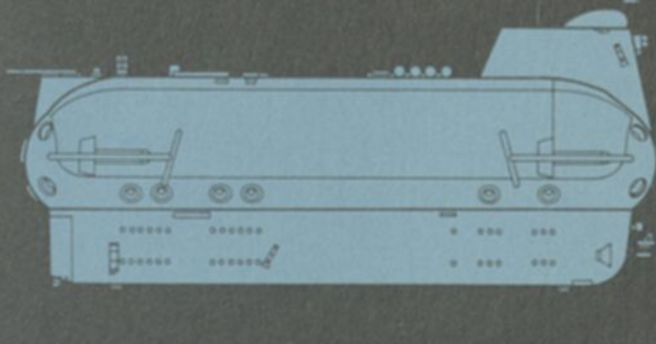
Use of the Ben Franklin Submersible As a Space Station Analog

VOLUME I

SUMMARY TECHNICAL REPORT

OSR-70-4



USE OF THE BEN FRANKLIN SUBMERSIBLE AS A SPACE STATION ANALOG

Volume I – Summary Technical Report
OSR-70-4

Prepared for
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Advanced Systems Office

Contract NAS 8-30172

Prepared by
Space Station Analog Study Team

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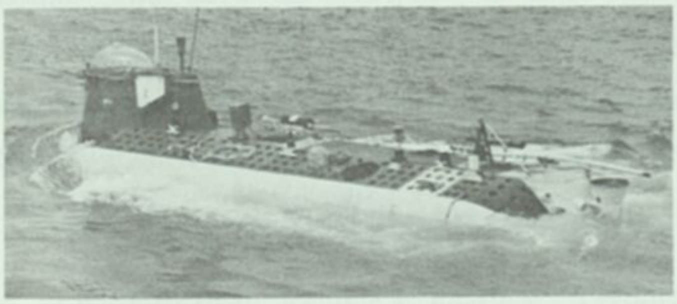
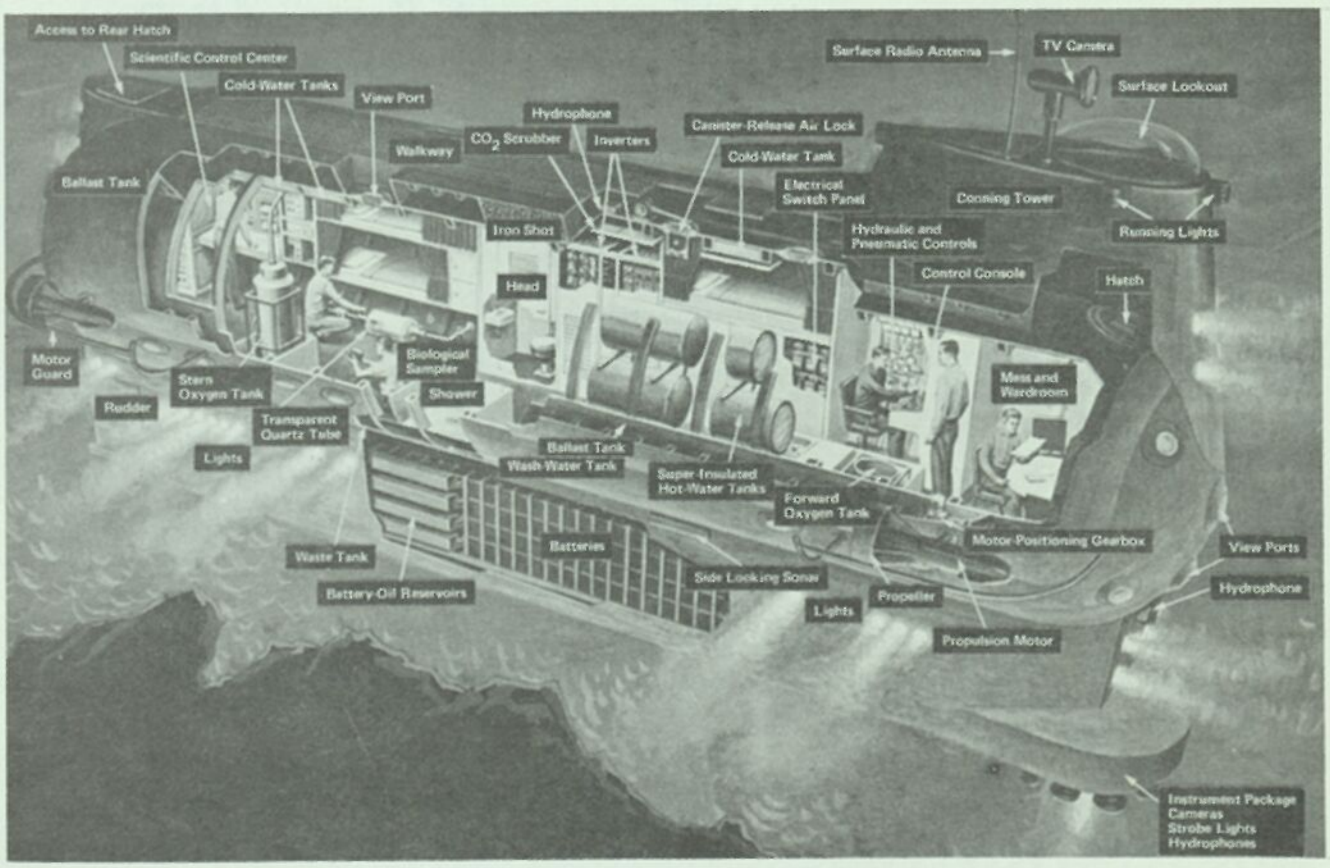
THE BEN FRANKLIN DURING THE GULF STREAM DRIFT MISSION





FOREWORD

During 1969, the Ocean Systems Department of Grumman Aerospace Corporation conducted the 30-day Gulf Stream Drift Mission, using the BEN FRANKLIN submersible. As a part of this mission, a NASA study was conducted to investigate man related activities which are analogous to long-duration space station missions. During the mission, a NASA crew member was aboard the BEN FRANKLIN for data collection, observation, and task participation. This work was performed in accordance with the Statement of Work in NASA Contract NAS 8-30172, "Use of BEN FRANKLIN as a Space Station Analog," for the George C. Marshall Space Flight Center, Advanced Systems Office, under the direction of C.B. May. The program was coordinated by M. Markey of NASA, Washington Headquarters.

The Final Report consists of the following five volumes:

- OSR-70-4, Volume I, Summary Technical Report
- OSR-70-5, Volume II, Psychology and Physiology
- OSR-70-6, Volume III, Habitability
- OSR-70-7, Volume IV, Microbiology
- OSR-70-8, Volume V, Maintainability

ABSTRACT

This report presents the NASA effort using the BEN FRANKLIN submersible as a space station analog during the 30-day Drift Mission in the Gulf Stream, starting July 14 and ending August 14, 1969. The areas of investigation include:

- Psychological and Physiological measurements during the pre-mission, mission, and post-mission phases
- Habitability in a closed ecology
- Microbiology evaluation of the water system, human flora, and environmental samples
- Maintainability considerations for scheduled and unscheduled tasks.

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VOLUME 1.

SUMMARY REPORT

BEN FRANKLIN/SPACE STATION

ANALOG

VOLUME 1. (Cont.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont.)

SECTION 1
INTRODUCTION

1.1 Background

The 30 day Gulf Stream Drift Mission (GSDM) was conceived by Dr. Jacques Piccard in 1965 to explore the Gulfstream from Florida to Nova Scotia, using visual observations, bottom photography, biological surveys, and acoustical surveys. Early in 1967 the Grumman Corporation agreed to undertake the mission and established a program for the design, development, and construction of the BEN FRANKLIN. See Appendix A for the characterisitcs of the vehicle.

During the design and development phase, the similarities between the GSDM and space missions became apparent. At the same time the NASA Office of Manned Space Flight awarded Grumman contract NASW-1965 to study the feasibility of using undersea facilities as space mission analogs. Final Report OSR-68-6 11 March 1968, Feasibility Study - Use of Submersibles as Space Mission Analogs, presents the results of the effort. It concluded that submersible missions would be reasonable analogs of space missions. Both types of missions would be manned by scientific and engineering crews motivated by a scientific purpose to work under operational hazards. Therefore, the submersible could provide space programs with data on crew reactions, the man-machine interface, habitability, and the effects of complete biological isolation during a long-term mission. In support of these conclusions, NASA awarded Grumman a contract to study these factors during the GSDM. The study is the subject of this report.

The Naval Oceanographic Office (NAVOCEANO) agreed to support the ocean mission by providing a surface vessel and two BEN FRANKLIN crew members to perform ocean experiments. The remainder of the crew of six consisted of two pilots (including Dr. Piccard), a relief pilot and oceanographer, and a NASA crew member responsible for the NASA effort.

The GSDM began on 19 July 1969 when the BEN FRANKLIN submerged into the Gulf Stream off West Palm Beach, Florida. It terminated 30 days, 11 hours later when the BEN FRANKLIN surfaced 360 miles south of Nova Scotia. The drift covered 1444 n mi at an average depth of 650 ft. Ten excursions were made to depths between 1200 and 1800 ft.*. The mission was supported by two oceanographic ships, two land bases, and a mobile support van.

1.2 Submersible Advantages

The Gulf Stream Drift Mission (GSDM) generated data and information applicable to space missions which could not be acquired through other forms of ground-based simulators. The mission tasks, the diversified crew, the sealed environment, and complete physical separation from the outside world, produced unique problems, for example:

- The diversified crew and their interaction with the support team indicated potential command (organizational) problems.
- Microflora of the crew and within the vehicle tended to simplify and to move toward a microbial imbalance which might prove harmful over extended periods of time in isolation.
- Limitations of communications provisions caused the crew to feel cut off from the world. In addition, a lack of private communications prevented personal discussions.
- Complete isolation and separation forced the initial provisioning of all food. Foods were pre-mission tested and accepted, but under mission conditions were found to be unsatisfactory.

The submersible provides a means for evaluating the operational effectiveness of crew habitability factors (food, clothing, accommodations), crew skill mix, command structure, and selected spacecraft subsystems checkout and maintenance during a real ocean mission.

To date, manned space operations, habitability provisions, and life support hardware have been tested in ground based static simulators or chambers. However, as test durations have increased in manned testing, motivational problems have resulted due to a lack of

*See Appendix B for a summary of scientific ocean data. Oceanographic scientific experiment results are detailed in the Grumman BEN FRANKLIN GSDM Report OSR 69-19. The captain's log is presented in Appendix C.

meaningful work activities. The GSDM showed that the submersible overcomes this problem since a variety of meaningful scientific tasks are performed by the crew in support of the mission. At the same time, the effectiveness of candidate long duration spacecraft hardware and operational procedures, as well as crew interaction factors, can be evaluated in the closed/ stressed environment.

Submersibles and ground based chambers are complementary facilities. Chambers are required for thermal, vibration, radiation, and life tests under simulated environmental conditions. The submersible offers a means for expanding on such tests, by providing men and equipment an analogous mission environment. Fig. 1-1 lists the many similarities between spacecraft and submersibles and compares them with chambers.

	Spacecraft	Submersible	Chamber
Confinement	x	x	x
Social Isolation	x	x	x
Deprivation	x	x	x
Close Quarters	x	x	x
Meaningful Mission	x	x	
Sustained Motivation	x	x	
Hostile Environment	x	x	
Operational Stress	x	x	
Remote Operations	x	x	
Abort Difficulty	x	x	
Require Maneuvering	x	x	
Scientific Crew	x	x	
Data Transmission	x	x	
On-Board Maintenance Provisions	x	x	
Complete Biological Isolation	x	x	
Command Structure	x	x	

Figure 1-1. Similarities - Spacecraft/submersible/chamber

1.3 BEN FRANKLIN GSDM Inputs to Manned Spacecraft Systems Design

The objective of the NASA contract on the GSDM was to explore the areas of Life Sciences, Habitability, Microbiology, and Maintainability for the purpose of obtaining space station design criteria. The GSDM schedule precluded the acquisition and installation of space subsystems. BEN FRANKLIN subsystems and operations were, therefore, the basis for the space studies, and only incidental space equipment was provided.

