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SKYLAB EXPERIMENT M487
HABITABILITY/CREW QUARTERS

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16. Abstract

Results of Skylab experiment M487 (habitability/crew quarters), which was designed to evaluate the habitability features of Skylab, are presented. General observations and conclusions drawn from the data obtained are presented in detail. The objectives of the experiment, the manner in which data was acquired, and the instruments used to support the experiment are described. Illustrations and photographs of the living and work areas of Skylab and some of the habitability features are provided. Samples of the subjective evaluation questionnaires used by the crewmen are included. Habitability-related documents, crewmen biographies, functional characteristics and photographs of the instruments used, and details of Skylab compartment sizes and color schemes are included as appendixes.

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SKYLAB EXPERIMENT M487

HABITABILITY/CREW QUARTERS

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FOREWORD

In the fall of 1966, I attended a meeting at NASA Headquarters with representatives of five other disciplines. The purpose of the meeting was to begin planning for the post-Apollo manned space flight activities. The meeting encompassed years of program planning and was marked by titles such as Apollo Extension Systems, Apollo Applications Program and, finally, Skylab. With the closing of the Skylab Life Sciences Symposium at the Lyndon B. Johnson Space Center Skylab was completed.

A prime objective of the post Apollo program was quickly confirmed — to conduct long duration space flight. The length of the duration was to be defined later but an initial and lasting concern arose immediately and persisted even throughout the program. How to define and provide for man the habitability requirements for long duration living and working in space?

The suggested solutions to this question were numerous and emanated from varied sources. After various approaches were considered and decisions regarding program direction were resolved, Principal Investigator Caldwell C. Johnson and Robert Bond were to direct the experiment and experimental conditions. The basic problem was that no data or reference material existed that could be examined for solutions to questions.

Three basic considerations dominated the experimental conditions. Based on whatever information or judgment or suggestions that could be assembled the layout of the crew quarters and the crew accommodations would be the best that could be provided. Second, systematic evaluation of the habitability provisions should be obtained throughout and after each mission and the accumulation of these evaluative comments should be accomplished in the least interruptive manner possible. Third, the data should be collated, interpreted, and reported to provide the base for designers and program planners for future space missions.

The comments of the three crews testify to the degree that the first two considerations were met. This report is designed to answer the third objective of the effort.

E. J. McLaughlin, Ph. D.
The University of Texas Health
  Science Center at Houston
March 1975

CONTENTS

TABLES

FIGURES

Figure Page

ACRONYMS

ATM	Apollo telescope mount
DTO	Detailed test objective
EREP	Earth resources experiment package
EVA	Extravehicular activity
FO	Functional objective
IV	Intravehicular
IVA	Intravehicular activity
MDA	Multiple docking adapter
MRD	Mission Requirements Document
OA	Orbital assembly
ODAE	Off-duty activity equipment
OWS	Orbital workshop
PGA	Pressure garment assembly
SL	Skylab
STS	Structural transition section
WMC	Waste management compartment

SKYLAB EXPERIMENT M487

HABITABILITY/CREW QUARTERS

By Caldwell C. Johnson*

SUMMARY

Skylab experiment M487 was established to evaluate and report the habitability features of Skylab in engineering terms useful to designers of future spacecraft. Habitability is often thought of only in terms of comfort and convenience but Skylab experience showed good habitability features could be measured in man hours made available to productive tasks. In many instances, slightly improved habitability provisions would have saved valuable time.

Except for mobility and restraint of crewmen in zero g, which were not well understood before Skylab, habitability requirements for spacecraft were found to be little different from those on Earth.

INTRODUCTION

Because of limited volume, weight, and energy budgets, manned spacecraft before Skylab could ill afford the measures of comfort and convenience required to make spacecraft modestly habitable. But because of the nature of the mission, spacecraft habitability was not of overriding importance or deemed necessary. However, Skylab could afford a measure of comfort and convenience. In consideration of the extended duration of Skylab missions and heavy workload imposed on its crews, the continued proficiency and well being of the crew was thought to justify the cost of modestly habitable living conditions. Skylab Experiment M487, Habitability/Crew Quarters, was established to evaluate the effectiveness of the habitability provisions of Skylab, not in terms of the crews' physiological and psychological reactions to those provisions, but in terms that may be useful to the designers of future spacecraft. This report presents many of the conclusions made at the end of Skylab.

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

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*Principal investigator.

BACKGROUND OF THE EXPERIMENT

The Beginning of Skylab

Habitability became a spacecraft design goal for the first time with the Apollo Applications Program (AAP) in 1965. The program represented a new approach in manned space flight. The initial concept called for using the S-IVB stage of the Saturn V launch vehicle as a three-man habitat for missions lasting 8 weeks. The propellants were to be purged and life support systems activated after orbital insertion. However, in July 1969 a redirection of the Apollo Applications Program called for equipping the S-IVB stage on the ground as a habitable system ready for immediate occupancy by the astronauts in orbit. Six months later the program was renamed the Skylab Program. The space station was called Skylab.

The Spacecraft

Skylab was the largest and most habitable manned spacecraft of its time. Total pressurized volume exceeded 340 cubic meters (approximately 12 000 cubic feet) compared to approximately 8 cubic meters for the Apollo command module. In addition, Skylab was the first spacecraft with crew quarters designed for living and work functions. The food and water systems, personal hygiene systems, restraint and mobility aids, and sleeping accommodations were new to the manned space program.

Skylab is shown on fig. 1 with sections of its skin cut away to show the principal living and working areas. The figure illustrates Skylab as it was intended to be with two solar energy collectors deployed and thermal shield intact. Actually, Skylab lost one of the solar energy collectors and a part of the thermal shield during launching and had to make do with less electrical power than planned and jury rigged thermal shields (fig. 2).

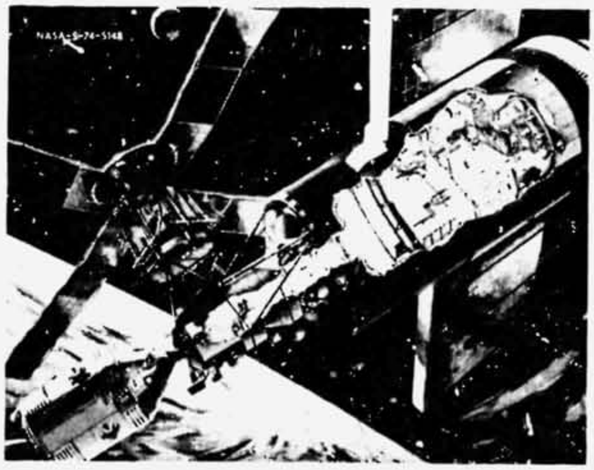

Figure 1.- Living and working areas in Skylab.

Figure 2.- Skylab with one solar array panel and jury rigged thermal shield.

The lower electrical power budget was a troublesome constraint for the overall operation of Skylab but was little more than an inconvenience from a viewpoint of habitability. The overheating of the living area and stowage ar during the early days of the mission and for a short while after the first thermal shield was rigged probably had a deleterious effect on the palatab of some of the stored food and interferred with sleeping.

In general, habitability accommodations of Skylab were rated high by all crewmen. The functional success of habitability accommodations means that the foundation for future orbital stations has been significantly enhanced. Except for food production and recycling of wastes, few advances beyond present space technology will be required for long missions. Credit for successful design and development of the habitability equipment must go to the combined man/machine engineering efforts of the spacecraft development contractors, NASA support contractors, and NASA personnel.

Comprehensive reports on Skylab, particularly its manned areas, life support systems, and habitability accommodations are contained in refs. 1 and 2.

Onboard Operations

The Skylab mission began May 14, 1973, with the launch of the Saturn Workshop into a nearly circular orbit at an altitude of 435 kilometers and at an inclination of 50 degrees to the Earth's equator. The mission lasted 272 days, during which time nine men in three different three man crews manned Skylab for periods of 28, 59, and 84 days. Despite some problems, the total time the crews spent aboard Skylab exceeded the planned time. Furthermore, the crew performed scheduled and unscheduled operations with less difficulty than was anticipated.

Life aboard Skylab was scheduled for all crewmen to work, eat, and sleep consonant with the day night cycle at Houston, Texas. The nominal day began at 6:00 a.m. and ended at 10:00 p.m., Houston time. One day in 7 or 8 was set aside as low activity day, but usually it was not Sunday. The crewmen usually ate breakfast together and planned the activities of the day. Lunch was usually eaten when convenient to other activities but the evening meal was eaten together. The crew often worked until bedtime. Occasionally, the normal routine for all three crewmen was completely interrupted by a major activity such as extravehicular activity (EVA). Often an individual crewman's day and night were rescheduled to suit a particular experiment.

If one doesn't look too closely, Skylab crews would appear to have apportioned their time in orbit about the same as they do when on Earth. While in orbit they spent approximately two-fifths of their 24 hour day performing experiments or operating the spacecraft and three-fifths of their time sustaining themselves; i.e., eating, sleeping, grooming, hygiene, exercise, and recreation. The difference between their spaceflight and normal Earth day was the large percentage of time spent on personal hygiene at the expense of recreation time. The crews consistently complained that they were worked too long. However, they worked about the same as most of us on Earth do but had to spend too much of their own time on chores that are generally considered incidental on Earth: grooming, personal hygiene, and to some extent, eating. It is not surprising that Skylab's accommodations for those necessary activities had a large bearing on the operational utility of the crew. Habitability provisions are often thought of only as a contribution to comfort and convenience, and measured only in esthetic terms. But from the experience of Skylab, many of the habitability provisions could be measured as in-flight man-hours made available to productive operation (refs. 3, 4, and 5).

Skylab Crewmen

Experiment M487 did not deal with the physiological or psychological reaction of the crew to the habitability provisions of Skylab. But, since many of the data taken in the course of the experiment were subjective, some knowledge of the physical character and professional background of individual crewmen may help to better understand their individual opinions on particular aspects of the spacecraft and daily operation. For the most part the opinions agreed. The few differences were inconsequential and were a matter of emphasis, which reflected a simple difference in physical stature or professional point of view. Pertinent biographies of the nine Skylab crewmen are presented in appendix A.

DESCRIPTION OF THE EXPERIMENT

Experiment M487, habitability/crew quarters, was established to evaluate and report habitability features of Skylab in engineering terms that would be useful to designers of future spacecraft. Experiment M487 was not an experiment in the classic sense. The experiment was more a demonstration of how well technology could reduce habitability to an activity entirely incidental to the spaceflight mission itself. Within the limits of programmatic resources, Skylab was configured to reflect the best understanding of the requirements for habitability. The experiment sought to evaluate the suitability of those requirements, not the technical excellence of their engineering implementation.

Objectives

To satisfy the objectives, specific tasks had to be identified within each mission that would satisfy the data requirements and be amenable to unobtrusive data collection techniques. Questionnaires and rating forms for areas of specific interest were included with the onboard checklists and periodically completed by each crewman. Environmental measuring instruments were placed onboard for periodic, quantitative assessment of the environment to supplement the crewmen's subjective evaluations.

A Mission Requirements Document (MRD), specified the mission requirements and objectives for mission activities (ref. 6). There were separate MRDs for each mission, which provided a medium for incorporating new requirements based on previous mission experience. A separate section of the MRD was devoted to each flight experiment. These sections were known as the Detailed Test Objectives (DTO). The schedule events that comprised the in-flight administration of the experiment protocol were known as Functional Objectives (FO) and made up the indentured details of the DTO. The FOs developed for Experiment M487 for each Skylab mission are:

Skylab 2 (SL-2) FOs.- Twenty functional objectives were scheduled for SL-2. The first three FOs called for periodic evaluation of habitability by each crewman.

