Paper No. 41

USE OF THE BEN FRANKLIN SUBMERSIBLE AS A SPACE STATION SIMULATOR

Matthew J. Ferguson[1]
Chester B. May[2]

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ABSTRACT: This paper presents the NASA-sponsored effort using the Ben Franklin submersible as a space station analog during the 30-day drift mission in the Gulf Stream, starting 14 July and ending 14 August 1969. The areas of investigation include: (1) Psychological and physiological measurements during the pre-mission, mission, and post-mission phases were related to observed crew behavior. The results reveal that detailed consideration must be given early in the design to those aspects which could cause crew annoyance and frustration, and which could be further aggravated by long confinement. Selection of crew pairs for compatibility of personality will help reduce stress in small closed systems. (2) Habitability in a closed ecosystem was investigated. The objective was to determine the suitability of BEN FRANKLIN submersible habitability data for providing guidelines for future spacecraft design. These include provision for privacy, control of temperature and humidity, and adequate facilities for personal hygiene. (3) Microbiological investigation as a study of the effect of total biological isolation upon the flora of the crew, environmental and life support subsystems. 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. (4) The maintainability experiment objective was to obtain detailed information on the frequency, duration, type, and complications of onboard maintenance during the mission.

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[1] Ocean Systems Dept., Grumman Aerospace Corp., Bethpage, N.Y.
[2] Advanced Systems Office, NASA, Huntsville, Ala.

KEY WORDS: space station simulator, submersible, closed ecological system, psychology, physiology, habitability, microbiology, microflora shift, maintainability prediction.

INTRODUCTION

Background. The 30-day Gulf Stream Drift Mission (GSDM) was conceived by Dr. Jacques Piccard in 1965 to explore the Gulf Stream 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 (Figure 1).

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 Contract NASW-1965 to Grumman 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 contractual effort. It was 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 mission. In support of these conclusions, NASA awarded Grumman a contract to study these factors during the GSDM.

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 15 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.

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 caused the crew to feel cut off from the world. In addition, a lack of private communications with the surface prevented personal discussions with families and physicians.
- 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 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, operational procedures, and crew interactions can be evaluated in a closed, stressful environment.

Submersibles and ground-based chambers are complementary. 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. Figure 2 lists the many similarities between spacecraft and submersibles and compares them with chamber studies to date.

GSDM Inputs to Manned Spacecraft Systems Design. The objective of the NASA contract was to explore the areas of psychology and physiology, habitability, microbiology, and maintainability to obtain spacecraft 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-related studies, and only incidental space equipment was provided. The following are a few examples of the types of spacecraft design guidelines supported by the data from the NASA contract:

Crew Accommodations

- Design and locate bunks for conversion to private lounges for relaxation, reading, and writing.
- Soundproof the crew quarters and locate them as far as possible from operating equipment and work areas.
- Separate work and living/recreation areas. 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 for comfort
- Provide for internal environment off-design temperature conditions.
- Provide two-piece garments rather than jumpsuits for ease of personal hygiene functions.

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 reduce spread of contamination.
- Provide negative pressure in hygiene areas to prevent issue of contaminants into living areas.
- Choose materials and designs to minimize 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.

Maintainability

- Develop specific maintenance skill levels, experience and training requirements for crew members on long duration space missions.
- Develop the facilities required for on-board off-line repair of space equipment.

A study of the command structure during the GSDM was not part of the 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 the handling and prevention of similar situations on future space missions.

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 skylab, the space station, and the space base programs.

Psychology and Physiology

- Crew performance evaluation
- Biomedical instrumentation
- Crew selection test verification
- Work task unit

Habitability

- Personal hygiene provisions
- Food management
- Clothing

- Recreation provisions
- Noise control
- Personal accommodations

Biotechnology

- 60/90 day mission with crew rotation
- H_20 and atmosphere contaminant measurement and control
- Spacecraft and subsystems decontamination

Subsystems Operation

- Water management
- Waste management
- Atmosphere storage/supply

Maintainability (of space equipment)

- Failure prediction techniques
- Scheduled and unscheduled task analysis
- Spares and tools requirements
- Repair techniques/operations

Mission Operations

- Command Structure evaluation

PSYCHOLOGY AND PHYSIOLOGY

Objectives. The objectives of this portion of the study were:

- To relate observed crew behavior to variables (engineering design, choice and training of crew) which designers and mission planners can use to influence space systems performance.
- To investigate the physiological aspects of the 30-day confinement.

