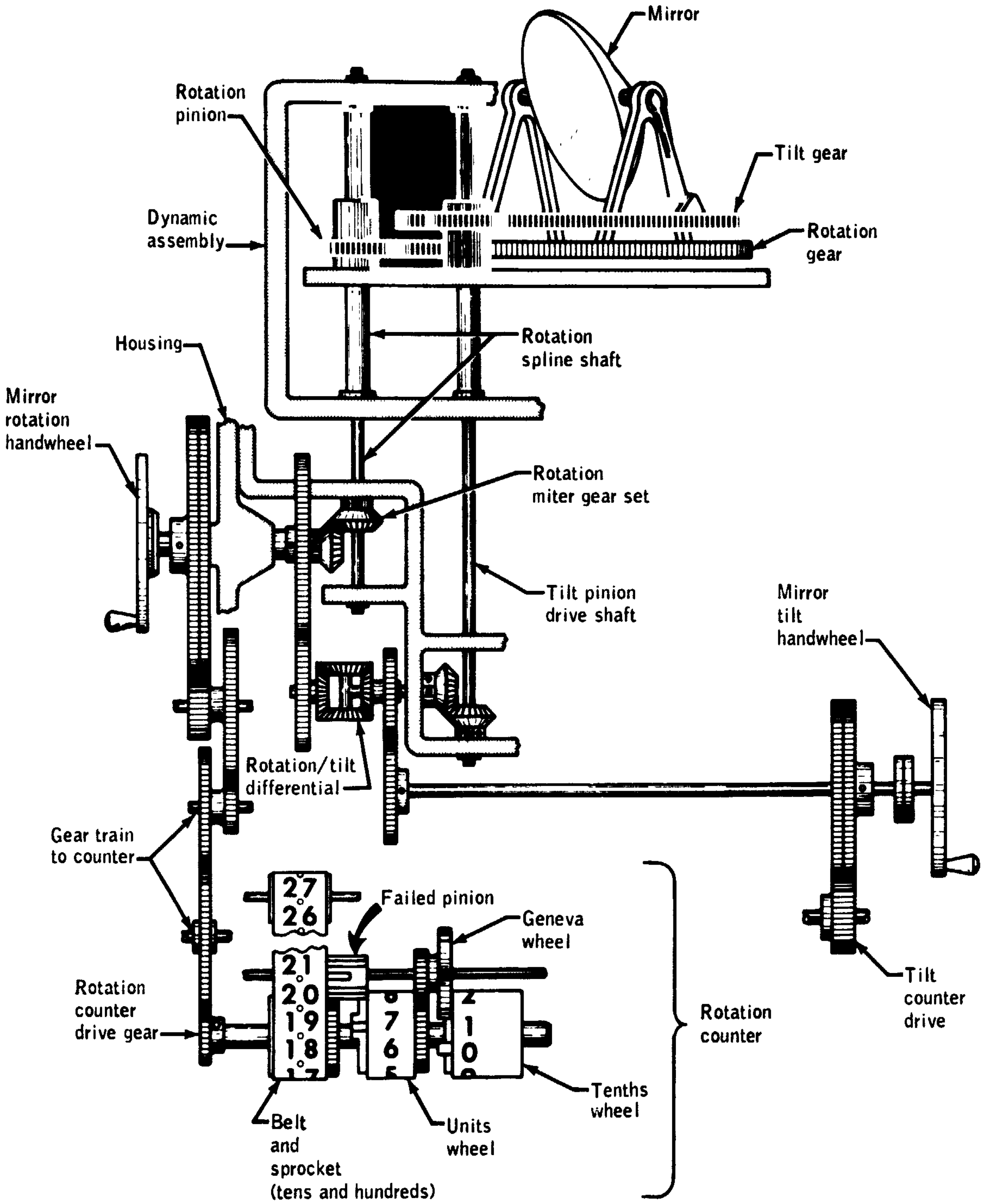


Figure 16-13.- Articulated mirror system rotation drive and counter.

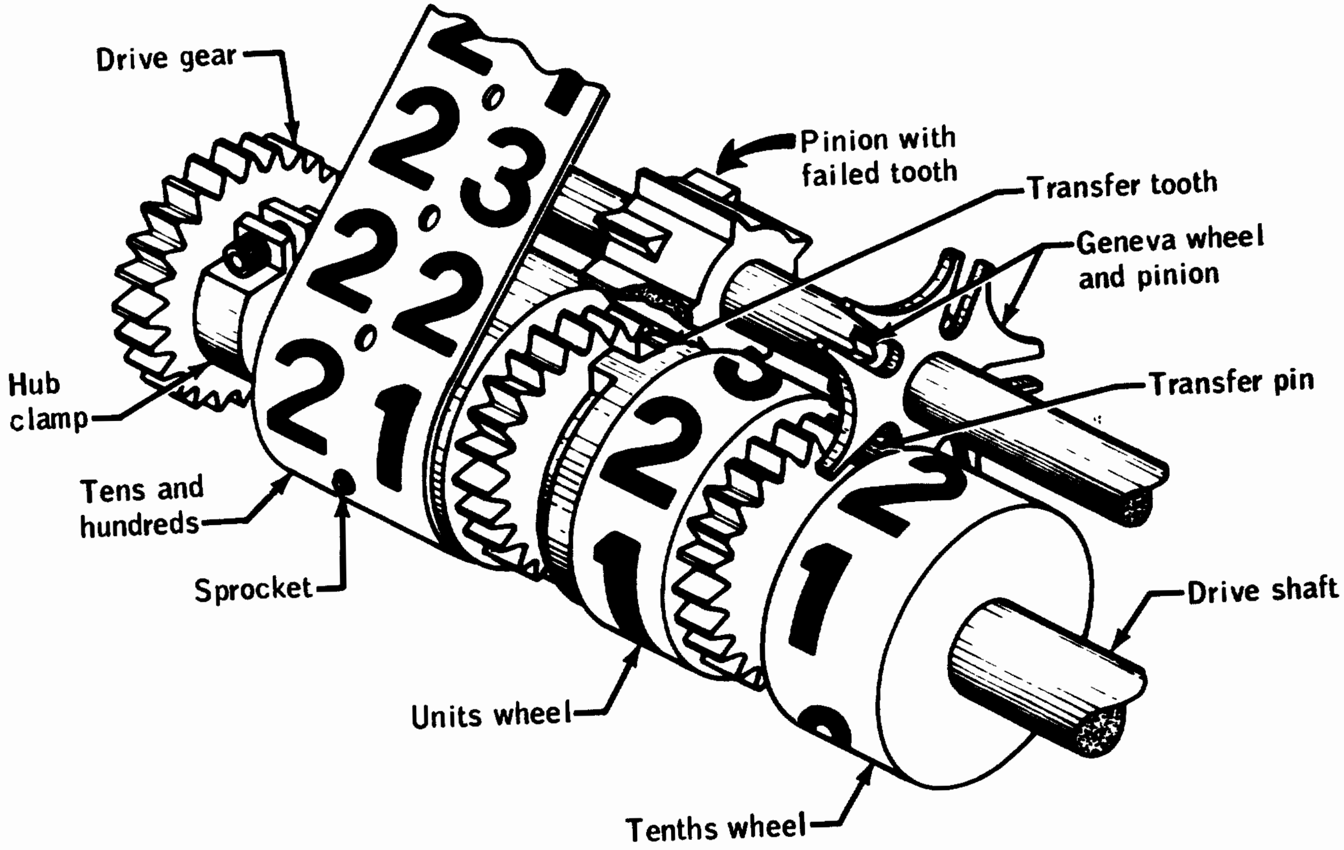


Figure 16-14.- Rotation counter.

Handwheel rotation was transmitted from the handwheel shaft to the mirror rotation gear and pinion telescoping spline shaft through a 27-tooth 48-pitch set of miter gears (figs. 16-13 and 16-15). The shafts and gears were pinned or keyed together, precluding any slippage on the shafts. However, wearing of gears, shims, or retainers could result in a loose set of gears and this could allow the miter gears to occasionally jump a tooth. A similar condition was duplicated with the much-used qualification unit. The counter on the qualification equipment would indicate movement as the handwheel was turned but the mirror would not rotate when the miter gears jumped a tooth. Jumping one tooth would make a difference of about 18 milliradians in mirror rotation (equivalent to a 1.05° indication on the rotation counter).

The drive from the handwheel through the compensating differential system for tilt/rotation synchronization (fig. 16-13) would cause a change in the mirror tilt position while the miter gears jumped a tooth, and the rotation gear was not moved. This condition was also observed in flight during visual reference alignment checks.

The equipment was restowed in the Workshop at the end of the visit and, consequently, no postflight examination was possible. The sealed counter assembly was not opened in flight because of the possibility of the crew inhaling the radioactive luminescent material.

The most probable causes of the third visit articulated mirror system problems were (1) failure of the pinion gear between the rotation counter units wheel and the sprocket wheel, induced by contamination from the luninescent material, and (2) an excessive increase in clearance between the rotation drive miter gears. No further experiment operations are planned; therefore, no corrective action will be taken.

This anomaly is closed.

16.2.5 Station 6 Malfunction Light Illuminated After Film Clearing for Experiment S190A

The film advance malfunction light for camera station 6 of experiment S190A (Multispectral Photographic Facility) illuminated when the experiment was placed in the automatic mode. This occurred after the three-frame film clearing advance for Earth Resources Experiment Package pass 30. The crew reported that all station counters had advanced three frames and that the station 6 malfunction light was illuminated during the remaining operations. Previously, during pass 29, the station 6 malfunction light had not illuminated when using the same magazine. The crew performed the malfunction procedure, and verified that magazine L-6 was advancing film and that the station 6 malfunction light did not illuminate when a replacement magazine was substituted for magazine L-6.

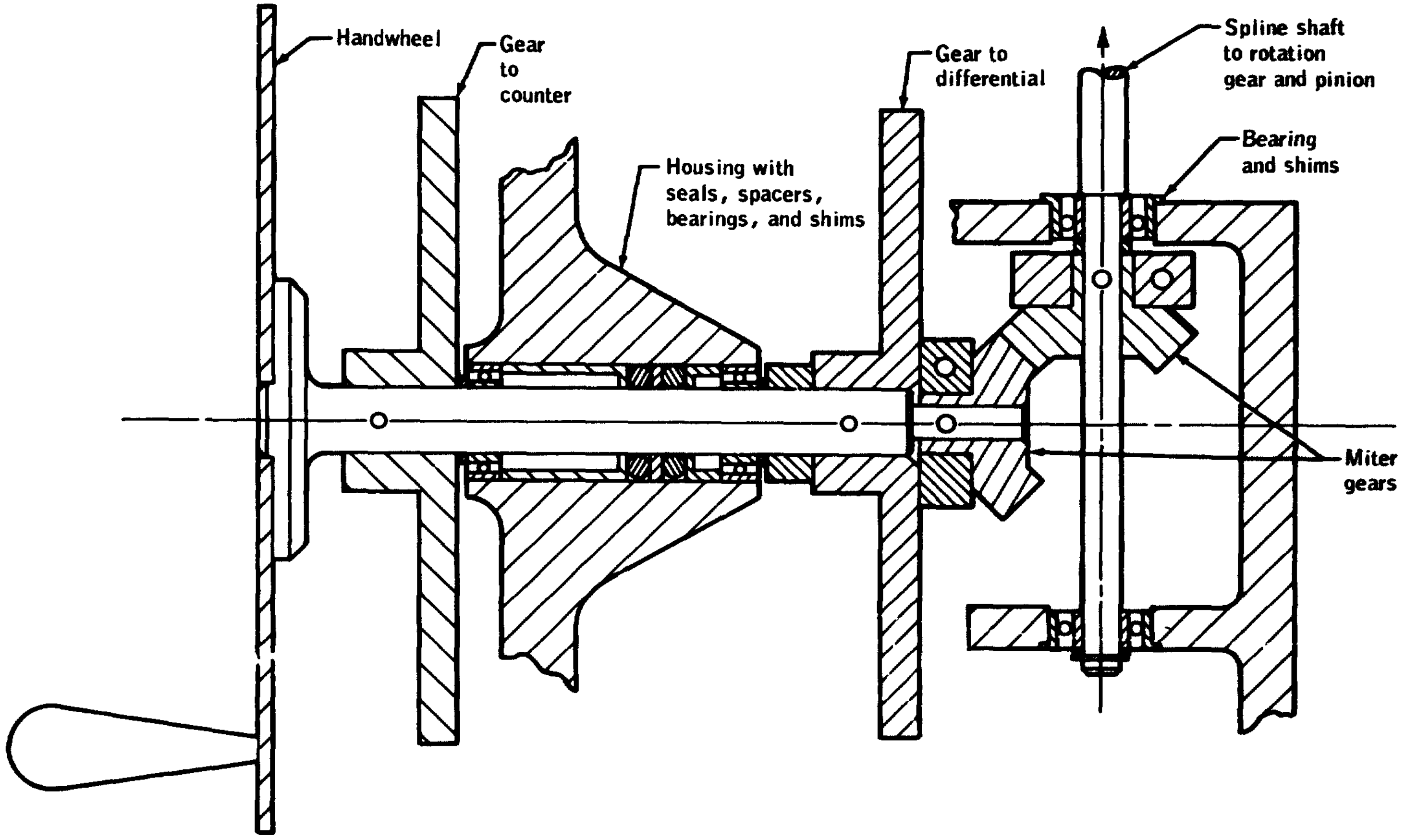


Figure 16-15.- Rotation drive assembly miter gear set.

The film motion indication is initiated by the rotation of the supply spool (fig. 16-16). Spool rotation is transferred through a linkage system and a series of gears to the motion sensor. The motion sensor generates a film motion pulse. If the film motion pulse is not generated after an exposure is made, the associated malfunction light will illuminate.

The film must be tight on the supply spool for the supply spool to rotate after an exposure is made. A film clip attaches the end of the film to the supply spool (fig. 16-16). The malfunction light will illuminate because of slack film within a cassette in a newly loaded magazine. This type of problem occurred during first visit operations. However, once the film is tightened on the supply spool, the film must break or detach from the film clip to come loose from the supply spool.

The film motion sensor is located in the magazine drive assembly which is external to the film magazine. A failure of the film motion mechanical linkage in the magazine would illuminate the station malfunction light.

Magazine L-6, in use during this time, either had loose film on the supply spool or a failed film motion drive train. Since no further experiment operations are planned, no corrective action is required.

This anomaly is closed.

16.2.6 Experiment M092 Blood Pressure Cuff Failed

The experiment M092 (Lower Body Negative Pressure) blood pressure cuff (fig. 16-17) failed to produce a blood pressure light and a readout on the experiment support system display panel.

Figure 16-18 shows the cuff output signal circuitry. The cuff produces two electrical signals, one of which is proportional to the cuff pressure with the other being proportional to the Korotkoff sound (arterial blood flow sound). The onset and decay of the Korotkoff sound is used to gate the sample times of the systolic and diastolic blood pressures. The gating is accomplished in the sound level detector circuitry and in the decision circuitry. Also, the Korotkoff light will flash when the Korotkoff sounds are detected by this circuitry.

The two cuff output signal leads and the preamplifiers (fig. 16-18) are contained internally in the insulated wire bundle, shown as part of the cuff assembly in figure 16-17. The remaining parts of the blood pressure system are contained in the experiment system.

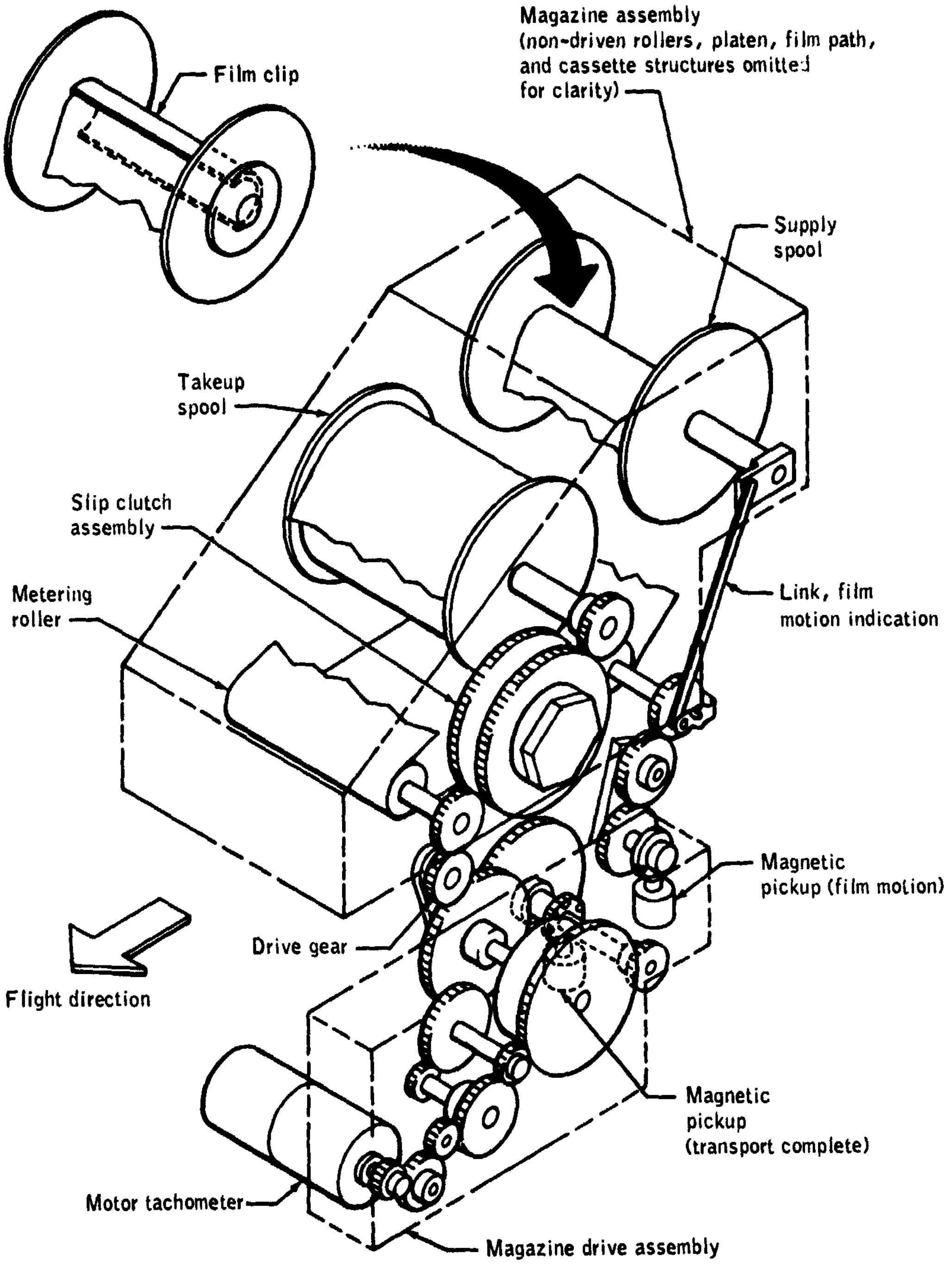


Figure 16-16.- Film transport mechanism.

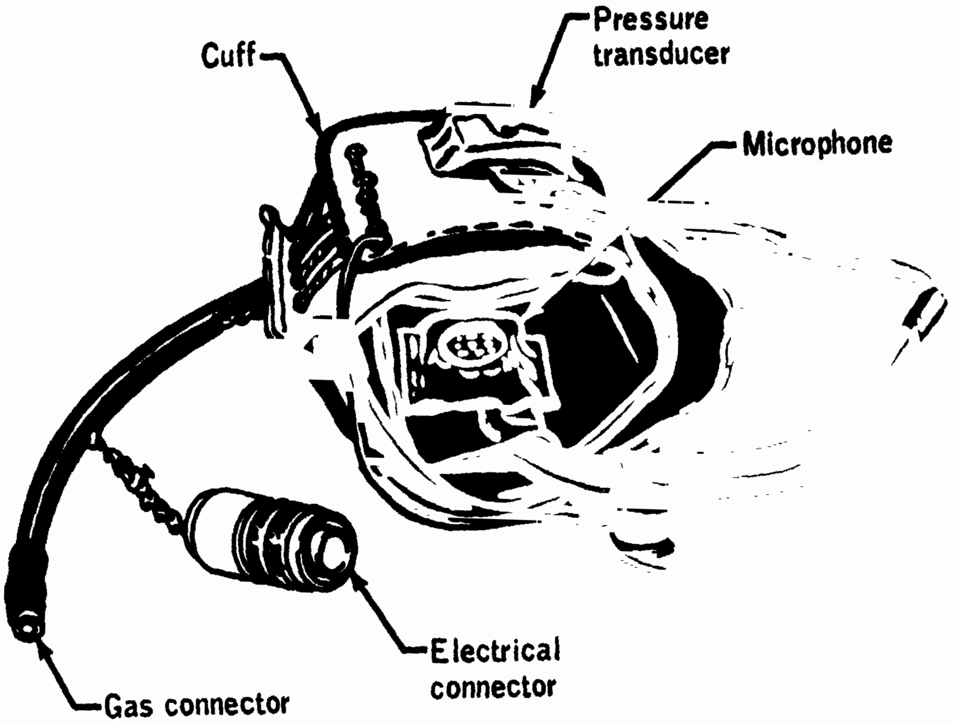


Figure 16-17.- Cuff assembly.