1. An assessment of the design and operation of habitability equipment

2. An assessment of the habitability aspects of the living compartments

3. An assessment of the frequency of use of habitability features

A roundtable discussion by all crewmen during the early part, midway, and late in the mission was required by FO 4, 5, and 6. Three sets of questions were provided as subject matter for these discussions.

Measurement of overall sound pressure levels and center band frequency spectrum at prescribed locations within Skylab constituted FO 7. Seven pieces of equipment were provided for the accomplishment of FO 8, which were a velometer to measure the air velocity, one digital and three ambient thermometers to measure surface and air temperatures, a force measuring gage to determine push/pull forces, and a measuring tape.

Functional objectives 9 through 18 were designed to acquire photographs early and late in the mission of the crew performing routine living, housekeeping, and maintenance tasks. These photographs were expected to demonstrate the efficacy of the habitability equipment and to reveal any difference in the utilization of the equipment by the crewmen as the mission progressed. These FOs were designed to support experiment M516, Crew Activities/Maintenance Study.

Functional Objective 19 was the waste management compartment photographic demonstration midway in the mission. The preferred method for mounting and dismounting the fecal/urine collector, use of all restraints including lap strap, methods used for various personal hygiene and grooming techniques such as shaving, hair combing, using the hand washer, washcloth squeezer, and mirror and associated restraints were all to be demonstrated and photographed.

Functional objective 20 allocated film for photographing off-duty and hygiene activities.

Skylab 3 FOs.- Eighteen FOs were scheduled for the SL-3 mission. Experience gained during the SL-2 mission led to several changes in the FOs proposed for SL-3. The following are the changes.

Functional objective 1 included an expanded subjective evaluation guide listing additional equipment and clothing to be evaluated. Functional objective 2 remained the same as on SL-2. Functional objective 3 called for using a revised evaluation guide pertaining to onboard tools, miscellaneous support items, and scheduled and unscheduled maintenance tasks. This item was designed to support the M516 experiment, which had no suitable checklist for crew comments. The SL-2 equipment frequency-of-use guide was deleted for this mission because the data were found to be available in the transcripts of daily crew conversations.

No major changes were made to the crew debriefing for FOs 4, 5, and 6. Functional objective 7 consisted of a new set of questions oriented toward a roundtable discussion of in-flight maintenance and supported experiment M516.

Skylab 4 FOs.- Nineteen FOs were scheduled for the Skylab 4 mission. Functional objectives 1 through 8 and 12 through 19 were unchanged. Functional objectives 9 through 11 were changed to determine the effects of zero g upon the crewmen's height. Height measurements were required in the morning and evening of the same day during the early, middle, and late parts of the mission.

Two additional FOs were added during the mission. Functional objective 20 called for additional photography and FO 21 called for an evaluation of conical cleats on the "triangle" shoes.

In-flight Data Acquisition

The conclusions of this report were based on objective and subjective data acquired from real-time television and video tapes, 16 mm film returned with the crews, operational conversations, subjective reports by the crewmen during the missions, and postflight debriefings. Of the data sources, video tapes and the 16 mm film provided the most useful objective data. The periodic reports by the crewmen during the mission provided the most useful subjective data, especially after group reporting was abandoned in favor of individual reporting and more meaningful questions were asked of the crewmen. Although televised activities tended to be somewhat staged, careful review of activities incidental to the main subject often would reveal nominal performance. Subjective reports by all nine of the crewmen did not always agree but the disparities were not of the degree or nature that would refute the consensus.

Data acquisition techniques were intended to be unobtrusive in the sense that staged demonstrations were avoided; however, time was required to set up cameras, use environmental measuring instruments, and tape of transmit inflight debriefings.

Subjective evaluation data.- Two types of subjective evaluation data were solicited from the crewmen. Questions were asked of the crewmen concerning general aspects of living and working in zero g, and rating scale evaluations of specific equipment items and compartment architectural arrangements. Questionnaire forms were furnished as part of the M487 data package. All subjective evaluations were voice recorded and transmitted to the ground. In addition to scheduled in-flight evaluations, ad hoc crew commentary was requested as the mission progressed. As the experiment support team gained experience with this method of data collection, certain changes in format were deemed appropriate. These mission-by-mission changes are shown in Tables I through IX.

Debriefing questionnaires: A series of general questions were formulated concerning the various aspects of living and working in zero g. The questions were varied so more specific questions were used during the early-mission evaluation and general questions were used during middle- and late-mission evaluations. The SL-2 crew debriefing questions are in Tables I, II, and III. The same questionnaire was used for SL-3 and SL-4 except for the deletion of question 2A, number five. The questions were intended to stimulate discussion between crewmen about the various habitability parameters but only the SL-2 crew used them in this manner. The other two crews chose to answer the questions individually as a matter of time-line and scheduling convenience.

Equipment items and compartment evaluations: The crewmen individually evaluated the various spacecraft equipment items and architectural parameters of each spacecraft compartment. A 5 point rating scale was designed specifically for use with the evaluation forms but the prime data return was expected to be the crews' comments and suggestions in support of their specific individual evaluations. The SL-2 rating scale evaluation forms are presented in Tables IV, V, and VI. Table VII lists the changes for SL-3, and Table VIII identifies the changes for SL-4.

TABLE I. - SL-2 M487-2A CREW DEBRIEFING
(ROUND TABLE DISCUSSION)

1. What particular aspects of the O/A seem well designed and arranged for living and working in zero g? What aspects are deficient and how?

2. Which restraint device offered the most assistance in performing tasks; which the least? What recommendations do you have for improvements?

3. How effective is non-equipment-assisted verbal communication throughout the O/A? How satisfactory have the intercom boxes been for IVA comm, voice recording, and ground comm? Are their locations in each compartment satisfactory?

4. How satisfactory are the food management and dining accommodations? How well does the food adhere to the utensils when eating? Would a closer tray-to-mouth proximity have improved eating ease?

5. What safety problems have arisen that are directly related to habitability?

6. How satisfactory have the various environmental elements of habitability been in providing a suitable habitat (lighting, noise, temperature, humidity, air flow)?

TABLE II. - SL-2 M487-2B CREW DEBRIEFING
(ROUND TABLE DISCUSSION)

1. How adaptable are the various compartments to multiuses beyond their prime design function (e.g., does the sleep compartment double for off-duty reading, etc.)?
2. How adequate has the sleep restraint been for sleeping? Has it been useful for anything other than sleeping? If so, what?
3. What noneating uses have been found for the wardroom table? Would a design modification of the table and its associated restraint be desirable for any or all uses?
4. What sanitation problems have developed and how have you dealt with them?
5. What is the most disconcerting personal hygiene problem you have encountered?
6. How effective and efficient are the cleanup procedures and hardware? How much of the time line imposition are cleanup chores?
7. How adequate is the ATM "Chair?" Is it readjusted for each crewman? Do you use the shoes/grid with it? Is the toebar useful? Do you use the chair anywhere other than at the ATM? Where? What design improvements do you recommend?
8. How comfortable are your garments in terms of fit, warmth, and don/doff ease? Were they sufficiently resistant to tearing and abrasion? Did they tend to snag as you moved about the O/A? What recommendations do you have for improving IVA garments?
9. What changes have you detected in the environmental elements discussed as the last question in the first debriefing? Have you used any of the M487 instruments to document these changes?

TABLE III. - SL-2 M487-2C CREW DEBRIEFING (ROUND TABLE DISCUSSION)

1. Which is preferable, the floor/ceiling orientation of the OWS, or the open cylindrical arrangement of the MDA/STS? How do the tasks to be performed influence your preference of orientation?
2. How adequate are the restraints and mobility aids throughout the O/A? Are more needed? Where? Are some unnecessary? Which ones?
3. How often have environmental factors (e.g., noise, temp, airflow, illumination) interfered with your ability to perform a task? Which tasks and where? Have any of these factors interfered with your ability to sleep?
4. What unique off-duty activities have you devised to supplement those provided in the ODAE kit? What recommendations do you have for improving recreational facilities and equipment for future programs? Are such items an important consideration for a mission the length of yours?
5. In terms of your zero-g living and working experiences during this mission, what specific habitability improvements would you recommend for the next Skylab crew; for future programs?
6. How satisfactory is the frequency of change of bedding and clothing?

TABLE IV.- SL-2 M487-3A SUBJECTIVE EVALUATION
(CONTINUED)

INSTRUCTION:

Evaluate and voice record the overall adequacy of the equipment items. Descriptive comments are encouraged, especially concerning the following:

Functional performance
Convenience of use location and orientation
Comfort and ease of use

EVALUATION DEFINITIONS

RATING	DEFINITIONS
EXCELLENT	IMPROVEMENTS ARE NOT NEEDED AND WOULD ONLY BE A MATTER OF PERSONAL PREFERENCE
VERY GOOD	MINOR IMPROVEMENTS ARE POSSIBLE BUT NOT REALLY NECESSARY
ADEQUATE	SOME SHORTCOMINGS FOUND AND A FEW IMPROVEMENTS ARE DESIRABLE
POOR	NUMEROUS SHORTCOMINGS FOUND AND IMPROVEMENTS ARE NECESSARY
UNACCEPTABLE	GROSS SHORTCOMINGS FOUND AND IMPROVEMENTS ARE MANDATORY

EQUIPMENT ITEMS

WORK RESTRAINTS/MOBILITY AIDS

- OWS fireman's pole
- OWS dome and wall handrails
- STS handrails
- MDA handholds/handrails
- Triangular shoes/grid
- Water tank foot platform
- ATM foot platform
- Portable M512/M479/EREP foot platform
- Portable PGA foot restraints
- Portable handholds (specify where and how used)
- Portable equipment restraints (tethers, bungees, universal mounts, etc.)
- ATM seat/backrest restraint
- Conical shoe cleats/grid

WASTE MANAGEMENT/HYGIENE EQUIPMENT

- Fecal collection equipment
- Urine collection equipment
- Urine-flush water dispenser
- Hand washer
- Fecal/urine collector lap strap and handholds
- WMC hand washer handrail
- WMC light-duty foot restraints
- WMC ceiling handrail
- Drying stations
- Shower

TABLE IV. - SL-2 M487-3A SUBJECTIVE EVALUATION (CONCLUDED)

FOOD MANAGEMENT EQUIPMENT	**MISCELLANEOUS**
● Wardroom table (eating station)	● Sleep restraint
● Thigh restraints	● Trash airlock
● Wardroom light-duty foot restraints	● Vacuum cleaner
● Food reconstitution dispenser	● Wardroom table (noneating uses)
● Water gun	
● Food tray	
● Food cans	
● Beverage dispensers	
● Seasoning dispensers	
● Eating utensils	

TABLE V. - SL-2 M487-3B SUBJECTIVE EVALUATION

INSTRUCTIONS

Evaluate and voice record the design features and accommodations of each compartment (it is not required to be in the compartment being evaluated). Descriptive comments are encouraged, especially for items considered only adequate or less than adequate. Use the following terms:

EVALUATION DEFINITIONS

RATING	DEFINITION
EXCELLENT	IMPROVEMENTS ARE NOT NEEDED AND WOULD ONLY BE A MATTER OF PERSONAL PREFERENCE
VERY GOOD	MINOR IMPROVEMENTS ARE POSSIBLE BUT NOT REALLY NECESSARY
ADEQUATE	SOME SHORTCOMINGS FOUND AND A FEW IMPROVEMENTS ARE DESIRABLE
POOR	NUMEROUS SHORTCOMINGS FOUND AND IMPROVEMENTS ARE NECESSARY
UNACCEPTABLE	GROSS SHORTCOMINGS FOUND AND IMPROVEMENTS ARE MANDATORY

Evaluate each of the following compartments with the habitability parameters:

COMPARTMENTS

WARDROOM

WMC

SLEEP

EXPERIMENT

FORWARD/DOME

AIRLOCK

MDA/STS

HABITABILITY PARAMETER TO BE EVALUATED

- General arrangement and orientation of compartment
- Volume of compartment
- Ceiling/floor proximity
- Ingress/egress provisions
- Trash collection provision
- Stowage volume & access
- Temporary equipment restraints
- Personnel mobility aids
- Personnel restraint devices
- Thermal comfort
- Noise level
- Illumination

TABLE VI. - SL-2 M487-3C SUBJECTIVE EVALUATION

INSTRUCTIONS

Evaluate and voice record the frequency of use of items in the following terms:

FREQUENCY EVALUATION TERMS

- Daily or every opportunity
- Every other day
- Once a week
- Every 2-3 weeks
- Never -

  If an item was seldom or never used, explain whether it was a function of poor design, malfunction, no requirement, etc. Though not specifically requested, the adequacy of any item may be independently evaluated by using the evaluation definitions.