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.

Time-lapse photographs were obtained of most of the vehicle with 3 cameras, and approximately 1 hour of conversation each day, was recorded on tape.

Upon their return to Bethpage, N. Y., the crewmembers were given the following to complete for the debriefing with the psychologists:

- The Group Confinement Inventory (Retrospective)
- The Isolation Symptomatology Questionnaire (Retrospective)
- The Hostility Symptomatology (Retrospective)
- The Primary Affect Scale

Five of the men returned them immediately, and the sixth about a month later.

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, inaccessibility 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 evidenced in part by the crewmen's tendency to eat more and more meals alone as the mission progressed. None of the crewmen reported psychosomatic or hypochrondrical symptomatology. Depression was greatest and the sense of personal well-being lowest at the midpoint of the mission (scores for these factors were extracted by Naval Medical Research Institute's factor analysis computer program).

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.

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 feel anguish and concern. 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, ap propriate avenues for the release of tension. Investigation is recommended to develop more acceptable techniques to relieve psycho-social tension.

The physiological investigation included analyzing data obtained prior to, during, and after the mission. These covered a physical fitness index, wrist and forearm strength, recovery pulse, blood pressure, oxygen utilization, and weight. None of the crewmen showed signs of physical deconditioning, although some had a weight loss. All were declared by the Grumman physicians to be medically fit subsequent to completion of the drift mission.

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:

- 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 of personality characteristics 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, solicitations 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.

HABITABILITY

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.

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.
- Ship's log.
- Crewmen's personal logs and questionnaires.
- Debriefing
- Comparison of actual activities with planned activities in the Mission Plan.

Results. 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 generally, half of the crew followed their plan and half did not. Figure 3 illustrates this type of analysis on day 1 of the mission, crewman #1 deviating from the plan and #6 following the plan. Also shown are the planned and actual hours spent at each location. These deviations are due in part to lack of pre-mission training establishing each man's role 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.

The ten top complants on questionnaires and volunteered complaints are shown in Figure 4. 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 and 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 5. 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 complaints were volunteered throughout the mission. The principal complaint was that each crew member needed a place 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.

Atmospheric conditions were monitored and recorded throughout the mission. Variations were readily maintained within allowable physiological limits. Atmospheric constituents and trace contaminants were monitored with Drager Tubes and a gas chromatograph. The Drager tubes identified a continuing rise in CO throughout the mission to a maximum of 40 PPM, identifying the need for greater capacity in the CO removal apparatus.

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 isolated from the noise of the work area.
- Food preparation devices and techniques should be simple.
- Environmental monitoring should be 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.

MICROBIOLOGY

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 flora of the crew, environment and life support subsystems.

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.

Results. There appears to have been a general simplification and shift towards gram-negative organisms, (Figures 6 and 7), particularly Pseudomonas and Aerobactor. 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 8.) Beta Hemolytic Streptococci were isolated from 5 of the 6 crew members (Figure 9). These 5 also developed upper respiratory infections during the early mission phase.

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.

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) were found to be contaminated with Pseudomonas when cultured post-mission. 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:

- Low-temperature incubation
- Poor lighting
- Lack of experience

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 intestinal origin.

As the mission progressed, the environmental flora 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.

Even with the limitations imposed by schedules and funding, the microbiology study produced 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 association with longer space missions.
- The personal hygiene areas, and humid areas in general, are fertile microbe breeding grounds and require microbial control.
- The water and waste management systems are 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 to create an undesirable microbial imbalance. 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.

MAINTAINABILITY

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.

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 trials, 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, troubleshooting 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.

Results. The crew performed 1354 individual maintenance tasks, an average of 45 per day. Figure 10 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 (Figure 11). 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. Figure 12 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.