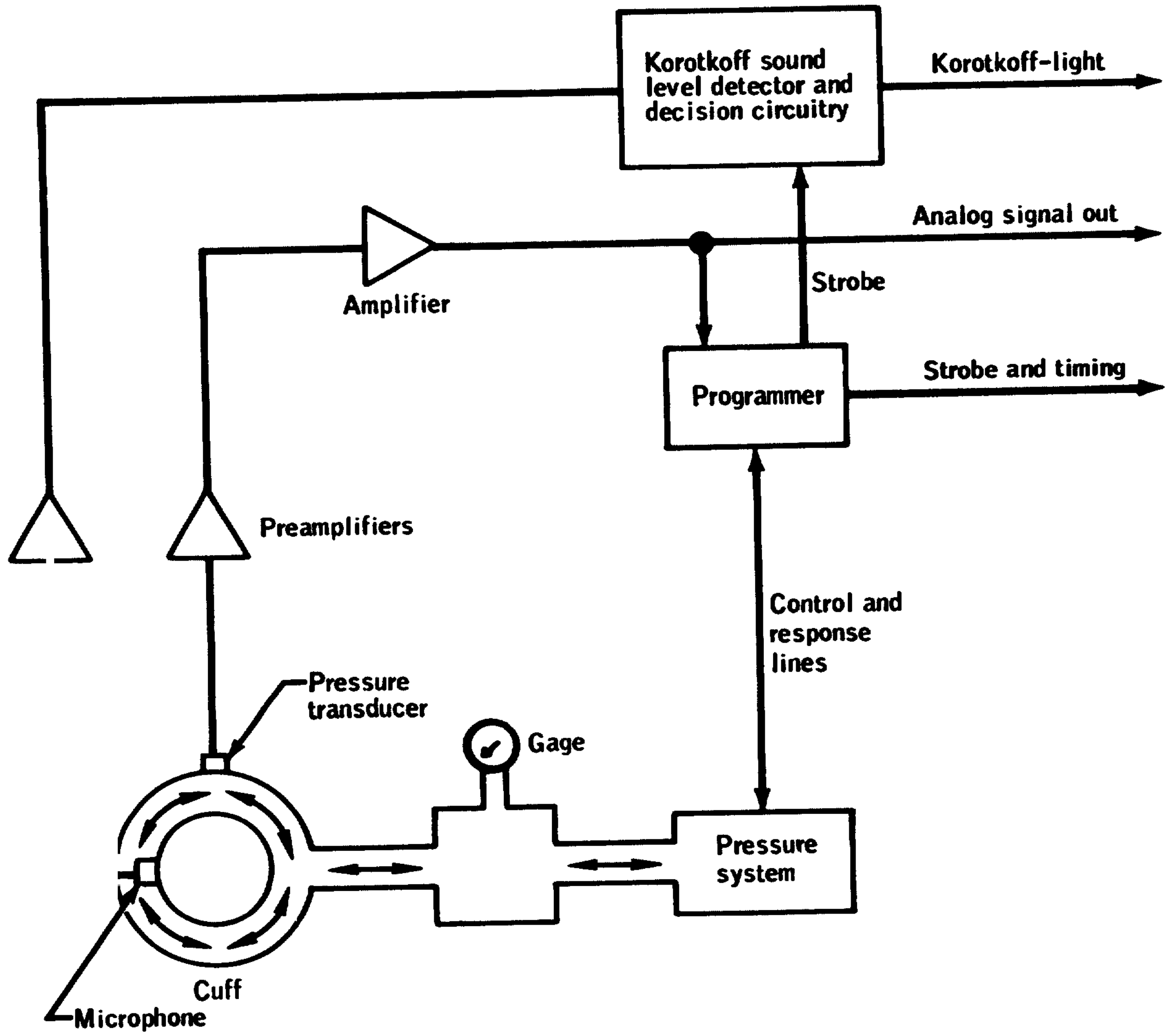


Figure 16-18.- Block diagram of cuff circuitry.

Blood pressure cuff 011 ceased to produce blood pressure readings on the experiment support system digital display on visit day 74. Also, the Korotkoff light ceased to flash. Loss of the pressure signal output would result in the loss of feedback control of the pressure system and in an increasing pressure at the cuff. These conditions would be observable on the cuff pressure gage and would be felt by the test subject. These indications did not occur so this possibility can be eliminated.

Loss of the Korotkoff sound signal output would result in the symptoms observed. This could result from a broken wire in the insulated wire bundle that connects the cuff to the rest of the system.

Broken wires occurred during ground tests and were expected. Consequently, spare cuffs were carried in flight. Replacing cuff 011 with cuff 012 completely restored the blood pressure measuring functions. Cuff 011 was not returned to earth precluding postflight failure analysis.

This anomaly is closed.

16.2.7 Experiment S193 Antenna Roll Gimbal Failed

The experiment S193 (Radiometer/Scatterometer and Altimeter) antenna would not drive to positive roll angles after visit day 55. Data showed that the antenna was being properly commanded for both positive and negative roll angles, but the gimbal motor power amplifier was supplying current for negative-angle drive only.

The gimbal motor is driven by a servo amplifier (fig. 16-19). The antenna position command signal is compared to the antenna position feedback signal at the input summing node. The feedback signal is generated by the antenna position transducer. The error signal output from the summing node drives the servo amplifier differential input stage. The input stage is followed by two push-pull amplifier stages which, in turn, drive a transistor bridge output which drives the gimbal motor.

Since the antenna position command supplied to the servo amplifier was proper, the problem must have been in the servo amplifier. Circuit analysis shows that a failure of one side of the differential input stage would cause a large bias shift in the other side, thus lowering the current delivered to the gimbal motor. However, the flight data showed no such current decrease. Additionally, a short in one of the bridge transistors would result in high currents (about 100 amperes) being taken during motor-drive periods when the shorted transistor should have been cut off. Likewise, such current surges were not seen in the flight data. The failure therefore, must have been in one side of one of the two push-pull amplifier stages (fig. 16-19).

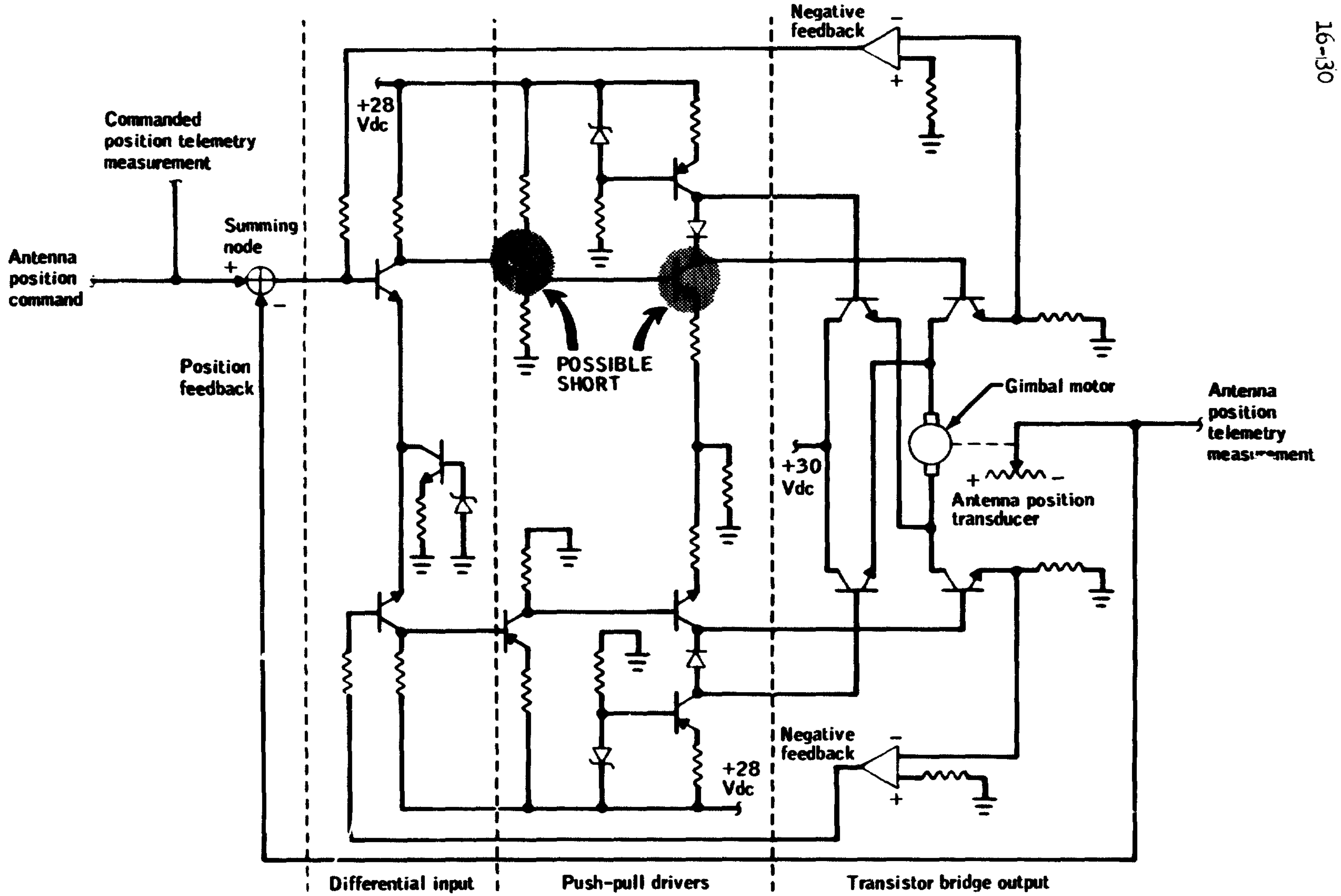


Figure 16-19.- Simplified roll gimbal motor servo amplifier schematic.

No corrective action is required since no Earth Resources Experiment Package hardware is scheduled for a future mission.

This anomaly is closed.

16.3 GOVERNMENT FURNISHED EQUIPMENT ANOMALIES

16.3.1 Astronaut Life Support Assembly Water Leaks

Water leaked from the Commander's astronaut life support assembly in the area of the pressure control unit/life support umbilical composite connector during the second extravehicular activity. Water also leaked from the same interface on the Scientist Pilot's astronaut life support assembly during the fourth extravehicular activity.

The astronaut life support assembly consists of a life support umbilical, a pressure control unit, and a secondary oxygen pack as shown in figure 16-20. The life support umbilical consists of a hose for carrying oxygen, a supply and a return cooling water hose, and a cable for electrical power, voice, and data. The life support umbilical is connected to an Airlock Module panel at the vehicle end, and to the pressure control unit at the astronaut end. The pressure control unit has fluid controls and warning indications for the crewman and has connectors that mate to the crewman's pressure suit and liquid cooling garment within the suit. If the Airlock Module oxygen supply is lost, the secondary oxygen pack will provide a 30-minute oxygen supply.

The composite connector at the life support umbilical/pressure control unit interface (fig. 16-21) consists of three fluid quick disconnects (one for oxygen and two for water), and a 41-pin electrical connector. The composite connector is mated by aligning the two connector halves and rotating the bail bar handle to the left to produce a camming action which mates the two halves of the connector. The bail bar is then locked by compressing its telescoping handle into a detent on the pressure control unit housing. A backup lock with a spring-loaded locking pin is rotated over the bail bar handle and then locked to prevent the handle from moving out of place.

Approximately 3 1/2 hours into the second extravehicular activity, yellow ice crystals were observed coming from the Commander's astronaut life support assembly. The oxygen temperature sensed in the pressure control unit at the inlet to the pressure suit dropped to about 273° K which is below the normal 283° to 289° K range. The temperature drop resulted from cooling by the freezing and sublimation of the water. The yellow color of the crystals resulted from the chromate (bright yellow), which is used in the water loop as a corrosion inhibitor.

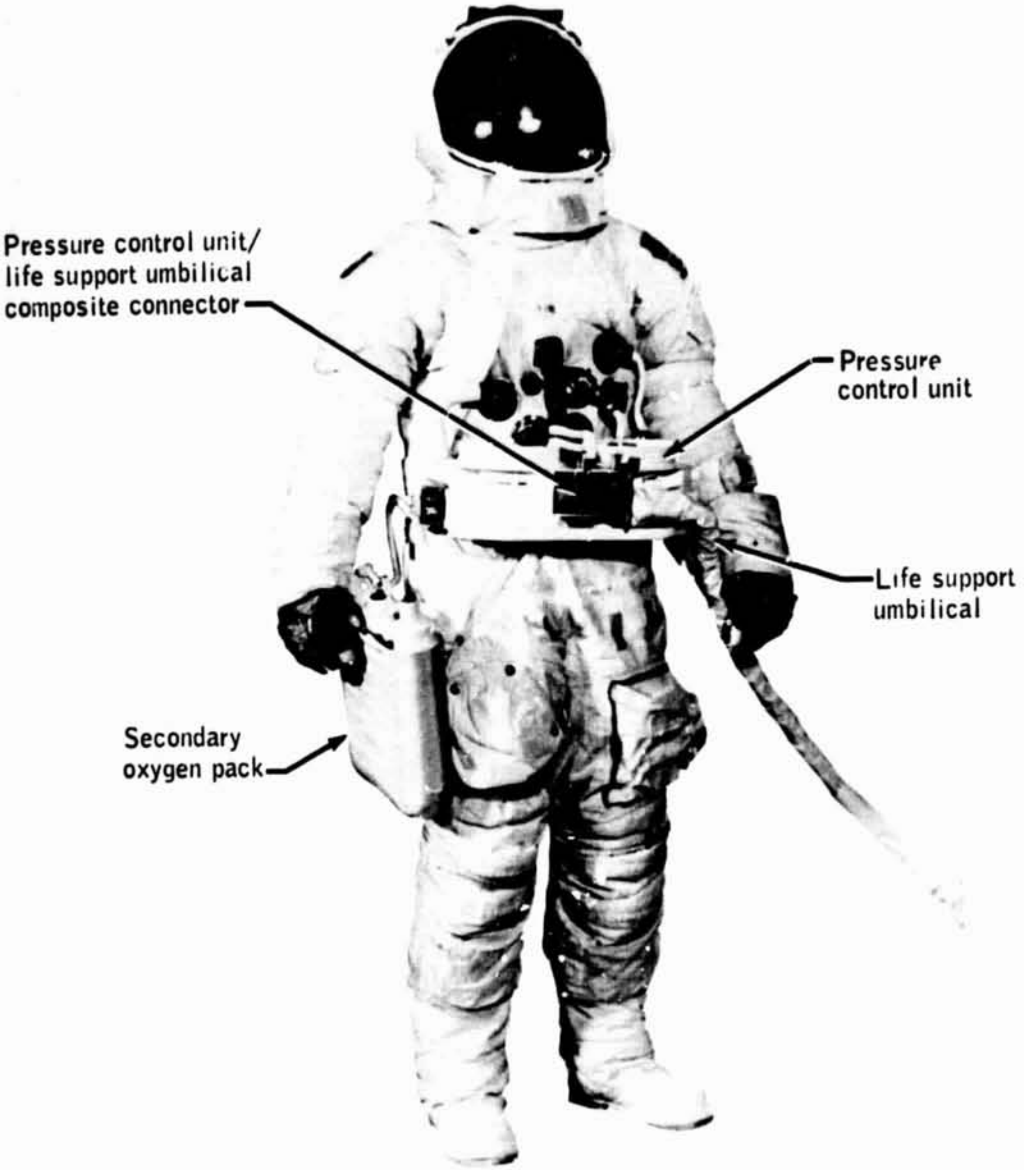


Figure 16-20.- Astronaut life support assembly.

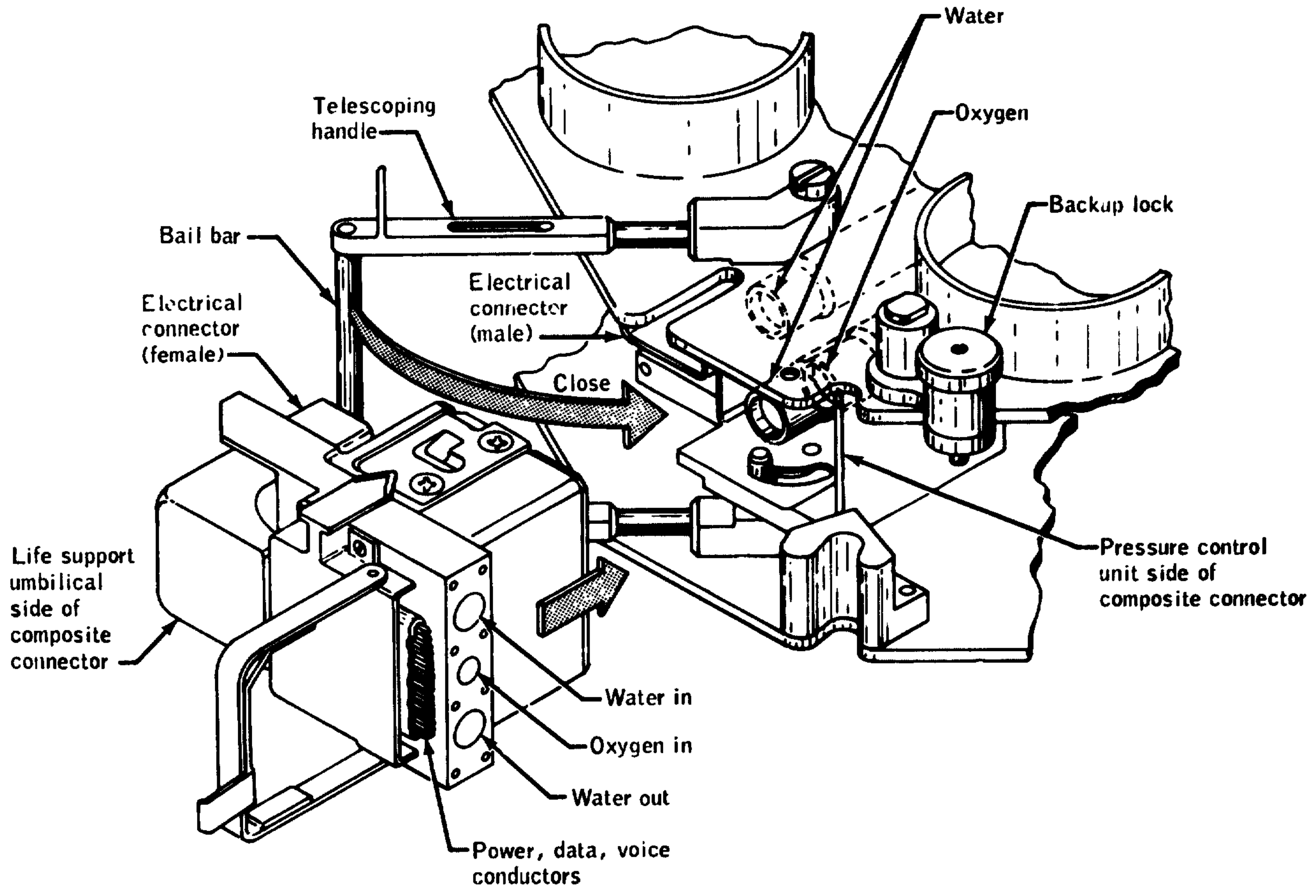


Figure 16-21.- Composite disconnect.

After the extravehicular activity, the crew observed a large yellow ice deposit around the composite connector. The ice indicated that the leak was in the water quick disconnect (fig. 16-22) of the composite connector. The pressure control unit and life support umbilical were replaced by spare units.

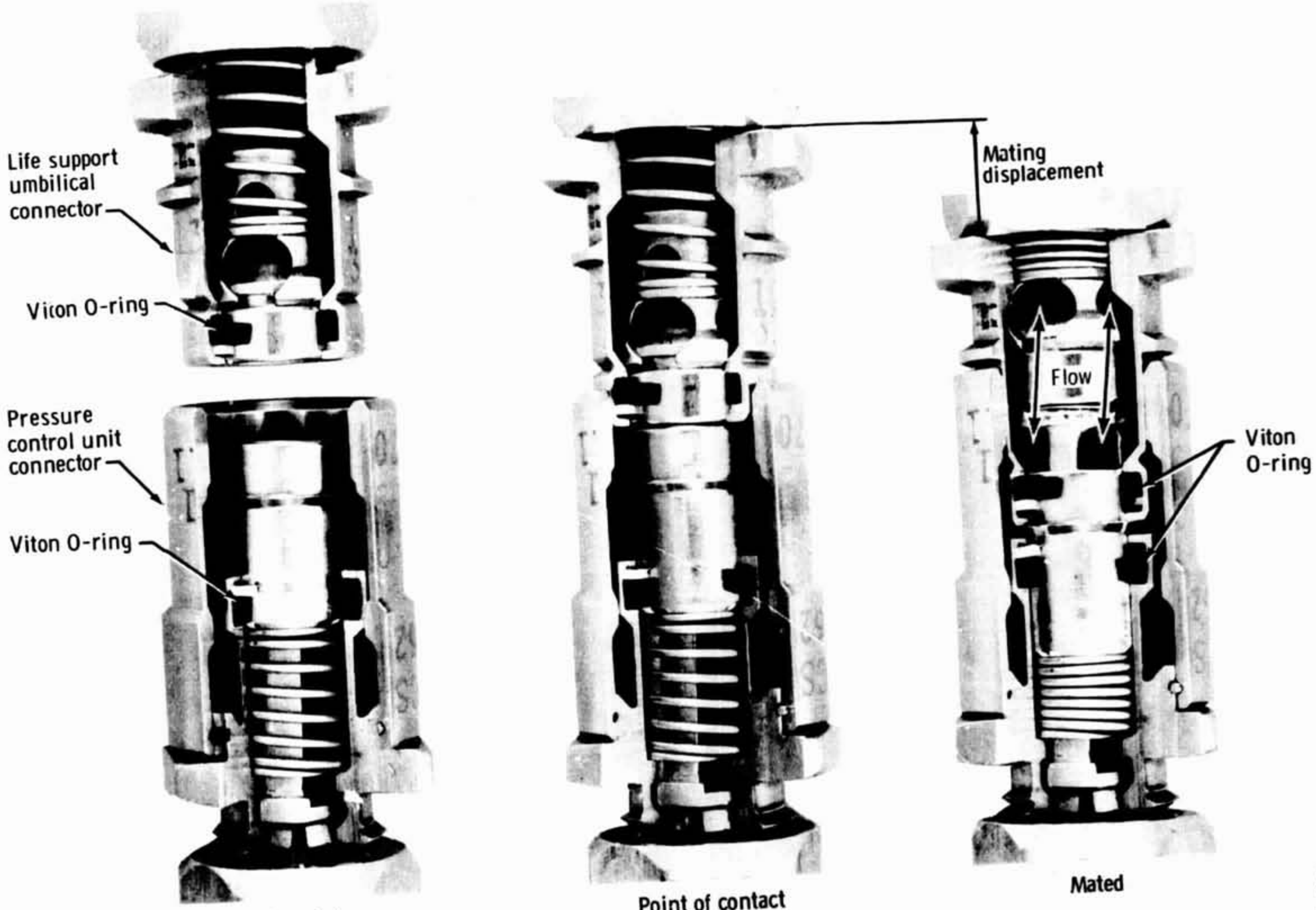
Approximately 3 hours into the fourth extravehicular activity, the Commander reported that a water leak had been noted about 25 minutes earlier on the Scientist Pilot's extravehicular equipment and that the leak was similar to that which occurred during the second extravehicular activity. The leak was described as a sporadic spaghetti-like stream about 1/4 centimeter in diameter that was squirting out and freezing instantly. The leak was almost eliminated by positioning the pressure control unit diverter valve to the minimum-flow setting.

About 53 minutes prior to this leak, the Scientist Pilot reported that the front of his life support umbilical had been bumped against a light fixture and some paint had been chipped. Later, while working in the fixed airlock shroud area, the Scientist Pilot reported that his composite connector backup lock had been caught by one of the clotheslines and was pulled open. The bail bar had moved out, but did not rotate more than a tenth of a radian. The Scientist Pilot then resecured the bail bar and backup lock. A ground test of an identical unit showed that leakage could not have occurred as a result of the clothesline incident.