ITEMS TO BE EVALUATED

- Jacket
- IV boots
- IV Gloves
- Bump Hat
- Pillow
- Blankets
- Light Baffle
- Privacy Curtain
- Penlights
- Scissors
- Tool Caddy
- Portable Fan
- Tape Player
- Headset
- Microphone
- Playing Cards
- Books (pleasure)
- Hand Exerciser
- Hand Balls
- Dart Set
- Exer-Gym
- Binoculars
- Windows (off duty)

TABLE VII. - SL-3 M487-3 SUBJECTIVE EVALUATIONS (SL-2 DEVIATIONS)

M487-3A SUBJECTIVE EVALUATION GUIDE	
WORK RESTRAINTS/MOBILITY AIDS CATEGORY	
Deletion	Portable M512/M479/EREP Foot Platform
WASTE MANAGEMENT/HYGIENE EQUIPMENT CATEGORY	
Addition	● Personal Hygiene Kit
Deletion	● Urine-Flush Water Dispenser
MISCELLANEOUS CATEGORY	
Additions	● Tool Caddy ● Portable Fan ● Off-Duty Activity Equipment (ODAE) Kit Garments ● Light Baffle ● Privacy Curtain
M487-3C SUBJECTIVE EVALUATION GUIDE	
Deletion	● The Entire Guide

TABLE VIII. - SL-2 M487 PHOTOGRAPHIC REQUIREMENTS

FO no.	Subject	Mission time	Frames/sec	Running time, min
9	Eating of meal (evening)	Early	6	10
10	Eating of meal (evening)	Late	6	10
11	Doff clothing and ingress sleep restraint	Early	6	2
12	Doff clothing and ingress sleep restraint	Late	6	2
13	Egress sleep restraint and don clothing	Early	6	2
14	Egress sleep restraint and don clothing	Late	6	2
15	Clean mixing chamber screens in dome	Early	2	10
16	Clean mixing chamber screens in dome	Late	2	10
17	Trash airlock operation	Middle	2	3
18	Trash airlock operation	Late	2	3
19	Demonstration of activity in waste management compartment	Middle	2	5
20	Crew choice various off-duty and hygiene activities	As available	Crew option	Crew option

<u>Environmental measurements</u>.- The experiment provided several environmental instruments to be used primarily at crew options for measuring various aspects of the Skyalb environment. The data were used to supplement the crews' subjective impressions. The instruments included the following and are described in appendix C.

1. A velometer to measure air velocity

2. Digital and ambient thermometers to measure surface and ambient temperatures

3. A force gage to determine push/pull forces

4. A sound meter to monitor the sound pressure levels

5. A frequency analyzer for measuring the acoustic spectrum

6. A measuring tape to gather quantitative data on dimensions and arrangement of the orbital assembly (OA) architecture

<u>Photographic coverage</u>.- The allocation of motion picture film for SL-2, SL-3, and SL-4 is shown in Tables IX, X, and XI. In addition to the scheduled photography, scheduled and unscheduled television transmission provided real-time and video-taped visual records of many crew activities. Motion picture frame rates were selected to conserve film but in retrospect, higher rates would have conveyed better the subtleties of performance in zero g and with an acceptable reduction of total time.

TABLE IX. - SL-4 M487-3A SUBJECTIVE EVALUATIONS (SL-3 DEVIATIONS)

WORK RESTRAINT/MOBILITY AIDS CATEGORY

Addition

- WMC Hand Washer Handrail
- Towels/Wash Cloths
- General Utility Wipes
- Wet Wipes
- Biocide Wipes
- Utensil Wipes
- Trash and Plenum Bags
- Urine/Fecal Bags

MISCELLANEOUS CATEGORY

Additions

- Air Diffusers
- Air Vents (sleep compartment)

TABLE X. - SL-3 M487 PHOTOGRAPHIC REQUIREMENTS

PO no.	Subject	Mission time	Frames/sec	Running time, min
9	Eating of meal (any)	Early	6	5
10	Eating of meal (any)	Middle	6	5
11	Eating of meal (any)	Late	6	5
12	Cleaning of mixing chamber screens in dome	Early	2	10
13	Cleaning of mixing chamber screens in dome	Middle	2	10
14	Cleaning of mixing chamber screens in dome	Late	2	10
15	Trash airlock operation	Early	2	5
16	Trash airlock operation	Middle	2	5
17	Trash airlock operation	Late	2	5
18	Restocking pantry	Middle	6	15

TABLE XI. - SL-4 M487 PHOTOGRAPHIC REQUIREMENTS

FO no.	Subject	Mission time	Frames/sec	Running time, min
12	Eating of meal (any)	Early	6	5
13	Eating of meal (any)	Middle	6	5
14	Eating of meal (any)	Late	6	5
15	Cleaning of mixing chamber screens in dome	Early	2	10
16	Cleaning in mixing chamber screens in dome	Late	2	10
17	Waste management compartment activity/personal hygiene	Early	6	4
18	Waste management compartment activity/personal hygiene	Late	6	5
19	Restocking pantry	Middle	6	14
20	Checklist updating	Late	6	20

<u>In-flight objectives accomplished</u>.- All functional objectives were accomplished for three missions, except the photographic requirements of FOs 10 and 20. However, it was evident as the mission progressed that the intent of those FOs was being achieved by television coverage and by photography for other purposes. Also, as the missions progressed, the formalities of real-time communication between the experiment support team and the crew relaxed to the point where pertinent questions could be discussed more readily while the circumstances of the issues were fresh in the mind of everyone. Taken together, enough voice comments, taped evaluations, and television images were transmitted and enough film was brought back by the crews to satisfy essentially all data acquisition objectives of the experiment.

Postflight Debriefings

A series of debriefings of the flight crews by several management and technical levels of NASA took place as soon as the crewmen returned to Houston and had an opportunity to rest. The debriefings provided another valuable source of data, not so much because additional facts were brought out but because earlier comments were clarified. In some instances, the crews were able to explain objective data that otherwise would have been misunderstood. There were three formal debriefings and a number of unscheduled discussions with individual crewmen.

Management debriefings.- As soon as practicable after their return, each of the crews briefed upper levels of NASA management on the highlights of the mission. Aspects of the mission of immediate importance to the following mission were emphasized. However, the debriefings were mostly overviews and not especially pertinent to experiment M487.

Technical crew debriefings.- A few days after a management debriefing, the three crewmen recounted their recollection of all aspects of their mission. To bring out as much information as possible they compared notes and impressions and mutually stimulated their individual recollections of the entire mission. They generally followed an outline of subject matter prepared for them as a guide but were free to digress. Since the technical debriefings were taped without an audience and the transcripts known to be intended for very limited distribution, the comments were candid but often unstudied and couched in language that easily could be misunderstood when transcribed (refs. 7, 8, and 9).

Systems and experiments debriefings.- Debriefings were conducted for technical specialists representing spacecraft systems, operations, and experiments. Debriefings lasted several days and were arranged according to subject matter. So the specialists could avoid repetitious questions and could seek clarification of a possibly misunderstood point, pertinent portions of transcripts of the technical debriefing were furnished the technical specialists beforehand. Although many pertinent comments were brought out by the question-and-answer type debriefings, some questions tended to become leading and the crewmen became both weary and wary (refs. 10 and 11).

Informal debriefings.- The support team for experiment M487 was located at the Lyndon B. Johnson Space Center (JSC) and was able to consult with the returned crewmen on a frequent and informal basis. These informal consultations were especially useful for pursuing an obscure point or explaining an apparent contradiction of data. And, in return, a crew or crewman sometimes used the experiment team and data bank to refresh their memory of how things went during a particular phase of a mission.

HABITABILITY EVALUATION CONCLUSIONS

Subjective and objective data, casual and studied comments, operational records and voice transcripts, and personal knowledge of the crewmen and the spacecraft, taken all together, allow the habitability aspects of Skylab to be evaluated with greater confidence than had there been only one source of available information. This section will summarize the results of the evaluations.

Habitability or whatever one chooses to call the quality of daily living is, at best, a nebulous concept. To lend some semblance of order when reporting on the subject, habitability is presumed to comprise the following nine elements.

1. Environment: Composition, temperature, and movement of the respirable atmosphere; acoustic and lighting levels

2. Architecture: Geometric arrangements of compartments and interior appointments of the spacecraft

3. Mobility and restraint: Locomotion and restraint of the crewmen and mechanical aids

4. Food and drink: Stowage, preparation, serving, and eating

5. Garments: Shirt-sleeve clothing

6. Personal hygiene: Facilities for waste collection, washing, and grooming

7. Housekeeping: Housecleaning, refuse disposal, and stowage

8. Communication: Intravehicular only

9. Off-duty activity equipment: Music, books, games, and other entertainment

The results of habitability evaluations are presented for each of the categories as narrative summaries that require one or more of References 12 through 34 to explain each category in greater technical detail and to present data and evidence supporting the conclusions. The references are essential to a comprehensive report of experiment M487.

Many of References 12 through 35 were published as Johnson Space Center bulletins. The bulletins were published to provide early access to the result of Skylab man/machine engineering experience relevant to current development programs. Each reference pertinent to Experiment M487 is referred to under the appropriate habitability category and sometimes several references address a single habitability category.

Environment

The respirable atmosphere in the Skylab was 70 percent oxygen and 30 percent nitrogen and maintained at an absolute pressure of approximately 347×10^2 N/m^2 (260 torr). Air leaving the conditioning apparatus was ducted to the aft end of the workshop and worked its way through the living quarters and experiment area to collectors in the forward dome area. Local flow in the crew quarters could be regulated by adjustable anemostats.

Portable fans were sometimes necessary because of an apparent lack of gravity induced air convection. Combinations of air and wall temperature, humidity, and general circulation were such that the crewmen would not be expected to become overheated. However, there were instances when the crewmen felt that they were submerged in a stagnant bubble of hot air. A good example is illustrated on fig. 3, which shows a crewman exercising on the ergometer. The lack of circulation due to a lack of convection undoubtedly accounted for a tendency of crewmen to overheat.