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 13 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

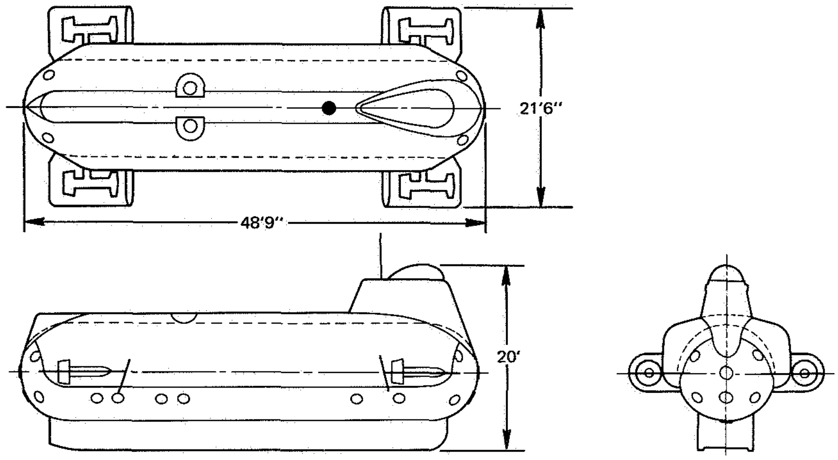
Method II was considerably better than Method III since it is more closely associated with actual hardware configuration and limitations.

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

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

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.



GENERAL SPECIFICATION

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

FIGURE 1 BEN FRANKLIN CHARACTERISTICS

	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 REAL NAVIGATION	X	X	
SCIENTIFIC CREW	X	X	
DATA TRANSMISSION DIFFICULTIES	X	X	
ON-BOARD MAINTENANCE PROVISIONS	X	X	
COMPLETE BIOLOGICAL ISOLATION	X	X	
COMMAND STRUCTURE	X	X	