A ground test was conducted on a spare quick disconnect assembly in an attempt to duplicate the leak observed on both occasions. The leak was reproduced by pressurizing the quick disconnect with gaseous nitrogen, chilling the connector to 273° K in an ice bath, and then applying a small side load, such as is caused by bumping the life support umbilical. The leak stopped when the quick disconnect was placed in a warm water bath. This condition was repeated five times with identical results.

Two similar types of failures had occurred during ground testing of other pressure control units. Failure analysis performed on these leaking quick disconnects indicated that leakage past the Viton O-ring (fig. 16-22) was induced by side loading. The side loading also induced a slight set to the Viton O-rings. Analysis indicated that a failure of this type would not require aborting the extravehicular activity. If all of the water were depleted from the suit umbilical system loop, the extravehicular activity could have been completed on gas cooling only; however, the crewman's work rate would have to have been reduced to about 1056 kilojoules per hour or less.

An astronaut will slide or bump against objects during any extravehicular activity. Therefore, the long life support umbilical protective shield will be struck and, acting as a long moment arm, provide enough stress on



Unmated

Point of contact

Mated

Figure 16-22. - Quick disconnect operation.

the composite disconnect to induce relative motion between the sealing surfaces. Tests have shown that Viton should not be used as a seal where relative motion between sealing surfaces is experienced in accompaniment with temperatures.

If the astronaut life support assembly or other hardware utilizing these connectors is used on any future programs, the composite disconnect and connectors should be redesigned to eliminate the problems associated with the backup lock and water leakage.

This anomaly is closed.

16.3.2 Data Acquisition Camera Anomalies

Inflight reporting and postflight testing of the 16-mm data acquisition cameras, the 43-meter film magazines, and the 122-meter film cassette transporters disclosed eight failures of the camera system. Postflight examination and testing of all nine returned cameras showed that seven had experienced operational failures of varying severity. These failures included a drive motor that started intermittently, a mode selection circuit that would operate only at 24 frames per second, an out-of-focus problem, a drive motor that would not start at all, a camera that would not advance film, an indicator light circuit that was open, and another light circuit that operated intermittently. One 43-meter film magazine jammed, causing an inaccessible fuse to blow in the ultraviolet panorama camera (experiment S183). This report discusses all of the 16-mm data acquisition camera hardware failures that occurred during the third visit.

The 16-mm data acquisition camera system was used to take still photographs or motion pictures of physical science experiments, medical experiments, and other crew activities. The system consisted of cameras, film magazines, lenses, ring sights, supporting fixtures, and accessories for power and remote control.

Each camera (fig. 16-23) is energized by 28-Vdc power and has five shutter speeds or mode-of-operation speeds. The five modes of operation are time exposure for still pictures, and 2, 6, 12, and 24 frames per second for motion pictures. The camera has three operating controls (figs. 16-23 and 16-24): the operate pushbutton, the shutter speed selector lever, and the mode selector lever. A 43-meter film magazine or a reloadable 122-meter film cassette could be used.

The 43-meter magazine stores both the unexposed and the exposed film. A film footage indicator is located on the magazine cover (fig. 16-23) and indicates the percent of the film load remaining. An end-of-film light illuminates when 183 centimeters or less of unexposed film remains in the

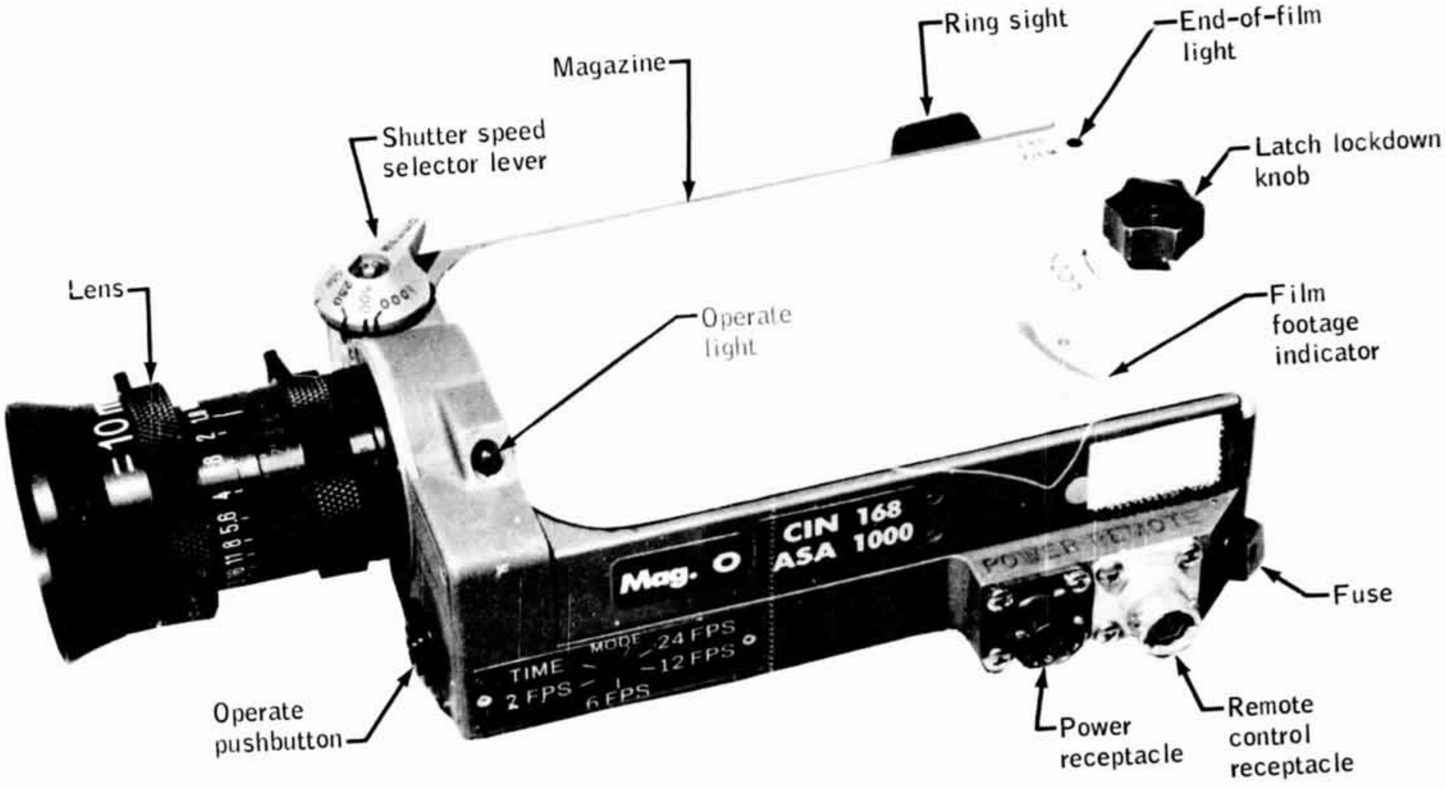


Figure 16-23.- Data acquisition camera and 43-meter film magazine.

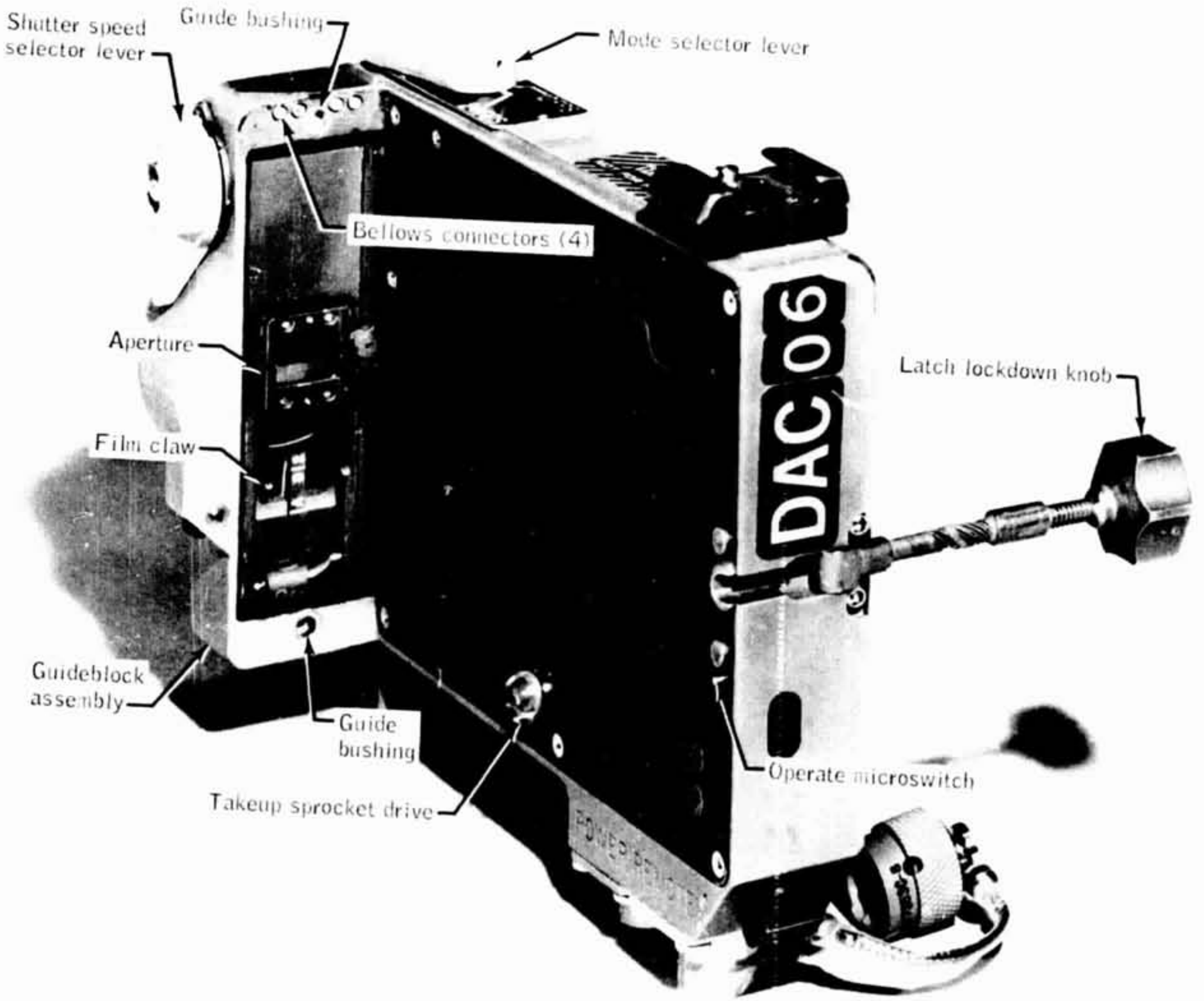


Figure 16-24.- Data acquisition camera magazine interface.

magazine. The camera provides the operational controls and the electrical and mechanical power for the 43-meter magazines (fig. 16-24). Two claws pull the film across the aperture in the magazine; the takeup sprocket drive engages and drives the magazine drive gear; the operate microswitch is depressed and actuated when a magazine is properly installed and locked; and four bellows connectors provide the electrical interface with the magazine.

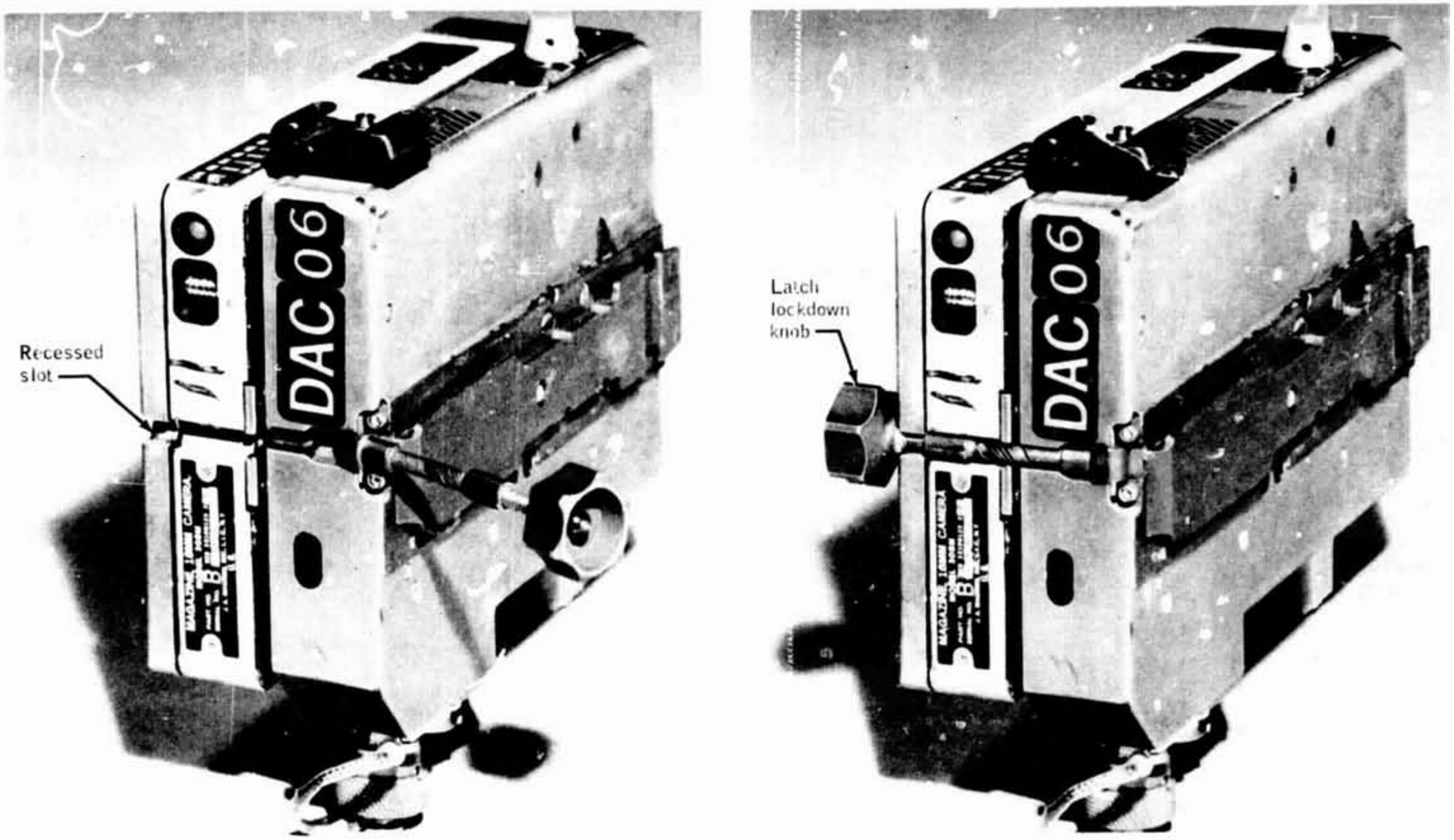
The camera and magazine also have alignment and locking interfaces. The alignment interface consists of two dowels on the magazine that align and mate with two bushings in the camera housing. The locking interface is a recessed slot in the magazine case (fig. 16-25) that fits the camera's latch lockdown knob assembly.

Before installing the magazine on the camera, the film perforations (fig. 16-26) in the aperture area of the magazine require alignment with the perforation alignment mark just below the aperture so that the camera film claws engage the perforations properly. When aligning the film, no more than two pairs of film perforations should be advanced. Over advancement could cause a magazine film jam because the resulting oversize service loop could fold over and become entrained in the magazine drive gear.

Proper installation requires that the leading edge of the magazine be placed in front of the camera takeup sprocket and moved forward so that the camera dowel pins mate with the respective bushings in the magazine. The rear surface of the magazine is aligned such that the camera lockdown shaft can be moved into the recessed slot in the magazine, thereby locking the magazine to the camera.

Camera 1 failure.- Camera 1 operated intermittently during the visit and also during postflight testing. A check of the drive motor armature resistance showed that for 170 milliradians of rotation, the resistance across the brushes was 27 ohms. At all other armature positions the resistance was a normal 10 ohms. The motor would not start in the 170-milliradian high resistance zone, but could be started by jiggling the camera to move the armature out of the zone.

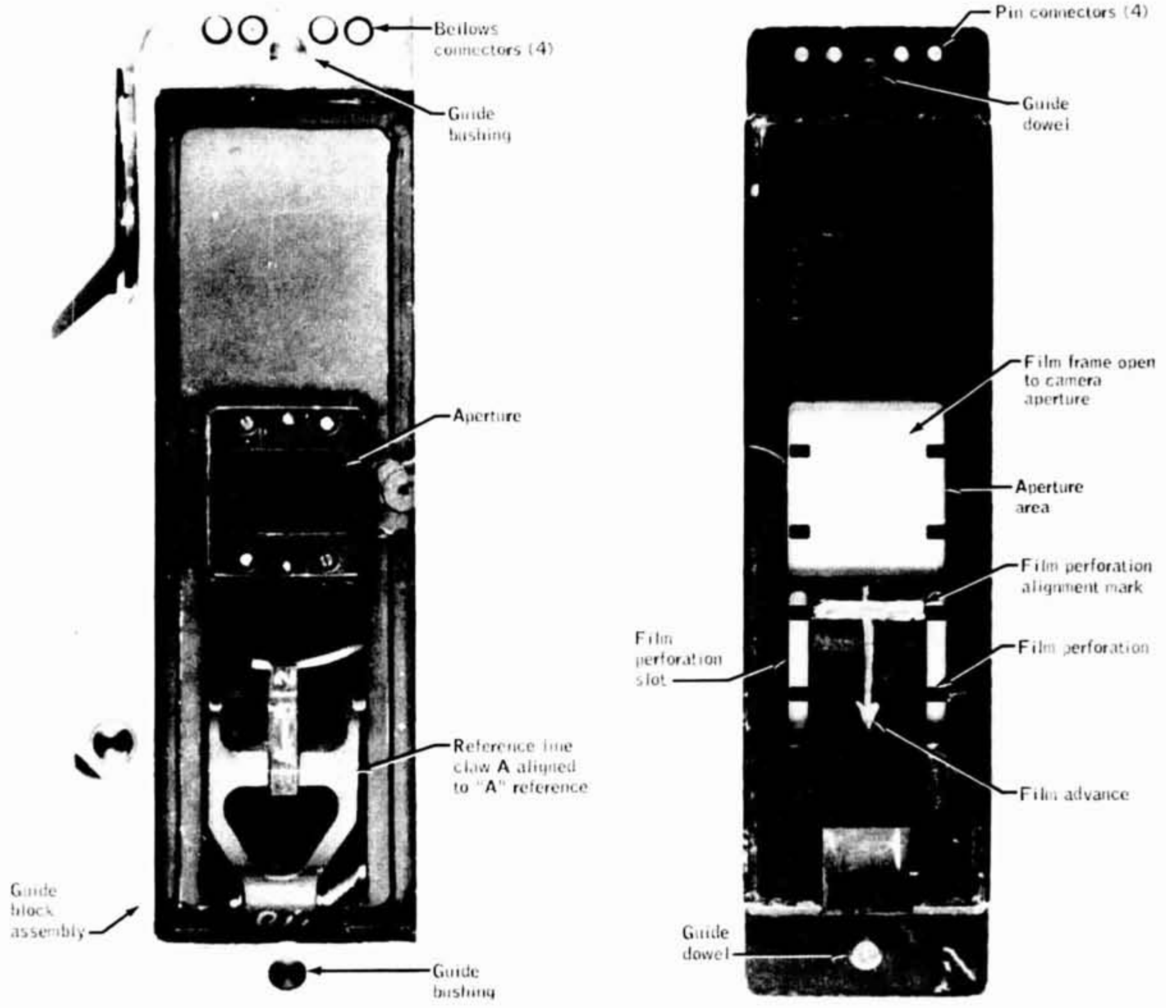
Similar failures have occurred in the past on other cameras. In some, oil migrated between the motor brushes and the commutator. The lubricant was changed, eliminating the problem. In others, the brushes hung up in the brush holders, opening the motor circuit. The brush and brush holder tolerances were corrected to solve that problem. Finally, in others, contamination generated within the motor was caught between the brushes and the commutator segments. Some of these particles were dielectric material that became imbedded in the segments, raising the resistance of one winding. This is what probably occurred in the camera 1 motor.



Magazine mated

Magazine latched and locked

Figure 16-25.- Camera rear view.



Camera

Magazine

Figure 16-26.- Aperture interface.

The motor vendor and design are being changed because of the extensive history of motor failures. Therefore, the failed motor was not opened to determine the cause of the high resistance reading. The failed motor will be replaced by one of improved design so that this camera may be used for future programs.

Camera 2 failure.- Camera 2 operated in the 24-frames-per-second mode, regardless of the frame rate selected.

The shutter and film takeup are driven by a motor and gear train through a slip clutch as shown in figure 16-27. The clutch slips when it is impeded by the de-energized solenoid plunger. When the solenoid is energized, the clutch is released and turns, driving the shutter and film takeup mechanism.

Normally, the solenoid is de-energized by the time the clutch completes one revolution, and the clutch pawl is caught by the solenoid plunger, whereupon the clutch resumes slipping. For each clutch revolution, the shutter rotates once, and the film advances one frame. For motion picture photography, the solenoid may be actuated intermittently to drive the camera at 2, 6, or 12 frames per second, or continuously at 24 frames per second.

The mode selector switch sets the clutch intervalometer command pulse rate. These pulses trigger a silicon-controlled rectifier (Q6 in fig. 16-27) that supplies voltage to the bases of transistors Q8 and Q9. Transistor Q8 is a startup switch and Q9 is a sustaining switch to permit current to flow through the solenoid coil. Both transistors are required for the startup load. As soon as capacitor C11 charges, transistor Q8 base current drops, and this shuts off Q8.

When silicon-controlled rectifier Q6 conducts, capacitor C9 charges through potentiometer R19 and resistor R20. This charging continues until the C9 voltage reaches the unijunction transistor Q7 trigger voltage. During this time capacitor C10 is also charging.

When unijunction transistor Q7 conducts, capacitor C9 is discharged through resistor R24 and diode CR24 and resistor R26. The resulting voltage drop across resistor R26 is in series with capacitor C10. Therefore, a voltage pulse is fed back from the positive side of capacitor C10 to silicon-controlled rectifier Q6, reversing the voltage across the rectifier and turning it off. Since transistor Q9 no longer has base drive, it shuts off and this action de-energizes the solenoid. The plunger springs extend the solenoid plunger into the clutch pawl, causing the clutch to slip. Therefore, the shutter and film takeup drive stop running. Upon receipt of the next command pulse, the clutch control circuit repeats the frame cycle.