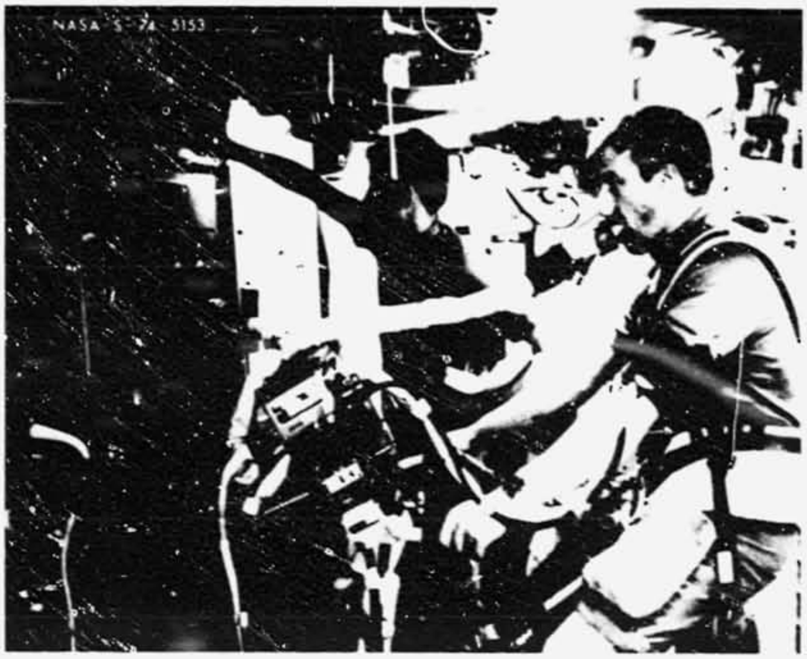

Figure 3.- Crewman on ergometer.

Airflow from foot to head in the sleeping compartments was undesirable. One of the crewmen reversed his sleeping bag so his head would be next to the air inlet.

Background noise was low, probably because of the low density of the air. Background noise was so low in the sleep compartments that very slight noises that propagated through the metallic structure disturbed the crewmen when they were asleep.

Local lighting was marginally adequate. In several areas, illumination levels were much less than handbook values, and portable lights were necessary. In some instances, switches were located so inconveniently that the crewmen "made do" without proper light rather than take the time to go to the switch panel in another area. Lack of local control of lighting sometimes interferred with scheduled activities. When an experiment was conducted that required the operator and experiment station to be in darkness, the entire experiment area and living area had to be darkened. Lighting and compartmentation did not allow sufficient localized control of light (ref. 12).

Spacecraft Architecture

Skylab consisted of five major compartments, none of which bore any architectural resemblance to another. The multiple docking adapter (MDA) was a 3-meter diameter cylinder with interior equipment arranged more or less to fit the cylindrical walls. The airlock module was little more than a passageway between the MDA and dome area of the workshop. The dome area was approximately 6.5 meters in diameter and 6.5 meters long. Equipment was arrayed about the periphery which left a large open area in the center. Architecturally, the dome area exhibited a sort of "up-and-down" arrangement. The lights were around the dome, there was a "floor" opposite the dome, and legends on lockers and equipment read as though one were perpendicular to the floor. The crew quarters area definitely exhibited the up-and-down convention. There was a definite floor, walls, and a ceiling. All equipment was mounted as though Skylab were to be manned in a gravity field. The contrasting architectural styles of the MDA and the crew quarters area are shown on fig. 4.

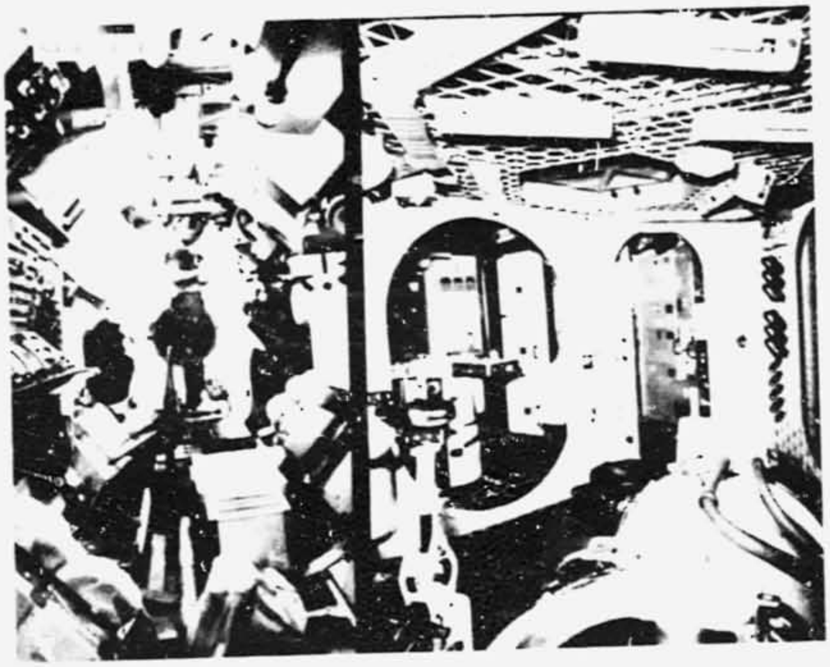

Figure 4.- Contrasting architectural styles.

The architectural adherence to the up-and-down convention proved to be more of a convenience than a constraint. Although it may be argued that more efficient use could be made of volume and wall areas in spacecraft by eliminating the conventional floor plane, the visual cues afforded by up-and-down architecture enabled the crew immediately and unconsciously to sense their positions relative to equipment position, and, in small compartments at least, to move from one duty station to another without much change in body attitude. And, of course, the gravity oriented architecture was a great convenience during prelaunch activities.

Volumetric efficiency of small manned compartments was little different from similar compartments on Earth. It was reasoned before flight that freedom of crewmen to move about in three dimensions in zero g flight would increase the effective size of a given compartment. This was not true in certain compartments in Skylab. For example, the wardroom (fig. 5) was crowded when occupied by all three crewmen. Yet, all crewmen seemed reluctant to use the space above the table to relieve the congestion. There seemed to be a natural reluctance to occupy or to pass through a space normally not used for such purposes on Earth.

Figure 5.- Wardroom.

Spacecraft sleep stations require more space than tier bunks on Earth. Because Earth gravity presses a sleeping person against a mattress and limits the extent to which he flails his arms and legs, very little space is required between the person and bunk above. In zero g, he is not so forcibly biased to one side of the compartment and requires little unconscious effort to bump his arms and feet against the far wall and disturb his own sleep. The station should be at least 0.7 meter from back to front. Additionally, men increase 30 to 40 millimeters in height after a period of time in zero g. That difference must be considered in the design of the sleep station.

"Vertical" sleep stations were acceptable. One crewman initially experienced some difficulty in sleeping against the "wall" of his compartment but the difficulty soon passed.

The design "eye" position and "reach" envelopes in zero g are different from those in Earth gravity. A crewman assumes a crouch position (fig. 6) when working at console stations; he neither sits down or stands fully erect. Consequently, his nominal eye position is approximately 0.3 meters higher than that at his normal seated position, and can reach approximately 0.4 meter beyond his normal seated reach. The best writing surface height probably should be between 0.90 and 0.95 meter above the foot restraints.

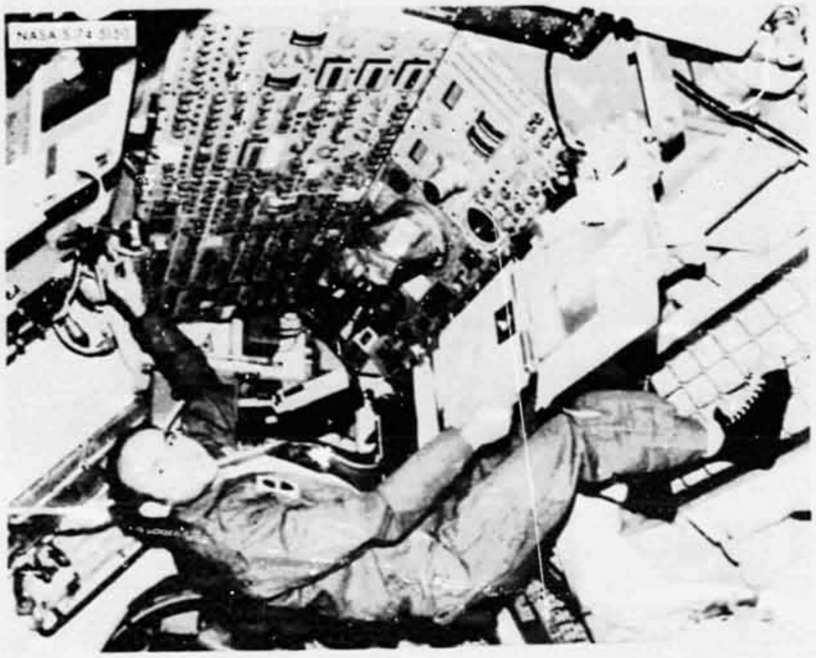

Figure 6.- Crewman at the crouch position.

The lack of an "office" was apparent. There was no central location in the spacecraft for keeping daily bulletins, orders, checklists, et cetera. Consequently, considerable time was lost in searching for misplaced printed information.

Instances of poor cabinet design were especially aggravating in zero g. Cabinet doors that hinged the wrong way or required a 180° opening for removal of contents, and latches that drifted back to the latched position after opening or broke or failed to latch when doors were slammed shut are minor annoyances when found in a home on the Earth, but are troublesome in a spacecraft (refs. 13, 14, 15, 16, and 17).

Mobility and Restraint of Crewmen

Mobility modes varied according to the architecture and free space of the compartment to be traversed. When in the relatively confined gravity-oriented crew quarters (fig. 7) the crewmen moved about more or less perpendicular to the floor by using their hands and toes to propel and guide themselves. The so called compression mode of walking was not adopted and little use was made of the overhead handrails. When in the relatively open dome area, crewmen usually crossed the open space headfirst and did not always reach their destination with the most desirable body attitude. The fireman's pole that ran the full length of the dome area along the centerline was used to some extent as a mobility aid by the first and third crews but not the second crew.

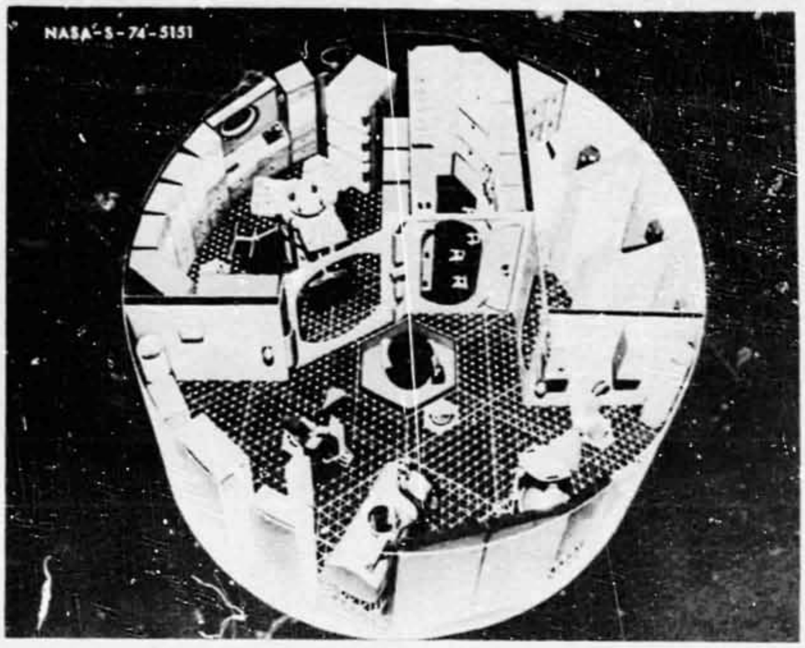

Figure 7.- Crew quarters.

During traverse, control of the legs and feet often was poor at the point where the crewman changed direction or passed through an opening. When using the hands to maneuver the upper body, the crewman often was unable to manage his lower legs and would inadvertently bump his feet against equipment or structures alongside the route. In many instances, switches on control panels alongside a busy route were inadvertently and unknowingly actuated by a crewman's foot.

When proper restraints were available, manual tasks were performed almost as well in zero g as in Earth gravity. Properly designed foot restraints provided sufficient restraint for tasks not requiring strenuous work with the arms. Many types of foot restraints were located in Skylab. The shoes with the triangular cleats that could be locked into the grid floor were a nuisance to put on and take off but they offered the best all around restraint (fig. 8). Flimsy instep straps such as those in front of the urinal were useless.