FIGURE 2 SIMILARITIES -SPACECRAFT/SUBMERSIBLE/CHAMBER

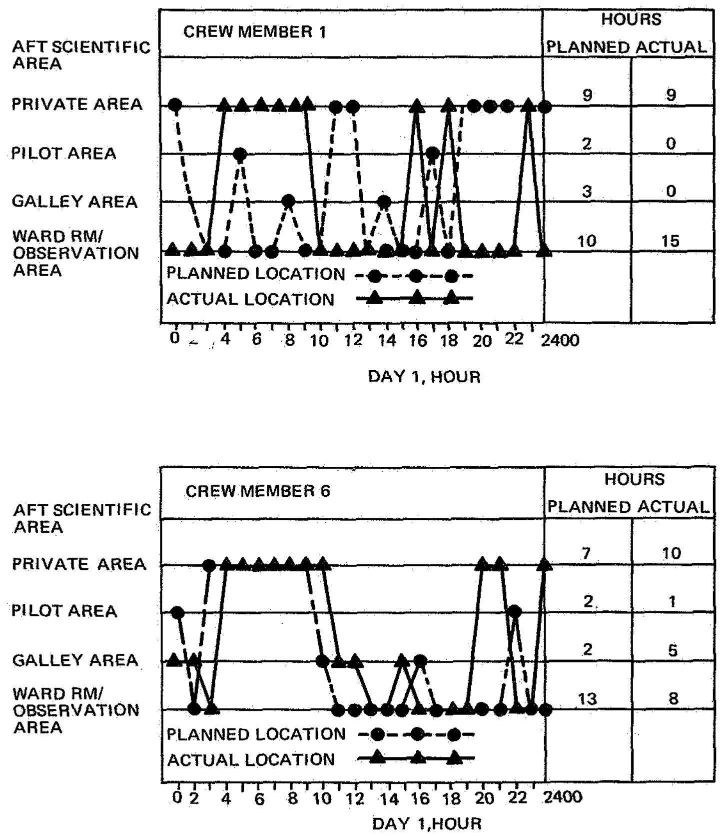


FIGURE 3 ACTUAL VERSUS PLANNED CREW MEMBER TIME LINES, DAY 1

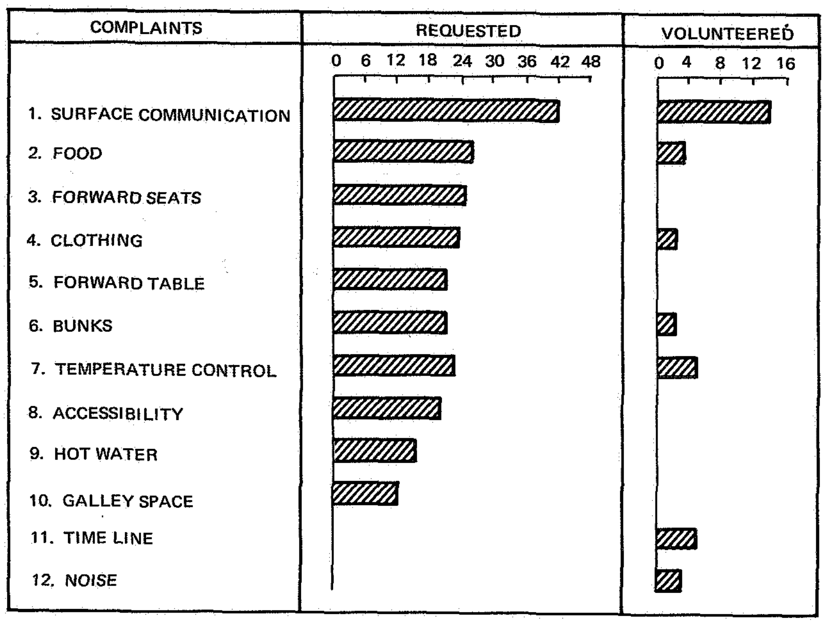


FIGURE 4 MAJOR HABITABILITY COMPLAINTS