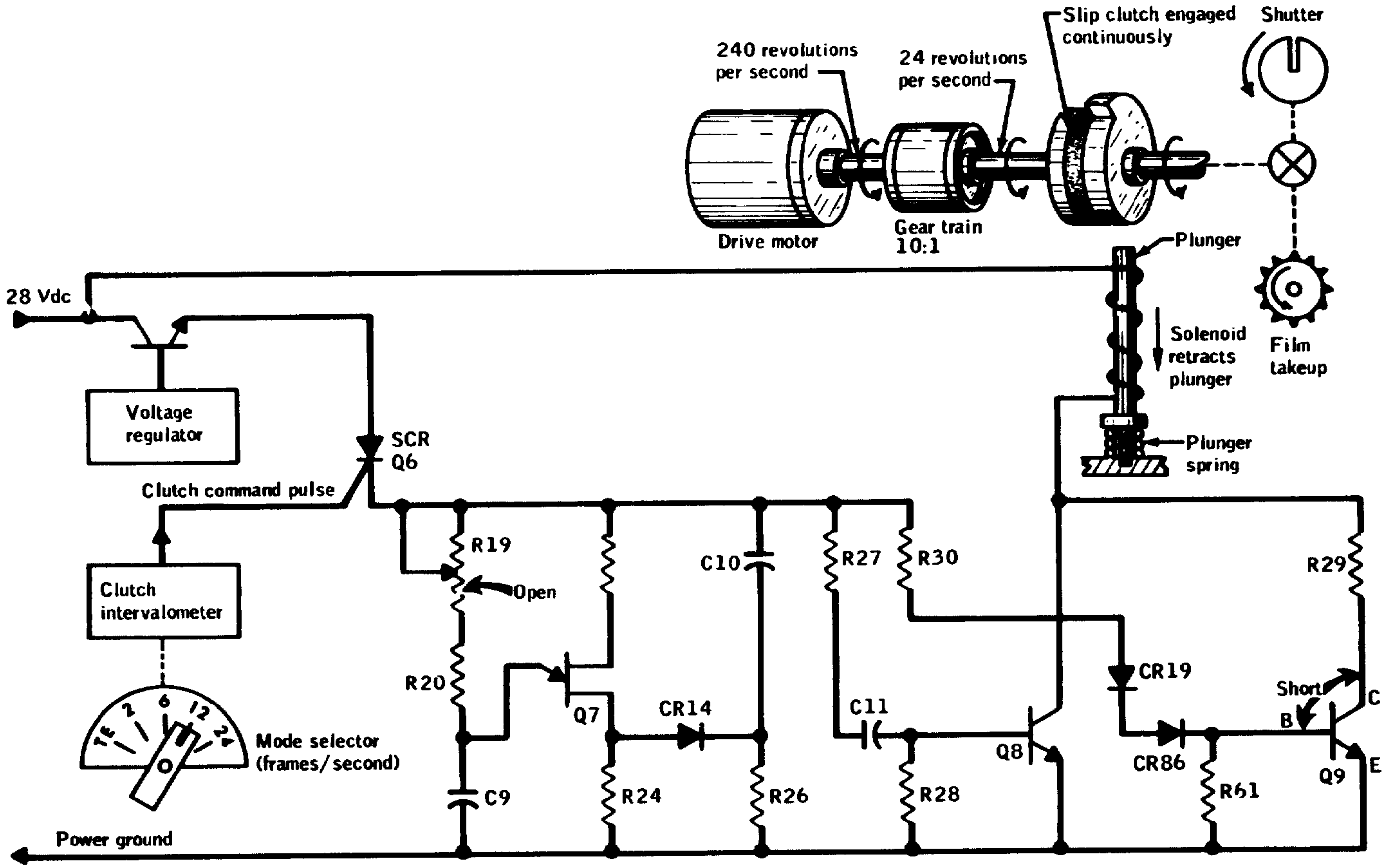


Figure 16-27.- Simplified schematic of the camera 2 clutch control circuit failure.

Due to an unknown cause, potentiometer R19 opened internally. As a result, capacitor C9 never charged, Q7 did not conduct, and capacitor C10 could not provide a shutdown pulse to silicon-controlled rectifier Q6. Since rectifier Q6 continued to conduct, transistor Q9 remained on until it heated sufficiently to cause the base to short to the collector. Thereafter, as long as 28 Vdc was provided to the circuit, current flowed through the solenoid coil and the shorted transistor Q9 to ground. The solenoid plunger remained retracted, allowing the clutch to remain continuously engaged to the gear train output shaft.

Both failed components (R19 and Q9) were replaced. The camera was reassembled and operated satisfactorily in all frame rates.

No corrective action will be taken because spare cameras are carried and this is the only camera electronic component failure to occur during the Apollo and Skylab programs.

Camera 3 failure.- Some of the film exposed by camera 3 showed soft focus, and some portions of the same film roll showed alternate sharp and soft focus. The soft-focus footage was clear enough that engineering data could be determined in most cases. The magazines and lenses used were eliminated as possible causes because they were exchanged regularly and no pattern could be deduced.

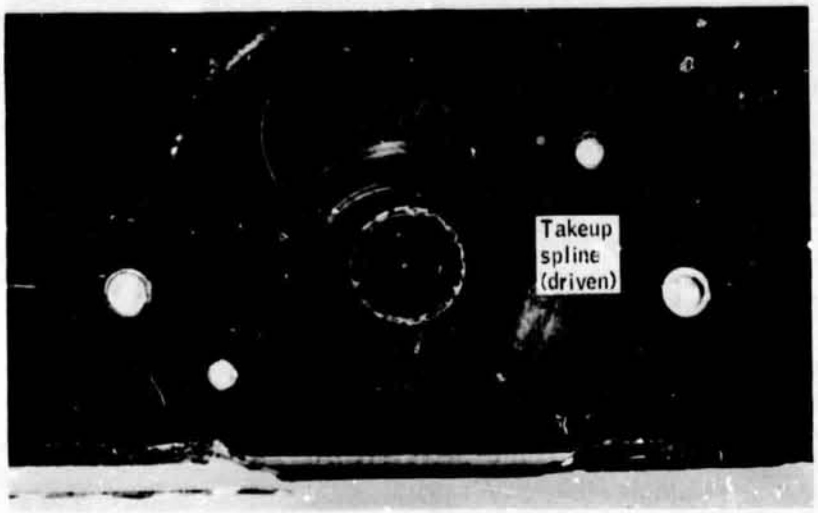
During postflight testing, the distance from the lens seat to the aperture film plane was found to be within specifications. The problem never recurred during postflight examination and test. The camera is currently operating normally.

The cause of the problem is unknown. Camera 3 will not be used for flight again.

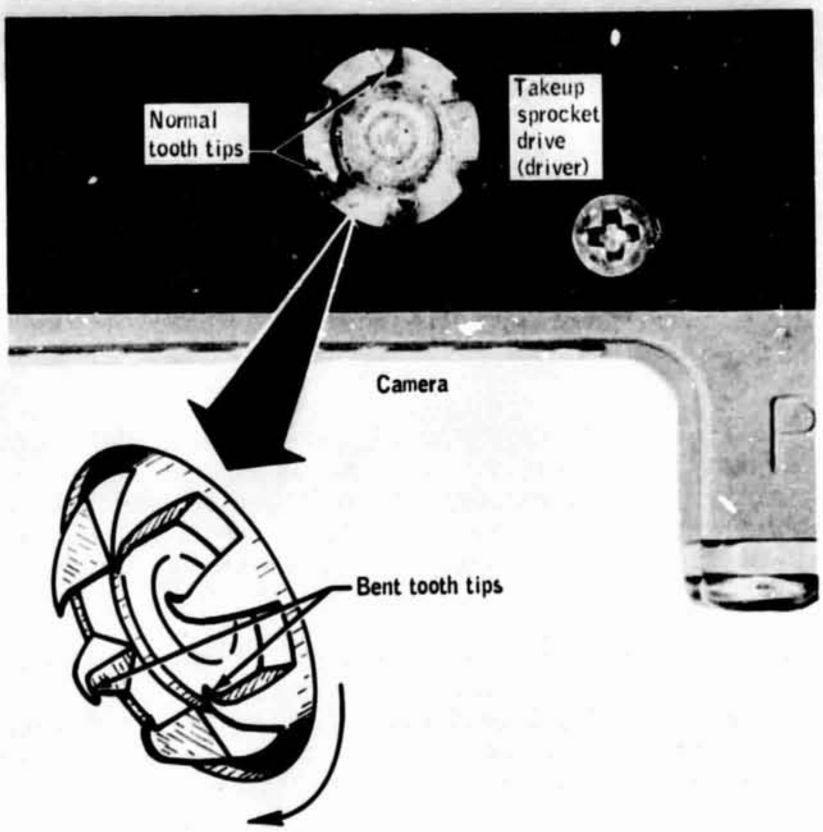
Camera 6 failure.- Camera 6 failed to drive during flight. Postflight testing disclosed a short from the motor brush circuit to the armature shaft. The motor was removed from the camera and disassembled. An internal short was located from the commutator to the shaft. This condition provided a short path to chassis and ground.

The failed motor will be replaced by one of improved design, so that this camera may be used for the Apollo/Soyuz Test Project.

Camera 8 failure.- Camera 8 failed to drive magazines and tore film. Postflight testing showed that the steel drive sprocket teeth were slightly bent at their tips, rendering them unable to engage any magazine spline as shown in figure 16-28. Since the spline could not be turned to drive the magazine takeup mechanism, the two camera claws that advance film across the aperture tore the film perforations.



Magazine



Camera

Damaged sprocket drive

Figure 16-28.- Camera 8 damaged takeup sprocket.

The tansporters were eliminated as the cause of the damaged sprocket teeth because the surfaces surrounding the spline countersink are made of a soft material (magnesium). The 43-meter magazines were eliminated as the cause because all of those used were returned and none showed any evidence of sprocket abrasion. The splines on the transporters and 43-meter magazines are also made of soft material (brass), so they could not damage the camera sprocket. Therefore, the sprocket had to be damaged by being held against a hard material other than a magazine while power was applied, the operate pushbutton actuated, and the interlock switch pin depressed. The cause of this occurrence is unknown.

The drive sprocket will be replaced so that the camera may be used for the Apollo/Soyuz Test Project.

Camera 9 failure.- Camera 9 failed to provide 28-Vdc power to the magazines and, therefore, the end-of-film lights and thread lights would not illuminate. However, since all magazines have film footage indicators, the camera was still usable. Postflight testing showed that the innermost camera bellows connector was broken and collapsed. Therefore, no electrical contact could be made with the mating conductor pin on any magazine used and no 28-Vdc power was provided to the magazine.

The bellows connectors have had a history of failures due to an inherent weakness in the bellows, which resulted from the extremely thin bellows walls. The failed bellows connector will be replaced if the camera is used on the Apollo/Soyuz Test Project mission. The bellows contact design will not be changed because it would require a major redesign of the guide block assembly. Spare cameras will be available to replace a failed unit.

Camera 11 failure .- Camera 11 caused intermittent operation of the film magazine indicator lights. Postflight examination and test showed that the outermost camera bellows connector was cocked and depressed 0 09 millimeter further into its recess than the other bellows. As a result, intermittent indicator light circuit operation resulted from the poor contact of the defective bellows connector and its mating pin on any magazine used.

The outer edge of one film claw was shiny, indicating a slight horizontal misalignment of the transporter-to-camera interface during the filming sequences. Horizontally misaligned film claws would ride against the sides of the two film perforation slots of the magazine (fig. 16-26) and would eventually become polished.

A transporter can slide onto the camera guide block assembly slightly off center so that a connector pin on the transporter enters a bellows connector recess at an angle to the bellows center line, permanently cocking and depressing the bellows. This action has occurred on other cameras during ground operations when installing the relatively heavy 122-meter film transporter on a camera, as opposed to the less massive 43-meter magazine. The off-center mating with the bellows connector is the most probable cause of the problem with camera 11.

The 122-meter cassette system will not be used in the Apollo/Soyuz Test Project. Therefore, no other corrective action is required.

Ultraviolet 43-meter magazine failure.- The 43-meter magazine, loaded with film used for ultraviolet light photography, jammed during a filming sequence, The film magazine metering sprocket (fig. 16-29) had snagged an overly large service loop of film that folded over and became obliquely entrained in the sprocket teeth, jamming the magazine drive mechanism.

Before using a film magazine, a pair of film perforations must be aligned to an indexing mark in the direction of film advance. This activity normally enlarges the film service loop a small amount. The possibility that many such alignments were performed in flight, creating an overly large loop and a subsequent jam, was eliminated since the Pilot stated that it was never necessary to align film perforations on any 43-meter film magazine. Therefore, the only possible cause of the problem was that the service loop was made too large when the magazine was loaded on the ground.

The failed magazine was mated to data acquisition camera 9. This camera, in turn, was optically and electrically mated to the ultraviolet panorama camera (experiment S183) as shown in figures 16-30 and 16-31.

The data acquisition camera power circuit was protected by a 1.5-ampere fuse. The data acquisition camera was automatically powered and operated by experiment S183. The accessory power circuit in experiment S183 was also protected by a 1.5-ampere fuse. However, that fuse also supplies power to the experiment S183 forward transfer motor, return transfer motor, magazine advance motor, and relay counter circuit. When the magazine jammed, the 1.5-ampere fuse in the S183 experiment opened first because its load was greater than that of the fuse in the data acquisition camera. Since the S183 fuse was inaccessible to the crew, a jury-rigged circuit was manufactured to provide experiment S183 with 28-Vdc power for the three motors and relay counter.

When a fuse protects multiple branches and one or more of the branches contains an additional fuse, the main fuse should be rated to guarantee that the blow time is greater than any of the branch fuses. If the main fuse is inaccessible, a lower rated control panel circuit breaker should be added to the circuit for accessibility and circuit protection.

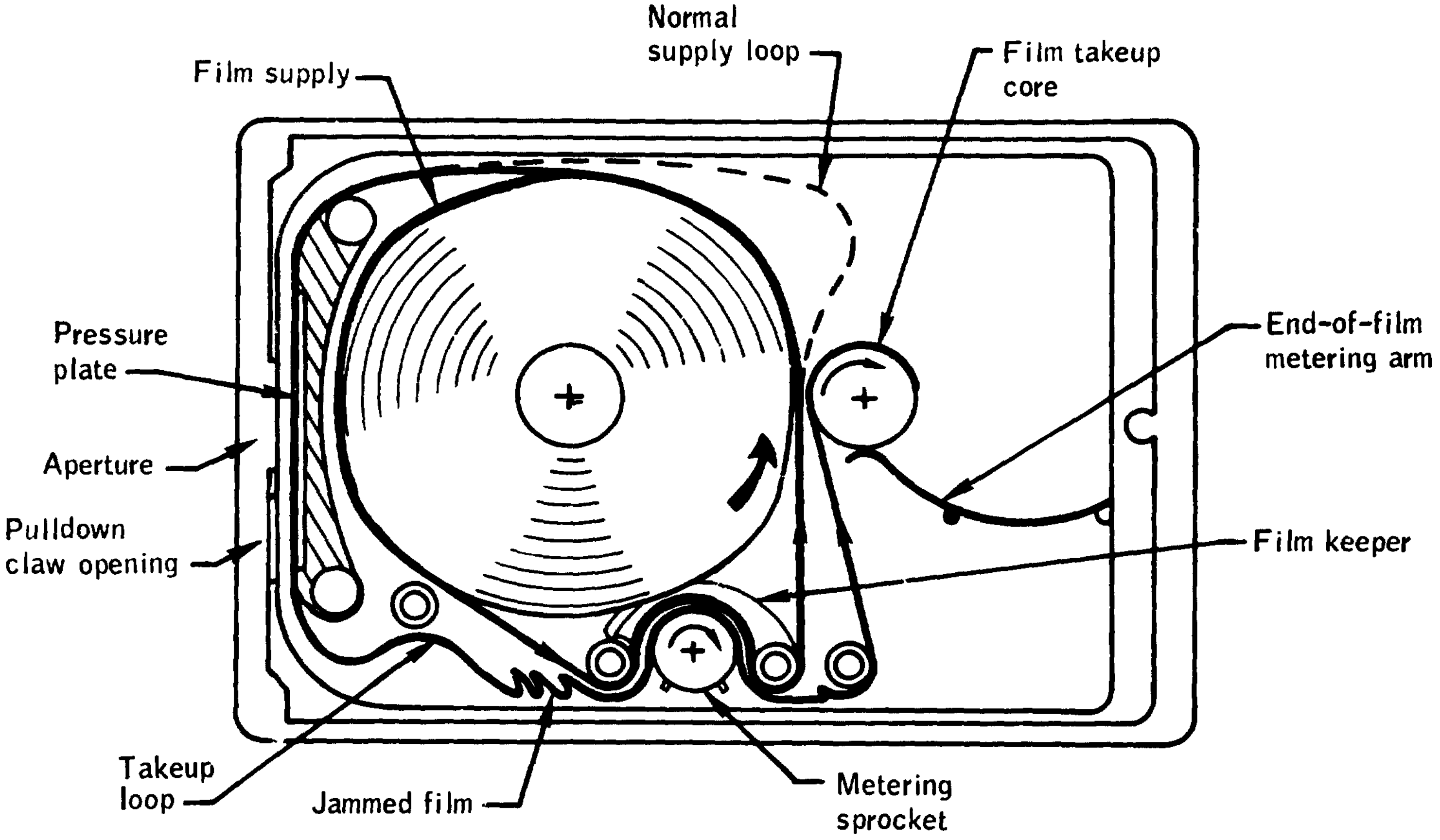


Figure 16-29.- Film threading diagram for 43-meter magazine.

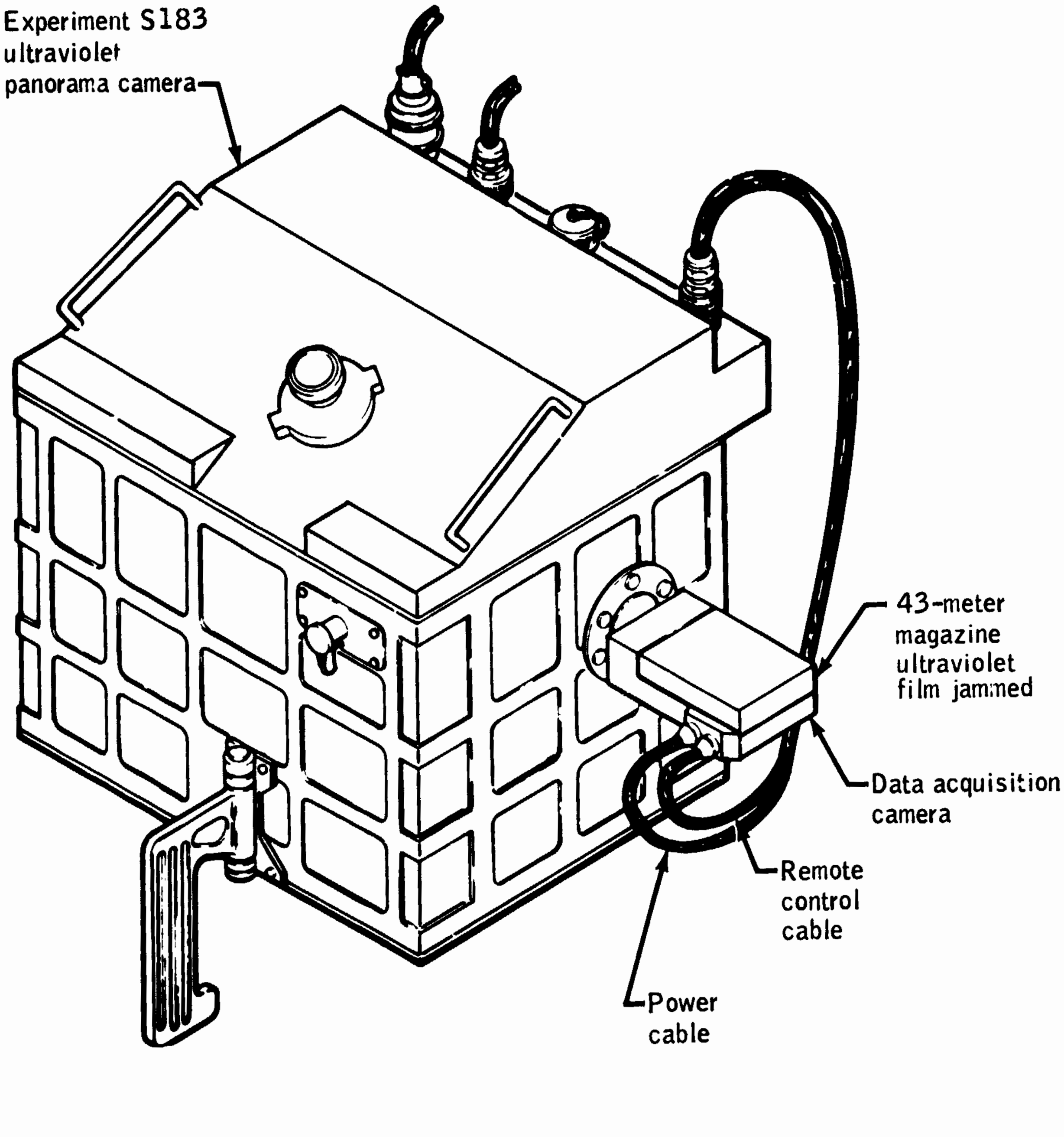


Figure 16-30.- Data acquisition camera/experiment S183 interface.