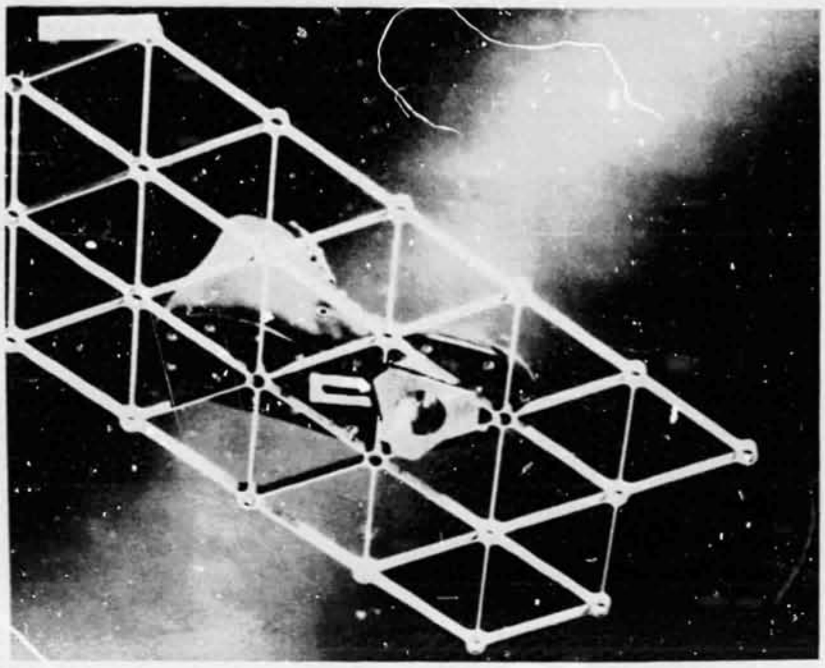

Figure 8.- Triangular cleats.

Chairs were not useful. In a weightless environment, sitting is not a natural body position, is tiring to maintain without lap straps, and serves no useful purpose. The semi-chair designed for use at the Apollo telescope mount console was used to some extent in the first manned mission but later discarded. The thigh restraints at the wardroom table were effective only when the feet were restrained also.

Fixed equipment was used for mobility and restraint whether or not it was designed with such a purpose in mind. When no dedicated restraint was available, any solid appearing object within reach was used especially when necessary to arrest motion. Sometimes this action resulted in minor damage to equipment. For instance, the latches holding the food trays to the table (fig. 5) were sprung by crewmen using the food tray as a mobility aid (refs. 13, 16, 17, 18, 19, 20, 21, 22, 23, 24, and 25).

Food and Drink

The Skylab food system was entirely different from those used for previous space flights. The system development was based on three considerations that were not dominant in earlier programs: a medical requirement to account for all food and beverage intake, a requirement for approximately 1 year of stowage at ambient pressures ranging from 0 to 1787×10^2 N/m^2 (0 to 26 psia), and a requirement for greater crew acceptance. The Skylab food tray, food cans, beverage container, and silverware are shown in the center of fig. 9; the Apollo food packages are in the foreground.

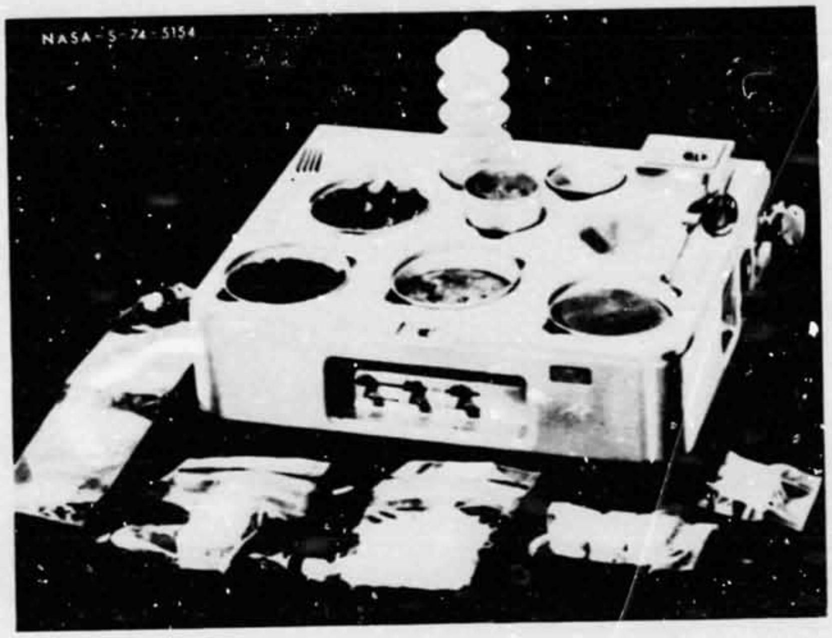

Figure 9.- Skylab food tray.

The onboard preparation of food was improved by using a higher percentage of ready-to-eat foods, programable heating devices, and dedicated galley.

The presentation of food was improved by using open dishes, conventional silverware, and a tray to retain several dishes, silverware, condiments, and napkins. Certain foods had been eaten in Apollo spacecraft with spoons from open plastic pouches, but the Skylab crewmen demonstrated in zero g the practicability of eating almost all ordinary foods from open dishes with ordinary silverware. Occasionally, portions of the less viscous soups and gravies were lost but usually only when opening the containers.

Palatability was improved by the addition of frozen and chilled foods and a higher percentage of thermostabilized wet foods. Skylab experience indicated that in-flight preparation of rehydrated foods was not performed as readily and conveniently as had been expected. The rehydration process often was time consuming or incomplete. The plastic pouches required for the rehydration process were unattractive and, in many respects, defeated the benefits of open dish eating.

All crewmen commented on the apparent blandness of the food although the control food on the ground tasted adequately seasoned. There is no generally accepted explanation for the crew's subjective opinion of the taste of the food in flight.

Regular, group eating periods and tabletop eating tended to dispel much of the catch as catch can effect of previous regimens (ref. 26).

Garments

Astronaut clothing for early space flight missions was designed principally to meet the requirements of biomedical instrumentation, pressure-suit operations, communications equipment, nonflammability, and null gravity. The influence of aircraft flight garments was noticeable in the preference for one piece garments, location of pockets, and insignia. Little attention was given to styling. For Skylab, comfort and overall appearance received increased consideration. However the garments were compromised by flammability constraints. The wardrobe was expanded to include a nonflammable jacket, a knit shirt, and trousers; conventional cotton T-shirts, undershorts, and socks were also added. The outer garments are shown on fig. 10.

Figure 10.- Outer garments.

The conventional pants/shirt/jacket combination proved to be convenient for the same reasons that the combination is convenient on Earth: easy adjustment to different temperatures, ease in donning and doffing, less sensitivity to fit, and waste management convenience.

Knitted or elastic cuffs inside the sleeves and pant legs were intended to prevent the sleeves and pant legs from riding up in null gravity. Several crewmen removed the cuffs and noted that only occasionally was [illegible] necessary to shake their sleeves or pant legs back into place. However, o[illegible] crewmen seemed to prefer the cuffs.

Clothing became soiled mostly from the wearer's body, not from the spacecraft. The outer garments could be worn much longer than anticipated and the converse was true of the underwear. Too many outer garments and not enough underwear and socks were included in the clothing budget.

The outer shirt was knitted of a nonflammable synthetic fiber, Durette. When it was worn without a T-shirt underneath, it quickly developed a particularly offensive odor.

The shoes, too, were made of Durette and wore out rapidly. The toes would not hold up under the scuffing they received as the crewmen pushed themselves about by sticking the toes of their shoes in the grid floor.

There was no requirement for protective headgear. Lightly padded, soft, bump hats were furnished but unused.

Pockets were especially useful in Skylab. Pockets provided one of the few places to temporarily stow and carry small articles. Skylab experience indicates that pockets deserve more engineering attention than they usually receive. The location and nature of pockets for use in space flight should be somewhat different than found optimum on Earth. The pockets should be deep enough to close over items and the pocket should close itself simply and naturally. Pockets on the lower part of the pant legs are not readily accessible. Additional bulk on the lower legs compounds the mobility problem (ref. 27).

Personal Hygiene

The Skylab provisions for personal hygiene, particularly body-waste collection, were luxurious compared to those provided for Mercury, Gemini, and Apollo crewmen. However, convenient use of the waste collection system was compromised by the requirement of medical experiments to process and return urine and fecal samples. The integrated fecal/urine collector in Skylab did not always work perfectly but the problems encountered were mechanical in nature and amenable to engineering solutions.

Because of the water budget and rag squeezer limitation, satisfactory rinsing of soap from a washrag was impracticable. Skylab crewmen found it almost impossible to satisfactorily rinse a soapy washrag. They discarded the soapy rag and rinsed successively with clean rags. The rag squeezer would have been more useful if it could have accommodated a towel.

The esthetic benefit of the shower was hardly worth its operational nuisance. Water management during showering was satisfactory but the collection of loose water afterwards was a tedious time consuming task. The shower and general view of the waste management compartment are shown on fig. 11 (refs. 27 and 29).

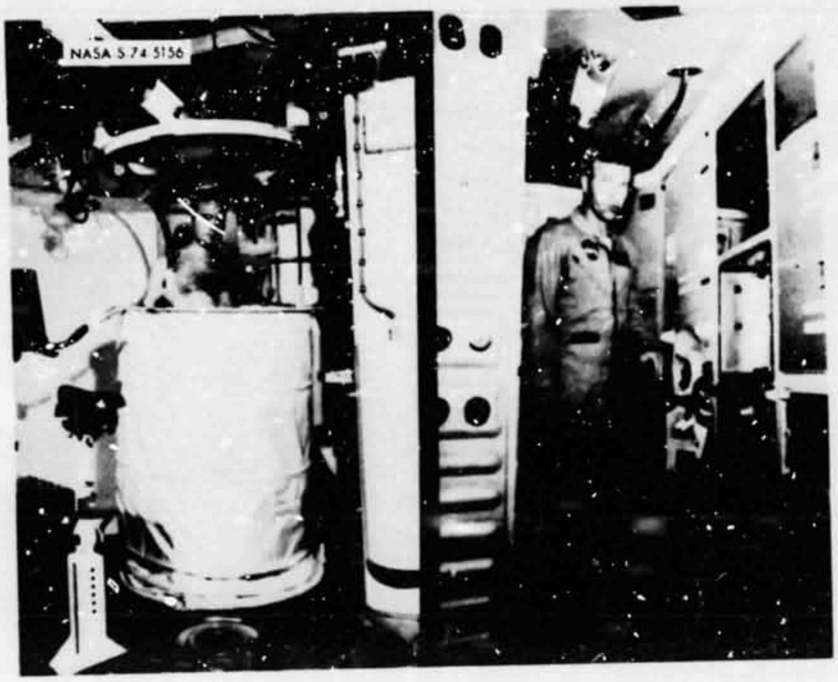

Figure 11.- Shower and waste management compartment.

Housekeeping

Housekeeping is an aspect of manned space flight that attracts little engineering attention, probably because that aspect of daily living on Earth is taken for granted. However, proper housekeeping in space flight was found to be as difficult and time consuming as it is on Earth. Fortunately, the Skylab crews appreciated the potential problems that could arise from sloppy housekeeping and disciplined themselves to run a taut ship.

Temporary trash receptacles were required at points of high trash production. Almost all articles used in flight arrive in some type of disposable package. As the articles are used, trash accumulates. In zero g, trash cannot be left lying around awaiting periodic pickup. Each item of trash must be placed in a receptacle as it is discarded.