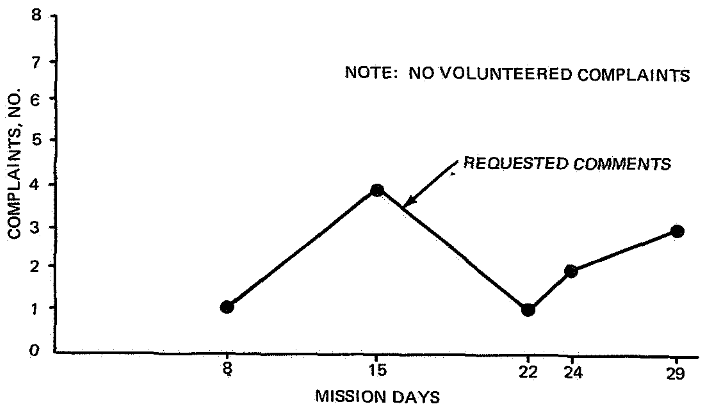


FIGURE 5 PRIVACY AND FREE SPACE COMPLAINTS

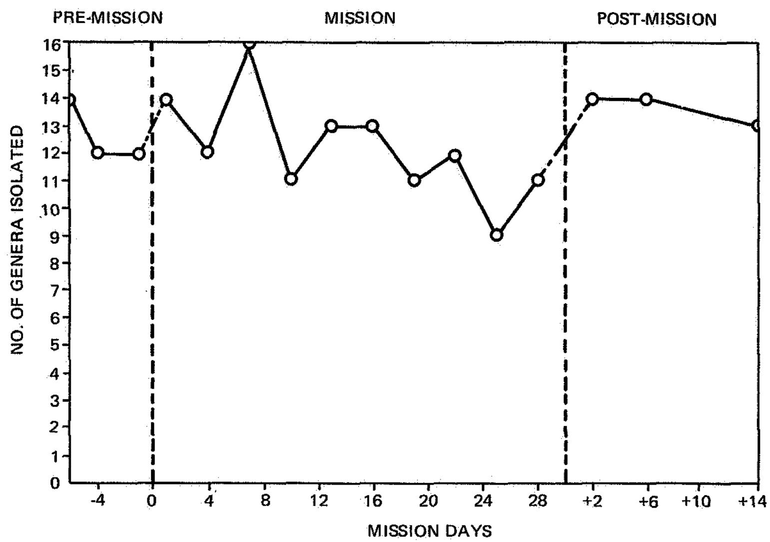


FIGURE 6 TREND OF TOTAL BODY SIMPLIFICATION

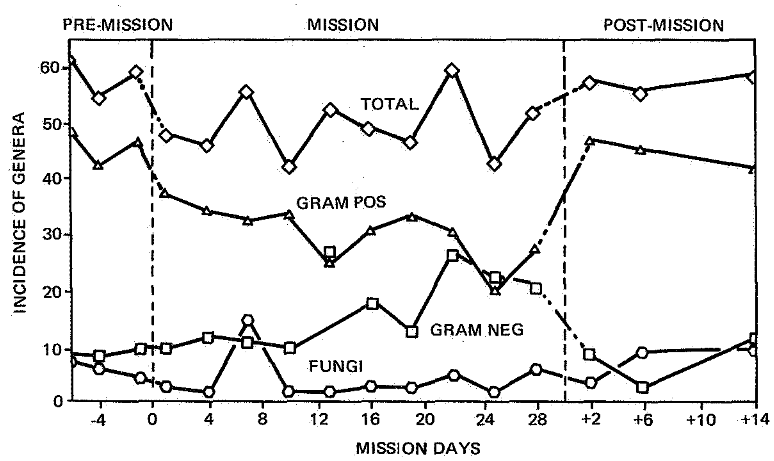


FIGURE 7 TREND OF TOTAL BODY SHIFT

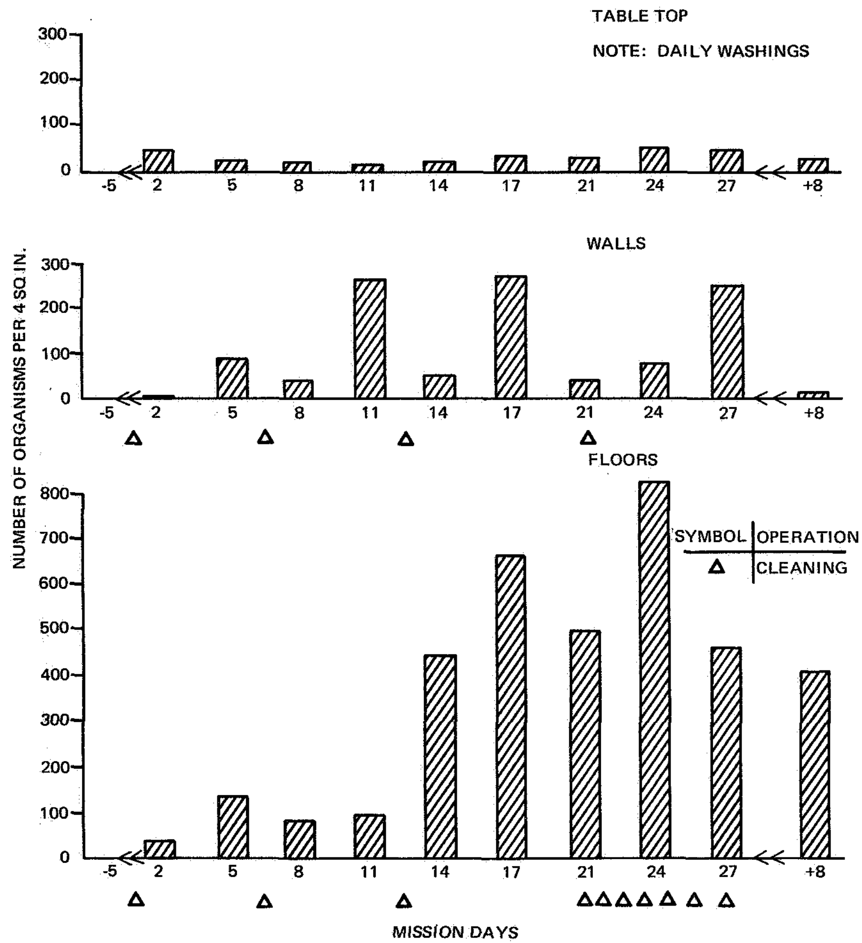