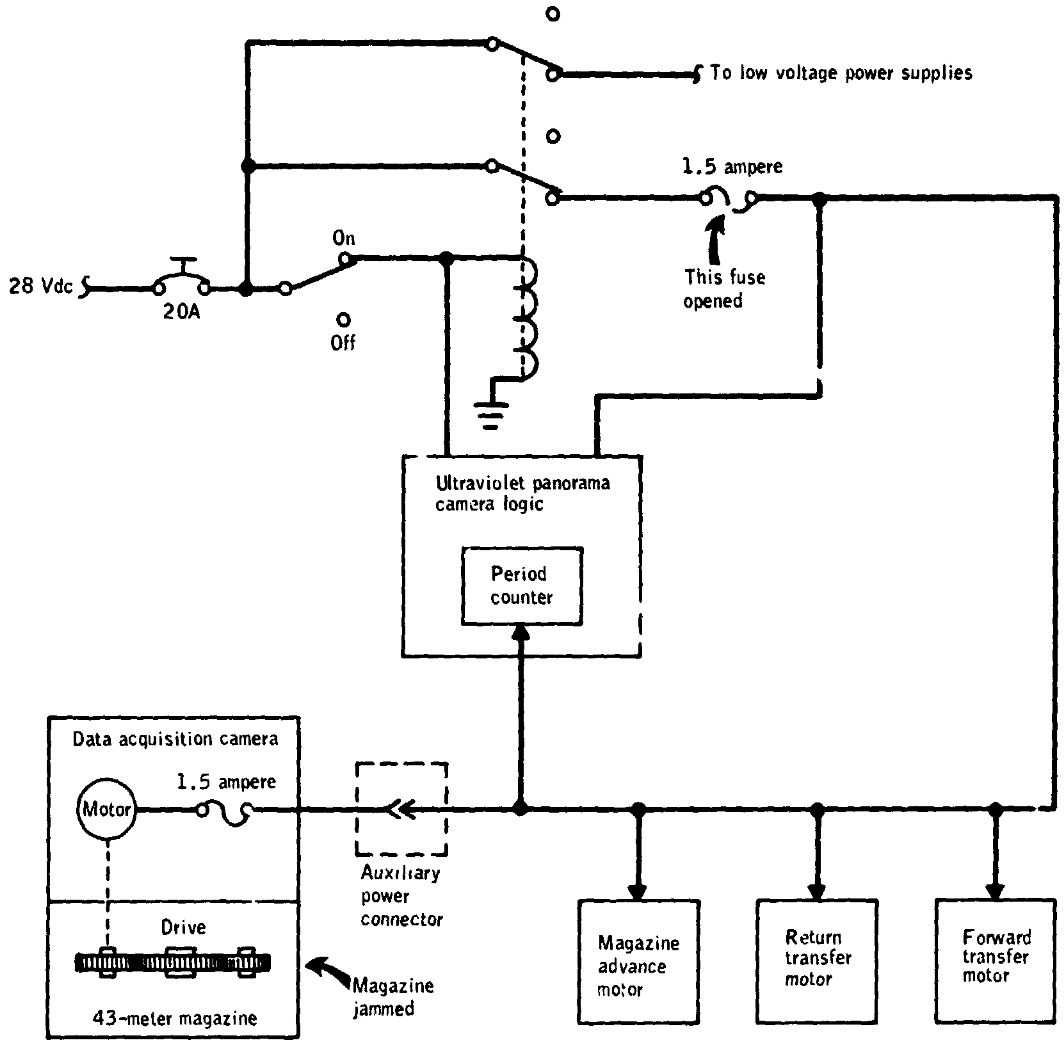


Figure 16-31.- Simplified schematic of data acquisition camera/experiment S183 power interface.

Since experiment S183 will no longer be used, no correction is necessary. When loading film magazines in the future, greater care will be taken to provide a service loop that is just large enough to provide smooth film advance.

These anomalies are closed.

16.3.3 35-mm Camera Anomalies

Each of the two electric 35-mm cameras had a problem which resulted in a loss of usable photographic data.

During the first extravehicular activity, after the first five exposures with camera NK-01, the crew noticed that the long-eye-relief viewfinder attachment was loose and the shutter speed extension knob was freewheeling. Therefore, 35-mm photography was abandoned for the remainder of the first extravehicular activity.

The second anomaly was discovered during postflight examination of the developed 35-mm film. The exposures taken with camera NK-02 on the 20 magazines used after visit day 16 were out of focus.

The 35-mm camera was a conventional-type single-lens reflex camera that was cassette loaded (ref. 3) and was provided with several interchangeable lenses. Film loading was accomplished by releasing a hinged backplate, inserting a film cassette (taking care that a closure tab was properly aligned), inserting the film leader into the slot in the takeup spool, verifying that the film engagement in the takeup spool was adequate, closing and latching the backplate, and advancing the film to the first frame position.

Five 35-mm cameras (NK-01 through NK-05) were provided for use during the third visit. Three of the cameras (NK-03, NK-04, and NK-05) were manually operated. Although the basic mechanism of all the cameras was identical, no known problems were found with the performance of the manually operated cameras. Two of the cameras (NK-01 and NK-02) had provisions for electrical actuation for use during extravehicular activities. A long-eye-relief viewfinder was provided, which could be attached to either camera in place of the standard viewfinder, because a man in a pressure suit could not get his eye close enough to the standard viewfinder to determine the camera field of view. A thermal blanket, tailored to fit either camera, was provided for thermal protection during extravehicular activities.

Camera NK-01 failure.- Troubleshooting procedures performed after the extravehicular crewmen returned to the Workshop confirmed that the long-eye-relief viewfinder was not completely seated in the camera attachment fitting and, therefore, the shutter speed extension knob was not engaged. Use of procedures to verify proper seating and latching of the viewfinder during subsequent attachments to cameras NK-01 and NK-02 precluded the recurrence of this condition.

Camera NK-02 failure.- During the postflight crew debriefing, the crew reported that they had had difficulty closing and releasing the camera back on camera NK-02 during cassette changeouts, and had found it necessary to pry under the camera back at the latch interface with a Swiss army knife to effect a latch lock or latch release. The back was taped to the camera each time as a precaution to seal off the interface against possible light leaks.

Because of the heavy workload, the crew's difficulty with the camera was inadvertently omitted from discussions relayed to the ground. Neither was there any discussion concerning the possible desirability of changing to camera NK-01 for the T025 and S063 experiment photography, rather than continuing with the initial arbitrary option by the crew to use only camera NK-02 for the extravehicular photography for these experiments. The crew experienced no difficulty in opening and closing the other four 35-mm cameras.

As mentioned previously, the imagery obtained with the camera on the 20 magazines used after visit day 16 showed an out-of-focus condition. However, the imagery on the film exposed with the camera on visit days 10 through 16 (magazine IR-08) did not display the out-of-focus condition. Some of the frames of the 20 magazines were exposed in the other 35-mm cameras and were in focus, isolating the problem to camera NK-02. In addition, lenses had been interchanged from camera to camera, and operated properly in the other cameras.

The out-of-focus condition of the developed film was unique in that, not only was the field of view out of focus, but the fiducial marks formed by notches in the film plane plates were also out of focus (fig. 16-32), indicating that the film was not in the normal film plane. In addition, the edge fiducials were missing altogether on several runs of exposures and, in some cases, the out-of-focus condition varied within the field of view.

Camera NK-02 was stowed in the Workshop at the end of the visit, and not returned. Testing was performed with like equipment to determine the cause of the problem and duplicate the results. Removal of the film pressure plate from an otherwise normally configured camera provided the condition which most nearly duplicated the unique out-of-focus results.

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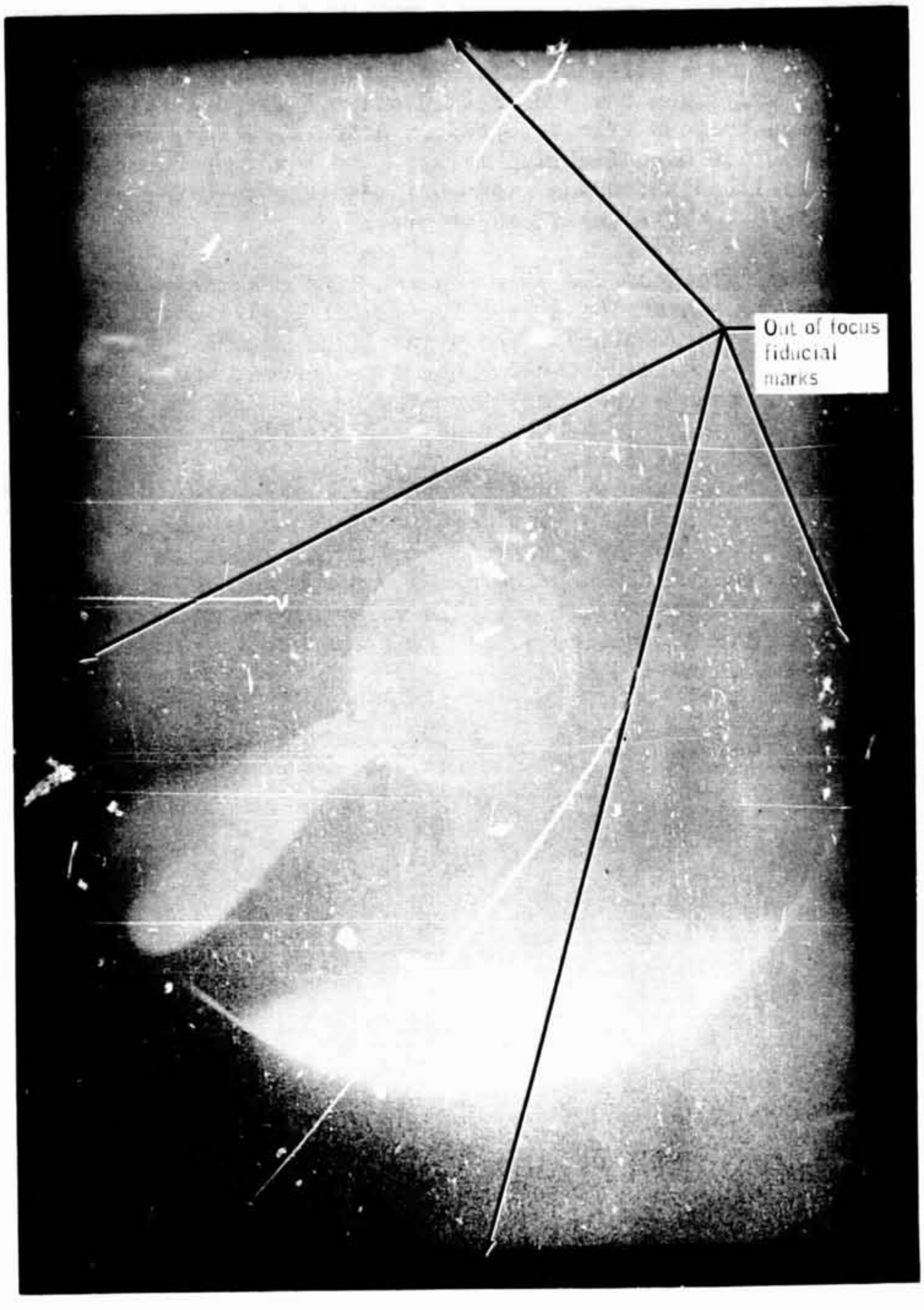
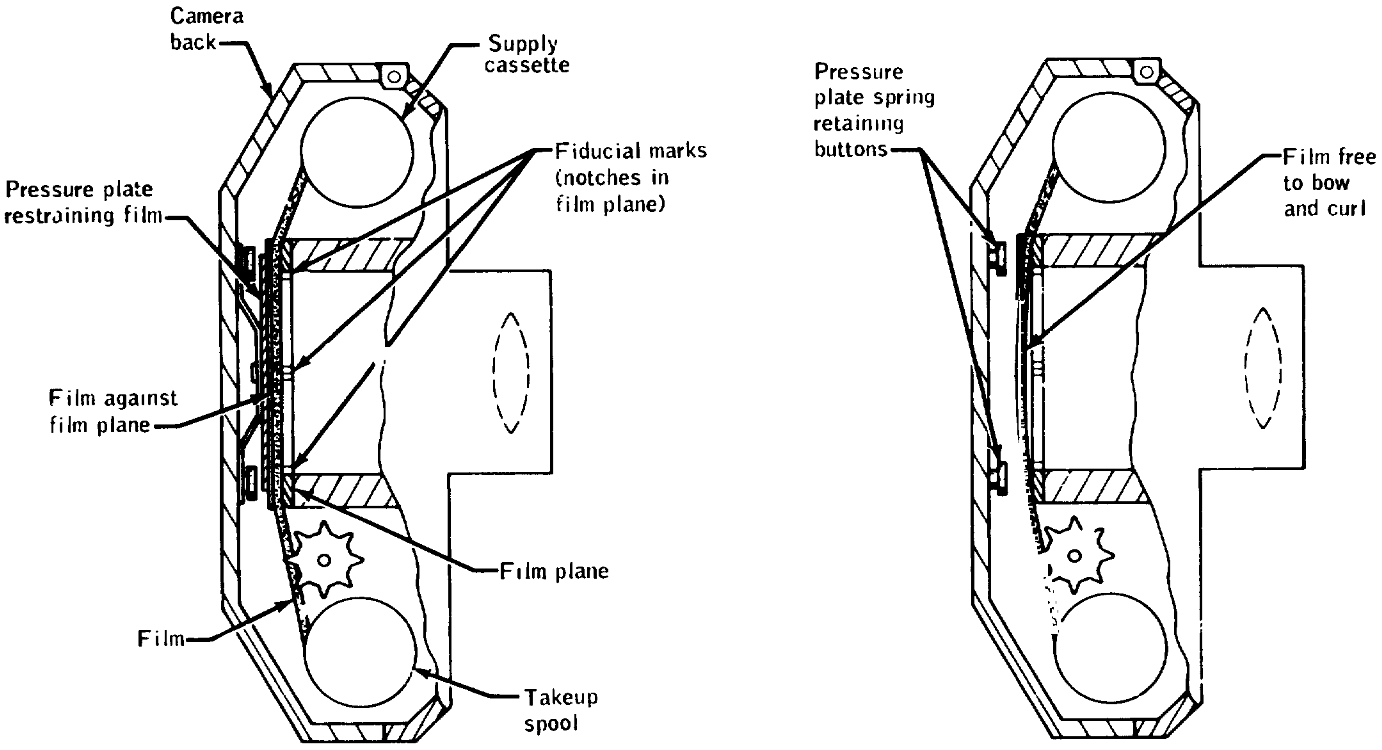


Figure 16-32.- 35-mm camera NK-02 photograph.

The film pressure plate maintained film flatness and position in the film plane during exposures. Without a pressure plate, the film would be free to move about in the free volume between the proper film plane and the back of the camera (fig. 16-33). With the pressure plate removed, the film bowed away from the proper film plane. The natural transverse curl of the unrestrained film resulted in distortion and, in some cases, disappearance of the edge fiducial marks. The combined curvature of the film longitudinal bow and transverse curl resulted in a variation in out-of-focus condition within the field of view.

The pressure plate on the 35-mm cameras was held in place on the camera back by the conventional type two-directional slotted spring and retaining button (four-button) arrangement (fig. 16-33). Deliberate pressure, movement in each direction in correct sequence, and release is normally required to remove the plate from the back. Inadvertent coincident duplication of the sequence as the result of the plate being caught unknowingly on a moving article, such as clothing, could result in release and detachment. Under zero-g conditions, the released black-anodized pressure plate could travel a considerable distance in the Workshop, unobserved by the crew, during a period when the attention of the crew was directed toward other details. The plate was not recovered at the Workshop screens, as had some other articles which had been lost during the visit. The crew did not notice at any time whether the pressure plate was in the camera or not.

These anomalies are closed.



Camera with pressure plate

Camera without pressure plate

Figure 16-33.- Effect of absence of 35-mm camera pressure plate.

17.0 CONCLUSIONS

This section contains the specific conclusions from the third visit. In addition objective-related and general conclusions are drawn from the entire Skylab program.

17 1 THIRD VISIT

The third Skylab visit provided a continuing series of activities from the first two visits. The following conclusions were apparent from this visit.

a. Crew refresher exercises in spacecraft operational modes and procedures are needed during long missions.

b. Free and open discussions between the crew and the ground are necessary for the expeditious resolution of sensitive issues. When one party feels that the other is at fault, the existence of a routine private communications loop, less restricted use of existing capabilities for special private conferences, or less reluctance on the part of the crew and the ground to use the open communications loop to critically discuss sensitive subjects would expedite the solution of problems.

17.2 SKYLAB PROGRAM

The Skylab program fulfilled all program objectives. The performance of the crews and their ability to correct systems problems permitted the program to continue, allowed the extended period third visit, and resulted in a bonus of information returned. The following conclusions are either related to the Skylab program objectives or have a general application.

17.2.1 Advancement of the Sciences

Objective: To increase knowledge of medicine, astronomy, earth meteorology, physics, and other fields, including the effects of space and solar-system phenomena on the earth environment.

a. The methods and techniques employed in the daily flight planning provided the flexibility to react to major departures from preflight plans and constraints. This ability was an important factor in optimizing the scientific return.

b. There are no operationally significant physical or psychological health problems associated with the space vehicle environment for the 84-day visit, and findings show that longer duration visits are unconstrained, however, longer missions would require periodic medical monitoring.

c. The food and sleep requirements on a long-duration mission are essentially the same as they are on earth; however, the maintenance of an established level of physical conditioning requires more programmed exercise.

d. Long duration flight with sophisticated multi-discipline experiments generate large amounts of data requiring ground data handling and processing capabilities.

e. The Skylab program demonstrated the advantage of Scientist Astronauts in providing effective data discrimination and optimization.

f. Complex scientific experiments should be designed for automatic sequencing to allow a more effective utilization of the Scientist Astronaut's time for making additional data observations, performing analysis, and applying scientific evaluation.

17.2.2 Practical Applications

Objective: To perfect sensing and data systems for use in agriculture, forestry, oceanography, geography, geology, water and land management, communications, ecology and pollution-control applications, and to develop zero-g manufacturing techniques.

a. The practical application aspects of the Skylab program will require many months of data evaluation. There are no immediate results which would support the accomplishment for this objective, however, the data were of good quality and preliminary evaluations indicate that practical applications will be possible in a number of the objective areas. One set of examples from section 4.4 of this report suggests that a mineral deposit has been identified near Ely, Nevada; that existing data can be used for an inventory of vegetation patterns; that the Puerto Rican trench depression is about 20 meters below the mean sea level; and that pollution has been identified off the coast of Puerto Rico. Another pair of examples from the Visual Observations Experiment section (4.4.8) indicates that new data on red plankton bloom occurrence may be of aid to biologists and that repetitive observations and photographs of snow accumulation and melting phenomenon will be useful in the study of snow as a water resource.

b. The success of the Visual Observations Experiment indicates the usefulness of a well designed visual observations facility.

17.2.3 Durability of Man and Systems in Space

Objective: To determine the ability of man, materials, and systems to maintain their qualities and capabilities during a long period of weightlessness.

a. The Skylab program demonstrated that man can perform major assembly and repair tasks in the zero-g environment. Extravehicular crewmen can perform any task that can be accomplished in a one-g suited environment, provided that he is furnished with adequate tools, restraints, and training. The design of spacecraft can take full advantage of man's capability to modify and repair. The ability of the crew to correct systems difficulties by actions such as deployment of the Workshop solar array, deployment of the parasol and sunshield, replacement of the rate gyro package, reservicing the Coolanol loop, and repairing the teleprinter allowed the Skylab program to exceed the original expectations.

b. The Skylab program reconfirmed that the timeline should indicate a relaxed activity at the beginning of the mission to allow for the crew to become acclimated to the zero-g environment.

17.2.4 Spaceflight Effectiveness and Economy

Objective: To improve spaceflight technology to develop long-duration mission capability for future programs.

a. The habitability provisions were satisfactory and contributed to the ability of the crew to work effectively for visits of these durations and no factors were identified to preclude longer duration missions.

b. The skills learned in underwater training are almost identical to the skills used in actual performance of tasks during an extravehicular activity and, if instructions are [illegible], a crewman can perform extravehicular tasks for which he has not specifically trained. Tasks are somewhat easier to perform in zero-g than in underwater training.

c. Ordinary handtools can be used effectively in place of special tools in the zero-g environment when making repairs and adjustments.

d. Skylab revisits provided the opportunity to correct hardware problems, restructure objectives, and revise replaceable commodities based on actual experience from the first two mannings.

e. Regularly scheduled meetings of individuals involved in experiments planning who were managed by the Program Scientist were effective in optimizing science data return. Additionally, the Skylab flight planning system allowed day-by-day planning with the flexibility to made adjustments to take advantage of special opportunities noted by the crew and ground personnel.

f. Direct communication during the visits between the crew and some of the experimenters proved to be a useful capability; however, the limited air-to-ground coverage, and the need to devote most of this time to operational subjects left little time for scientific discussions.

17.2.5 General

A number of noteworthy program conclusions that were not directly applicable to program objectives are included as follows:

a. Extensive training is required for a productive visual observations program. The crew must be trained, pre-mission, to recognize selected areas on the ground and to discriminate important features within the areas. This requires that adequate maps and charts be provided for orientation in flight. In addition, several passes over a selected site are required for the attainment of complete data.

b. All work areas within a spacecraft should be provided with a suitably designed work station with minimal considerations being: adequate restraint (triangular grid floor or otherwise), workbench (where required), stowage provisions, writing provisions, and an orientation scheme that is indiginous to the local work area.

c. Relocatable handholds should be provided to allow the crew to tailor work and maneuvering areas in order to optimize inflight activities.

d. To optimize time utilization, data station design requires automatic recording of a number of parameters which have been reported by crews in previous programs. Examples are: pointing position of experiment hardware, frame count of recording instruments, f-stop position, shutter speed, magazine or cassette being used, lens identification, filter identification, etc.

e. Planning should allow for crew judgement to obtain data over earth sites that may be obscured by cloud cover.

f. A shopping list would provide crews with a selection of activities to utilize when not constrained by the timeline.

g. The existence of a dedicated communications loop for the Program Scientist would have been a significant asset.

h. Underwater simulations and training are not required for intravehicular tasks unless a crewman is to be operating in a pressure suit.

APPENDIX A - SYSTEMS AND EQUIPMENT DESCRIPTION

This section describes those differences in the command and service module systems and equipment, as well as configuration changes to equipment for which Johnson Space Center has technical cognizance.

A.1 THERMAL CONTROL SYSTEM

The command and service module thermal control system configuration was modified from the first and second visit spacecraft because of the differences in the thermal environment for the third visit. A thermal control coating was painted on the service module outer surface covering the bay I area over the three descent battery locations. The coating reduced the solar energy absorbtive characteristics in that area, thus enabling the battery temperatures to be maintained within the desired temperature range.

A.2 SKYLAB FIRE EXTINGUISHER

The Skylab fire extinguisher was designed to combat open fires and fires behind electrical panels in the oxygen-rich, zero-g environment of the Saturn Workshop. The extinguisher consisted of a stainless steel pressure vessel with an internal collapsible bellows, a toggle valve for actuation, and a rigid nozzle assembly. The bellows contained an aqueous gel extinguishing agent, and the space between the pressure vessel and the bellows was pressurized with freon. In the stowed (normal) configuration, a removable spray nozzle was available to extinguish open-type fires. Removal of this nozzle exposed another nozzle that could be used to attach the extinguisher to fire extinguishing ports on the electrical panels. When discharged, the extinguisher would expel approximately 0.057 cubic meter of foam in 30 seconds at 69 newtons per square centimeter. Figure A-1 shows the extinguisher in the stowed configuration.

A.3 CAMERA HARDWARE

The following hardware was added to the third visit camera equipment primarily to support the additional photographic tasks of experiments T025 and S063 in photographing Comet Kohoutek. The camera elements are shown in figure A-2.