Volumes 2, 3, 4, and 5 describe the results of the investigations in detail. The following are a few examples of the types of spacecraft design guidelines which resulted from the NASA contract:

Habitability:

Crew Accommodations

- Where volume is limited, bunks should be designed and located to be convertible to private lounges for relaxation, reading, and writing.
- Soundproof the crew quarters and locate as far as possible from operating equipment and work areas.
- Work areas and living/recreation areas should be separate. Where limited volume prevents this, activities must be scheduled to avoid overlap and interference.
- Provide for private communications with family and friends.
- Provide privacy, recreation, and storage for personal belongings.

Food

- Provide home type food and preparation facilities.
- The crew should not be forced to accept a monotonous diet and disagreeable foods.
- Variety and individual preference should be considered.

Clothing

- Daily underwear change is essential
- Provide for internal environment off-design temperature conditions.
- Provide two piece garments rather than jumpsuits.

Biotechnology

- Develop automated on-line contamination monitoring and provide simple means for decontaminating the vehicle surfaces, internal atmosphere and water management subsystem.
- Compartmentize the spacecraft to prevent spread of contamination.
- Provide negative pressure in hygiene areas to prevent issue of contaminants into living areas.
- Review all materials and designs to eliminate microbial nutrients and breeding grounds.
- Provide microbiological screening of crew to eliminate pathogen carriers.
- Monitor individual crew microbial makeup to detect potential spread of infection.
- Provide for microbe incineration, in addition to filters, to assist in atmosphere decontamination.
- Provide safe means for final disposal of microbially contaminated items.
- Provide an on-board microbiological laboratory to facilitate prompt analysis.

A study of the command structure during the GSDM was not part of NASA contract, but it is evident that such a study would have provided valuable data for space missions. The BEN FRANKLIN crew comprised a "mini" crew of scientists and operational personnel similar in composition to spacecraft crew mixes. During the GSDM, operations problems arose related to command structure, scientific/operations personnel skill mix, and the mission control team decisions made on the support ship, PRIVATEER. These problems are analogous to those anticipated in Space Station operations. An investigation into the causes and resolution of such problems in submersible missions could help provide insight into similar situations on future space missions.

1.4 Recommendations

During BEN FRANKLIN ocean missions in the future, the space investigations of the GSDM should be expanded to further develop general space technology, and to support the Orbital Workshop (OWS), the Space Station, and the Space Base Programs.

A joint NASA/Grumman effort is required to establish a definitive space operations and test program. The OWS and future space program needs should be reviewed jointly to select candidate tests. Grumman would establish a program which integrates hardware and tests into the BEN FRANKLIN and ocean missions schedules.

Recommended BEN FRANKLIN Future Space Tests:

1. Life Sciences
   - (a) Crew performance evaluation
   - (b) Biomedical instrumentation (e.g. IMBLMS) *
   - (c) Crew Selection Test Verification
   - (d) Work Task unit
2. Habitability
   - (a) Personal Hygiene Provisions
   - (b) Food Management
   - (c) Clothing
   - (d) Recreation Provisions
   - (e) Noise control
   - (f) Personal Accommodations
3. Biotechnology
   - (a) 60/90 day mission with crew rotation
   - (b) H_2O and atmosphere contaminant measurement and control
   - (c) Spacecraft and subsystems decontamination

*Integrated Medical Behavioral Laboratory Measuring System

4. <u>Subsystems Operation</u>

(a) Water management

(b) Waste management

(c) Atmosphere storage/supply

5. <u>Maintainability</u> (of space equipment)

(a) Failure prediction techniques

(b) Scheduled and unscheduled task analysis

(c) Spares and tools requirements

(d) Repair techniques/operations

6. <u>Mission Operations</u>

(a) Command Structure evaluation

SECTION 2
LIFE SCIENCES

2.1 Objective

The objective in "observing" the crew during the GSDM was to relate observed crew performance to variables which designers can use to influence space systems performance, ie:

- the engineering design (human engineering, environment)
- the choice of crew
- crew training

2.2 Approach

Pre-mission data were obtained to establish a personality profile of the crewmen, to establish a physical fitness index, and to develop a baseline on a motor skills test.

Data were obtained during the mission by means of a daily questionnaire or log that included, in addition to items related to the operation, the mission and the environment, the Cornell Medical Index, a Mood Scale Check List, a Subjective Stress Scale, a Sleep Recall Questionnaire, a number of tests to evaluate fitness, and daily tests of proficiency on the Langley Research Center Complex Coordinator.

These observations were supplemented by time-lapse photographs of most of the vehicle by judicous location of 3 cameras and by recording approximately 1 hour of conversation each day.

At the end of the mission, most of the pre-mission tests were repeated and the crewmen were intensively interviewed.

2.3 Results

Although selected only for special skills and desire to participate, the crewmen assigned to work together were reasonably compatible. Predictions of crew behavior based on pre-mission psychological tests, clinical interpretation and observation of the crew were proven reasonably accurate in the mission. However, the number of personality tests might be considerably reduced and still provide the same degree of insight.

Predicted annoyance and psychological stress were produced by the austere BEN FRANKLIN characteristics. These included the bunks, their location, food, the small galley, people noise, odors, lack of privacy, clothing, inaccessability of equipment, limited personal hygiene facilities, and environmental control.

As time increased, the men showed a general trend toward withdrawal and an increased need for privacy. This was in part evidenced by a tendency of the crewmen to eat more and more meals alone as the mission progressed. None of the crewmen reported psychosomatic or hypochrondrical symptomatology. Levels of depression and lack of personal well-being were greatest at the mid-point of the mission (days 13-15) when there were procedural disagreements with the surface crew.

None of the crew suffered serious deterioration in proficiency. However, as judged from measurement of complex coordination, changes in proficiency in one instance could be related to a mood of depression. Potentially serious problems resulted from failures and misunderstandings in communications with the surface crew. This was especially true when expected personal news was inexplicably lacking. None of the crewmen showed signs of physical deconditioning (there were no significant changes in recovery pulse or in hand and wrist strength) and all were declared by the Grumman physicians to be medically fit subsequent to completion of the drift mission.

Events in the GSDM indicate that expected communication of personal news at regular intervals probably is unwise because, if communications are delayed or interrupted, crewmen tend to become distressed and concerned. On the other hand, a lack of private communications to the surface was a source of annoyance during the mission.

Food provided a topic of conversation and possibly allowed for at least limited sublimation of psychological stress. Other topics such as daily questionnaires, and the interactions with support personnel, accomplished the same result. These are not, however, appropriate avenues for the release of tension. Investigation is recommended to develop more acceptable techniques to relieve tension.

2.4 Inputs to Space

Detailed consideration must be given early in a design to those aspects which could cause crew annoyance and frustration, and which could be further aggravated by the long duration confinement. Particularly important are:

- the environmental control/life support system
- privacy areas
- illumination
- noise
- food/preparation/clean-up facilities
- recreation
- work areas
- multiple use of spaces
- personal hygiene

Selection of crew pairs for compatibility will help reduce psychological stress in small closed systems. In addition, the mixed crews of future space missions should have a voice in the selection of teammates. A better understanding of the importance of this input is required and further investigations are recommended.

Performance rating both psychological (clinical) and operational can be obtained by self reporting of the crew if they believe that the information they provide will be held in confidence. The development of improved techniques is recommended for obtaining self evaluations by the crew with the intent of reducing the number of questions, eliciting observations not specifically called for, solicitiations of reports about others and for reporting during a mission. An objective measure of skill by a device like the Langley Research Coordinator appears to be predictive and was accepted by the crew. Further investigation to develop its utility is recommended.

SECTION 3

HABITABILITY

3.1 Objective

The objective was to determine the suitability of BEN FRANKLIN habitability data for providing guidelines for future spacecraft design. Factors considered in the study were food, clothing, control of environmental conditions, hygiene provision, crew equipment items, and crew reactions to these provisions.

3.2 Approach

The procedures and records used in the study included:

- Time-lapse cameras located at three places, set to function every two minutes.
- Environmental measurements (light, noise, temperature, etc.).
- Counters to measure use of toilet facilities, etc.
- Ships logs.
- Crewmembers personal logs and questionnaires.
- Debriefing
- Comparison of actual activities with planned activities in the Mission Plan.

3.3 Results

3.3.1 Area Utilization Studies

Analysis of the camera photos coupled with a study of the logs established a record of each man's location and activity throughout the mission. From these studies of area utilization and deviations from planned activities, it was determined that half of the crew followed their plan and half did not. Figure 3-1 illustrates this type of activity on day 1 of the mission, crewman #1 deviating from the plan and #6 following the plan. These

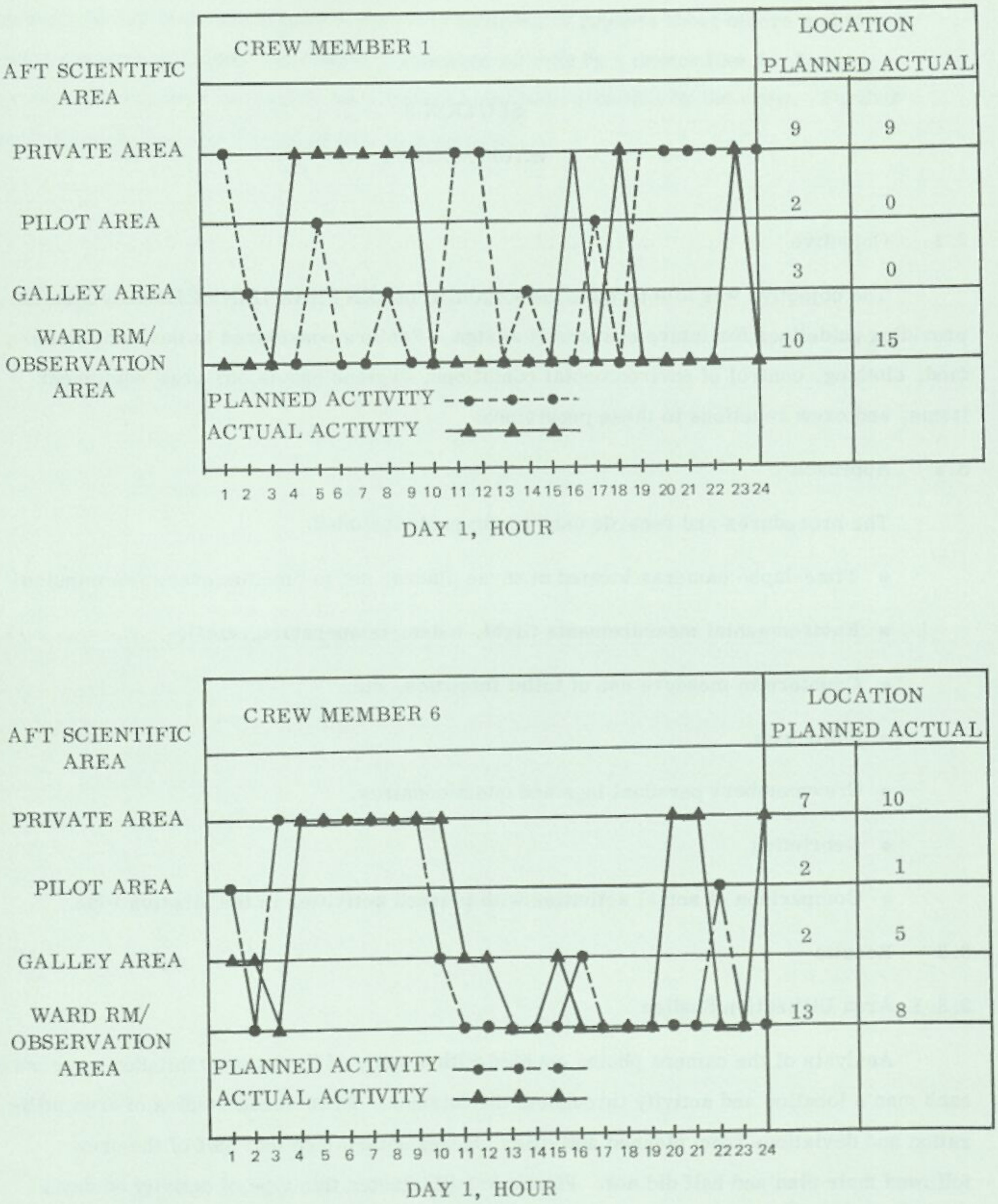


Figure 3-1. Actual Versus Planned Crew Member Time Lines, Day 1

deviations are due in part to lack of pre-mission training establishing each man's roll and to changes in work/rest cycles. The significant factor from this habitability standpoint is the overlap of work and recreation activities in a given area.