FIGURE 8 ENVIRONMENTAL CONTAMINATION

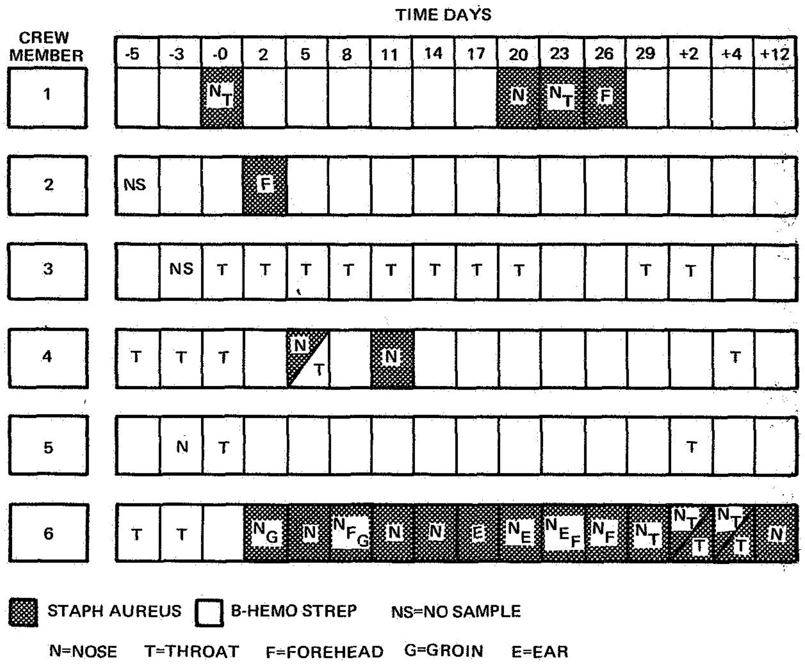


FIGURE 9 POTENTIAL PATHOGEN INCIDENCE

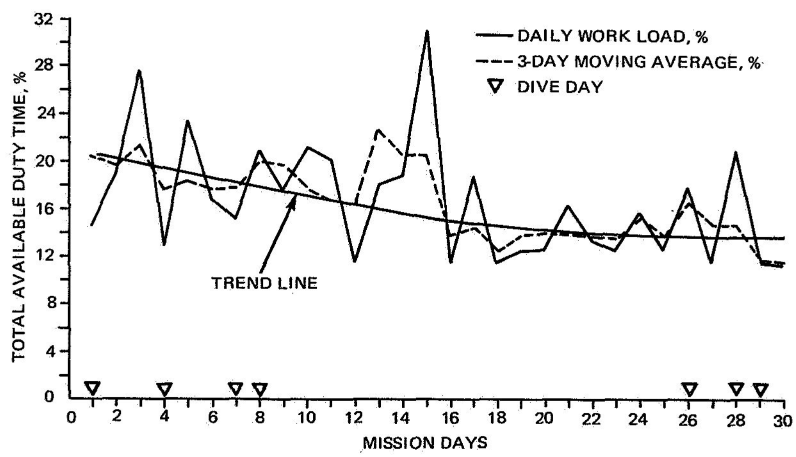


FIGURE 10 PERCENT MAINTENANCE MAN-HOURS OF TOTAL WORKING HOURS PER DAY