Figure A-1.- Skylab fire extinguisher.

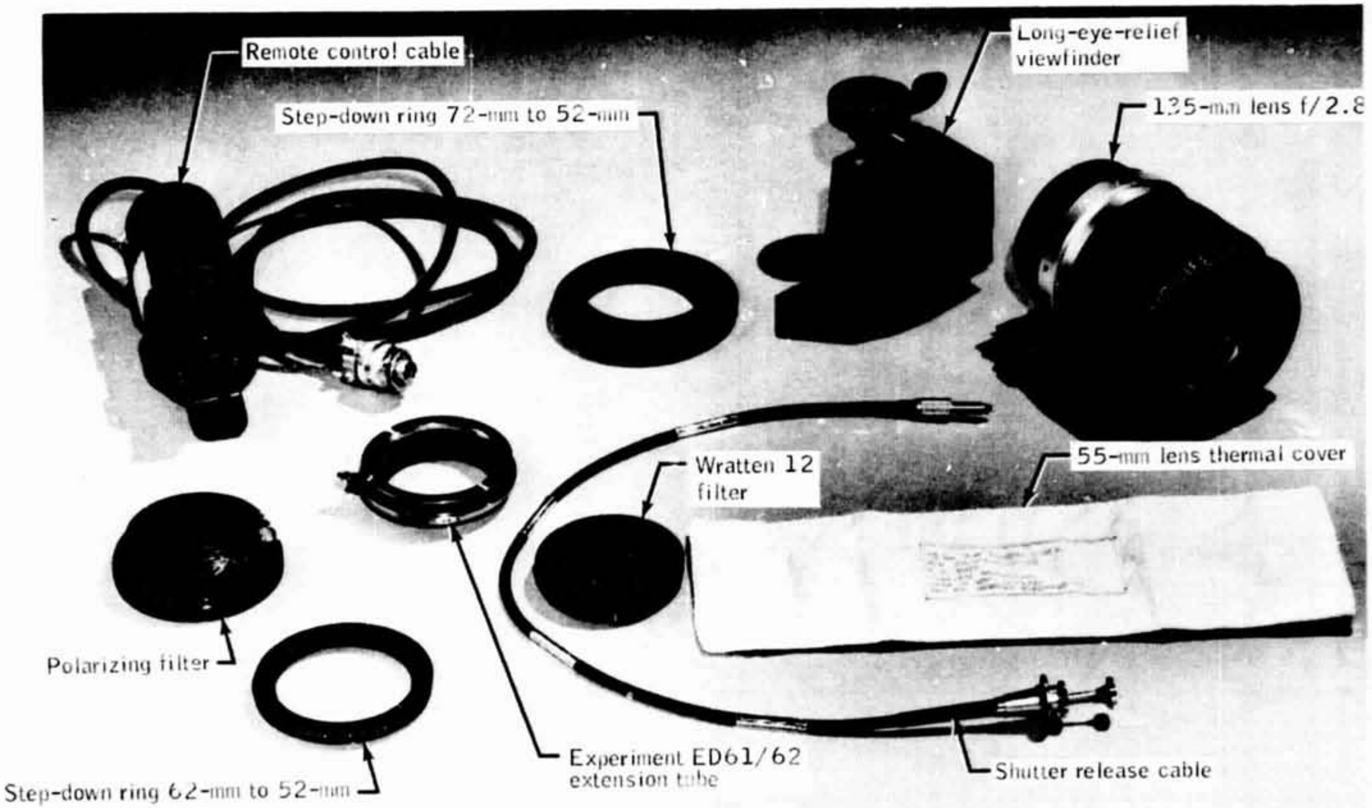


Figure A-2.- New photographic equipment for third visit.

a. 135-mm f/2.8 lens - The 135-mm f/2.8 lens provided the medium telephoto capability for the 35-mm camera system. This lens was used for predocking photographs and some Comet Kohoutek photography.

b. Long-eye-relief viewfinder - The long-eye-relief viewfinder provided the capability of viewing the subject matter during extravehicular activities.

c. Remote control cable - The remote control cable was provided for remote actuation of the 35-mm electric camera while being used during extravehicular activity for experiment T025.

d. Shutter release cable - The shutter release cable provided the capability of remotely actuating the 35-mm manual camera.

e. Step-down rings - The 72-mm to 52-mm step-down ring was used to provide a means of attaching the experiment S063 filters to the 300-mm lens. The 62-mm to 52-mm step-down ring provided a means of attaching the experiment S063 filters to the polarizing filter.

f. Filters - The polarizing filter provided a means of polarizing the light entering the 35-mm camera. It was primarily used for experiment S063. The Wratten 12 filter was used in conjunction with the infrared film for proper color correction.

g. Thermal cover - The 55-mm lens thermal cover provided the thermal protection necessary for the 55-mm ultraviolet lens to insure that no focal shift occurred from the low temperature encountered during the extravehicular activity for experiment T025.

h. Experiment ED61/62 extension tube - The experiment ED61/62 extension tube provided the proper spacing for accomplishing the closeup photographic requirements of experiment ED61/62.

A.4 TREADMILL EXERCISER

A treadmill-like exerciser was provided for the third visit crew to supplement other types of exercisers in maintaining the acquired conditioning of the legs. The exerciser was developed for minimum stowage and weight considerations. The device (fig. A-3) consisted of a Teflon-surfaced baseplate and four bungee cord load inducers. A shoulder strap and waist-belt harness (stowed in the Workshop and originally provided for use with the experiment M093 ergometer) was also required when using the treadmill exerciser. The baseplate and bungee cords had attachment provisions for mounting to the triangular-grid Workshop floor.

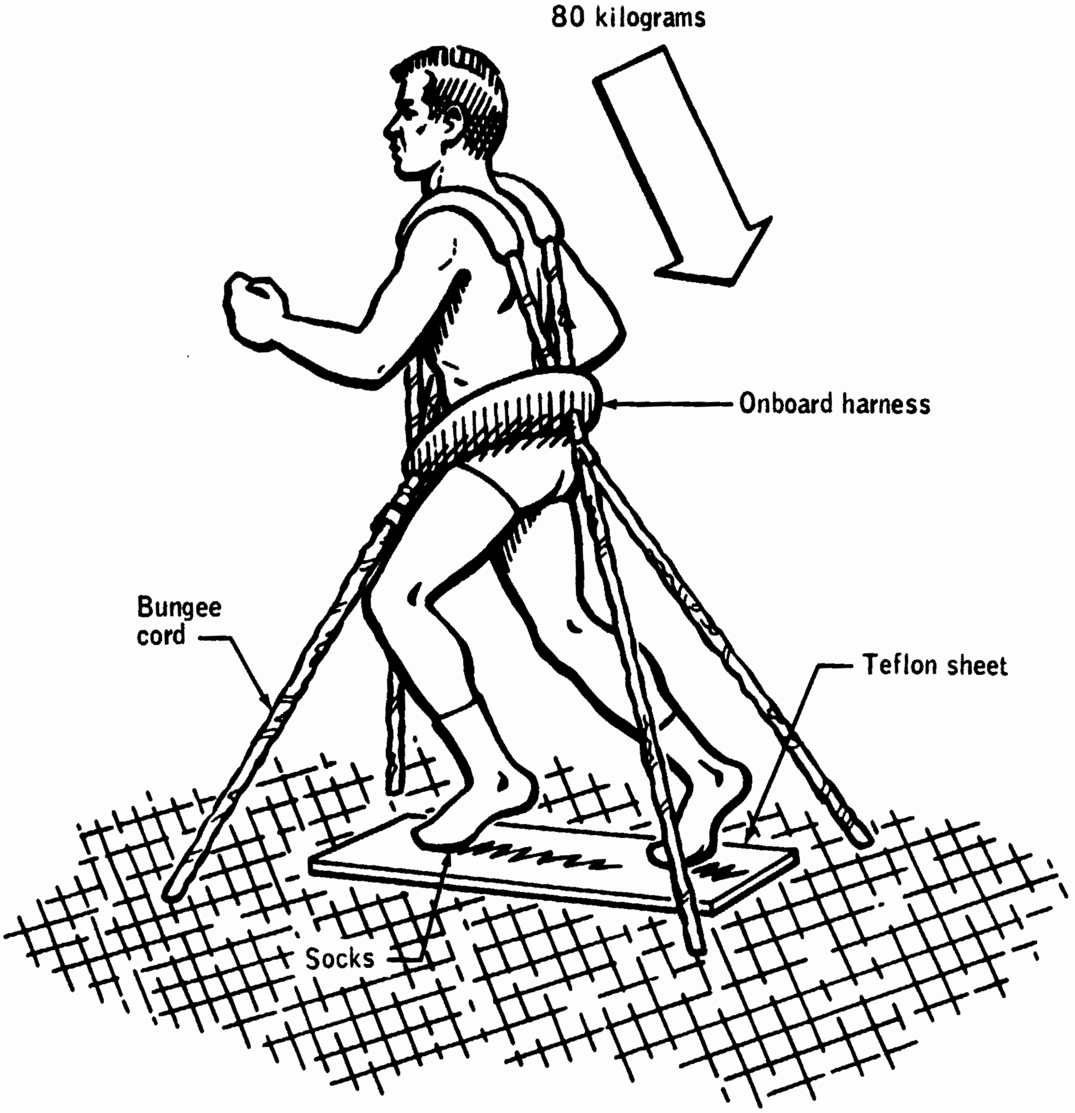


Figure A-3.- Treadmill exerciser assembly.

When in use, the four floor-mounted bungee cords terminated at the harness assembly and the crewman was intended to exercise by moving his feet on the baseplate in a shuffling or sliding manner. The slippery Teflon surface allowed for a walking-type motion while the bungee cords induced a downward load of approximately 80 kilograms. Total weight of the assembly was 1.6 kilograms.

A.5 EXTREME ULTRAVIOLET ELECTRONOGRAPHIC CAMERA

The backup far-ultraviolet electronographic camera prepared for experiment S201 on the Apollo 16 mission was modified to fit on the articulated mirror system in the anti-solar scientific airlock. The camera was removed from the tripod mounting required for the Apollo 16 application and mounted in a vacuum-tight aluminum canister together with a high-voltage power supply and modified electronic sequencer. The canister was 49.5 by 35.6 by 31.8 centimeters in size and weighed 26.3 kilograms. The covers at both ends were removable and sealed with O-rings. A double-ring visual sight was mounted on one side to allow the crewmen to see the extent of the 349-milliradian field of view. Power ON-OFF and sequence START switches were located on an adjacent side, as well as lights indicating film advance and sequence in progress. A special bracket was attached to the canister before extravehicular activity so that the crewmen could attach the S201 canister to the Apollo Telescope Mount truss near the hatch (fig. A-4).

Light entering the forward end passed through a transparent corrector plate and was focused by a 5-inch spherical mirror on a potassium bromide photo-cathode. The photo-electrons were accelerated by a -20 kV potential on the cathode and focused by a magnetic field on 35-mm NTB-3 film at the near end, as shown in figure A-5. Three small motors were used: one to advance the 35-mm film at the end of each exposure, and two to change corrector plates (lithium fluoride for 1050 to 1600 angstrom bandpass, and calcium fluoride for 1250 to 1600 bandpass).

The electronic sequencer was modified to reduce the exposure times to about 1/50th of those used on the moon, taking account of the higher geocorona background in the views from the Saturn Workshop. The modified sequence advanced the film 11 times after the sequence switch was pressed, providing exposures of 1, 2.5, 6 and 15 seconds through the lithium fluoride corrector plate, and 3, 10, 30 and 107 seconds through the calcium fluoride corrector plate. In each sequence, three frames (15-sec exposures) were wasted during corrector plate change.

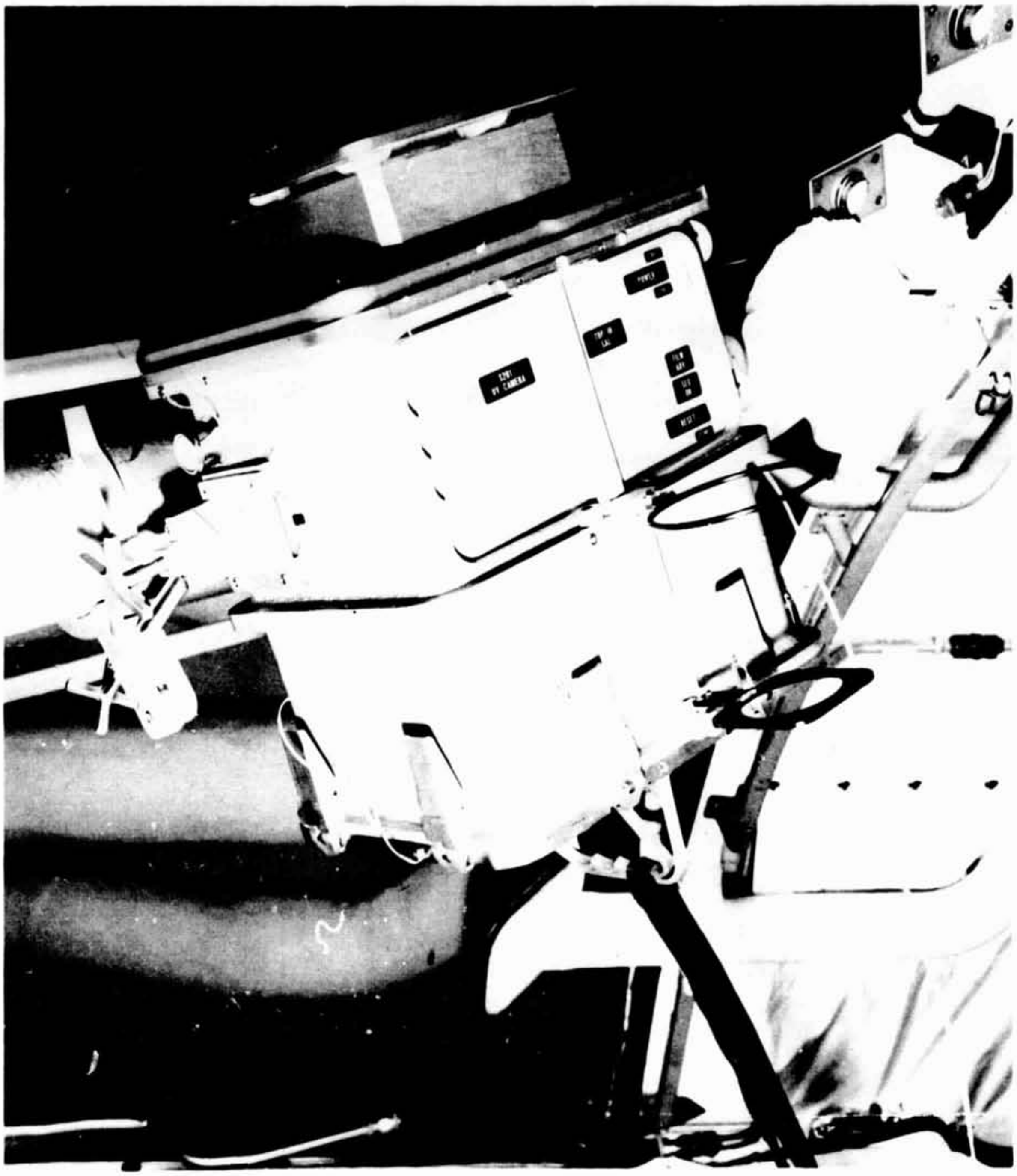


Figure A-4.- Extreme ultraviolet electronographic camera.

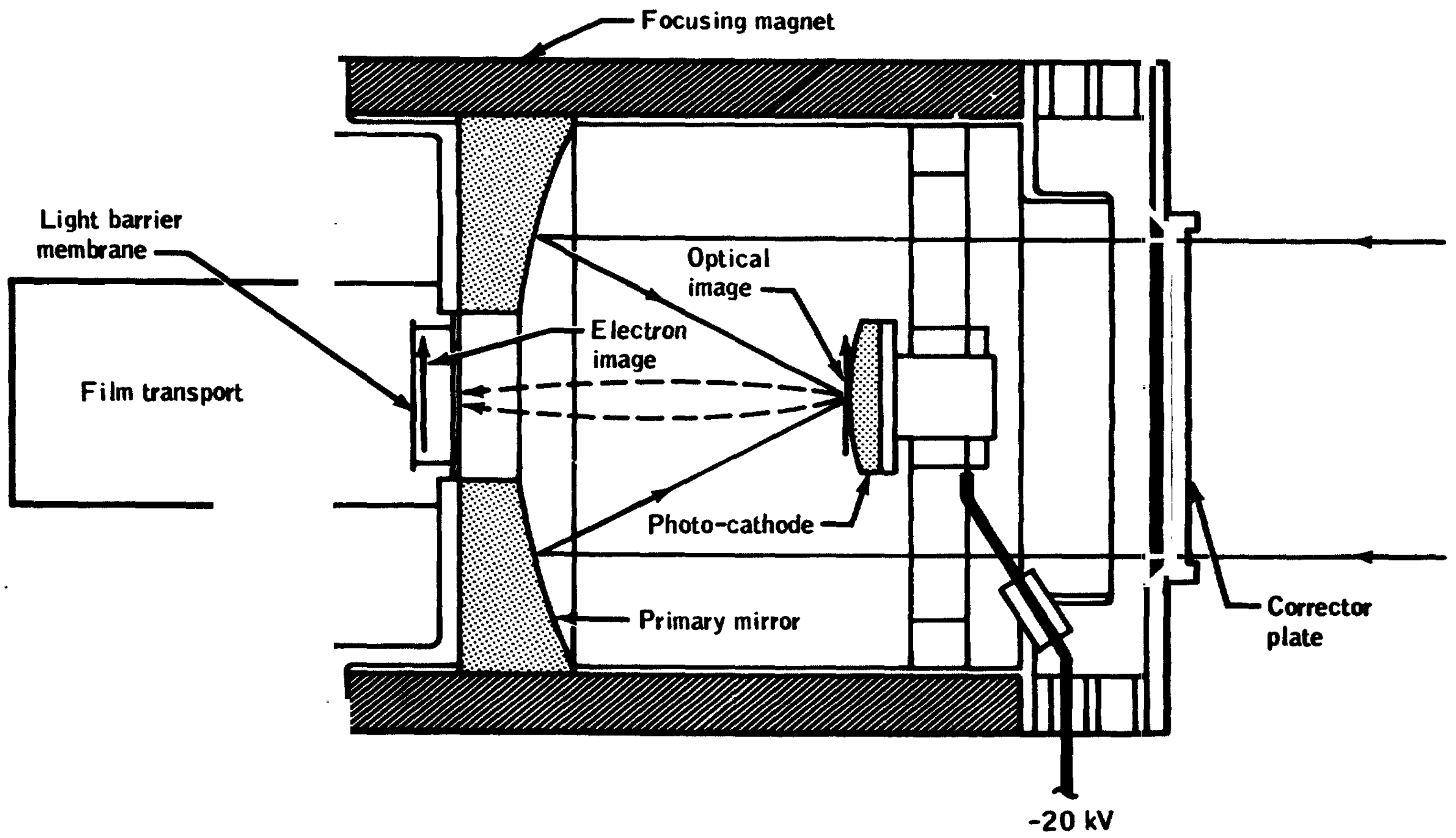


Figure A-5.- Cutaway view of electronographic camera.

APPENDIX B - STOWAGE DIFFERENCES

The third visit launch and return stowage differences from the baseline configuration are shown in tables B-I and B-II, respectively.