3.3.2 Questionnaire Results

The ten top complaints on questionnaires and volunteered complaints are shown in Figure 3-2. These indicate items which demand man/machine consideration both in submersible and spacecraft design.

Food complaints stemmed principally from the difficulties in preparation. Cooking was ruled out since it would contaminate the atmosphere. Canned, freeze dried, food was provided and was satisfactory from a nutritional and storage viewpoint. However, complaints about food increased with time.

The crew complaints on privacy and free space are presented in Figure 3-3. A maximum of four complaints were made on Day 15. The complaints decreased to one on Day 22 and started to increase to Day 29. It is interesting to note that no volunteered complaints were made throughout the mission. The principal complaint was that there was a need for a place for each crew member other than his bunk.

Although the bunks were oversized, the crew complained that it was not possible to sit up or bend knees without hitting the pressure hull.

3.3.3 Environmental Measurements

Atmospheric conditions were monitored and recorded throughout the mission. Variations were readily maintained within reasonable limits.

Atmospheric constituents and trace contaminants were monitored with Drager Tubes and a gas chromatograph. The Drager tubes identified a continuing rise in C0 throughout the mission to a maximum of 40 PPM, identifying the need for greater capacity in the C0 removal apparatus.

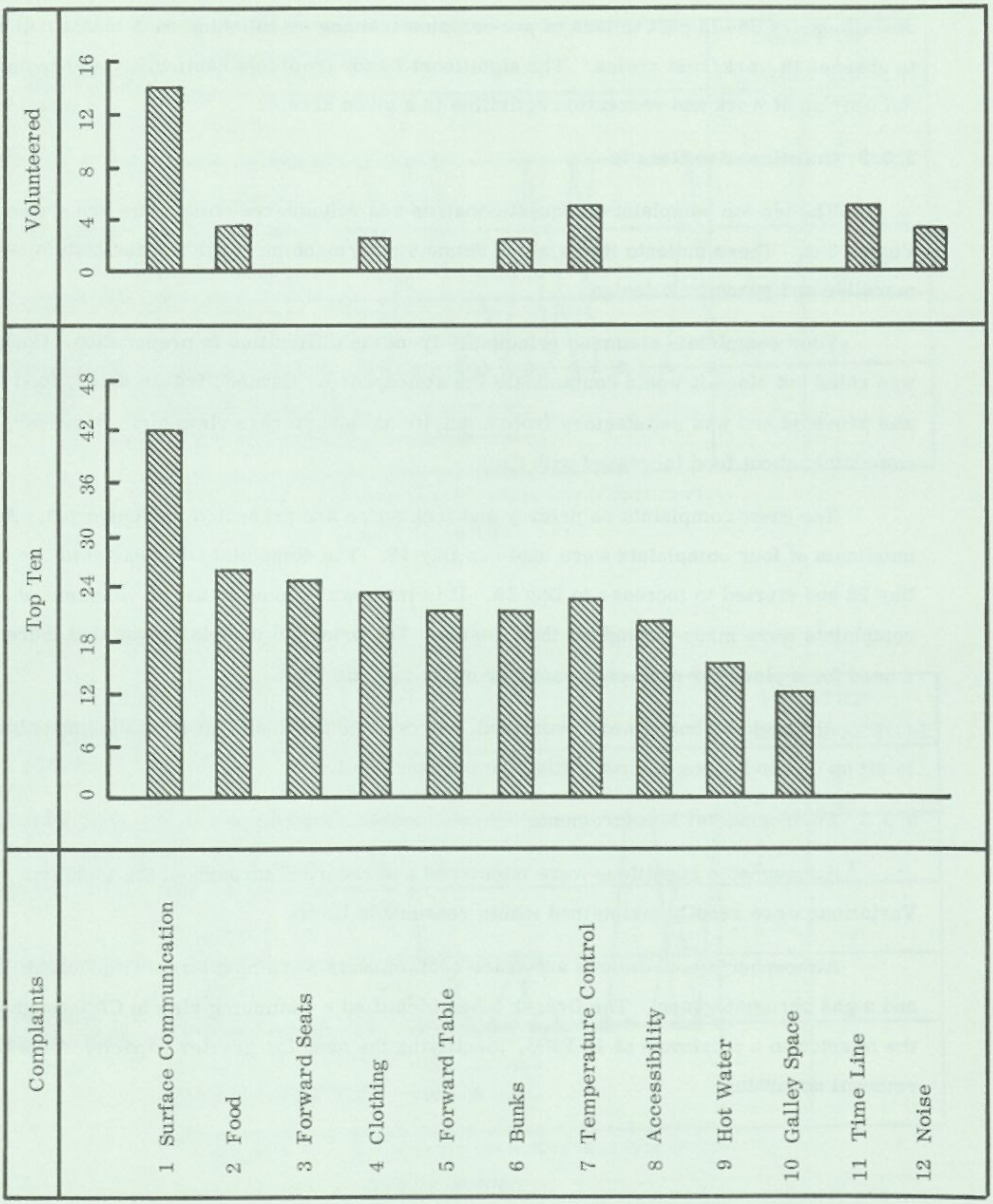


Figure 3-2. Major Habitability Complaints

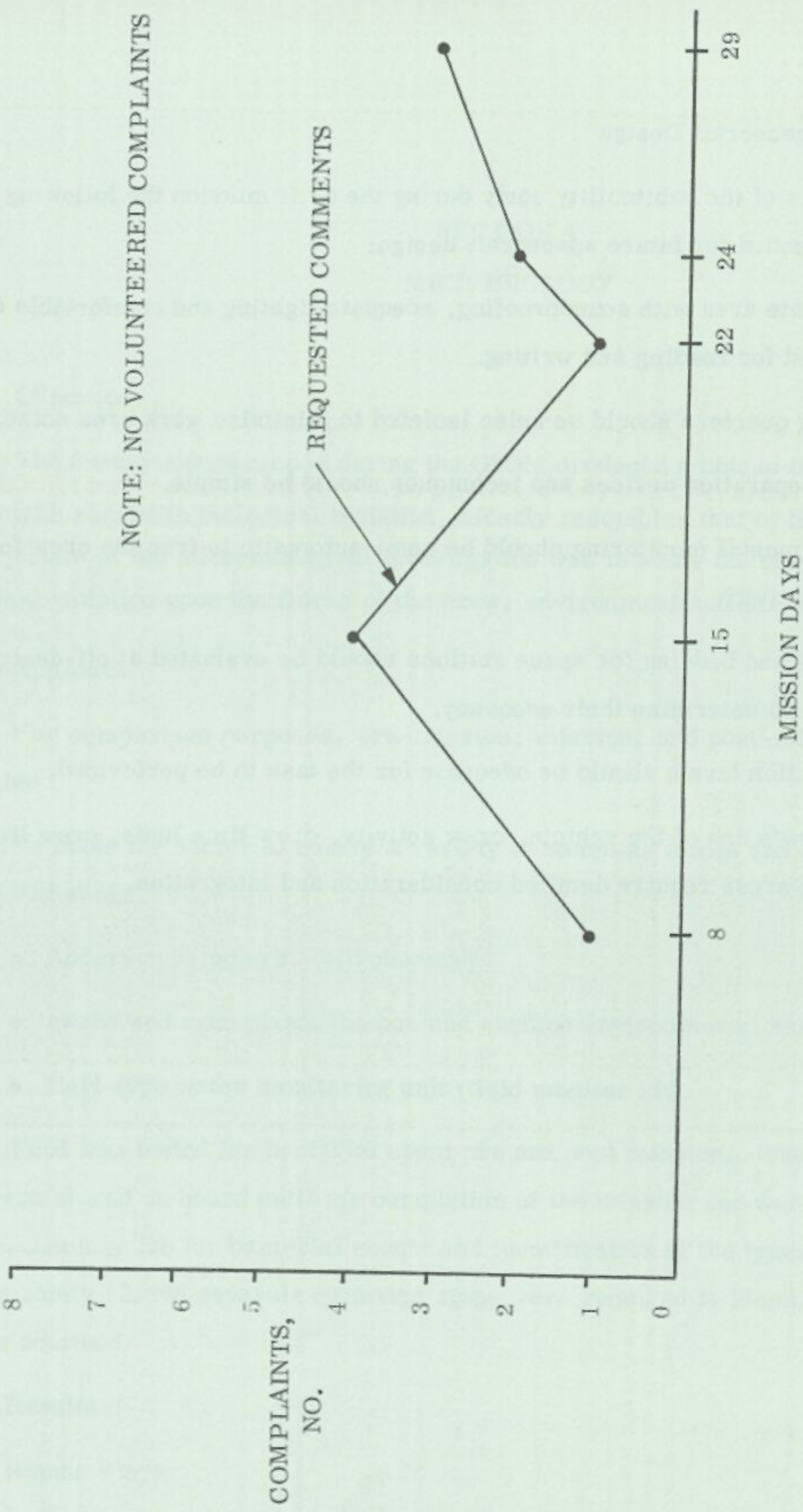


Figure 3-3 Privacy and Free Space Complaints

3.4 Inputs to Spacecraft Design

On the basis of the habitability study during the drift mission the following guidelines are recommended for future spacecraft design:

- A separate area with soundproofing, adequate lighting and comfortable chairs, is needed for reading and writing.
- Sleeping quarters should be noise isolated to minimize work area noise.
- Food preparation devices and techniques should be simple.
- Environmental monitoring should be semi-automatic to free the crew for more useful activity.
- Clothing and bedding for space stations should be evaluated at off-design conditions, to determine their adequacy.
- Illumination levels should be adequate for the task to be performed.
- The crew's use of the vehicle, crew activity, crew time lines, crew living and working areas require detailed consideration and integration.

SECTION 4

MICROBIOLOGY

4.1 Objective

The 30-day submergence during the GSDM produced a unique internal environment which, with regard to biological isolation, closely resembles that of future spacecraft. The objective of the microbiological investigation was to study the effects of total biological isolation upon the floras of the crew, environment and life support subsystems.

4.2 Approach

For comparison purposes, pre-mission, mission, and post-mission sampling were scheduled.

To make the bacterial counts, a variety of sampling media and devices were taken aboard including:

- Andersen samplers, (atmosphere)
- swabs and agar plates (human and surface environmental sampling)
- field-type water monitoring unit (field monitor kit).