Fig. 12 illustrates how debris migrated to the screens of the air collectors. Pieces of tissue, loose washers, tape, and other debris eventually arrived at the filters. Filters should be readily accessible for retrieval of lost articles and for frequent cleaning or replacement.

Small articles must be stowed with appreciation for the lack of gravity. Small articles are well packed for launch but after they are unpacked in orbit are aften no longer properly restrained when put back into stowage lockers. When a locker is opened to get an article, all the other small articles float out. Articles placed in drawers often float about haphazardly and jam the drawer.

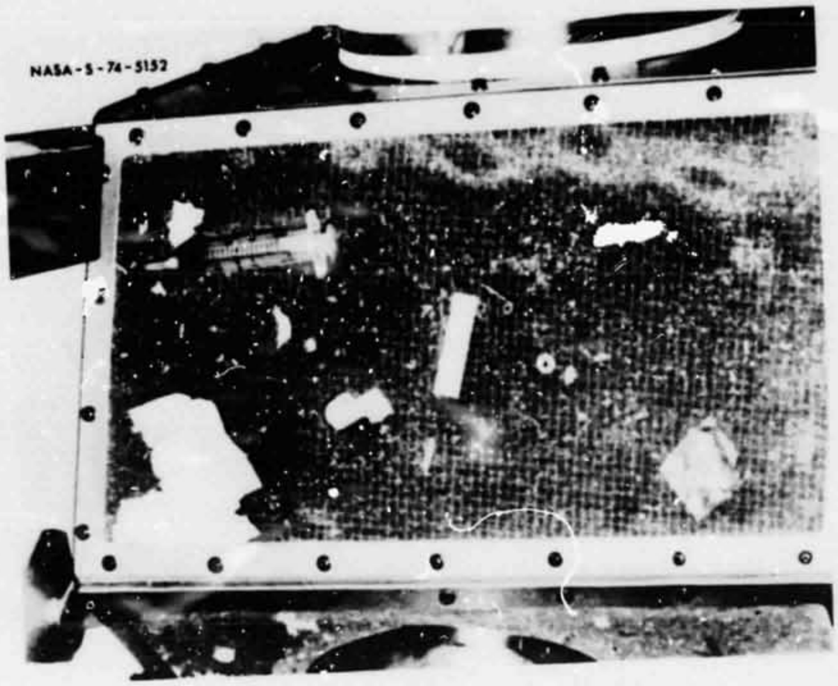

Figure 12.- Debris on air collector screens.

Provisions to aid stowage location are necessary. Many stowage lockers were aboard Skylab and many of them looked alike (fig. 13). Because many lockers were switched around at the last minute, the identification numbers were out of sequence and location gave little clue to the contents. The ground knew where everything was at launch but after the various crews had switched articles to more convenient locations, both the ground technicians and crewmen lost track of many articles. A great deal of time was wasted looking for lost articles.

Sleep stations require provisions for "hanging" clothing at night. Skylab crewmen resorted to stuffing clothing taken off at night or not needed during the day into or under any handy piece of equipment in and around the sleep stations.

Skylab did not develop unpleasant odors despite the inevitable spills during food preparation and minor accidents during urine and feces processing. The low ambient humidity may have contributed to this condition by speeding the drying of spills, but the rigorous cleaning by the crews was probably responsible (refs. 30, 31, and 32).

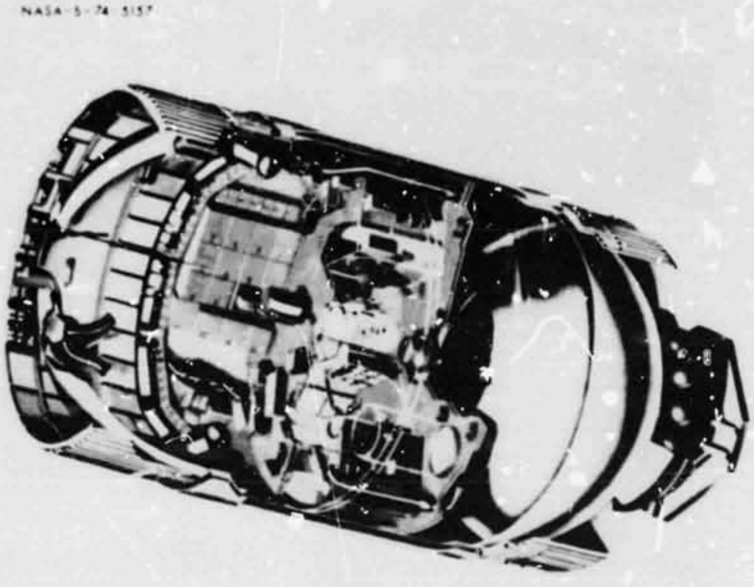

Figure 13.- Stowage locker location.

Communication Within the Spacecraft

Voice communication between crewmen in Skylab was not entirely satisfactorily, principally because of the poor impedance match of the human voice and ear in the low-density atmosphere. The crewmen soon gave up trying to converse when separated by more than several meters (ref. 33).

Off-Duty Activity Equipment

Books, tape decks and individual players, and several types of games were stowed aboard Skylab as recreational or entertainment equipment. With the exception of the tape players, few were used. The crewmen made little or no use of competitive type games. Whatever the explanation, there appears to be little reason to stock spacecraft with checkers, chessmen, or playing cards. The darts were aerodynamically instable in the 345×10^2 N/m^2 (5 psia) atmosphere of Skylab.

The wardroom window provided one of the more important means of relaxation. Most of the time, the Earth was in view. The crewmen never seemed to tire of the view. On some occasions, the casual viewing of Earth by a crewman was the means of serendipitous discovery.

The bicycle ergometer was not placed onbaord Skylab in the interest of recreation, however, the crews found exercise provided a significant degree of relaxation (ref. 34).

GENERAL OBSERVATIONS

When preparing and conducting and evaluating the results of Experiment M487, several editorial observations were made of Skylab man/machine engineering that may be useful to designers of future spacecraft.

Operational Importance of Habitability Provisions

Habitability provisions in spacecraft are often thought of only as a contribution to comfort and convenience, to be measured only in esthetic terms. But in the experience of Skylab, the contributions could be measured as in-flight man-hours made available to productive operation.

Skylab crewmen spent one half of their waking hours in activities where habitability provisions had a significant effect upon the time required to carry out individual tasks. There were many instances where slightly more sophisticated equipment or accommodations would have saved worthwhile time.

Less than optimum habitability provisions are not difficult to discern and correct, but spacecraft development finds it difficult to accept corrections that are not sponsored by one of the classic engineering disciplines. Unfortunately habitability engineering is not regarded as one of those disciplines.

Spacecraft Architecture

The architecture of Earth-based facilities reflects in many ways the nominal posture of people. It can be expected that the architecture of spacecraft will likewise reflect the nominal posture of the crewmen. It is important at the outset of design to establish the nominal posture of crewmen with respect to one another and to the spacecraft.

Since the Earth's gravity undoubtedly had much to do with man's adoption of the erect posture as a matter of mechanical convenience, it may be presumed that upon being freed of the gravitational field man would resort to other postures. Such may often be the case but the body has evolved so suitably to the erect posture that even when free of a gravitational field men will find most of their daily activities more conveniently carried out when they maintain their accustomed relationship to the floor, wall, ceiling, and eye-to-eye and toe-to-toe relationship with other men.

The arms and hands are so important to operational and experimental tasks that mobility and restraint incidental to the principal tasks at hand should be relegated to the lower body, legs, and feet. Mechanical aids to that end certainly can be made less complex if translation is nominally planar, especially if all crewmen can employ the same surface to act against. Additionally, the tactile sense and dexterity of the foot is so much less than the hand that it is prudent to select one wall of habitable compartments to be trod upon, making the other five available for relatively delicate equipment.

People communicate better when they are face to face and right side up. They recognize visual symbols best when viewed from right side up and get in their own light less when light shines from above. The only way to achieve those relationships between crewmen is to have all crewmen "stand" on a "floor" and place the lights in the "ceiling."

Controls and manually operated devices are designed to suit the articulation mechanics of the body. Devices are difficult to operate unless they are right side up. Eyes can scan and hands can reach a much greater swath when the head, trunk, and legs twist side to side rather than bend forward and backward. Mutual overlap of scan and reach swath of crewmen is greatest when all crewmen are erect to a given plane.

These arguments are not intended as an effort to prevent crewmen in zero g situations from assuming whatever posture or attitude seems most appropriate to the circumstances; but mobility and restraint aids, tactile senses of the hand and feet, visual recognition, lighting, person-to-person communication, and the articulation character of the human body suggest that the architecture and appointments of spacecraft should presume that crewmen will go about their nominal duties more or less erect to a common "floor." There may be powerful psychological reasons to maintain some semblance of the accustomed Earth-like orientation, but the engineering reasons alone suffice.

Mobility and Restraint as a Spacecraft System

Ever since EVA during Gemini flights called attention to the kinesthetic problems of zero g mobility and restraint, it has been apparent that zero g space flight requires the development of an engineering rationale to deal as rigorously with crewman mobility and restraint as with the mechanics of other space flight systems. Nevertheless, mobility and restraint of the crewmen were not afforded the same degree of engineering attention as other dynamic and kinematic systems in Skylab, probably because the designers were misled by the apparent ease with which the astronauts handled themselves in the confines of the Apollo spacecraft.

The few rigorous, end-to-end, analytical or experimental simulations that were performed dealt with the operation of particular experiments. Few simulations dealt with mobility and restraint considerations for routine activities or sought to develop uniform procedures and mechanical aids. As a result, Skylab contained all kinds of restraint devices and mobility aids, some worked and some were useless.

Testing Habitability Equipment

Had it not been for the Skylab Medical Equipment Altitude Test (SMEAT), some habitability equipment would not have been found faulty until too late to correct. Principally, SMEAT was not intended to test habitability equipment.

In the course of living 56 days in a ground based simulator, outfitted mostly with Skylab gear, three crewmen subjected much of the habitability equipment to the only functional test it received or would receive before flight.

Habitability equipment received more or less the same development and component tests as did other Skylab equipment but functional tests of the man/machine interface often were overlooked. When the man/machine interface was tested, the tests seldom reflected the vagaries of human performance.

BIBLIOGRAPHY

NOTE

Some documents listed were not given general distribution or written as formal references but may be used as such by qualified applicants or writers.