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES

Item	Reason
Additions	
Shirts, socks, and underwear	For crew comfort and habitability considerations
Triangle shoe tops (3 pr)	To replace worn items
Constant wear garment (3)	For potential use during air-cooled extravehicular activity
Flight data file changes	To update onboard documentation for the extended visit
Visor wipes pouch assembly (3)	To clean helmet visors
A5 locker	To provide additional stowage provisions; replaced experiment S082
General purpose tape	For crew usage
Off-duty equipment package	For crew usage
Cap for aircraft tubing fittings (3)	To reduce condensation leakage
Experiment D024 package	To replace failed items; during first visit
Experiment M092 tank vent fitting (2)	To allow non-propulsive venting
Experiment M518 samples (21)	To provide additional data
Experiment S009 package	To replace failed equipment; during first visit
Experiment S190 desiccant canister and cover (2)	To resupply items used by previous crews
Experiment S192 attenuator	To repair experiment S192

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
Experiment S193 jumper box and related components:	
Jumper box	To repair experiment S193
Inhibit switch	
Manual gimbal lock	
Screwdriver	
Spatula and brush	
Roll gage	
Repair foot restraint	
Jumper box pouch	
Repair equipment pouch	
Insulation	To repair experiment S193
Experiment S201 sequencer	To provide contingency repair capability
Experiment S228 detector module	Required by extravehicular activity procedure
Experiment S230 package	To replace failed equipment during first visit
Experiment ED31	To replace heat damaged equipment
Experiment ED61/62 lens extender	To resolve camera focus problem
Experiment ED63	To provide new equipment; need evidenced from ground test failures
Experiment ED76 neutron detector	To determine neutron flux source
Experiment pointing control cage/uncage cable	To replace failed item
Apollo Telescope Mount television bus connector module	To bypass failed equipment
Gypsy moth egg container	To support detailed test objective

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
Science demonstration package	To perform science demonstration
Neutron detector package	↕
Rochelle salt package	↕
Charged particle package	To perform science demonstration
Persistent image scope	To enhance Apollo Telescope Mount operations
Magnetic tape reel (7)	To extend collection of earth resources data
Articulated mirror system mirror and case	To provide backup mirror for experiment S019
Timer light cap (4)	To protect experiment S054 timer lights
Video overlay	To replace experiment S055 telesc
Earth terrain camera clock and lock knob	To repair experiment S190B cloc
Cooler/dewar/preamplifier	To supply modified equipment for experiment S192
Rigidizing bracket (2) and restraint strap (8)	To modify experiment T020 retention hardware
Sieve fan cable assembly	For molecular sieve redundancy
Experiment S019 film canister	To document Comet Kohoutek data
Experiment S052 film magazine	↕
Experiment S054 components:	↕
Film cassette and container	↕
Takeup reel and container	↕
Magazine test box	↕
Equipment bag	To document Comet Kohoutek data

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
Experiment S056 film magazine and control	To document Comet Kohoutek data
Experiment S063 components: Polarizing filter 72-mm to 52-mm adapter Polarized adapter 35-mm film cassette (8)	↕
Experiment S063/T025 filter adapter	
Experiment S082A film magazine	
Experiment S183 film container	
Experiment S201 components: Far ultraviolet camera Film magazine Film magazine bag (2) Extravehicular bracket	
Experiment S201K film magazine/bag	
Experiment S232 35-mm film cassette	
Experiment S233 35-mm camera	
Experiment S233 35-mm cassette (4)	
Experiment T025 components: 35-mm film cassette (5) Extravehicular bracket Modified occulting disc 35-mm camera battery Shutter speed adjustment and knob	To document Comet Kohoutek data

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
Remote timer cable	To document Comet Kohoutek data
Eye relief viewfinder	
55-mm lens blanket	↕
Mounting screw kit	
Filter carrying case	To document Comet Kohoutek data
Carbon monoxide/atmospheric volatile concentration monitor	For Workshop atmosphere evaluation
Carbon dioxide partial pressure canister O-ring package	To provide contingency repair capability
Food stick (4)	To extend extravehicular consumables
Supplemental food package	Extended mission capability
Survival food package	Rescue mission survival
Vitamin pill vial (5)	To supplement diets
Insuit drinking device (2)	To extend extravehicular consumables
Iodine tablet package assembly	For treatment of return water
Towel (30)	For extended mission capability
Urine sample bag (20)	For extended mission capability
Urine disposal bag (16)	For extended mission capability
Urine collection transfer assembly and related equipment (3)	To extend extravehicular waste management capability
Lithium chloride syringe canister	To determine urine volume
Inflight medical support system urine refractometer	Operational support requirement for inflight diagnosis
Boric acid tablets (4 packs)	To preserve urine samples
Suppository	Inadvertently returned by previous crew
2-cc syringe	Inadvertently returned by previous crew

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
Treadmill exerciser	To comply with additional exercise requirement
Inflight medical support system hemoglobinometer	Operational support requirement for inflight diagnosis
Limb volume measurement band (30.4 to 33.0 centimeters) (3)	To provide experiment M092 support equipment
Video tape recorder circuit board (4)	To repair television recorder
Communications adapter cable	To provide Saturn Workshop-to-command module audio loop
S-band cable assembly	To provide dump capability for Airlock Module tape recorder
Command module/Saturn Workshop communications adapter	To improve spacecraft-to-ground transmissions
Audio load compensator cable	For Airlock Module tape recorder input redundancy
Television power cable (2)	To replace failed item
70-mm film magazine (6)	To photograph targets of opportunity
Experiment S190A film cassette (12)	To extend collection of earth resources data
70-mm camera mount adapter	To adapt camera to universal mount
35-mm camera and film cassette	To photograph targets of opportunity
Universal camera mount window adapter	↕
35-mm film cassette (11)	To photograph targets of opportunity
35-mm film cassette (8)	To document experiment S073 data

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
35-mm film cassette (2)	To document experiment ED31 operations
35-mm film cassette (6)	To document visual observations
35-mm cassette (7)	For medical profile photography
Infrared filter	For medical profile photography
Experiment ED61/62 film cassette (2)	To comply with procedural change
Experiment T053 35-mm film cassette	To perform new experiment and medical stereo photography
Experiment S233 35-mm camera cable	To allow required time exposures
16-mm film cassette (122 meters) (4)	To document onboard activities
16-mm film magazine	To document experiment S183 data
Experiment S019 film canister	For extended mission capability
Experiment S183 16-mm camera optics	To provide required focus
Experiment S183 film container	To replace failed item; during first visit
16-mm film magazine (43 meters)	To document experiment S191 data
Modified 16-mm camera power pack (1 of 3)	To provide camera power
135-mm lens	To allow long range photography from command module
10-frame polaroid film pack (26)	To provide experiment data
Hydrogen-alpha 1 film magazine and container	For extended mission capability

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
Apollo Telescope Mount exposure timer and cable	To provide accurate timing for experiment S082
Aerodynamic demonstration kit	To perform science demonstration
Third visit science demonstration kit	To perform science demonstration
Liquid crystal thermometer kit	To monitor rate gyro temperature
Taste test kit (3)	To support detailed test objective
Coolant loop fluid kit	To reservice coolant loop
Urine drawer repair kit (3)	To repair urine hose connections
Exerciser repair kit	To repair exerciser
Teleprinter repair kit	To repair teleprinter
Tape recorder repair kit	To replace tape recorder belts
Sharpening kit	To resharpen knives and scissors
Data card kit	To facilitate data management
Data card double clip (5)	↕
Restraint tape	To facilitate data management
Tape dispenser	To dispense restraint tape
Tape, red	For equipment identification
Cement container	To repair broken items
Swiss army knife	For command module destowage
Kick plate tool	To remove control and display access panel
Experiment pointing control connector tool	To repair Apollo Telescope Mount pointing control

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
Apollo Telescope Mount television module and tool	To replace failed equipment
3.57-mm by 12.7-cm Allen bit (2)	To provide for contingency repair of rate gyro six-pack
3.57-mm Allen wrench (2)	To repair exerciser and the Earth Resources Experiment Package
22.23-mm crowfoot wrench	Operational support requirement
14.29-mm flare nut wrench	Operational support requirement
Diagonal cutter	To replace broken item
Tape measure	To allow crew body measurements
Experiment S063 timer batteries (2)	To replace expended batteries
Charger shorting plug	To repair charger battery regulator modules 3 and 5
Battery charger	To recharge calculator batteries
Tone generator battery (4)	Resupply item
Radiation survey meter battery	↑
35-mm light meter battery assembly (3)	
35-mm flash battery bag	
16-mm film cassette (122 meters)	
Experiment M133 tape canister (2)	
Experiment M133 electrolyte (2)	↓
Experiment M151 16-mm film cassette (122 meters)	Resupply item

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
Experiment M171 absorption cartridge (28)	Resupply item
Velcro kit	
Bal-seal (2)	
4.76-mm wide screwdriver	
Inflight medical support system drugs	
Inflight medical support system canister (4) and heat sink	
Inflight medical support system Workshop drug kit, including: Hemolysis applicator package Urine calibration sample 2.5-cc syringe Bone saw 20 gage needle	
5-cc syringe	
2-cc syringe and needle (2)	
Penicillin package (20)	
Catsup resupply package	
Beverage kit	
Food spice kit	Resupply item
4.76 Allen wrench	Requested by crew
Blood sample vial kit	
Bungee cord (12)	
Tape recorder head cleaning kit (14)	Requested by crew

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
Deletions	
Gas/water separator cartridge	Weight reduction item
Tissure dispenser (3)	
Spotmeter	
75-mm lens for 16-mm camera	
Portable timer	
B-3 cushion	
Constant wear garment electrical harness	
Crewman communications umbilical and control head	
Lightweight headset (3)	
Snag hook container	
70-mm camera	
Liquid cooling garment (8) and fecal containment system (8)	
Experiment M509 film magazine (122 meters)	
Experiment T002 battery (2) and battery container	
Experiment S190A filter container	
Experiment ED31	
Experiment ED52	
Survival kit no. 1	Weight reduction item

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
Command module hatch shade and latches	Weight reduction item
Left and right-hand rest restraint	↑
Urine filter	
Temporary stowage bag (3)	
Jack screw (3)	
16-mm camera power pack (2 of 3)	
Lithium hydroxide canister and container (2)	
Command module water gas separator	
Secondary oxygen pack	
Polychoke orifice	
Inflight medical supply system resupply container	
Inflight exerciser	
Tunnel handhold (4)	
Panel shields (4)	
Standard sun filter	
Long eye relief sun filter	
Main display console guard mounts	
L2 door and R5 door	↓
Internal mirror (2)	Weight reduction item

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
Intravehicular umbilical/gage	To save weight and reduce volume
Pressure control unit/controller (2)	To save weight and reduce volume
Carbon monoxide/atmospheric volatile concentration kit	Workshop supply adequate for reduced medical requirements
Inertia reel (2)	Workshop supply adequate for reduced medical requirements
Waste management compartment foot restraint	Not mission critical
Experiment M071/M072 return bag (2)	Weight improvement
Experiment 487 digital thermometer	Alternate equipment available in Workshop
Experiment S149 return support	Onboard materials available for cushioning
Experiment T025 35-mm film cassette (10)	Data requirements reduced
Experiment T027 canister	Different experiment available
Experiment T027/S073 film cassette (43 meters) (3)	No experiment capability
Multiple Docking Adapter power umbilical	Workshop supply adequate (3)
Multiple Docking Adapter control umbilicals (2)	Workshop supply adequate (5)
Locker A1 and locker A3	Experiment S082 stowed in locker space
Contingency package (2)	All stowage items and spaces were defined

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Continued

Item	Reason
16-mm film magazine (43 meters)	One 122-meter cassette dedicated to multiple experiments
Inflight medical support system brackets	Inflight medical support system container was deleted
Off-duty calculator battery kit	Batteries replaced with dc-dc converter
Teleprinter cartridge	Workshop supply adequate (3)
Food sticks (5 of 9)	Crew not trained in use
Water hose/gun/bracket	Food preparation water dispenser adequate
Miniature television monitor	Workshop equipment adequate
Television camera lens	Workshop equipment adequate
Data acquisition camera and 16-mm film cassette	Camera not required in command module during launch
Camera equipment container and data acquisition camera bag	Alternate stowage equipment selected for returned camera items
Pressure garment assembly maintenance kit	Not required in command module operations
Cryogenic vent valve and hose	Second visit equipment available
Television camera mount	Hand held camera used in command module during docking
Headrest pads	Onboard materials available for cushioning
Radiation survey meter and bracket	Workshop equipment available

TABLE B-I.- THIRD VISIT LAUNCH STOWAGE DIFFERENCES - Concluded

Item	Reason
Waste disposal bag (50)	Deleted 25 because of reduced urine dump requirements; deleted 25 because of alternate waste stowage capability
Orbital Workshop urine bag (3)	Urine collection transfer assembly available
Overboard urine dump equipment	Urine collection transfer assembly available
Lower equipment bay curtain and equipment (2)	Alternate interior thermal control method employed
Extravehicular oxygen umbilical restraint	No extravehicular activity planned from command module
Earth Resources Experiment Package cushion (6)	Onboard materials available for cushioning
Locker U4 and mounting bracket	Return cushions deleted; locker not required
Crew optical alignment sight filter	Alignment sight operations not required
Locker U3	Towels available to pack locker items
Locker F1 and locker F2	Alternate return stowage locations available
Towel pack (3)	Resupply towels available
Experiment M749 16-mm film cassette (122 meters) (1)	No requirement
Oxygen umbilical interconnect (3)	↕
Fecal/vomitus bag (9 of 18)	
Secondary oxygen package container clamp	No requirement

TABLE B-II.- THIRD VISIT RETURN STOWAGE DIFFERENCES

Item	Reason
Additions	
Experiment T025 filter tray A	To enhance experiment data analysis
Experiment T025 filter tray C	To enhance experiment data analysis
Experiment T025 filter tray D	To enhance experiment data analysis
Experiment T025 filter tray B	To enhance contamination data analysis
Experiment T025 filter tray bag	Required to protect filters
16-mm data acquisition camera film canister	To return data (film broke in cassette)
Student demonstration 21 silver crystal vial	To comply with Mission Requirements Document
Student demonstration 23 soap lens	To comply with Mission Requirements Document
Rochelle salts	To comply with Mission Requirements Document
Neutron detector	To comply with Mission Requirements Document
Stereo photography distance lacing twine	Required for analysis of medical data
Zero-g fixture cover	Required for materials evaluation
Airlock module meteroid cover sample	Required for materials evaluation
Experiment S063 twin filter (3200 and 2700 angstroms)	To enhance experiment data analysis
Experiment S063 twin filter (5577 and 6300 angstroms)	To enhance experiment data analysis
Experiment S063 35-mm filter assembly	To enhance experiment data analysis
Experiment S063 single filter (2500 angstroms)	To enhance experiment data analysis
Experiment S063 single filter (3914 angstroms)	To enhance experiment data analysis

TABLE B-II.- THIRD VISIT RETURN STOWAGE DIFFERENCES - Continued

Item	Reason
Utility bag (2)	Required to protect experiment S063 filters
16-mm data acquisition camera (8)	For use in future programs
Water sample (2)	Required for systems evaluation
Oxygen partial pressure cartridge	Required for systems evaluation
Charcoal sample (8)	Required for systems evaluation
Experiment S056 aperture doorstop	Required for materials evaluation
Experiment S082A aperture doorstop	Required for materials evaluation
Urine separator and motor	Required for bearing/lubricant evaluation
Extended mission food bag	Required to protect urine separator and motor
Experiment M479 fuel specimen no. 2	To enhance experiment data analysis
Experiment M479 fuel specimen no. 8	To enhance experiment data analysis
Experiment S192 preamplifier assembly/dewar cooler	To enhance experiment data analysis
Perspiration sample (9)	Required for data analysis
Experiment M133 biomedical recorder	Required for performance evaluation
16-mm data acquisition camera transport mechanism	To allow evaluation of failed component
16-mm data acquisition camera film canister (122 meters)	To allow evaluation of failed component
Rope sample (solar array system beam erection tether)	Required for materials evaluation
Material specimen (selected by crew during last extravehicular activity)	Required for materials evaluation

TABLE B-II.- THIRD VISIT RETURN STOWAGE DIFFERENCES - Concluded

Item	Reason
Earth Resources Experiment Package tape recorder components: Turn-around idler Reel drive assembly Recorder head (4) Lower compliance assembly Upper compliance assembly Upper reel carrier Pinch roller	Returned for degradation assessment
Deletions	
Experiment S228 detector module	Left for possible retrieval during a future program
Experiment S190 filters: Type GG Type HH Type II Type JJ Type KK Type LL Type MM Type RR	No return requirement; filters were not used

APPENDIX C - SPACECRAFT HISTORY

The history of command and service module (CSM-118) operations at the contractor's facility, Downey, California, is shown in figure C-1, and the history of the operations at Kennedy Space Center, Florida, is shown in figure C-2.

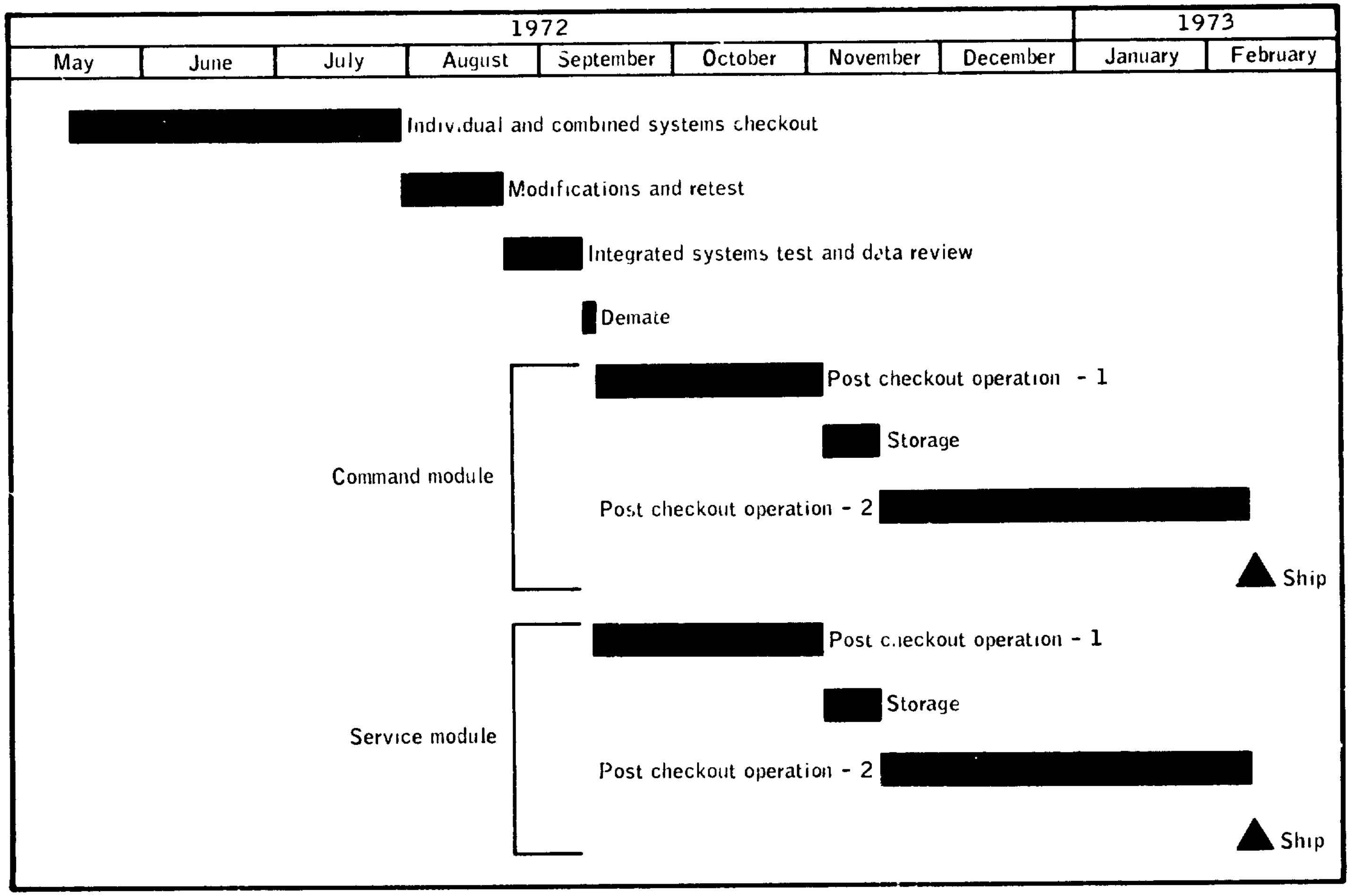


Figure C-1.- Third visit command and service module (118) at contractor facility.

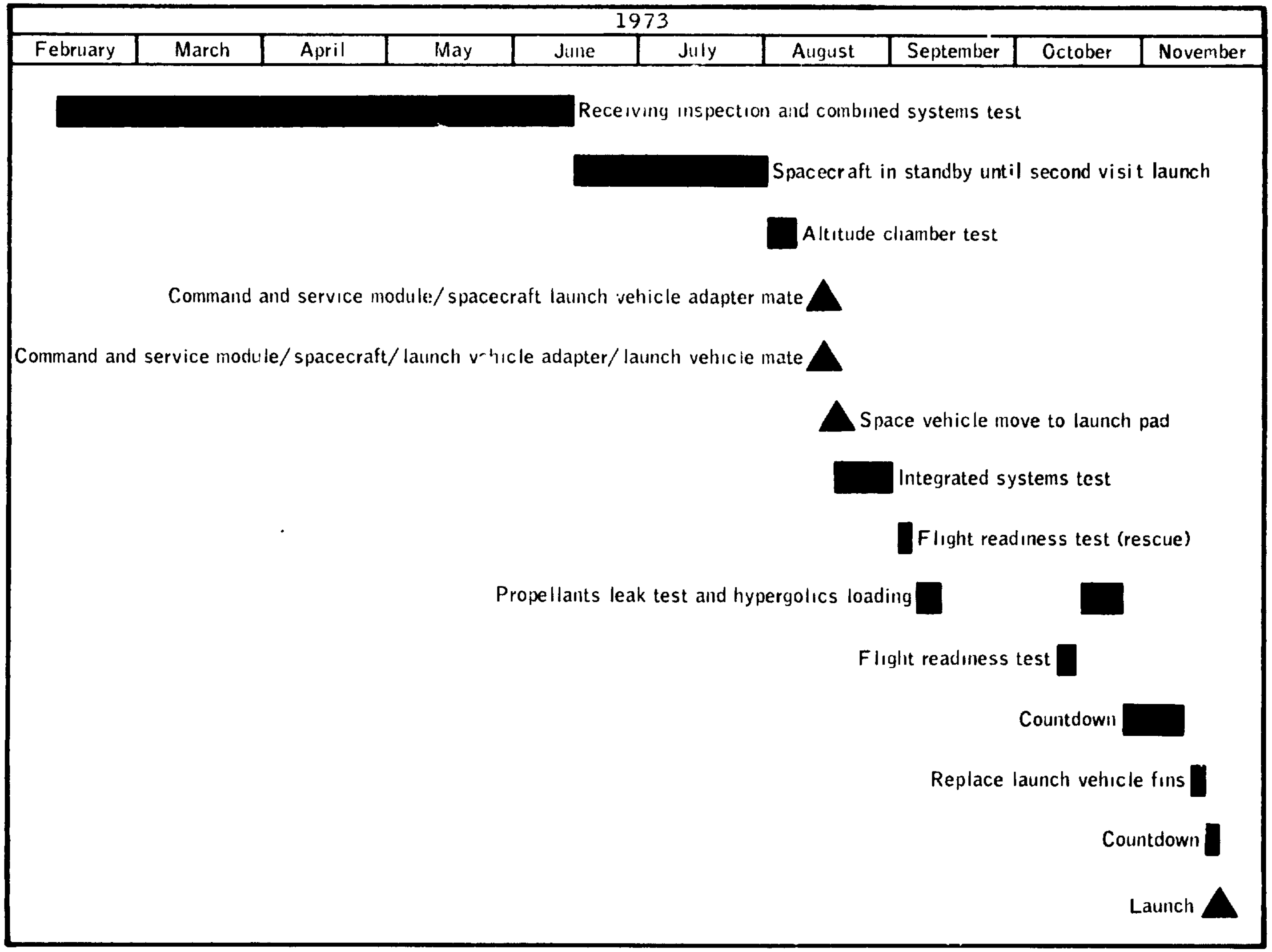


Figure C-2.- Third visit command and service module (118) history at Kennedy Space Center.

APPENDIX D - POSTFLIGHT TESTING

Postflight testing and inspection of the command module and crew equipment for evaluation of the inflight performance and investigation of flight problems was conducted at the contractor's and vendor's facilities and at the Johnson Space Center in accordance with approved spacecraft hardware utilization requests. The tests performed as a result of inflight problems are described in table D-1 and discussed in the appropriate systems performance sections of this report. Tests conducted for other purposes in accordance with other spacecraft hardware utilization requests and the basic contract are not included.

TABLE D-I.- POSTFLIGHT TESTING SUMMARY

SHUR number[a]	Purpose	Test performed	Results
Reaction Control			
118500	Determine cause for command module system 2 helium loss during reaction control system activation period.	Perform leak test of helium system. Teardown and analysis of isolated hardware.	Leak is located on the outlet side of helium squib isolation valve and was caused by an incomplete braze joint.
Electrical			
18014	Determine cause for circuit breaker initially failing to supply power from battery A to battery bus A.	X-ray circuit breaker and perform teardown and analysis.	Contact was positioned at an angle which did not provide wiping action when breaker was closed. Resulting arc spot caused high resistance.
Guidance and Navigation			
118013	Investigate optics/electronics coupling data unit failure indication.	Remove equipment and perform teardown and analysis.	Equipment removed from command module. Teardown and analysis is in progress.
Crew Equipment			
18006 18017	Investigate miscellaneous failures of 16-mm data acquisition cameras, transporters, and magazines.	Perform inspections and failure analyses.	See section 16.3.2.