Food was tested for bacterial count pre and post mission. Waste, garments and linen were stored on board until the completion of the mission and were then returned to the biotechnology lab for bacterial counts and identification of the types of bacteria present. Approximately 15,000 separate culturing steps were required to identify to Genus the 2230 isolates obtained.

4.3 Results

4.3.1 Human Flora

There appears to have been a general simplification and shift towards gram-negative organisms, (Figures 4-1 and 4-2), particularly Pseudomonas and Aerobactor.

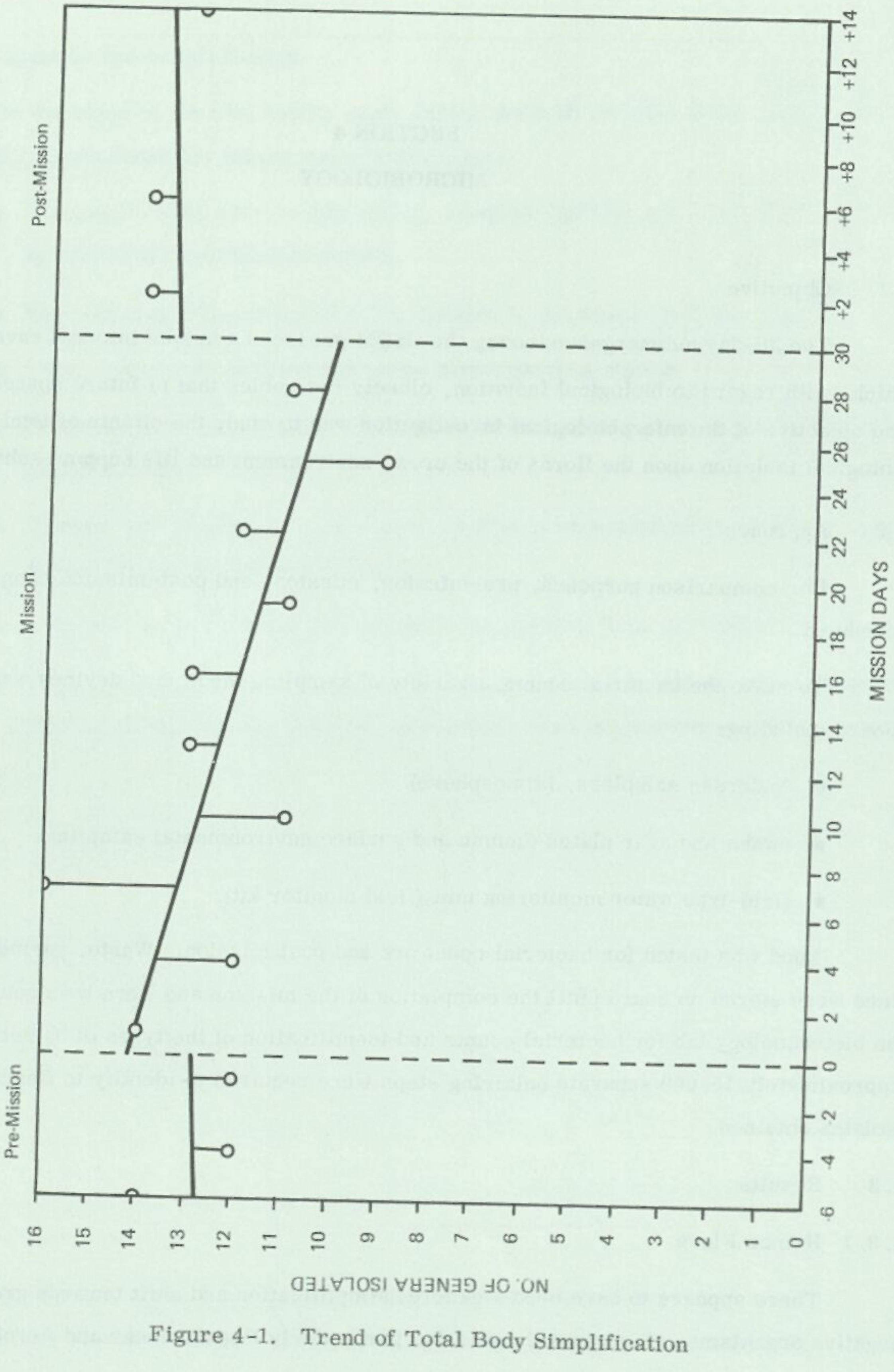


Figure 4-1. Trend of Total Body Simplification

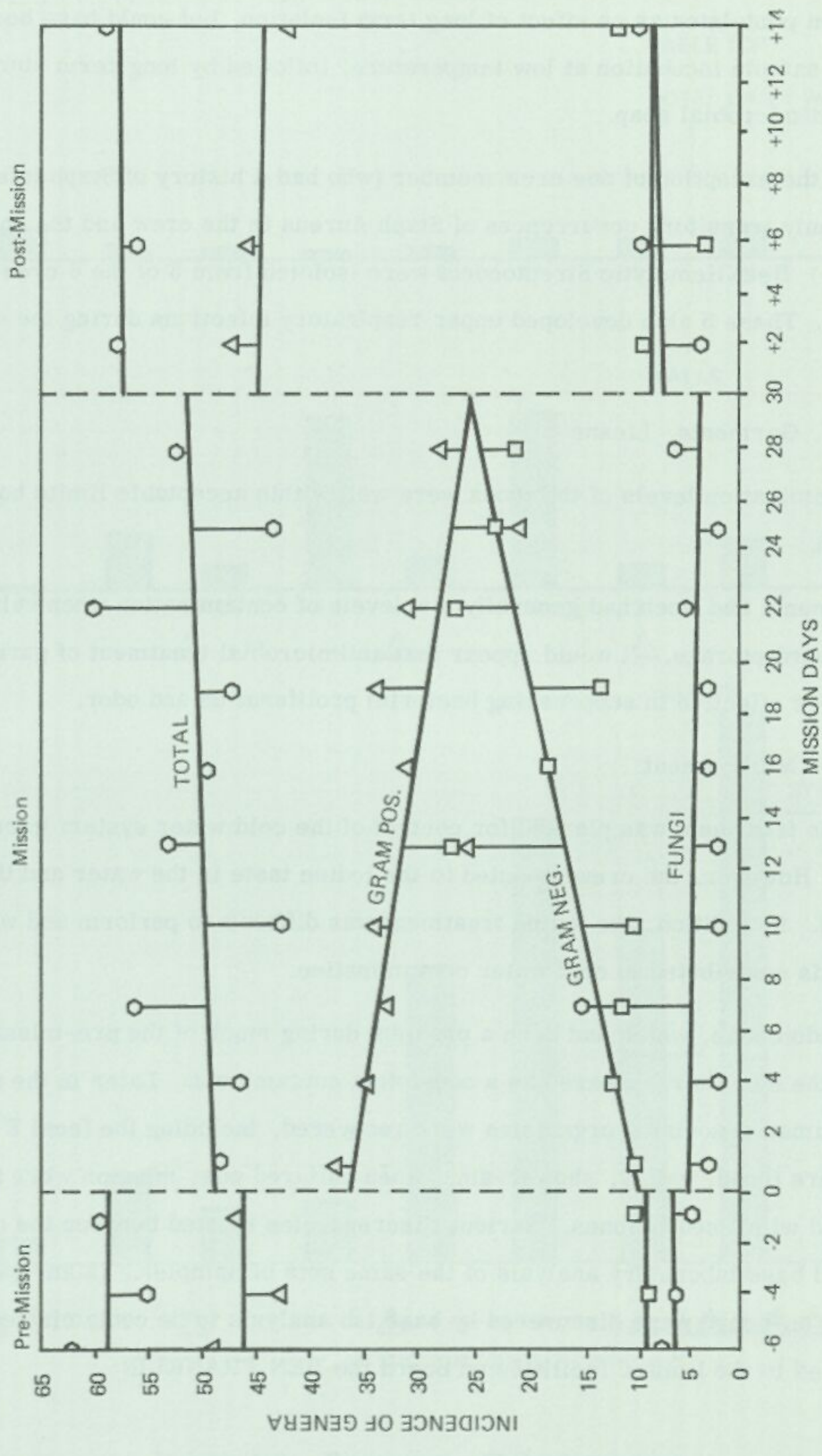


Figure 4-2. Trend of Total Body Shift

This has been postulated as an effect of long term isolation, but could have been biased by on-board sample incubation at low temperature, followed by long-term storage, or by the use of antimicrobial soap.

With the exception of one crew member (who had a history of Staph infections), there were only transitory occurrences of Staph Aureus in the crew and the environment (Figure 4-3.) Beta Hemolytic Streptococci were isolated from 5 of the 6 crew members (Figure 4-4). These 5 also developed upper respiratory infections during the early mission phase.

4.3.2 Food, Garments, Linens

Contamination levels of the foods were well within acceptable limits both pre and post mission.

Garments and linen had generally low levels of contamination when cultured after use and onboard storage. It would appear that antimicrobial treatment of garments and linen were effective in suppressing bacterial proliferation and odor.

4.3.3 Water Management

Iodine treatment was planned for control of the cold water system microbial contamination. However, the crew objected to the iodine taste in the water and the reconstituted food. In addition, the iodine treatment was difficult to perform and was not implemented. This contributed to cold water contamination.

Pseudomonas, which had been a problem during much of the pre-mission attempts at cleaning the system reappeared as a consistent contaminant. Later in the mission a variety of human associated organisms were recovered, including the fecal E coli. Several filters (head, galley, shower-sink) when cultured post-mission were found to be contaminated with Pseudomonas. Serious discrepancies existed between the on-board readings and base laboratory analysis of the same sets of samples. (Many samples read as "sterile" on-board were discovered by base lab analysis to be contaminated.) This was attributed to the limited facilities on board the BEN FRANKLIN:

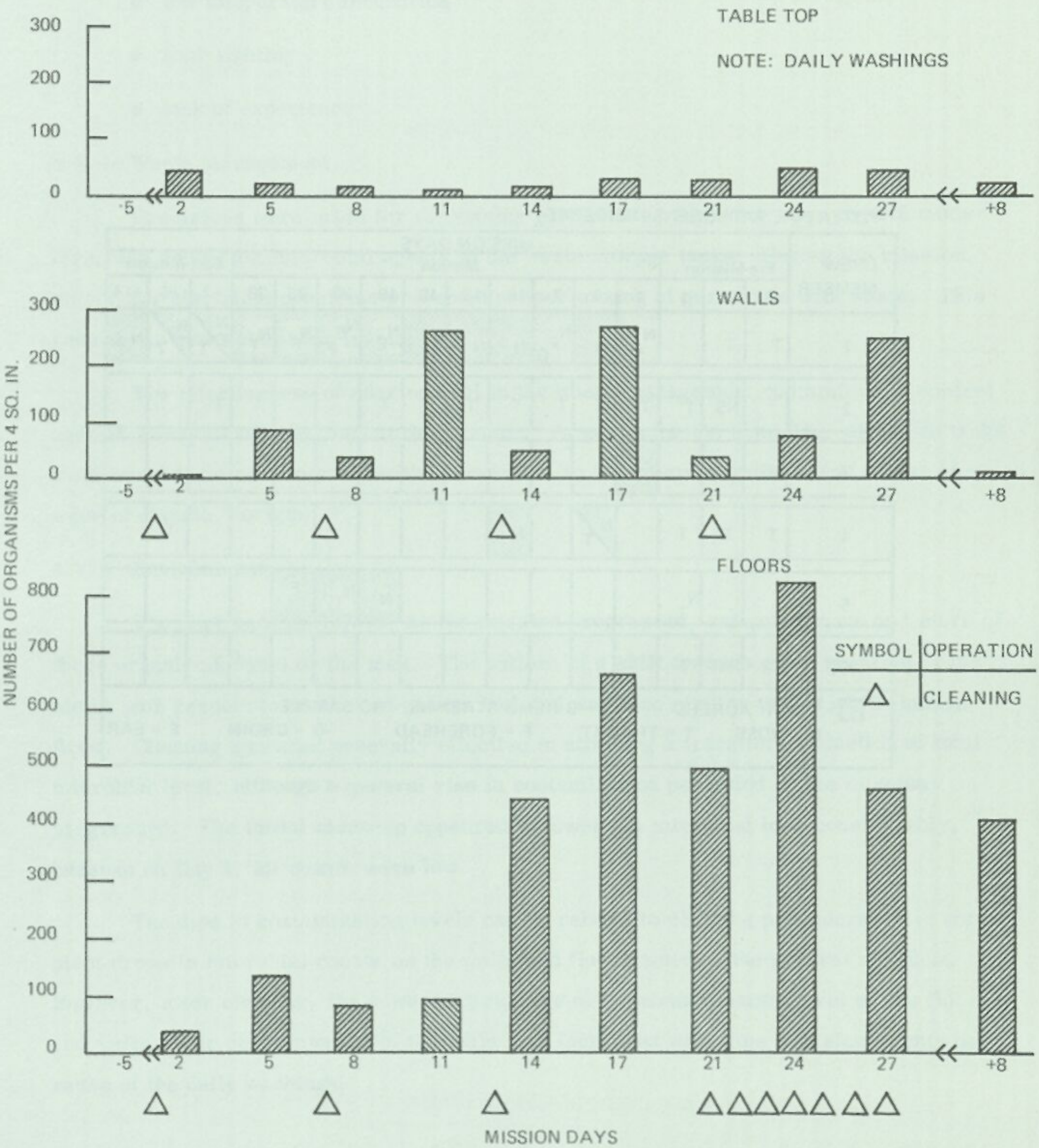


Figure 4-3. Environmental Contamination

POTENTIAL PATHOGENS INCIDENCE

CREW MEMBER	MISSION DAYS															
	Pre-Mission			Mission										Post-Mission		
	-6	-4	-1	1	4	7	10	13	16	19	22	25	28	+2	+6	+14
1	T	T		N G	N	N F G	N	N	E	N E	N E F	N F	N T	N T / T	N T / T	N
2		NS	T	T	T	T	T	T	T	T			T	T		
3	NS			F												
4	T	T	T		N / T		N								T	
5			N T							N	N T	F				
6、		N	T											T		

▩ = STAPH AUREUS ☐ = B HEMO STREP NS = NO SAMPLE
N = NOSE T = THROAT F = FOREHEAD G = GROIN E = EAR

Figure 4-4. Potential Pathogen Incidence

- low temperature incubation
- poor lighting
- lack of experience

4.3.4 Waste Management

Provisions were made for dispensing germicides, replacing odor control canisters, and adding antimicrobial agents to the waste storage tanks. During the mission, macerator electrical problems prevented proper mixing of germicide with waste. This resulted in noticeable odor levels.

The effectiveness of odor control in the waste management contamination control system was not evaluated during the mission. At post-mission sampling, all waste tanks were found to be contaminated with between 10^6 to 10^7 micro organisms/ml, most of which were of enteric * origin.

4.3.5 Environment

The environmental flora, as the mission progressed, reflected more and more of those organisms found on the men. The pattern of a shift towards gram negative organisms with respect to number of genera isolated was also similar to that of the human flora. Cleaning appeared generally effective in attaining a transitory reduction of total microbial level, although a general rise in contamination persisted as the mission progressed. The initial clean-up appeared to lower the microbial load considerably, because on Day 2, all counts were low.

The dips in contamination levels can be related to cleaning procedures with transient drops in microbial counts on the walls and floors noted at the general cleanups. However, after cleaning, there was a rapid rise of the contamination level on the floors and walls. The contamination of the table tops increased with time at a slower rate because of the daily washings.

*Enteric microbs are those found in the intestinal track.

4.4 Input to Space

Even with the limitations imposed by schedules and funding, the microbiology study was productive in providing guidelines for spacecraft design. Many unknowns exist in the area of space microbial technology, and this test should be considered only as a basis for much additional work, i.e.:

- The continuing shift and simplification of microbial flora on the 30-day mission indicates a need for investigation of the problem in association with longer space missions.
- The personal hygiene areas, and humid areas in general, will prove to be fertile microbe breeding grounds and require microbial control.
- The water and waste management systems will be particularly fertile areas and require suitable contamination monitoring and simple decontamination provisions.
- The use of anti-microbials offers temporary advantages but the overall effect may be undesirable. Additional work is required in this area.
- The stored hot water system was effective in controlling contamination and should be a candidate for spacecraft. It could eliminate the need for biocides such as iodine or chlorine which are disagreeable in food and drink.
- Further testing is required on the effects of crew rotation, i.e., putting a new crew member into an altered environment.

SECTION 5
MAINTAINABILITY

5.1 Objective

The objective of the Maintainability Experiment was to obtain detailed information on the frequency, duration, type and complications of the onboard maintenance performed during the Gulf Stream Drift Mission. This would permit evaluation of existing maintainability techniques for application to space vehicle missions.

5.2 Approach

The maintainability study covered:

- Analysis of the systems and equipment in the BEN FRANKLIN to establish spares, tools, test equipment, and estimated work loads.
- Preparation of maintenance procedure and data sheets, crew training, and dock side maintenance time trails, etc.
- Maintenance recording during the mission
- Reducing and evaluating data

This maintainability experiment did not encompass all of the equipment aboard the vessel. Systems and equipment were selected on the basis of criticality and available information on which analysis could be performed. This became the "controlled" portion of the study. Actual mission data was collected for all maintenance performed.

Logistics preparation consisted of crew training and of maintenance procedures, trouble shooting information, checklists, computation charts, spares, tools, and test equipment for the equipment in the controlled maintenance portion of the experiment. This was successful in satisfying the maintainability objectives. Crew comments indicated that this preparation was precisely what they needed for approaching the mission with confidence.

5.3 Results

5.3.1 Maintenance Workload

The crew performed 1354 individual maintenance tasks, an average of 45 per day. Figure 5.1 shows the percent of total available manpower expended on maintenance during the mission. The maintenance workload actually required from 12 to 31% of the crew's total available duty time each day. On the average maintenance occupied the equivalent of one man full time throughout the mission.

Scheduled maintenance accounted for 1312 of the 1354 maintenance tasks (See Fig. 5.2.). Successful completion of the remaining 42 unscheduled repair actions, however, assured mission success.

Two crew members performed 58% of all the maintenance work, but more significantly they accomplished 96% of the unscheduled repair actions primarily because of their highly skilled and maintenance-oriented background. Fig. 5-3 illustrates the maintenance workload assumed by the one crew member who was the prime mover in all of the unscheduled repairs. His skill contributed to the mission's success and attest to the need for this type of crew member on all such missions.

5.3.2 Maintenance Prediction Analysis

A. Task Times

The statistical analysis of mission data indicated that maintenance tasks time predictions by Method II of MIL Handbook 472 were reasonably effective in determining task times. Figure 5-4 shows a comparison of the results when regression analysis was applied to these predictions in mission action dock-side time trials, and an aircraft program as a control case. In view of the results, we concluded that Method II was considerably better than Method III since it is more closely associated with actual hardware configuration and limitations.

B. Effect Of An Isolated Environment

Mission data analysis indicated that there was no discernable time differential for the performance of maintenance in the stress of this mission environment versus the