1. NASA TMX 64814, MSFC Skylab Mission Report - Saturn Workshop
2. NASA TMX 64825, MSFC Skylab Crew System Mission Evaluation
3. NASA JSC-08414, Revision A, Skylab Mission Report, First Visit
4. NASA JSC-08662, Skylab Mission Report, Second Visit
5. NASA JSC-08963, Skylab Mission Report, Third Visit
6. NASA 1-MRD-001F, Mission Requirement Documents:

   Volume I, First Skylab Mission
   Volume II, Second Skylab Mission
   Volume III, Third Skylab Mission
7. JSC-08053, SL1/2 Technical Crew Debriefing
8. JSC-08478, SL1/3 Technical Crew Debriefing
9. JSC-08809, SL1/4 Technical Crew Debriefing
10. JSC-08082, SL1/2 Corollary Experiments Debriefing
11. JSC-08482, SL1/3 Corollary Experiments Debriefing
12. JSC-09555, Skylab Experience Bulletin No. 21, IVA Environment
13. JSC-09535, Skylab Experience Bulletin No. 1, Translation Modes and Bump Protection
14. JSC-09536, Skylab Experience Bulletin No. 2, Architectural Evaluation for Airlock
15. JSC-09537, Skylab Experience Bulletin No. 3, Architectural Evaluation for Sleeping Quarters

16. JSC-09551, Skylab Experience Bulletin No. 17, Neutral Body Posture in Zero-G

17. JSC-09552, Skylab Experience Bulletin No. 18, Evaluation of Skylab IVA Architecture

18. JSC-09538, Skylab Experience Bulletin No. 4, Design Characteristics of Sleep Restraint

19. JSC-09541, Skylab Experience Bulletin No. 7, An Overview of IVA Personal Restraint Systems

20. JSC-09543, Skylab Experience Bulletin No. 9, Foot Restraint Systems

21. JSC-09544, Skylab Experience Bulletin No. 10, Body Restraint Systems

22. JSC-09545, Skylab Experience Bulletin No. 11, Personal Mobility Aids (IVA)

23. JSC-09546, Skylab Experience Bulletin No. 12, Temporary Equipment Restraints

24. JSC-09547, Skylab Experience Bulletin No. 13, Tools, Test Equipment, and Consumables Required to Support Inflight Maintenance

25. JSC-09549, Skylab Experience Bulletin No. 15, Cable Management in Zero-G

26. JSC-09553, Skylab Experience Bulletin No. 19, Food System

27. JSC-09540, Skylab Experience Bulletin No. 6, Space Garments for IVA Wear

28. JSC-09542, Skylab Experience Bulletin No. 8, Cleansing Provisions Within The Waste Management Compartment

29. JSC-09548, Skylab Experience Bulletin No. 14, Personal Hygiene Equipment

30. JSC-09559, Skylab Experience Bulletin No. 25, Waste Management Systems

31. JSC-09539, Skylab Experience Bulletin No. 5, Inflight Maintenance as a Program Element

32. JSC-09556, Skylab Experience Bulletin No. 22, Evaluation of Requirements and Provisions for Housekeeping

33. JSC-09562, Skylab Experience Bulletin No. 28, Mass Handling and Transfer

34. JSC-09557, Skylab Experience Bulletin No. 23, IVA Communications

35. JSC-09569, Skylab Experience Bulletin No. 26, The Importance of Man-Machine Engineering Evaluations in Zero-G

APPENDIX A

BIOGRAPHIES OF SKYLAB CREWS

APPENDIX A

SKYLAB CREWMEN BIOGRAPHICAL DATA

Skylab 2 Crew

Commander (CDR) Charles Conrad, Jr.- Captain, USN born June 2, 1930; height, 1.69 meters (5 feet, 6.5 inches); weight, 62.6 kilograms (138 pounds).

He received a B.Sc. degree in Aeronautical engineering from Princeton University in 1953 and became a naval aviator soon after. He attended the Navy Test Pilot School and was assigned as a project test pilot.

Capt. Conrad was selected as an astronaut by NASA in 1962. In 1965, he served as pilot of Gemini V; in 1966, he was commander of Gemini XI; and, in 1969 he commanded Apollo 12, man's second lunar landing mission. He completed three space flights for a total of 506 hours and 48 minutes in space.

Science Pilot (SPT) Joseph P. Kerwin.- Commander, MC, USN born, Feb. 19, 1932; height, 1.83 meters (6 feet); weight, 77.1 kilograms (170 pounds).

He received a B.A. degree in philosophy from Holy Cross in 1953 and received a doctor of medicine degree from Northwestern University Medical School in 1957. He completed his internshop at District of Columbia General Hospital and attended the U.S. Navy School of Aviation Medicine. Comdr. Kerwin served 2 years as flight surgeon with the Marine Corps, and became a pilot in 1962. He then became flight surgeon for Fighter Squadron 101 and subsequently served as staff flight surgeon for Air Wing 4 at the Naval Air Station Cecil Field, Fla. He was selected as a scientist astronaut by NASA in 1965.

Pilot (PLT) Paul J. Weitz (Commander, USN) Born: July 25, 1932; height: 1.78 meters (5 feet, 10 inches); weight: 81.6 kilograms (180 pounds).

He received a bachelor of science in aeronautical engineering from Pennsylvania State University in 1954 and a master's degree in aeronautical engineering from the U.S. Naval Postgraduate School in 1964.

Comdr. Weitz received his commission as an ensign in 1954 and completed his flight training in 1956. From 1956 to 1964 he served at the Naval Air Stations at Jacksonville, Fla.; China Lake, Calif.; and, the Naval Air Station Whidbey, Wash. He has logged more than 3700 hours of aircraft flying time.

He was selected as an astronaut by NASA in 1966. He served as a member of the astronaut support crew for Apollo 12.

Skylab 3 Crew

Commander (CDR) Alan L. Bean (Captain, USN) Born: Mar. 15, 1932; height: 1.75 meters (5 feet, 9 1/2 inches); weight: 70.3 kilograms (155 pounds).

He received a bachelor of science degree in aeronautical engineering from University of Texas in 1955. Comdr. Bean was commissioned upon graduation. After completing flight training he was assigned to the Naval Air Station in Jacksonville, Fla. for 4 years. He attended the Navy Test Pilot School at Patuxent River, Md., and upon graduation he was assigned as a test pilot. He has flown 27 types of military aircraft and logged more than 4400 hours of flying time.

He was selected as an astronaut by NASA in 1963. He served as backup command pilot for Gemini X and backup lunar module pilot for Apollo 9. He was lunar module pilot for Apollo 12.

Science Pilot Owen K. Garriott, Ph. D.- Born, Nov. 22, 1930; height: 1.75 meters (5 feet 9 inches); weight: 63.5 kg (140 pounds).

He received a bachelor of science degree in electrical engineering from University of Oklahoma in 1953, and a master of science degree and a doctorate in electrical engineering from Stanford University in 1957 and 1960, respectively.

Dr. Garriott taught electronics, electromagnetic theory, and ionospheric physics in the Department of Electrical Engineering at Stanford University. He performed research in ionospheric physics and has authored and co-authored more than 25 scientific papers and one book in that area.

He was selected as an astronaut by NASA in 1965, and has since completed a course in flight training at Williams Air Force Base, Ariz. He has logged more than 1600 hours of flying time. In addition to NASA ratings, he maintains FAA commercial pilot and flight instructor certification.

Pilot (PLT) Jack R. Lousma (Major, USMC) Born: Feb. 29, 1936; height: 1.83 meters (6 feet); weight: 83.9 kilograms (185 pounds).

He received a bachelor of science degree in electrical engineering from University of Michigan in 1959 and a degree of aeronautical engineer from the U.S. Naval Postgraduate School in 1965.

Maj. Lousma was commissioned in the Marine Corps in 1959 and received his wings in 1960. He was assigned to the 2nd Marine Air Wing, and later with the 1st Marine Air Wing at Iwakuni, Japan. He was a reconnaissance pilot with 2nd Marine Air Wing before coming to NASA. He has logged 2600 hours of flight time.

He was selected as an astronaut by NASA in 1966. He served as a member of the astronaut support crews for Apollo 9, 10, and 13 missions.

Skylab 4 Crew

Commander (CDR) Gerald P. Carr (Lieutenant Colonel, USMC) Born: Aug. 22, 1932; height: 1.75 meters (5 feet, 9 inches); weight: 70.3 kilograms (155 pounds).

He received a bachelor of science degree in mechanical engineering from University of Southern California, a bachelor of science degree in aeronautical engineering from the U.S. Naval Postgraduate School in 1961, and a master of science degree in aeronautical engineering from Princeton University in 1962.

Lt. Col. Carr was commissioned in the Marine Corps in 1954. After receiving his flight training, he was assigned to Marine All Weather Fighter Squadron 114. After postgraduate training, he served with Marine All-Weather Fighter Squadron 112 in the United States and Far East. When informed of his selection for astronaut training, he was assigned to the Test Directors Section, Marine Air Control Squadron 3. He has logged more than 3100 hours of flying time.

He was selected as an astronaut by NASA in 1966. He served as a member of the astronaut support crews for Apollo 8 and 12 and was involved in the development and testing of the lunar roving vehicle.

Science Pilot (SPT) Edward G. Gibson (PhD) Born: Nov. 8, 1936; height: 1.75 meters (5 feet, 9 inches); weight: 72.6 kilograms (160 pounds).

He received a bachelor of science degree in engineering from University of Rochester in 1959; a master of science degree in engineering from California Institute of Technology in 1960; and a doctorate in engineering from California Institute of Technology in 1964.

Dr. Gibson was a research assistant studying in the fields of jet propulsion and classical physics. His technical publications were in the fields of plasma physics. He was senior research scientist with the Applied Research Laboratories of Philco Corporation from June 1964 until coming to NASA.

He was selected as an astronaut by NASA in 1965. He completed his flight training at Williams Air Force Base, Ariz., and earned his Air Force wings. He has logged 1500 hours of flying time. He served as a member of the astronaut support crew for Apollo 12.

Pilot (PLT) William R. Pogue (Lieutenant Colonel, USAF) Born: Jan. 23, 1930; height: 1.75 meters (5 feet, 9 inches); weight: 73.9 kilograms (163 pounds).

He received a bachelor of science degree in education from Oklahoma Baptist University in 1951 and a master of science degree in mathematics from Oklahoma State University in 1960.

Lt. Col. Pogue received his commission in the Air Force in 1952. While serving with the 5th Air Force during the Korean conflict in 1953 and 1954, he flew 43 combat missions. From 1955 to 1957, he was a member of the USAF Thunderbirds.

He was a mathematics instructor at the Air Force Academy from 1960 to 1963. In 1965 he completed a 2-year tour as test pilot with the British Ministry of Aviation. He has flown more than 50 types and models of American and British aircraft, and is qualified as a civilian flight instructor. He has logged 4,400 hours of flying time.

He was selected as an astronaut by NASA in 1966. He served as a member of the astronaut support crews for Apollo 7, 11, and 14 missions.

APPENDIX B

INSTRUMENTS USED FOR EXPERIMENT M487

APPENDIX B

EXPERIMENT M487 INSTRUMENTS

Instruments for measuring habitability parameters were provided for experiment M487. Experiment instruments, were augmented by operational equipment, and used to obtain quantitative data at specific locations within the spacecraft. The instruments carried onboard Skylab principally for use experiment M487, and were:

1. Velometer: A portable instrument for measuring air velocity (fig. B-1).

2. Measuring tape: A conventional flex tape graduated in inches (fig. B-2).

3. Sound level meter: A portable instrument for measuring sound pressure levels (fig. B-3).

4. Frequency analyzer: A portable instrument for analyzing the sound spectrum (fig. B-3).

5. Ambient-air thermometers: A portable instrument for measuring air temperatures (fig. B-4).

6. Digital thermometer: A portable instrument for measuring surface temperatures (fig. B-5).

7. Force Gage: A portable spring balance for measuring push/pull forces required to operate various equipment (fig. B-6).

8. Equipment containers (fig. B-7): See table B-1 for instrument functions and display characteristics.

Figure B-1.- Velometer.

Figure B-2.- Measuring tape.

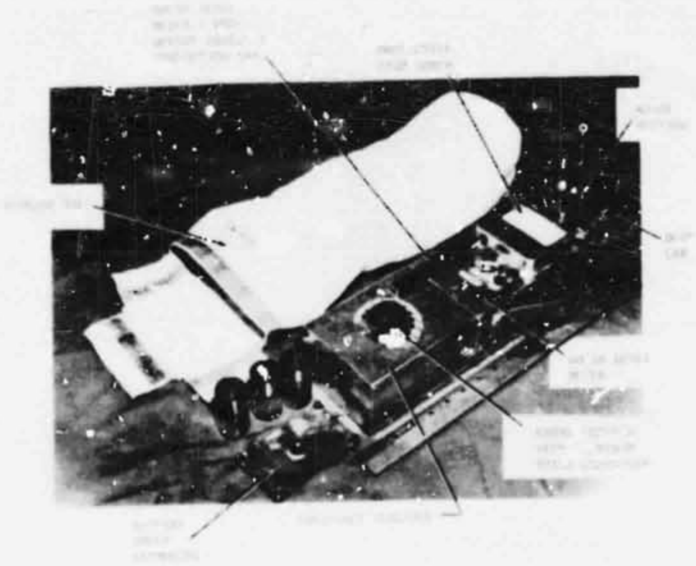

Figure B-3.- Sound level meter, frequency analyzer, and stowage bag.