[a] SHUR - Spacecraft Hardware Utilization Request.

APPENDIX E - MASS PROPERTIES

Mass properties for the third visit are summarized in table E-1. These data represent the conditions as determined from analyses of expendable loadings and usage. Variations in the command and service module and Saturn Workshop mass properties are determined for each significant mission phase from lift-off through landing. Expendables usage is based on real-time data. The weights and centers of gravity of the individual modules were measured prior to flight and inertia values calculated. All changes incorporated after the actual weighing were monitored, and the mass properties were updated.

TABLE E-I.- MASS PROPERTIES

Event	Vehicle coordinate code[a]	Weight, kg	Center of gravity, cm			Moment of inertia, kg m^2			Product of inertia, kg m^2		
			X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}	P_{XY}	P_{XZ}	P_{YZ}
Lift-off	A	20 850.4	2 537.72	6.60	4.69	39 923	544 430	546 630	-4 438	1 208	-1 417
Initial orbit achieved	A	14 888.7	2 434.74	8.81	5.57	25 233	75 614	77 993	-2 025	944	-1 418
Coelliptic orbit	A	14 197.0	2 444.35	7.97	5.74	24 089	72 478	74 107	-1 782	912	-1 472
Rendezvous complete	A	14 049.0	2 445.50	7.46	6.48	23 813	72 114	73 734	-1 722	828	-1 382
Command and service module at docking	V	14 014.6	641.67	2.11	-9.70	23 752	71 315	74 428	1 854	-323	-309
Saturn Workshop at docking	V	73 114.5	-827.36	-9.35	79.56	877 326	3 880 372	3 725 575	65 185	528 764	27 487
Orbital assembly configuration	V	87 126.0	-591.04	-7.50	65.20	910 656	6 514 917	6 353 956	86 962	373 217	25 968
Command and service module orbital assembly transfer complete	V	86 923.4	-603.16	-7.90	65.48	912 919	6 477 961	6 315 050	89 215	384 386	25 665
Orbital assembly prior to command and service module separation	V	85 588.3	-602.84	-8.53	68.15	890 546	6 578 713	6 415 333	87 131	369 690	27 093
Saturn Workshop remaining in orbit	V	71 633.89	-835.62	-10.60	83.28	875 143	3 946 682	3 790 632	63 613	526 394	29 016
Command and service module at CM/SM separation	A	12 924.8	2 455.18	6.31	7.16	22 087	65 859	66 970	-1 455	861	-1 113
Command module at entry interface	A	5 931.5	2 638.24	-0.20	14.42	8 049	7 252	6 511	50	-591	-12
Command module at drogue mortar firing	A	5 743.0	2 635.34	-0.13	14.39	7 859	6 825	6 106	52	-485	-9
Command module at landing	A	5 504.5	2 629.70	-0.15	14.75	7 747	6 339	5 615	50	-457	-8

[a] A in the coordinate code signifies Apollo and V signifies Saturn Workshop.

APPENDIX F - CONVERSION DATA

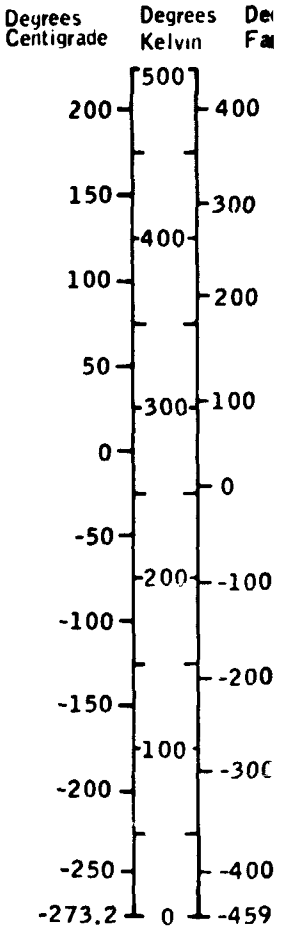
The values shown in this report conform to SI standards. Relationship to conventional units of measurement is shown in figure F-1.

FOLDOUT FRAME

F-2

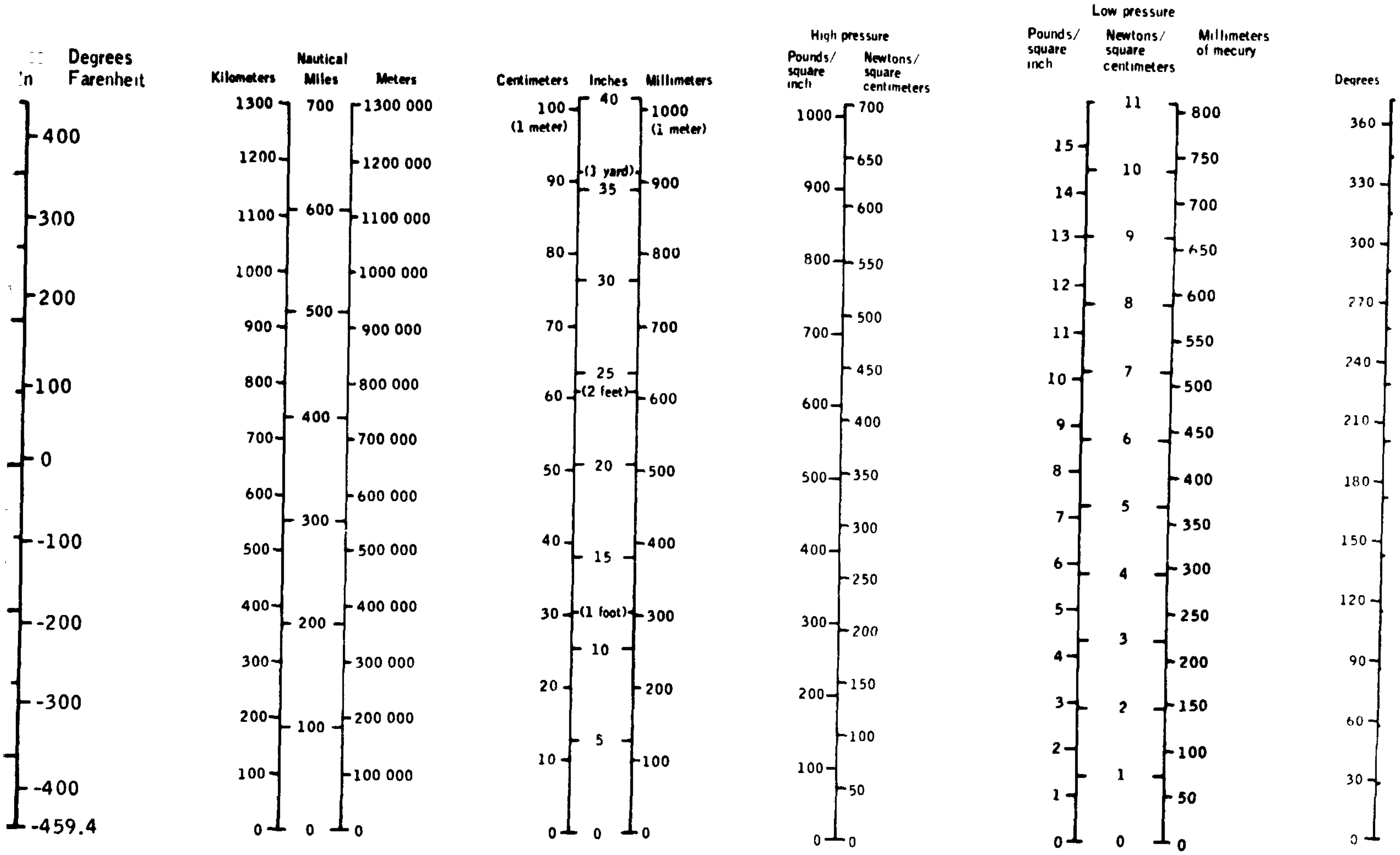
1973 date	Day of year	Visit day	1974 date	Day of year	Visit day
Nov 16	320	1	Jan 1	1	47
17	321	2	2	2	48
18	322	3	3	3	49
19	323	4	4	4	50
20	324	5	5	5	51
21	325	6	6	6	52
22	326	7	7	7	53
23	327	8	8	8	54
24	328	9	9	9	55
25	329	10	10	10	56
26	330	11	11	11	57
27	331	12	12	12	58
28	332	13	13	13	59
29	333	14	14	14	60
30	334	15	15	15	61
Dec 1	335	16	16	16	62
2	336	17	17	17	63
3	337	18	18	18	64
4	338	19	19	19	65
5	339	20	20	20	66
6	340	21	21	21	67
7	341	22	22	22	68
8	342	23	23	23	69
9	343	24	24	24	70
10	344	25	25	25	71
11	345	26	26	26	72
12	346	27	27	27	73
13	347	28	28	28	74
14	348	29	29	29	75
15	349	30	30	30	76
16	350	31	31	31	77
17	351	32	Feb 1	32	78
18	352	33	2	33	79
19	353	34	3	34	80
20	354	35	4	35	81
21	355	36	5	36	82
22	356	37	6	37	83
23	357	38	7	38	84
24	358	39	8	39	85
25	359	40			
26	360	41			
27	361	42			
28	362	43			
29	363	44			
30	364	45			
31	365	46			

(a) Date conversion



(b) Temperature conversion

FOLDOUT FRAME 2



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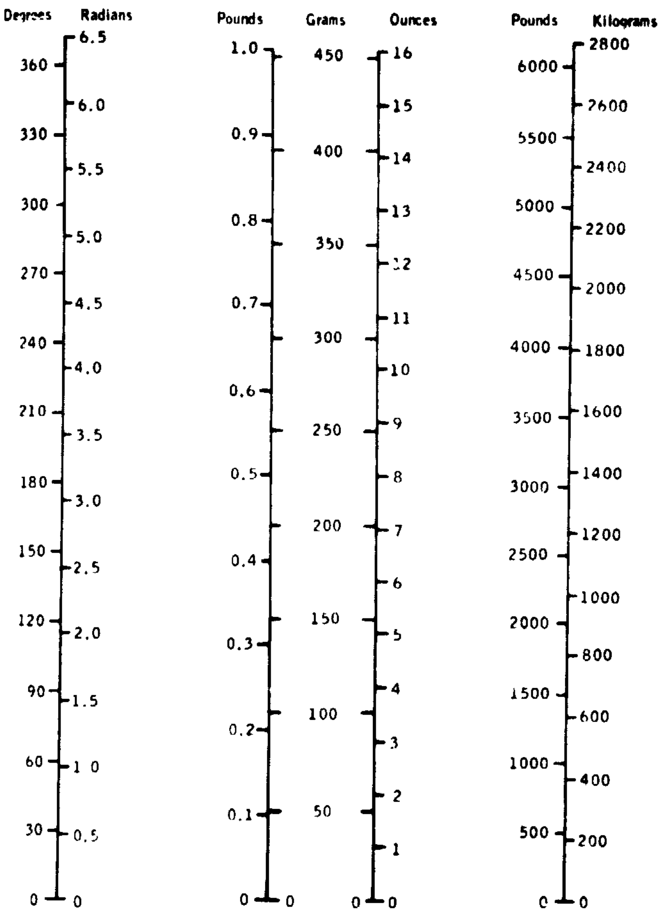
sion

(c) Linear measurement conversion

(d) Pressure conversion

(e) Ang
con

Figure F-1.



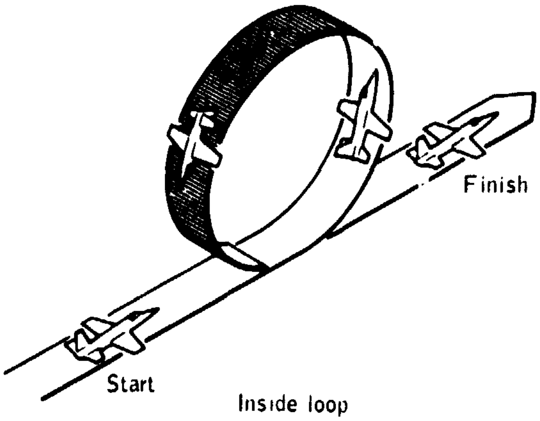
(e) Angular conversion

(f) Mass conversion

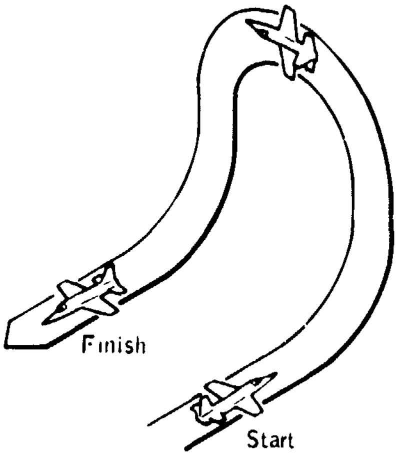
igure F-1.- Conversion data.

APPENDIX G - GLOSSARY

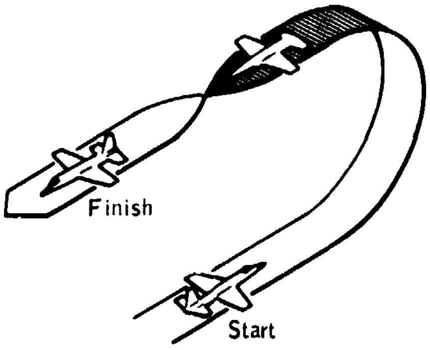
Aerobatic maneuvers performed by the crew in a T-38 aircraft.



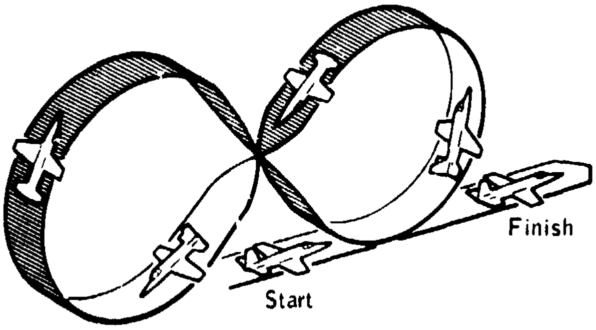
Inside loop



Wingover



Immelman



Cuban eight

Aldosteronism	Increase in the steroid hormone which is very active in regulating salt and water balance in the body.
Aliquots	A fraction taken for analysis.
Anaerobic	Without oxygen; in referring to bacteria, means growing only in the absence of molecular oxygen.
Anoptral	The reversal of optical density to produce phase-contrast microscopic images.
Anterior	The forward part of an organ.
Arrhythmias	Any variation from the normal rhythm of the heart beat.
Ataxic	Muscular incoordination.
Atrophy	Wasting away or diminution in size.
Autonomic	Referring to self-regulated as opposed to volitional.
Balm	A healing or soothing medicine.
Cerenkov radiation	Polarized light produced by particles traversing a solid or liquid medium having an index of refraction greater than one at a speed greater than that of light in the same medium.
Cermet	A strong heat-resistant metal compound made by powder metallurgy.
Chloral hydrate	A hypnotic sedative and anticonvulsant.
Cirrus	A white filmy variety of cloud in the highest cloud region, usually consisting of minute ice crystals.
Coccyx	Bony tip at end of sacrum.
Conjunctiva	The delicate membrane that lines the eyelids and covers the eyeball in front.
Contusion	Bruise.
Cortisol	A carbohydrate regulating hormone isolated from adrenal cortex.
Cranial	Pertaining to the part of the skull enclosing the brain.

Diapause	A period of spontaneous dormancy independent of environmental conditions occurring during hibernation.
Diastolic	Corresponding to phase in which dilation of the heart is present.
Distal	Farther from any point of reference.
Distended	Enlarged.
Double Master's test	An exercise test to evaluate the heart under standardized conditions.
Electronystagmography	Recording of involuntary rapid movements of the eyeball.
Embryonated	Containing an embryo (an organism in the early stages of development).
Endotracheal tube	Any tube passed through the mouth or nose and into the trachea.
Epigastric	The upper middle portion of the abdomen.
Epinephrine	A vasopressor drug causing increased force and rate of heart contraction as well as increasing blood pressure.
Fiducial	Confidence.
Flaccidity	Soft and limp.
Geomagnetic cutoff	The minimum particle rigidity of a cosmic particle required to reach a specific point in a magnetic field.
Gingiva	The gum.
Glutathione	A co-enzyme of gyoxalase and acts as a respiratory carrier of oxygen.
Hematocrit	a. A centrifuge or device for separating the cells and other particulate elements of the blood from the plasma. b. The volume of erythrocytes packed by centrifugation in a given volume which consists of erythrocytes or as the volume in cubic centimeters of erythrocytes packed by centrifugation of blood.

Hemoglobin	The iron-containing pigment of the red blood cells. Its function is to carry oxygen from the lungs to the tissues.
Hemolyzed	Separating hemoglobin from the red blood corpuscles by physical or chemical destruction.
Hypervolemic	Abnormal increase in the volume of plasma in the body.
Immunoglobulins	A group of protein molecules important to the body's immunologic system.
Intraocular	Within the eye.
Karyotyping	Analyzing the chromosomal constitution of a cell.
Klebsiella pneumoniae	A microorganism causing a severe form of pneumonia.
Lymphocytes	A variety of white blood corpuscles associated with maintaining immunity.
Lysozyme	An enzyme with antibacterial activity that is present in saliva, tears and other body fluids.
Malaise	A vague feeling of body discomfort, uneasiness or indisposition, often indicative of infection.
Maxillary sinusitis	Inflammation of the sinus in the upper jaw.
Mitosis	The indirect and more common method of cell division.
Morphology	The science of the forms and structure of organized beings.
Norepinephrine	An organic nitrogen hormone produced by the adrenal medulla. It is chiefly a vasoconstrictor or a vasopressor drug, differing from epinephrine in not having a methyl group on the nitrogen.
Nystagmus	An involuntary rapid movement of the eyeball.
Oculogyral illusion	The apparent movement of an image in space in the same direction as that in which one seems to be turning when the semicircular canals are stimulated.

Ornade	Oral medication containing a decongestant, an antihistamine, and a drying agent.
Orthostatic	Pertaining to or caused by standing erect.
Otoscope	An instrument used to examine the ear canal and drum.
Pallor	Paleness of the skin.
Palpation	Physical diagnosis technique utilizing the application of the fingers with light pressure to the examination site.
Paresthesia	An abnormal spontaneous sensation such as numbness, burning, pricking, etc.
Pericardial rub	Friction sound produced by the rubbing together of inflamed or roughened parietal and visceral pericardia, which are linings external to the heart.
Perifollicular	Surrounding a hair follicle.
Petechiae	Minute hemorrhagic spots, of pinpoint size, in the skin.
Pinocytosis	The absorption of liquids by cells.
Pleural rub	Friction sound produced by the rubbing together of the roughened surfaces of the parietal and viceral pleurae, which are linings external to the lungs.
Posterior	Situated behind or towards the rear.
Presyncopal	The state immediately preceding a brief loss of consciousness associated with transient cerebral anemia.
Pseudomonas aerugenosa	A microorganism causing certain antibiotic resistant secondary infections.
Pulmonary	Pertaining to the lungs.
Rad	A unit of absorbed dose of ionizing radiation equal to an energy of 0.01 joules/kilogram of irradiated material.
Rales	Abnormal respiratory sounds.
Relatavistic particles	Moving at speeds close to the speed of light.

Rem	A radiation biological effectiveness factor of biological injury to human tissue for any dose of ionized radiation equivalent to one roentgen of X-ray or gamma ray.
Reticulocyte	A young red blood cell detectable by a purplish network appearing under staining.
Romberg test	Evaluation of stability when standing with feet close together and eyes closed.
Secretory IgA	Antibody present in secretions on mucosal surfaces.
Serous otitis	Inflammed ear associated with accumulation of fluid, typically noninfectious, in the middle ear.
Serratia marcescens	Bacteria species included in enterobacteriaceae family.
Sleep latency	Period of time from "eyes closing" until actual sleep stages are noted. "Eyes closing" is determined retrospectively from the electroencephalograph tracings.
Soporific	A drug or other agent that induces sleep.
South Atlantic Anomaly	A pocket of trapped protons and electrons in the Van Allen Belt located over a large portion of South America, the South Atlantic and the Southern tip of Africa.
Spatial localization	In the context of the vestibular function experiment, visual and nonvisual (touch, pressure, etc.) perceived directions of space in the roll and pitch planes.
Staphylococcus aureus	A microorganism causing boils and other skin lesions; found in air and milk and produces a lemon-yellow pigment.
Streptococcus mutans	Bacteria species included in lactobacillaceae family.
Subscapula	Below the shoulder blade.
Sulcus	A groove, trench or furrow.
Supine	Lying on the back.
Suture	A surgical stitch or seam.

Total awake time	Includes sleep latency plus awake times noted during the night.
Total rest time	Time from electroencephalograph cap being donned to time the cap is doffed.
Total sleep time	Includes all times in which definite sleep stages are noted.
Tracheotome	Any device for cutting into the trachea.
Tracheotomy	Forming an artificial opening into the windpipe.
Triceps	Posterior upper arm muscle.
Triglyceride	Fat compounds consisting of esters of fatty acids with glycerol.
Vagal	Pertaining to the vagus nerve.
Vasovagal	Referring to the reflex slowing of the heart and dropping of blood pressure.
Vertigo	A sensation of revolving, either subjective (you spin) or objective (surroundings spin).
Vital capacity	The greatest volume of air that can be expressed from the lungs after a maximum inspiration.

APPENDIX H - MISSION REPORT SUPPLEMENTS

The following table contains a listing of all reports that supplement the three Skylab visit reports. The table indicates the title and publication status of each report.

TABLE H-I.- SKYLAB MISSION REPORT SUPPLEMENTS

Supplement number	Title	Publication date/status
1	Micrometeoroid Impact on Command Module Windows	Preparation
2	Light Flashes Observed by Crew on Third Skylab Visit	Preparation
3	Flight Crew Contributions to the Skylab Mission	July 1974
4	Evaluation of Skylab Pilot Reports	Preparation

REFERENCES

1. George C. Marshall Space Flight Center: Saturn IB Launch Vehicle Flight Evaluation Report, SA-208, Skylab-4. MPR-SAT-FE-74-1. January 31, 1974.

2. Johnson Space Center: Scientific Data Analysis and Reporting Plan - MSC Skylab Experiments. MSC-03-22. July 14, 1972.

3. Johnson Space Center: Skylab Mission Report - First Visit. JSC-08414. August 1973.

4. Johnson Space Center: Skylab Mission Report - Second Visit. JSC-08662. January 1974.

5. NASA Headquarters: Mission Operation Report, Skylab Supplement. OMSF Report No. M-960-73. March 1, 1973.