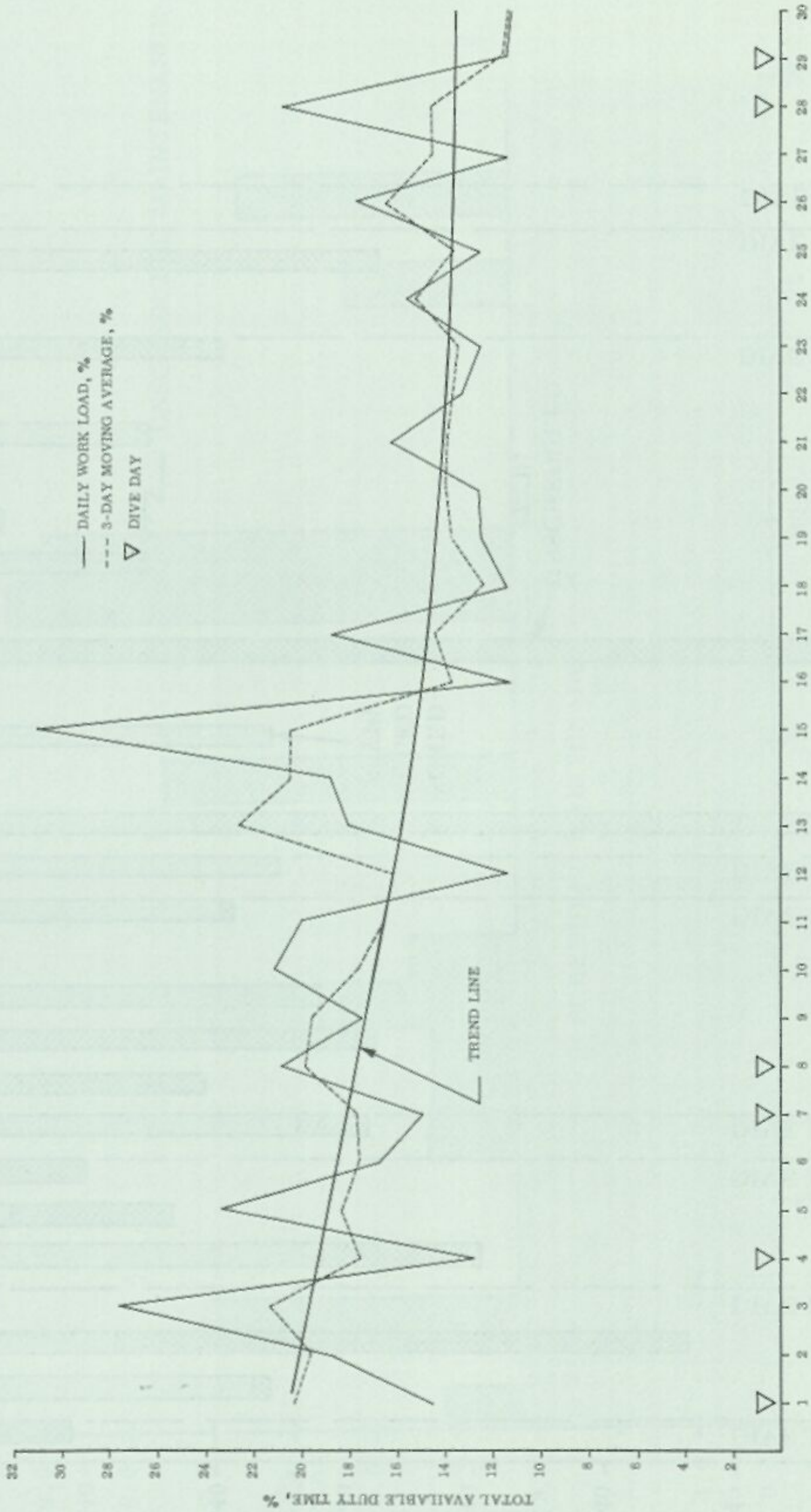


Figure 5-1. Percent Maintenance Man-Hours of Total Working Hours Per Day

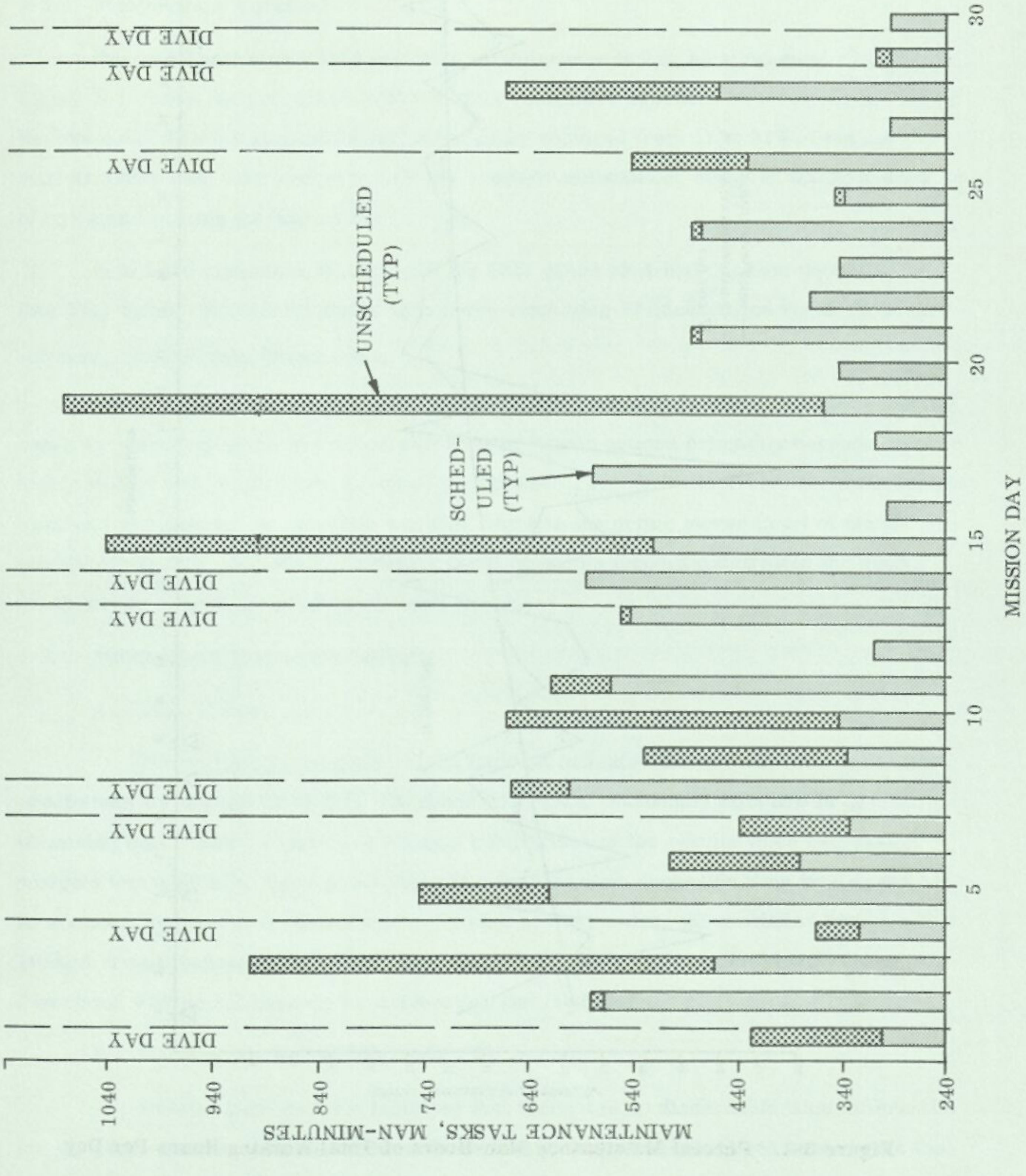


Figure 5-2. Maintenance Action Summary

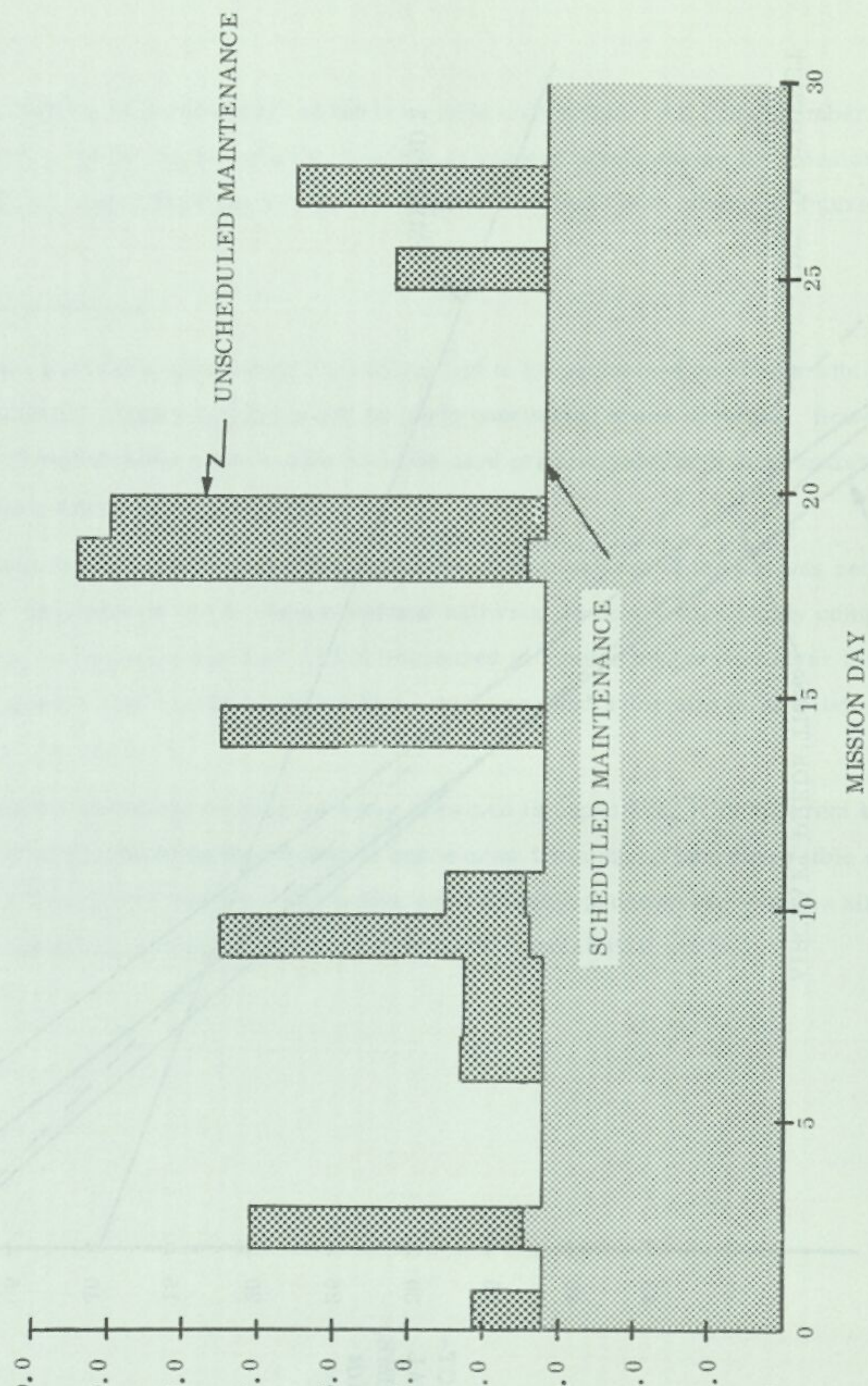


Figure 5-3. Crewmember No. 4 Maintenance Workload by Day

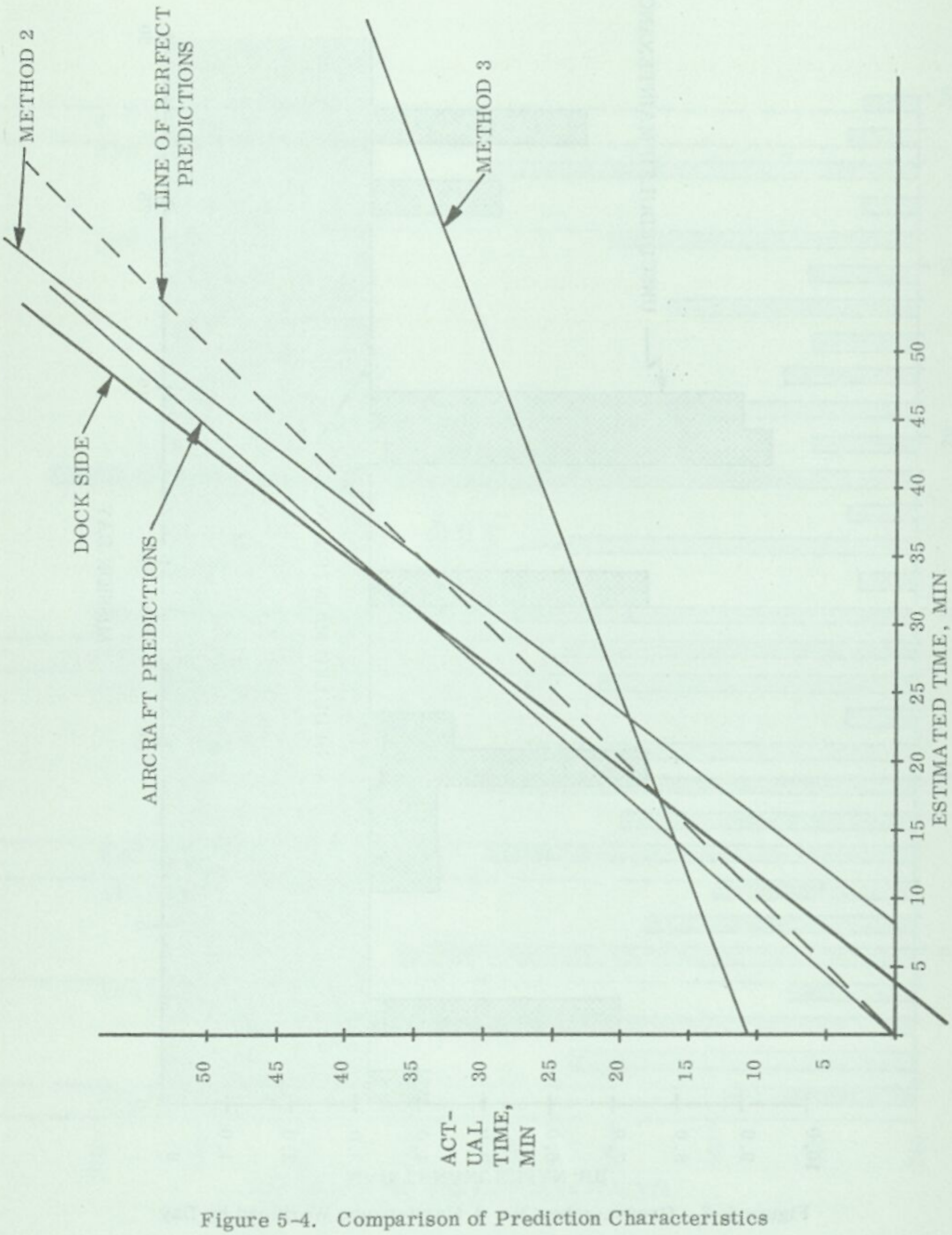


Figure 5-4. Comparison of Prediction Characteristics

relatively unstressed environment of the dock-side time trials. All crew members however, did admit to feeling the effects of stress at various points during the mission. This indicates that a better baseline should be prepared to detect these effects on future missions.