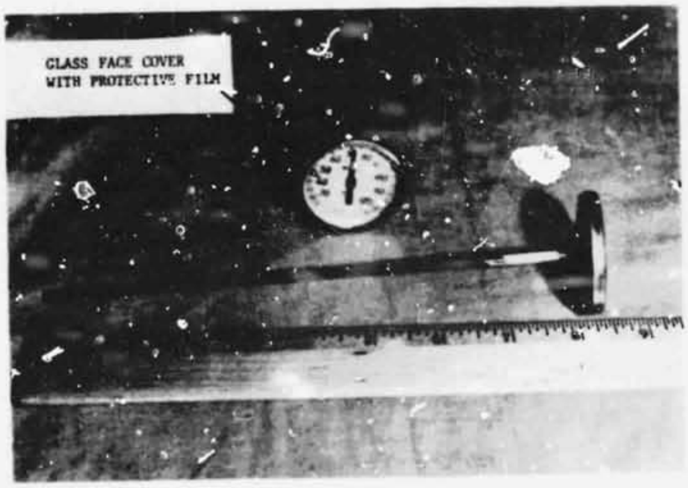

Figure B-4.- Thermometer.

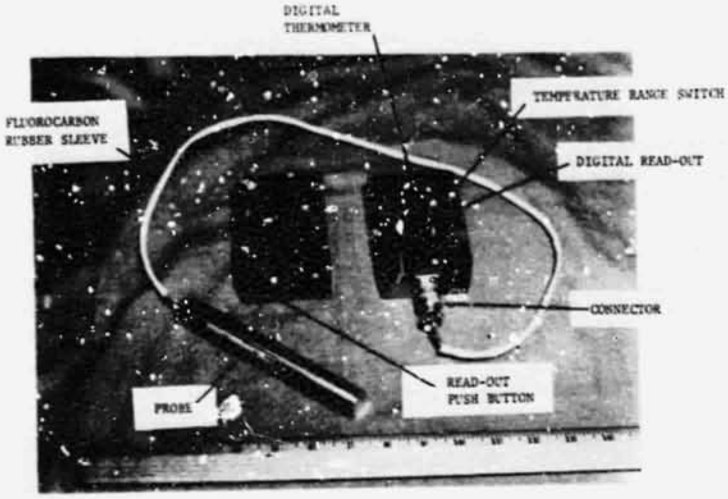

Figure B-5.- Digital thermometer.

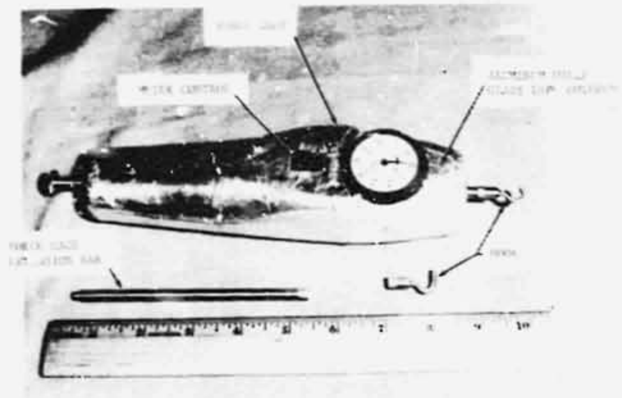

Figure B-6.- Force gage.

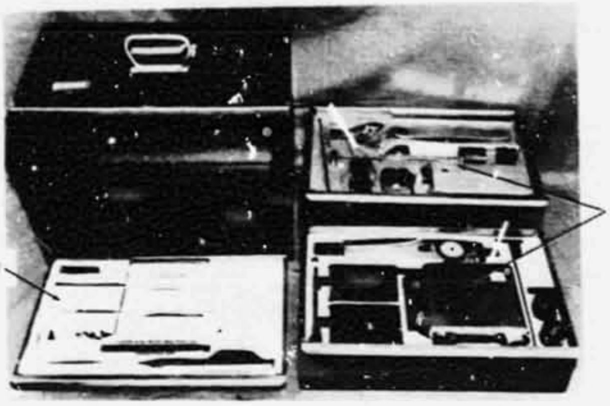

Figure B-7.- Equipment containers.

TABLE B-I. - INSTRUMENT FUNCTIONS AND DISPLAY CHARACTERISTICS

Instrument	Display type	Monitoring capability	Threshold of activation	Measurement accuracy	Function/remarks	Figure reference[1]
Sound level meter and frequency analyzer	Meter	+10 to 10 dB (upper black scale)	1 dB	±2 dB to 5 kHz ±3 dB to 10 kHz	Indicates sound pressure levels	B-1
	Meter	Red band (lower red scale)	+1.25 V	Not applicable	Battery check	
	Meter	-2 to + dB (upper red scale)	.5 dB	.5 dB	Microphone K-factor check	
	Pilot lamp	Flashing light	Not applicable	Not applicable	Indicates meter "on"	
Velometer	Meter scale	0 to 100 ft/min	2 ft/min (.61 m/min)	±4 ft/min (±1.22 m/min)	Indicates air velocity	B-2
Ambient thermometers	Meter scale	-40° to 160° F	2° F (256.5 K)	.1 percent full scale	Indicates ambient temperature	B-3
Digital thermometer (quantity 2)	Digital readout	0° to +400° F (low scale) 0° to 750° F (high scale)	1° F (255.4 K)	±2.5° F (±1.38 K)	Indicates surface temperature - operational life 20 min (not continuous)	B-4
Measuring tape	Scale	0 to 10 ft	.125 in. (3.32 mm)	±.125 in. (±3.32 mm)	Calibrated scale in inches	B-5
Force gage	Dial indicator	0 to 50 lb (outer scale) 0 to 50 lb (inner scale)	1 lb (.454 kg)	±2 percent full scale	Indicates push/pull force (Outer scale indicates pull force from forward end and push force from aft end. Inner scale indicates push force from forward end and pull force from aft end.)	B-6

[1] Containers for equipment are shown in figure B-7.

APPENDIX C

COMPARTMENT SIZES AND COLOR SCHEMES

Skylab compartment volumes are contained in table C-I. Colors used in crew quarters and for common surfaces throughout the workshop are identified in table C-II.

TABLE C-I. - SKYLAB COMPARTMENT VOLUMES

(a) Orbital workshop

Section or crew station	Floor area, m² (ft²)	Volume		
		Total, m³ (ft³)	Uninhabitable, m³ (ft³)	Habitable, m³ (ft³)
Forward	33.6 (362)	173.1 (6110)	48.4 (1708)	124.7 (4402)
Forward dome	—	73.3 (2590)	23.8 (838)	49.6 (1751)
Forward compartment	33.6 (362)	99.7 (3520)	24.6 (860)	75.1 (2651)
Crew quarters	32.9 (353)	65.4 (2309)	17.0 (599)	48.4 (1710)
Wardroom	8.1 (87)	16.1 (569)	5.9 (209)	10.2 (360)
Waste management compartment	3.3 (35)	6.5 (229)	2.8 (98)	3.7 (131)
Sleep compartment	4.7 (50)	9.3 (327)	1.8 (62)	7.5 (265)
Experiment compartment	16.9 (182)	33.5 (1184)	6.5 (230)	27.0 (954)

(b) Airlock module

Section or crew station	Length, cm (in.)	Diameter, cm (in.)	Floor area, m² (ft²)	Volume		
				Total, m³ (ft³)	Uninhabitable, m³ (ft³)	Habitable, m³ (ft³)
Airlock module	[a]388.6 (153)	[a]165.1 (65)	[a][illegible] (153)	16.1 (571)	4.9 (174)	11.2 (396)
Structural transition section	170.2 (67)	304.8 (120)	—	[b]8.1 (287)	3.5 (124)	4.6 (163)
Forward compartment	--	--	2.9 (31)	[c]1.6 (55)	.7 (26)	.8 (29)
Lock compartment	--	--	4.6 (50)	4.3 (153)	[illegible] 3	4.2 (150)
Aft compartment	--	--	3.9 (42)	[b]2.2 (76)	[d].6 (20)	1.6 (56)

[a]STS not included in AM dimensions.

[b]Aft bulkhead not included.

[c]Forward bulkhead not included.

[d]Includes portion of duct.

(c) Multiple docking adapter

Section or crew section	Length, cm (in.)	Inside diameter, cm (in.)	Volume		
			Total, m³ (ft³)	Uninhabitable, m³ (ft³)	Habitable, m³ (ft³)
Multiple docking adapter.	[a]477.5 (188)	284.5 (112)	27.9 (985)	11.5 (406)	16.4 (579)
Dome (conical section)	54.4 (21.4)	78.7 (31)	1.6 (55)	.1 (5)	1.4 (50)
Forward section 2	96.0 (37.8)	284.5 (112)	6.1 (216)	2.7 (94)	3.5 (22)
Center section 3	112.9 (44.46)	284.5 (112)	7.2 (254)	3.3 (117)	3.9 (137)
Center section 4	88.7 (34.9)	284.5 (112)	5.6 (198)	2.6 (91)	3.0 (107)
Aft section 5	110.2 (45.75)	284.5 (112)	7.4 (262)	2.8 (99)	4.6 (163)

[a]From forward part of dome to structural transition section.

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TABLE C-II. - COLORS FOR CREW QUARTERS AND COMMON VISIBLE SURFACES

Item	Color	Item	Color
Crew quarters:		Common visible surfaces:	
Floor and ceiling grid and beams; plenum cover	Yellow	Communication boxes:	Off-white (Micatan)
		Lettering	Black
		Knobs	Gray
		Switches	Satin chrome
Compartment walls	Gold		
		Fire extinguishers	Red
Waste management compartment:			
		Emergency controls:	Striped yellow/black
Ceiling	Clear	Panel location	Red outline
Floor	Red-tan		
Lockers	Light blue	Control/display panels:	
Fecal/urine collector	Clear	Faces	Off-white (Micatan)
Waste processor	Clear	Lettering	Black
		Control knobs	Black
Wardroom:		Toggle switches	Satin chrome
Soft door	Natural	Instrument faces	Black with white lettering
Lockers	Gold, red-tan, off-white		
		Indicator bezels	Gray
Table	Off-white and clear		
		Electrical outlets:	
Sleep compartment:		Utility	Gold anodized
Lockers	Gold	Television	Gold anodized
Sleep restraints	Natural	Switches	Natural metallic
Privacy curtains	Natural	Lettering	Black
Privacy partition	Gold	Receptacle	Natural metallic
Individual crew equipment color code:		Internal mobility aids:	
		Handholds/handrails (fixed and portable)	Dark blue
Crewman 1	Red		
Crewman 2	Off-white	Foot restraints	Dark blue
Crewman 3	Dark blue	Polyamide parts	Brown (natural)
Emergency repair kit	Red	Vacuum valves:	
		Handles	Black
Tool kit	Gray	Direction lettering	Black
		Faceplate	Gold anodized
		Ventilation control system:	
		Ducts (hard)	Light yellow
		Diffusers	Yellow or light yellow
		Flexible ducts	Natural
		Structure walls	Light yellow
		Containers	Off-white

[a] Color finish (Federal standard number): yellow (33538), blue (15123), red (11105), black (37038), off-white (37886), gray (26231), light yellow (37855).