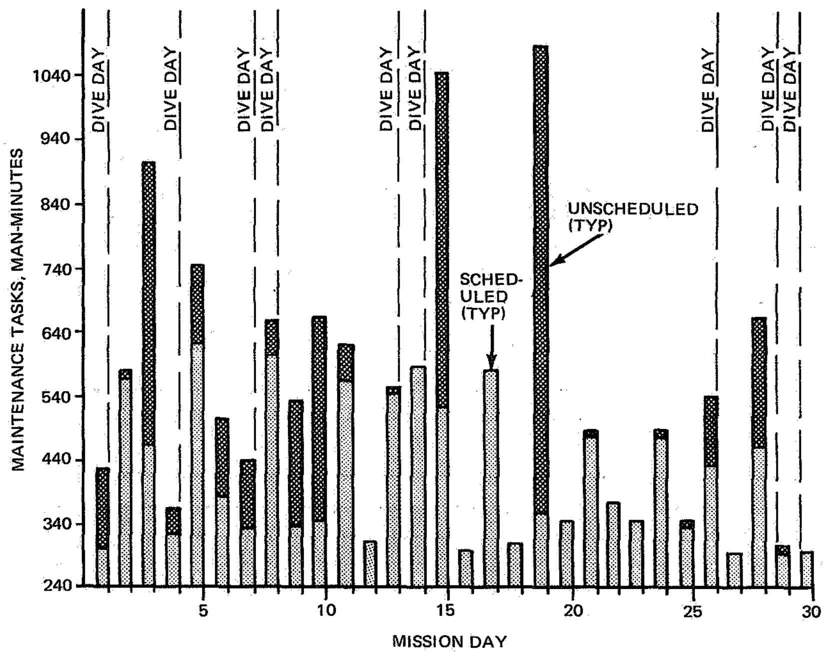


FIGURE 11 MAINTENANCE ACTION SUMMARY

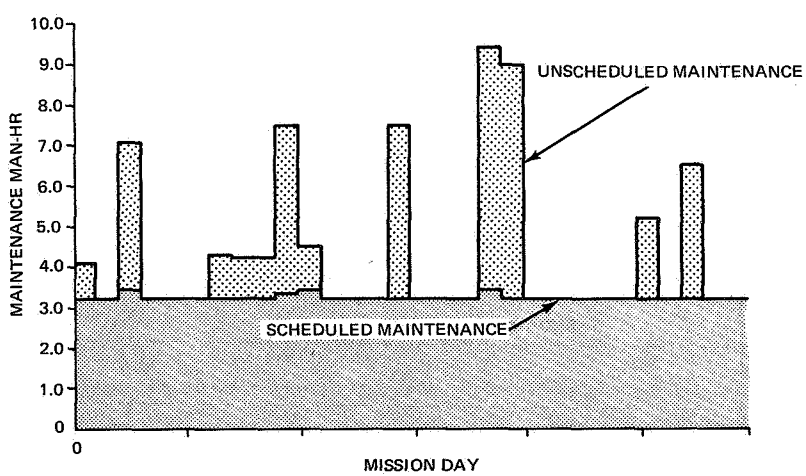


FIGURE 12 CREWMEMBER NO. 4 MAINTENANCE WORKLOAD BY DAY

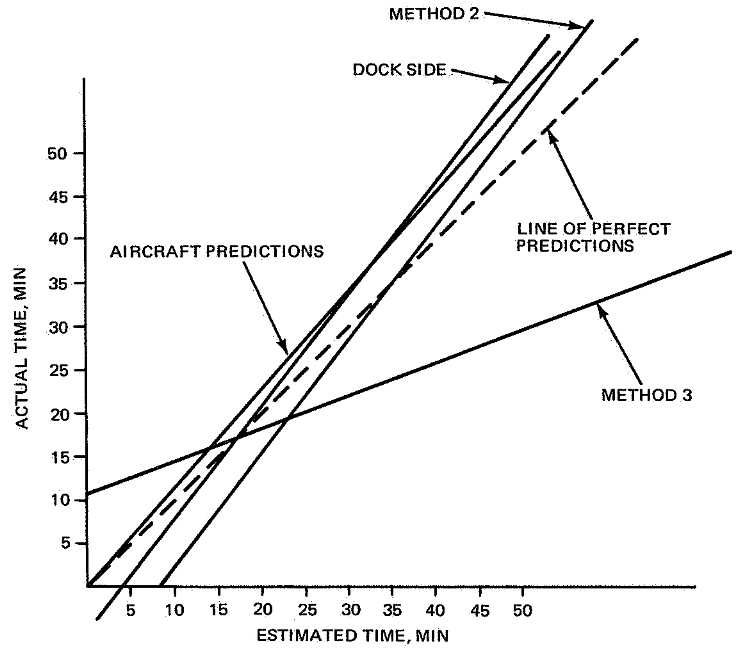


FIGURE 13 COMPARISON OF PREDICTION CHARACTERISTICS