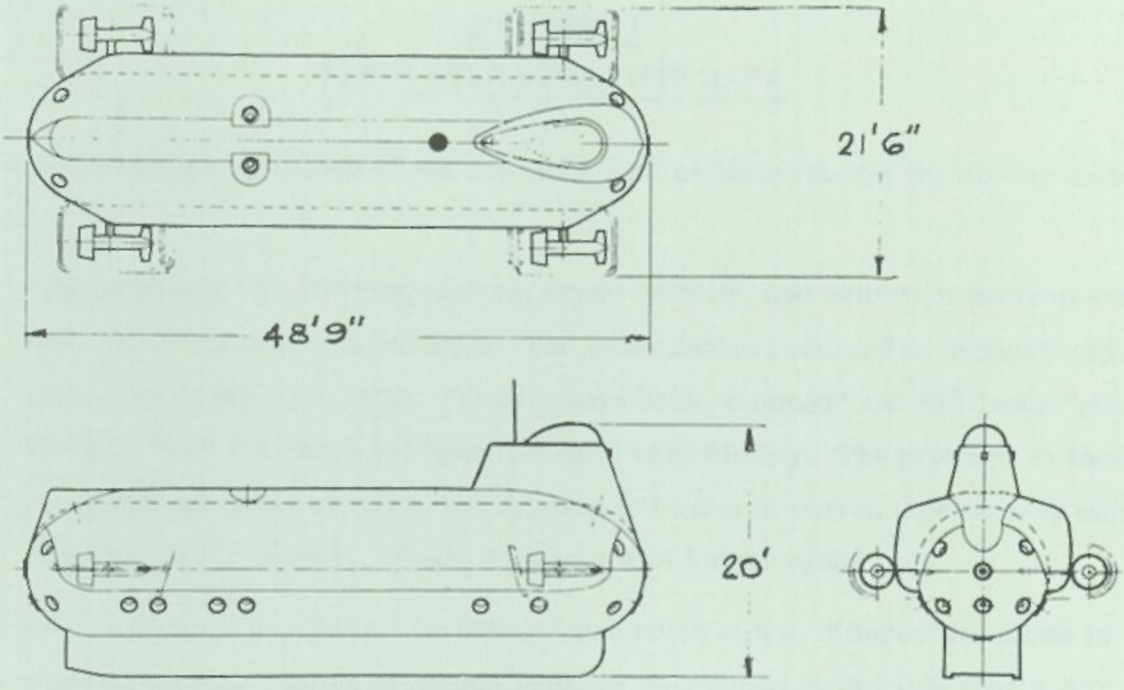
5.4 Inputs to Space

Since the GSDM maintainability studies had to be performed on submersible systems, no specific recommendations can be made concerning space systems. However, the study showed that the submersible could be used productively for testing maintainability techniques on space hardware.

It was revealing to find that the equivalent of one man out of the six was required to perform maintenance tasks. Space stations will require many more highly complex subsystems, and mission duration will be measured in months and years rather than days. Hence, it appears that sophisticated analysis, training, and automatic failure detection methods will be required.

Since sophisticated training of many crewmen is expensive, it is apparent that means must be developed to reduce future space crew training. The submersible offers a facility to develop and evaluate alternative crew training procedures, with the aim of reducing crew training requirements and associated special skill needs.

APPENDIX A
BEN FRANKLIN CHARACTERISTICS



<u>General Specification</u>

Displacement	130 Tons
Length	48 feet, 9 inches
Beam (over motor guards)	21 feet, 6 inches
Height	20 feet
Operational Depth	2000 feet
Collapse Depth	4000 feet
Submerged Speed (maximum)	4 knots
Life Support	6 men for 6 weeks
Payload	5 Tons
Total Power	756 Kwh
Viewports	29

APPENDIX B

TABULATED SCIENTIFIC DATA

The following is a tabulation of the scientific data collected during the 30-day drift mission:

1) Approximately 900, 000 temperature, sound velocity, and salinity measurements were recorded with time and depth. The water sensor recorded on magnetic tape each parameter every 2 seconds. The data have been "dumped" and 80% looks "good". The 20% "bad" data have not been looked at very closely. The problem on these data were not in the sensors, but appears to be due to uneven tape take-up on the magnetic tape recorder. These data may still be salvaged.

2) Stereo-photographs (848) of the bottom were taken at five different locations in conjunction with 3 miles of bottom mapping performed by the side scan sonar. All the film has been processed, but only a few samplings have been printed.

3) The Gulf Stream current was measured continuously by tracking the BEN FRANKLIN over the entire 30-day mission. In addition, a total of 6 hours of insitu current measurements were made while the BEN FRANKLIN was bottomed.

4) The side scan sonar operation was stalled in the beginning due to its over-voltage protection circuit (more than 30 volts). Although this was anticipated, the dropping resistor added to the input was too low a wattage rating and operation could not begin until 28-volt BUS dropped below 30 volts. The data that were collected (approximately 3 miles) are available.

5) Over 371 hours of ambient light measurements were recorded on BEN FRANKLIN and on the M/V PRIVATEER. These data were recorded on the WASP's magnetic tape. The transmissometer flooded due to improper seating of seals just before GSDM and light transmission experiments were voided.

6) Two hours (4 miles) of magnetic anomalies were recorded on paper strip charts before magnetometer sensor flooded during early stages of GSDM. A rubber pressure equalizing diaphragm ruptured - cause unknown.

7) Over 1100 bottom reflectivity and volume reverberation measurements were made by setting off explosive charges from both the M/V PRIVATEER (blasting caps) and the USNS LYNCH (SUS charges). The direct and bottom reflected pulses were recorded on magnetic tape aboard the BEN FRANKLIN. Preliminary analysis of the tape is presently underway and the data looks very good. Typical views of the scientists in the BEN FRANKLIN performing the volume reverberation experiment are illustrated in Figure C-1.

8) Approximately 24 hours (50 miles) of gravitational anomalies were recorded on strip chart recorder aboard the BEN FRANKLIN; data are still to be analyzed.

9) Forty-one temperature-depth transists across the Gulf Stream were conducted from the USNS LYNCH, resulting in a total of 500 profiles made by expendable bathythermographs (X-BT). Three surface temperature transists were made by airborne radiation thermometer (ART) to assist in positioning BEN FRANKLIN in the Gulf Stream.

10) A minimum of 360 hours were spent directly viewing and selectively photographing the organisms within the water column from the BEN FRANKLIN. This work was assigned by 24 plankton sampling tows from the USNS LYNCH. Twenty-four deep Nansen casts were also conducted to further assist in positioning BEN FRANKLIN.

11) The 70-mm camera system did not function properly; a bad external wire-splice is suspected. Films are being processed, but no images expected since strobes seemed to be out of synch.

Some general comments in conjunction with experiments and the GSDM that come from NAVOCEANO's F. Busby:

1) The deep scattering layer along the path followed by BEN FRANKLIN was non-existent.

2) There was a notable scarcity of any form of sea life.

3) When the submersible was trimmed for a selected depth, vertical displacements up to 100 meters were experienced as the vessel followed undulating isotherms.

4) One swordfish was observed to attack the vessel, reluctantly accepted defeat, and retreated (similar to an occurrence experienced by ALVIN).

In addition to the data taken by the NAVOCEANO, a log was kept by Dr. Piccard in which he recorded a time history of depth, salinity, inside temperature, outside temperature, humidity, and control actions pertaining to the variable ballast system.

APPENDIX C

CAPTAIN'S LOG

The following is a condensed version of the Captain's Log, describing how the mission progressed day-by-day and highlighting the significant events.

14 July 1969

At 1025 hours the "Ready for Sea" checkout was completed. It was hoped the BEN FRANKLIN could leave port quietly with little fanfare; however, quite a crowd was on hand. The BEN FRANKLIN got underway at 1043 hours and passed the sea buoy at 1123 hours with only H. Dorr and D. Kazimir aboard to prepare the boat for diving. The remainder of the crew was aboard the M/V PRIVATEER. At 1635 hours, the LiOH was deployed. We were on station at 1844 hours, waiting for the boat DRAGON LADY with additional LiOH panels that arrived after FRANKLIN was underway. At 2030 hours, the hatch was secured with the crew aboard. "Rig for Dive" was completed, and both VBT's were empty. At 2056 hours the main ballast tank vents were opened - diving (Dive number 41). The boat descended smoothly - dribbled shot occasionally to slow descent. Trim good, no propulsion needed. At 2150 hours, we bottomed in 510 meters of water. Commenced checking boat and NAVOCEANO equipment. NAVOCEANO gear working well except transmissometer, sub bottom profiler, and magnetometer. Side scan sonar will not operate due to high voltage provided by ships batteries. It was estimated that it would take a few days before the voltage was less than 30 volts.

15 July 1969

The checks were completed at 0100 hours; all hands settled down. Commenced dribbling the shot to achieve neutral buoyancy at 20-ft altitude. The BEN FRANKLIN was underway drifting north in the Gulf Stream at 0119 hours; visiblity good but the current was quite slow. Sonar in standby when not in use. One landing light used for forward visibility. At 0150 hours noticed a slight air leak in the air reducer and tightened the plug but it still leaked (very slightly) so it was decided to secure all air flasks. During this period, a few output fuses blew in the auxiliary 60-cps inverters due to operator error (too much load on the inverter). Also discovered a slight hydraulic leak around the valve stem of the depth gage. The bonnet was tightened and the leak stopped. At 0500 hours, we were drifting very slowly; the boat was getting colder and colder. We dribbled shot occasionally to account for hull shrinkage as the boat cooled down. At 0900 hours, our position was about 19°, 19 miles from Palm Beach Inlet. Decided to terminate bottom cruise due to slow drift speed. Began ascent to 600 ft by dribbling shot. At 1135 hours, noticed a small drip at NAVOCEANO's penetrator in H-6*. Penetrator tightened. During the 1200 hour routine checkoff, Drager CO_2 gage failed; shifted to the Fyrite gage which worked well throughout the 30 days. Lost communications with PRIVATEER at 1420 hours; had to use new 504 unit (underwater telephone) at full power to regain communications. Evidently, the PRIVATEER trackers lost us. Range checks were used to regain position. The Straza 504 paid for itself already. At 1500 hours, we achieved neutral buoyancy at 300 meters with both VBT's (variable ballast tanks) empty. The cabin temperature was still about 55°F, but gradually rising. During this depth change, the current occasionally came from the north. For these first 2 days, everyone was quite busy with very little sleep; however, spirits were quite high.

16 July 1969

We were drifting nicely at 200 meters. The ampere-hour system was in operation; however, the B-2 counter occasionally counted rapidly for no apparent reason. F. Busby, D. Kazimir, C. May, and J. Piccard have slight colds. The cabin temperature got up to a comfortable 66°F. C. May checked iodine concentration in the number 1 and 2 fresh water tanks and found no iodine - cannot understand why, the concentration should be 6 ppm. The same for tanks 3 and 4. C. May was having difficulty with the bunk counters and some sleep monitoring caps. The number 1 hot water tank was cooling down fast since the vacuum was lost - will shift tanks soon. Good luck message was sent to Apollo 11 astronauts.

17 July 1969

We were drifting at approximately 200 meters. Took the first set of battery ground readings at 0810 hours; they looked fine. The macerator needed repairs; it wouldn't stop running, so we had to defuse it. C. May and K. Haigh found a ground on the case and

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*This penetrator dripped occasionally during the 30 days. It was very slight and usually dry.

corrected it. At 1030 hours we deployed the LiOH panels. The motors were meggered at 1530 hours; they looked fine. The boat seems to drift with the stern pointing north. She oscillates a little to either side and occasionally turns around. Began the descent to the bottom at 1705 hours by flooding the port VBT in increments. At 1800 hours, the compass was found to be unreliable; shifted to the portable compass**. At 1855 hours, we bottomed in 458 meters after sitting on the guide rope and gradually reached the bottom as the hull cooled. Measured the current speed, which was quite slow, less than 0.2 knots. At 2036, we blew the port VBT slightly to ascend to cruise depth - about 20 ft off the bottom. Sat on the guide rope waiting for the current to push us, but to no avail - the current was too slow. The Privateer dropped 50 blasting caps for acoustic studies. The drift rehearsal now over - we will go for 30 days.

18 July 1969

At 0112 hours, a slow ascent was begun by blowing the port VBT in increments. The stern 250-watt light was used mainly for observations at shallow depth - it attracts quite a bit of plankton. At 0609 hours, two swordfish were observed at the aft hemisphere swimming around rapidly. Once actually attacked the viewport that F. Busby was using. At 0900 hours, (at 200 meters) the humidity went up to 82%, and more silica gel was deployed. This reduced the level to a satisfactory 75%. Coricidin pills helped in reducing our cold symptoms. Each day we computed power usage based on the equipment logs and compared with the actual usage; however, wide variations existed. We will secure the ampere-hour system when the computed method becomes accurate.

19 July 1969

We were drifting routinely at approximately 230 meters; our position was 60 miles NE of New Smyrna Beach, Florida. At 1450 hours, at 187 meters, we secured all lights to check light level. Large print can be read easily. At 2014 hours, we changed the LiOH panels (we were averaging about 3 days per set of 12). The Egan Experiment was working well except for bioluminescence. The boat continues to be very stable at depth.

**This compass worked well throughout the mission.

20 July 1969

We were drifting along nicely at 170 meters. We discovered some carbon monoxide (10 ppm) and a small amount of hydrazine and acetone during our routine checks with the Drager tubes. The four main and four positioning motors meggered out OK. We had to flood some water in the starboard VBT as the depth decreased to 142 meters. The communications with PRIVATEER have been excellent. K. Haigh completed the seismic studies with LYNCH supplying the SUS charges. The highlight of the day was the moon landing as reported by the PRIVATEER.

21 July 1969

We continued drifting at approximately 190 meters. Our position was 90 miles east of Brunswick, Georgia. We commenced another set of SUS charges at 1340 hours for acoustic tests. At 1414 hours, we began the descent to the bottom by flooding the starboard VBT in increments. By 1555 we were cruising at the 20-ft altitude in a depth of 372 meters. The current was quite strong. At 1830 hours, we bottomed briefly to measure the current using our motors to hold position. At 1850, we were cruising at the 30-ft altitude. We spotted multiple sonar targets and ascended to 100-ft altitude. Decided to remain well above the bottom and then take another look at 0200 hours. We detected the first bacterial contamination, using endo and total media in Petri dishes at the head sink. The Grumman movie camera malfunctioned while attempting to photograph the bottom.

22 July 1969

Drifting at 260 meters; commenced descent at 0150 hours. At 0415, at 70-ft altitude, conducted acoustic test using blasting caps which were released from the surface vessel. At 0500 hours we were cruising close to the bottom at a good speed, operating the sonar continuously. The bottom was hard and bumpy with some small escarpments seen. At 0600, we commenced ascent to a shallower depth. It would be better to study this area in three separate excursions during a 24-hr period due to the physical strain, cold, and high-power usage. At 1400 hours, we conducted another 1-hour bottom cruise in conjunction with the seismic studies. Discovered the B-2 counter* was malfunctioning; decided to rely on the computed power figures for the 110-vdc load. The ocean bottom in this area was fairly interesting. The effects of internal waves caused large, slow depth changes.

23 July 1969

Today we were drifting at 200 meters, about 100 miles east of Charleston, South Carolina. For a short period, internal waves were noted at 1000 hours. The boat sometimes changes depth of 40 meters in wave periods of 15 minutes. At the end of the day, decided to secure ampere-hour system and rely on equipment logs to compute the power usage (saves power).

24 July 1969

At approximately 200 meters today. We were having fits again due to internal waves. The boat oscillated between 180 and 220 meters. Changed the bacteria filters and replaced the purafil in the head blower. Had to drain some fresh water into the mini-waste tank for flushing. The sinks were clear of contaminants - possibly due to changing of the bacteria filters. The mission has gone well - the crew and boat in good shape.

25 July 1969

Drifting at 270 meters approximately 90 miles south of Cape Fear, North Carolina. Motors meggered OK at 1112 hours. At 1123 hours, PRIVATEER reported that we broke through the north wall of the Gulf Stream; we then commenced running on two motors at 60 amps to power back into the Stream, on a course of 100°. At 1705 hours, we completed the transit. Today we observed endo and total contamination of water at the head sink.

26 July 1969

At 233 meters at 0400 hours, it was quite clear that we did not make our way back into the Stream. At 0928 hours, we commenced the ascent to the surface. The decision was made to have PRIVATEER tow FRANKLIN. We ascended slowly in order to prevent battery gas from escaping too fast. We saw many sharks and a barracuda enroute to the surface.

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*This counter in the ampere-hour system monitored the power used from the B-2 battery string.

We also heard gas escaping from the batteries. Sometimes it would escape more rapidly from one side and actually cause a very small roll. At 1205 hours, we surfaced. We then blew the MFT's only slightly. Divers used scuba air to blow the MBT's and then added shot to ensure negative buoyancy on the next dive. While under tow, we listened to "News Radio 88" - the CBS radio station from New York City. The boat got quite warm while on the surface and the sea was calm. The boat was left sealed during the surfacing and towing in order not to disturb the "closed environment" which was important to the NASA study.

27 July 1969

At 0313 hours, FRANKLIN arrived at the dive site in the Gulf Stream core. Divers re-rigged the noise boom, removed the magnetometer and disconnected the tow line. Dive number 42 commenced at 0401 hours. FRANKLIN submerged rapidly while shot was dribbled to slow the descent. Several battery vent valve salt water sensors came "ON". It took several hours for the boat to stabilize in the temperature and she finally settled out at approximately 200 meters at about noon. Megger readings taken in the evening showed quite a drop for the number 2 main motor but the reading is still OK. At this point in the mission, two crew members picked up a rash, probably due to perspiration and the fact that underwear was changed every 3 days (not often enough). The carbon monoxide level was now up to 15 ppm. The acetone and hydrazine levels had not increased.

28 July 1969

We drifted today quite nicely at 200 meters. High bacteria counts throughout the boat necessitated a thorough wash down with microguard. Also, a routine setup to wash down the galley, shower, and head areas daily was instituted. At 1222 hours, we began the descent to 565 meters to measure the ambient light and to conduct acoustic tests for mid-water scatterers and bottom reflectivity. Commenced the ascent at 1944 hours. The boat was very stable, no internal waves. F. Busby and E. Aebersold repaired the wobbly wardroom table with two C-clamps, one "Vise Grip" and two butter knives for shims.

29 July 1969

Drifting at shallow depths approximately 85 miles SSE of Cape Lookout, North Carolina. We passed the halfway point in the mission at 2030 hours.

30 July 1969

Drifting at 165 meters. The boat was rising slowly. The carbon monoxide level was up to 20 ppm. We ran the contaminant removal system for 1 hour. The mission was getting to be quite routine now with plenty of sleep for everyone.

31 July 1969

Today we drifted at shallow depths. We went past Cape Hatteras and headed out to the open sea. The hot water was heated for 2.5 hours in tank number 3.

1 August 1969

Again we drifted at shallow depths approximately 35 miles east of Cape Hatteras. At 2055 hours, we released a SAS ball with urine and feces samples in it. The ball was retrieved immediately by PRIVATEER. Surprise for someone if it wasn't retrieved. The galley, shower, and head faucets all show contamination. This is no problem since cold water was used only for washing.

2 August 1969

Drifting again at shallow depths today. Motor number 2 meggered - holding steady at 5 megohms. Had to heat the hot water for 2.5 hours. The carbon monoxide level was at 20 ppm. Swiss National Day was celebrated by lighting a match in front of the United States and Swiss flags.

3 August 1969

Approximately 120 miles east of Cape Hatteras, we drifted at shallow depths. Our drift speed has increased to close to 3 knots. J. Piccard caught a salp in the plankton sampler.

4 August 1969

At approximately the 200-meter depth, we drifted 300 miles south of Block Island. Internal waves made life interesting. The drift speed was up to 3 knots. Plenty of power available as the batteries continue to hold up well.

5 August 1969

Drifting at shallow depths (200 meters) again at a good speed approximately 270 miles south of Martha's Vineyard. During the day, many tuna were sighted. The USS LAPON (SSN661) transited the area on the surface. FRANKLIN and PRIVATEER had underwater phone contact with her as she passed through the area. The carbon monoxide level was up to 30 ppm; ran the contaminant removal system for 4 hours. Drager readings before and after running the system indicated no change in the level.

6 August 1969

Again drifted at shallow depths approximately 165 miles south of NANTUCKET SHOALS LIGHTSHIP. Had difficulty blowing the starboard VBT for depth-keeping - the lines seemed to be plugged. Cleared the system by building air pressure up to 10 atmospheres over sea pressure. Many whales and porpoises have been heard on sonar for past few days. Internal waves continue to plague us; however, the experience level in trimming the boat has increased to a point where it is no problem. Ran the contaminant removal system for 4 hours. The carbon monoxide level was at 30 ppm.

7 August 1969

Drifted at 298 meters, moving up and down with no need for accurate depth keeping. Our position is now about 195°, 320 miles from Cape Sable, Nova Scotia. Heated hot water tank number 3 for 8 hours. Ran the contaminant removal system again for 4 hours.

8 August 1969

Proceeded nicely at shallow depths at a good speed. Meggered the motors - all OK. The batteries are in good shape also.

9 August 1969

Drifted at 265 meters. At 1811 hours, commenced the descent to 500 meters. At this level, conducted acoustic work using SUS charges. Vibrations could be felt through the hull even though the charges were set to explode at 60 ft.

10 August 1969

Drifted at 500 meters. Completed the deep excursion at 0030 hours. The carbon monoxide level was up to 40 ppm. The crew is getting restless. We still have not seen the deep scattering layer.

11 August 1969

Again drifted at shallow depths. Our speed slowed to less than 2 knots. At 2007 hours, commenced the descent to 500 meters for acoustic work.

12 August 1969

Conducted acoustic experiments at 500 meters. Commenced return to shallow depths at 0028 hours. The mascerator switch burned out; the system can be used without the mascerator. Heated the hot water tank number 3. The crew has channel fever - quite anxious to surface. Conducted another descent to 500 meters, commencing at 2017 hours. Ran the contaminant removal system for 4 hours.

13 August 1969

Today we drifted routinely at 408 meters ascending to shallow depths. We checked the number 2 motor and it meggers OK. The carbon monoxide level was at 40 ppm. Commenced preparations for surfacing. The Coast Guard Cutter COOK INLET, arrived and will standby in order to transport personnel to Portland, Maine. Since no deep scattering layer was found during the drift, BEN FRANKLIN will surface with excess power available.

14 August 1969

Drifted at 288 meters while preparations continued for surfacing. The boat was rigged for heavy weather, all data packaged for transfer to COOK INLET. Commenced slow ascent at 0432 hours and surfaced at 0757 hours. LYNCH, COOK INLET, PRIVATEER, two vessels from WHOI, and two rubber boats stood by. The crew and data was transferred to the COOK INLET. FRANKLIN was taken in tow by the PRIVATEER after the PRIVATEER received fuel and provisions from LYNCH.

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